Can earthquakes be predicted?

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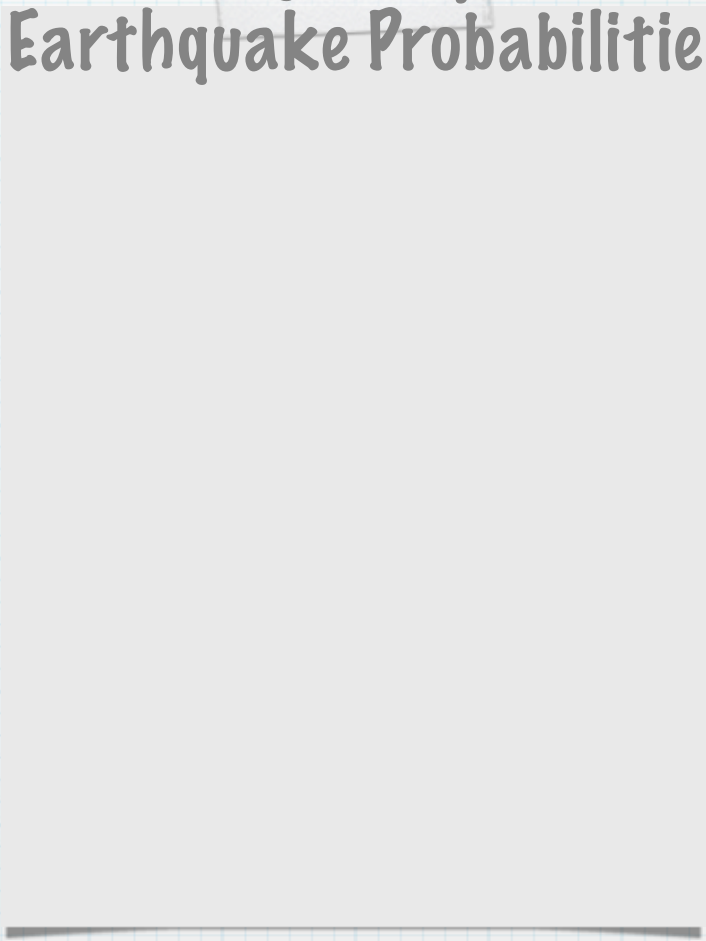
Earthquake predictions that most seismologists agree with

Long term earthquake probabilities

2008 Working Group on California Earthquake Probabilities

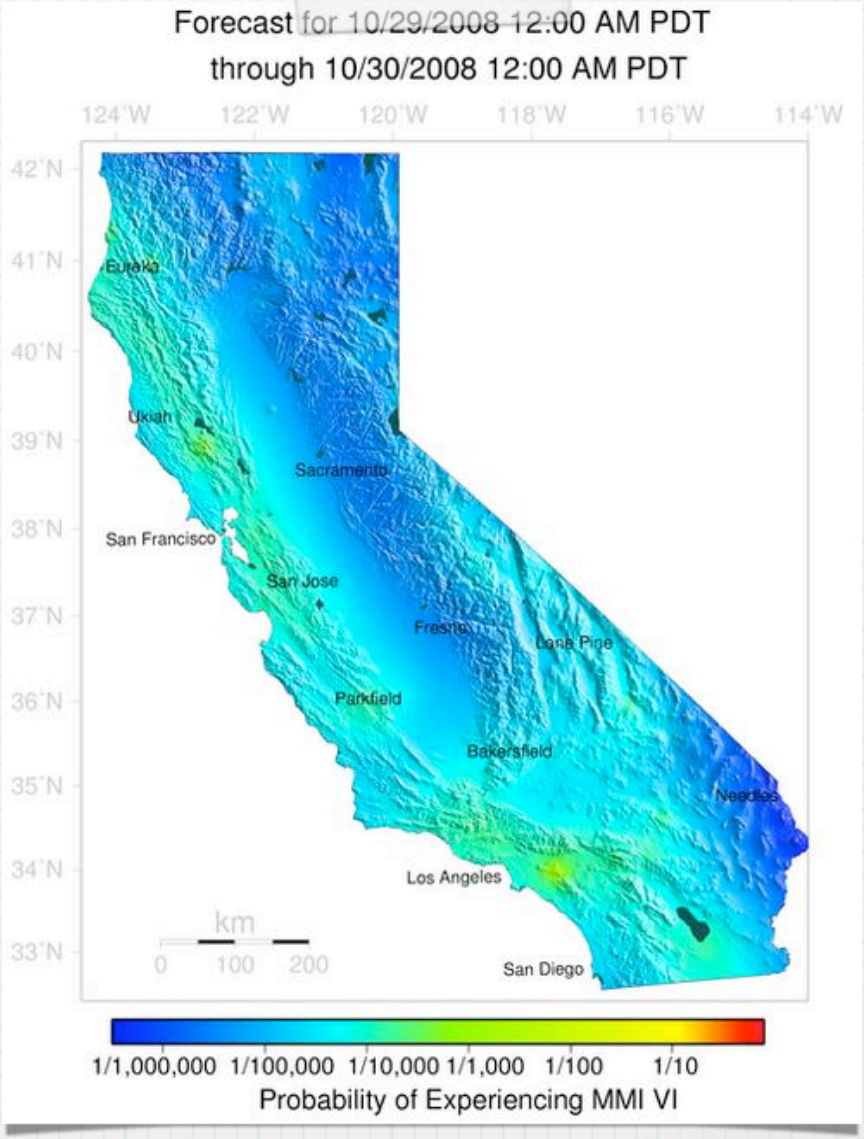
* These kinds of predictions are important for construction codes, insurance rates, and emergency preparedness, but they are a long time to duck and cover!



>99% chance that a M ≥6.7 earthquake will occur in CA within 30 years.

Aftershock Probabilities

* Seismologists assign probabilities to how large the aftershocks will be, including the probability that an aftershock will be larger than its mainshock.



STEP probability map

Whether any more precise prediction is possible has long been debated

"Since my first attachment to seismology I have had a horror of predictions and predictors. Journalists and the general public rush to any suggestion of earthquake prediction like hogs to a full trough"

-Charles Richter, 1977

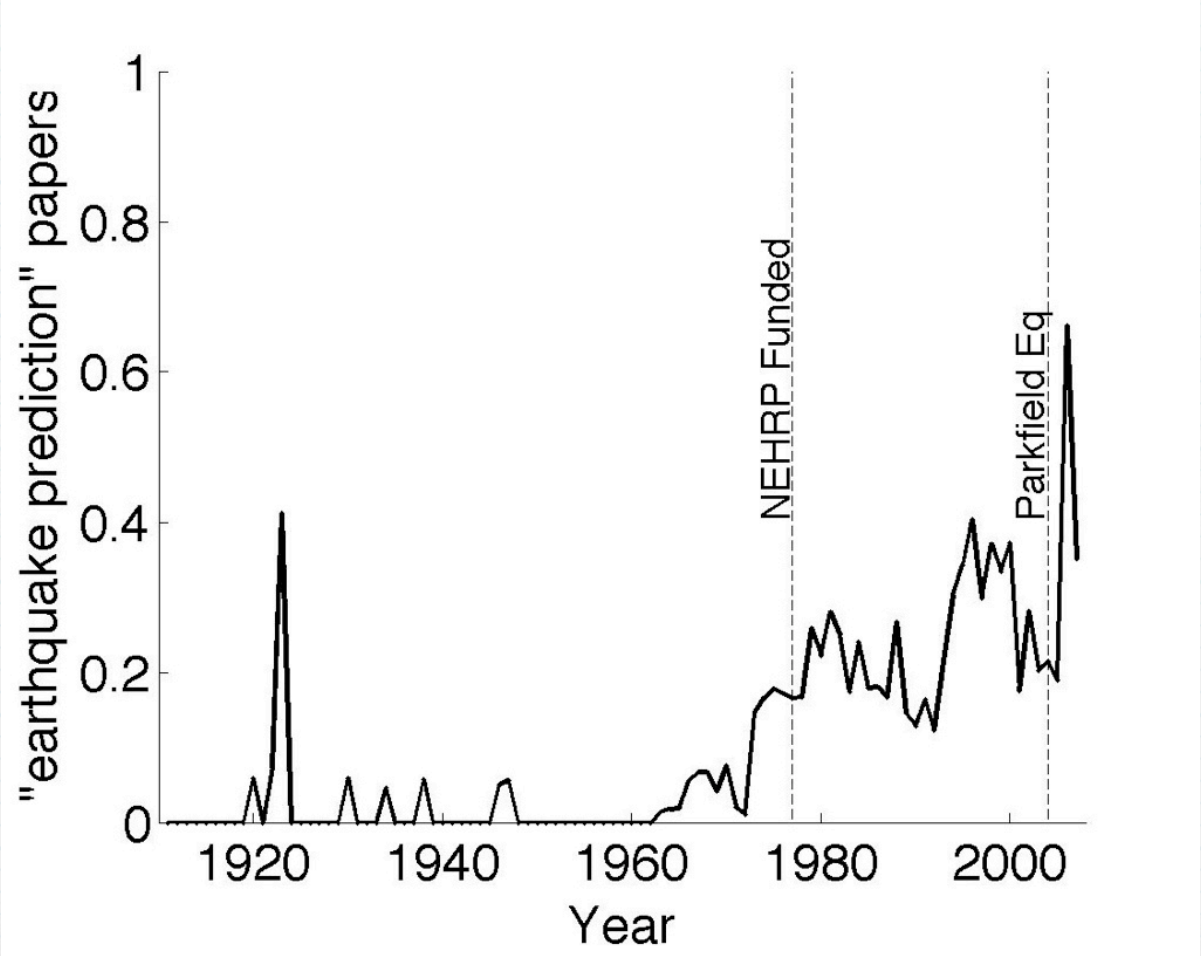
"I can tell you scientists who will bet good money that no one will ever be able to [predict earthquakes]. I'm not one of them."

-Tom Jordan, 2006
Director of the Southern California Earthquake Center

Office Survey, USGS Pasadena

50% think prediction is possible given unlimited time and resources

Fraction of articles in Bull. Seis. Soc. Am. with "earthquake prediction" keyword

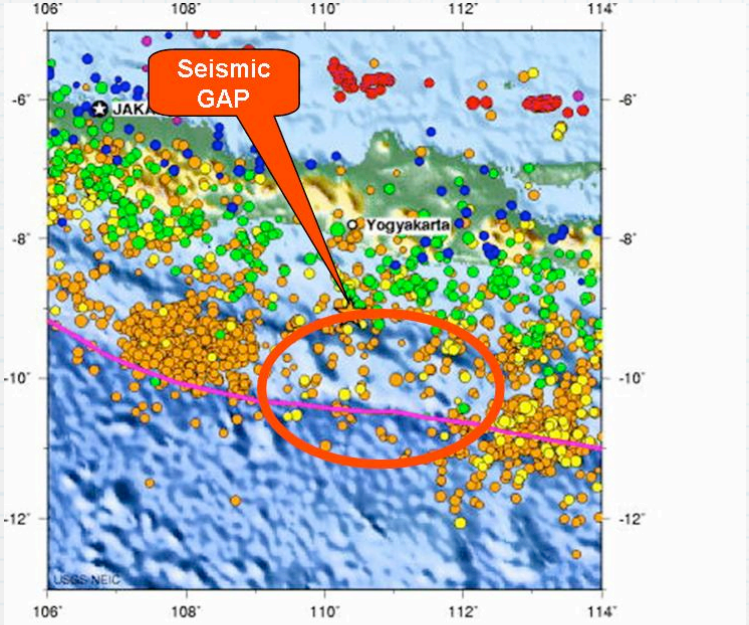


Two types of predictions commonly attempted:

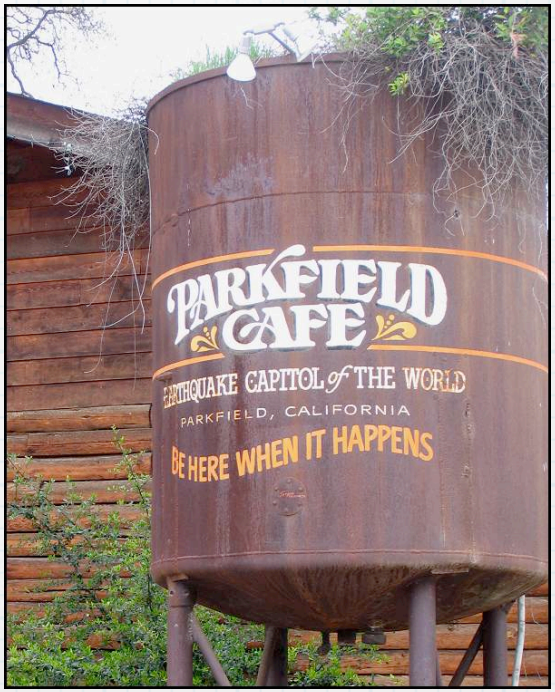
* Intermediate term: Narrow region and magnitude, time range 5-30 years.
* Short term: Narrow region and magnitude, time given to the day or month.

Intermediate term prediction

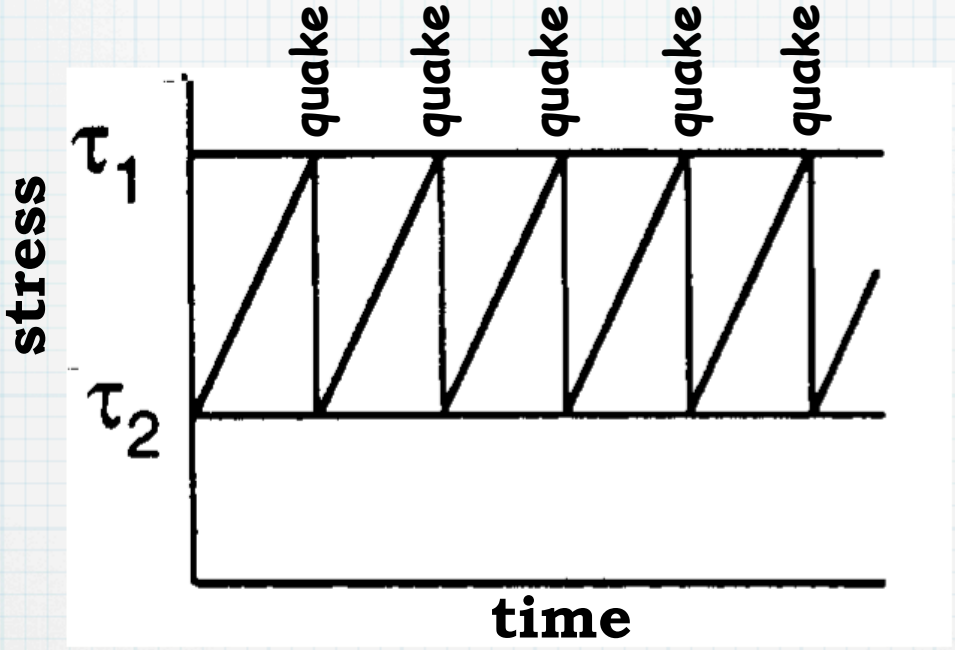
Very popular intermediate term prediction model: Seismic Gap



SOUTH OF JAVA, INDONESIA
2006 09 21 18:54:48 UTC 9.07S 110.37E Depth: 10.0 km, Magnitude: 5.9
Seismicity 1990 to Present



The seismic gap model

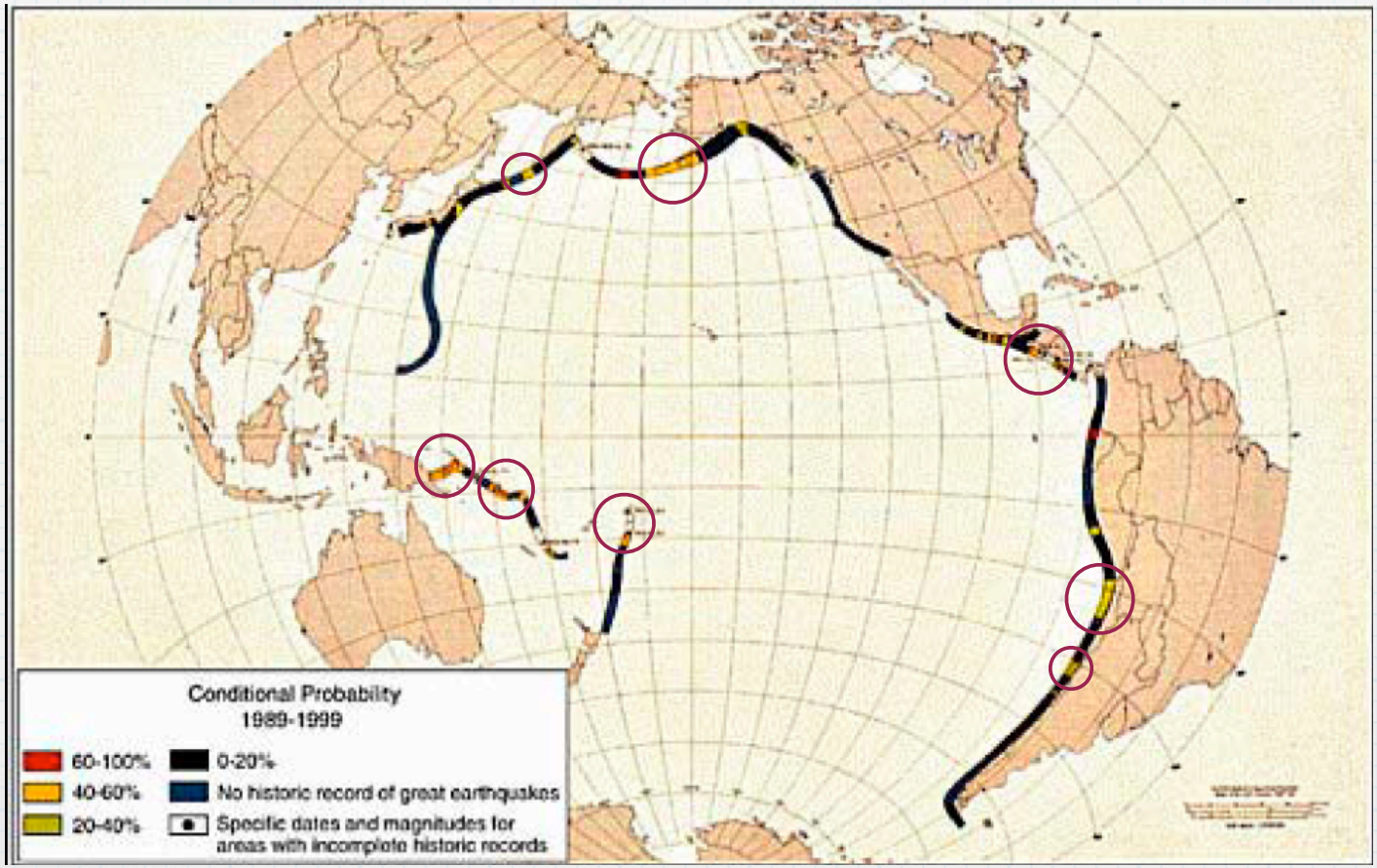


Stress is "low" after a large earthquake and must rebuild before another large quake can occur

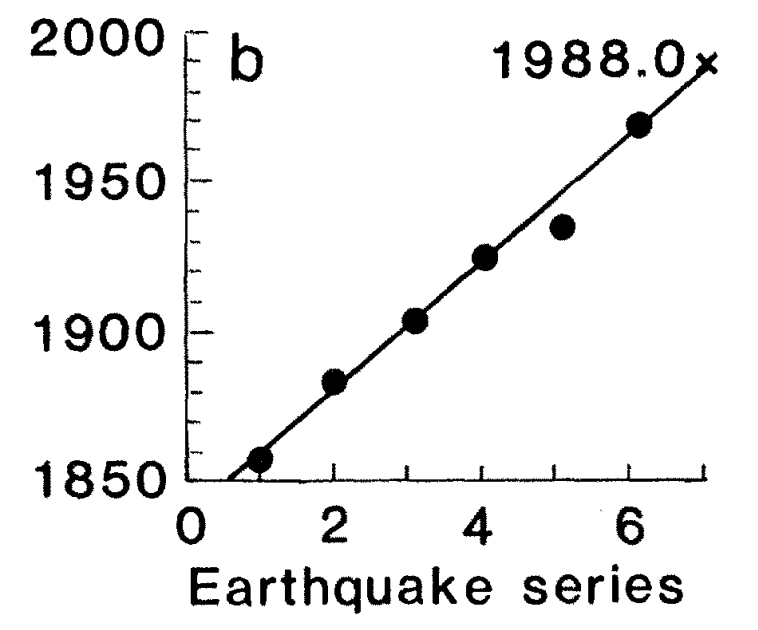
The Seismic Gap Model

* Earthquakes occur periodically or quasi-periodically.
* A fault that has just ruptured is "safe".
* A fault that has not ruptured for some time is a "gap" that will be filled soon.

Nishenko (1991) made global predictions based on seismic gaps



Bakun and Lindh (1985) used the model to predict a Parkfield eq



Earthquake supposed to occur 1985 - 1993 with 95% certainty

Figure from Bakun and Lindh, 1985

M 6 earthquakes predicted at Parkfield every 22 years

Like Old Faithful!

Quotes from the Media

* "Scientists say the Hayward Fault is overdue for a major earthquake" -ABC News
* "Geologist uncovers earth's secrets, says Southern California is overdue for a major earthquake" -University News
* "The [San Andreas Fault] is 10 months pregnant"! -guardian.co.uk

Short term prediction

Short term predictions are generally based on anomalies or patterns

Photo taken by Shou in Pasadena, 1997

Do lines in the clouds predict earthquakes?

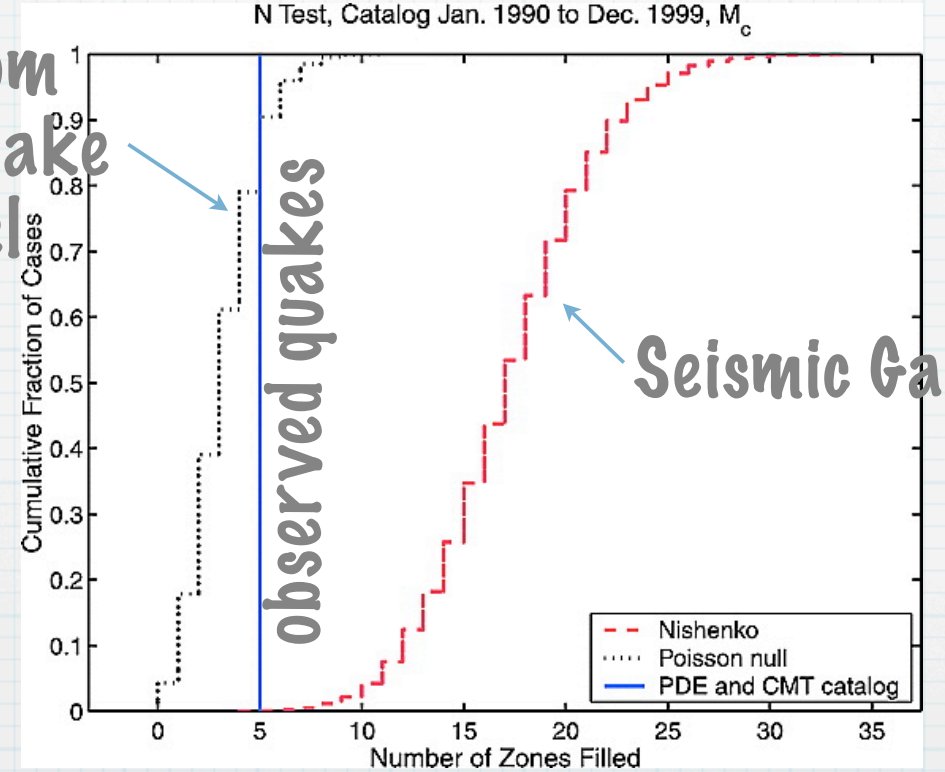
Short term prediction publications

- Accelerating seismicity and stress release before large earthquakes, *Bowman et al.*, 2001
- Precursory seismic quiescence, *Wyss and Habermann*, 1987
- Ground water radon anomaly before the Kobe earthquake in Japan [radon observed to increase] *Igarashi et al*. 1995
- A mechanism for anomalous decline in radon precursory to an earthquake, *Kuo et al*. 2006
- A drop in mean earthquake magnitude before large earthquakes found by *Smith*, 1986
- An increase in mean earthquake magnitude before large earthquakes found by *Nuannin et al*., 2007

So -- Has anyone made successful predictions?

Global seismic gap predictions of Nishenko not fulfilled

Random Earthquake model

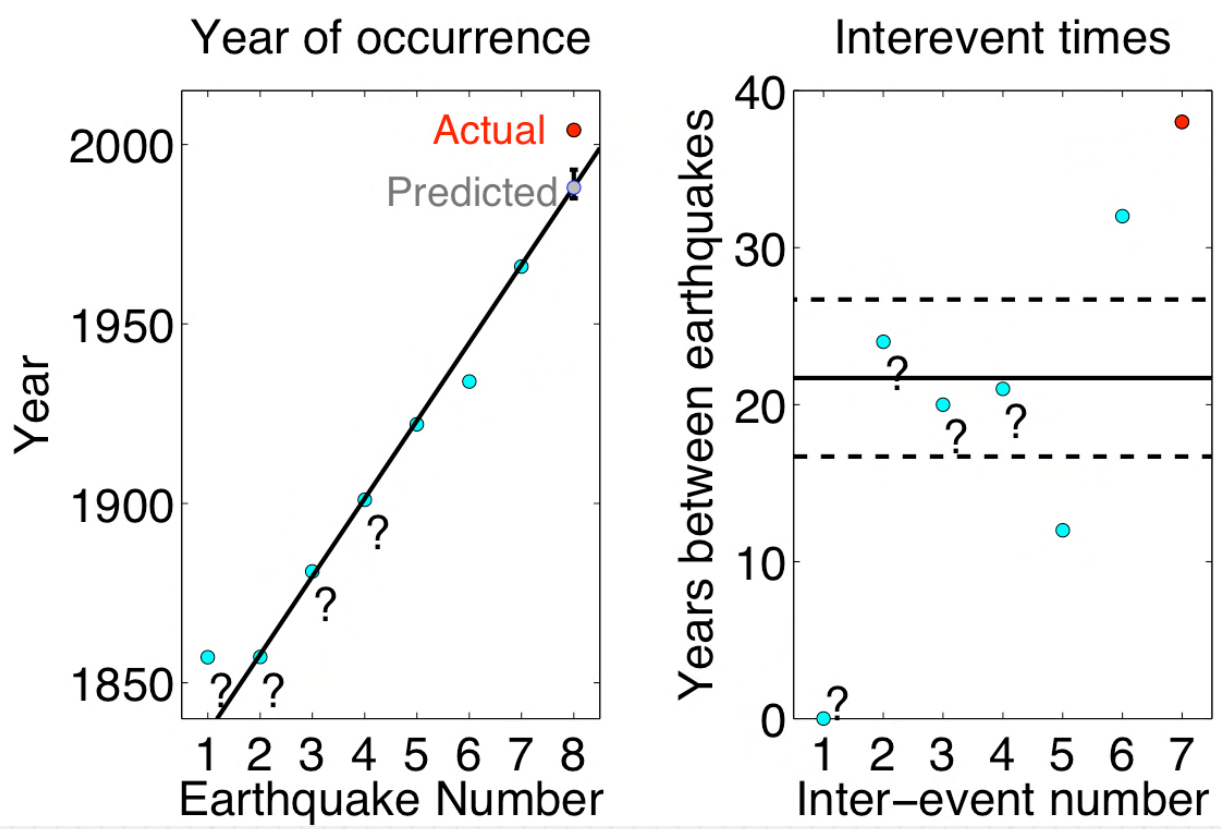


Seismic Gap Prediction

Figure 1 From Rong et al. (2003)

A M 6 at Parkfield did occur -- but not until 2004!

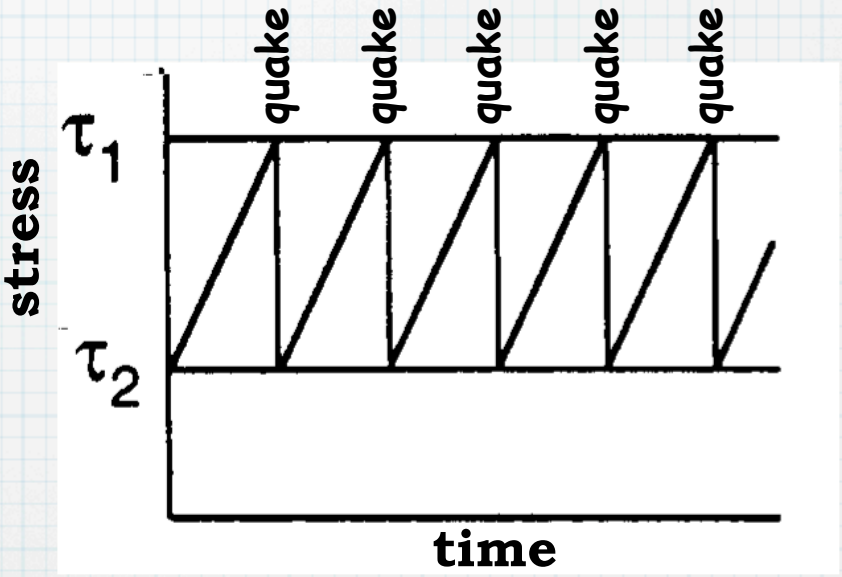
: What was the
ility of occurrence
4



And earthquakes may not have been so periodic there to begin with!

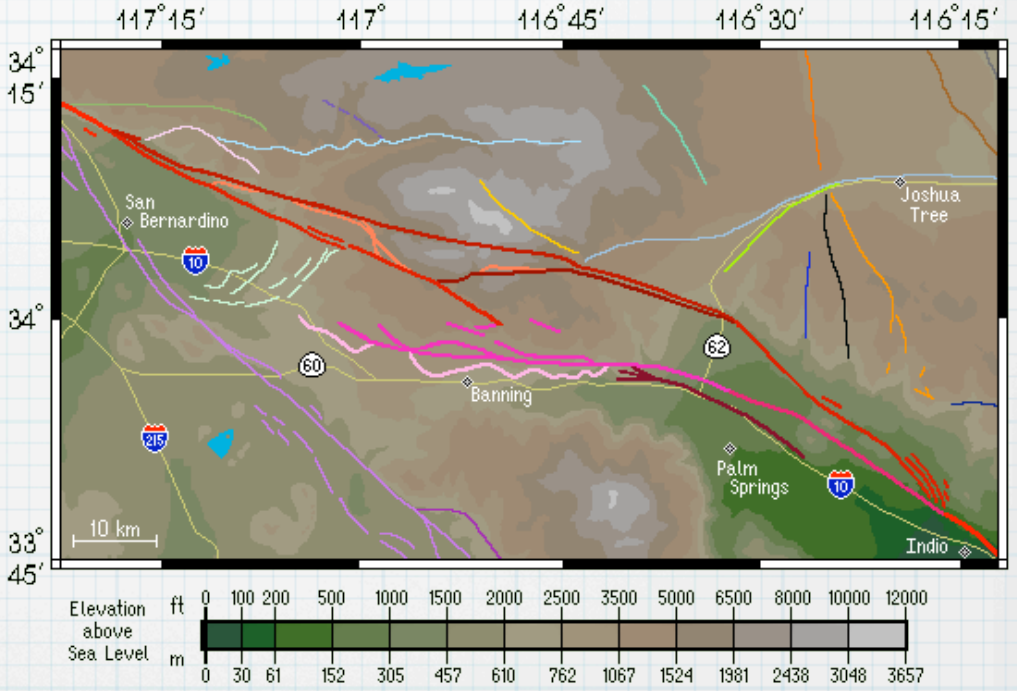
What's wrong with the seismic gap model??

* Earthquake stress drop << fault stress, so stress is always high.
* Rupture occurs not because of slow stress increase but because of rapid shaking-induced strength decrease.



What's wrong with the seismic gap model??

* And/Or: There are so many sub-parallel faults strands in the crust that some are always ready for failure.



Section of the San Andreas, from SCEC website

No short term schemes has been verified to date

- Accelerating seismicity and stress release before large earthquakes, *Bowman et al.*, 2001
- Precursory seismic quiescence, *Wyss and Habermann*, 1987
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Reporter to Richter: Did anyone predict this earthquake?

Richter: Not yet!

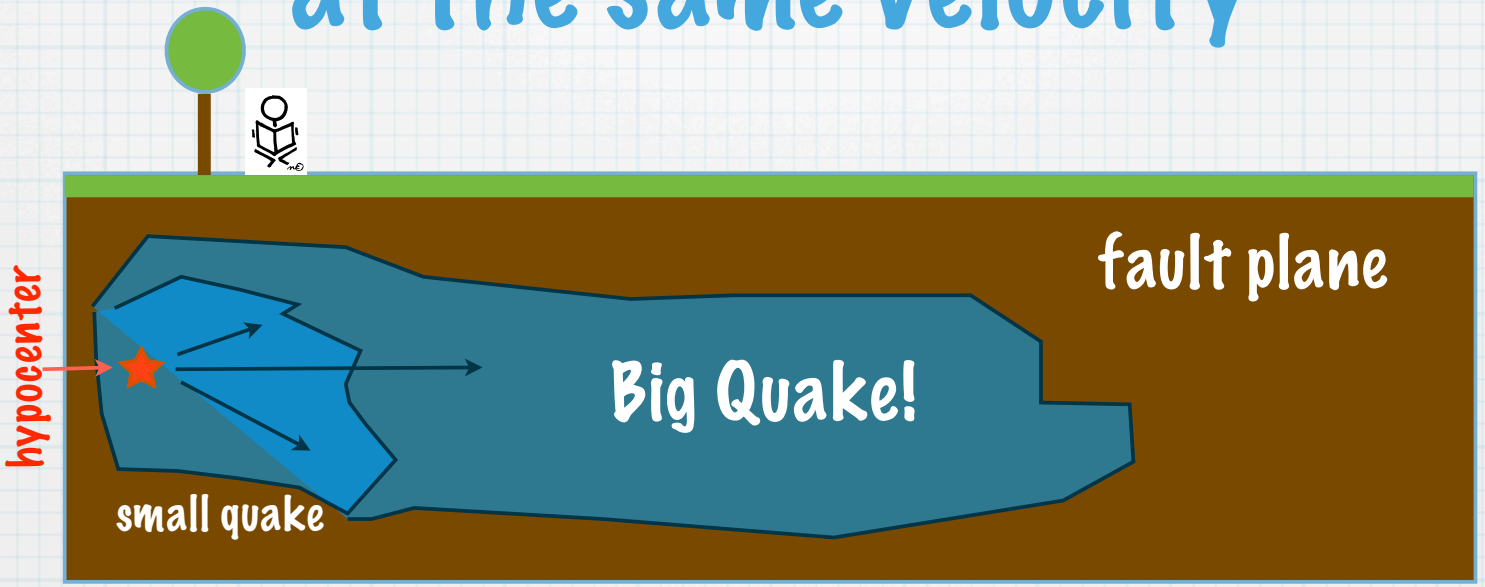
Summary results of serious predictions for SoCal

Prediction	Predictor	Result
Major SoCal earthquake 1925-1935	Bailey Willis, Stanford University	no earthquake
M 6.0 at Parkfield, 1985 - 1993	W. H. Bakun and A. G. Lindh, USGS Menlo Park	no earthquake
Palmdale Bulge - large San Andreas earthquake, 1970s	Robert Castle, USGS Menlo Park	no earthquake
M 6.4, Jan - Sept. 2005, Eastern Southern California	Vladimir Keilis-Borok, UCLA	no earthquake

Is earthquake prediction just really difficult or is it impossible??

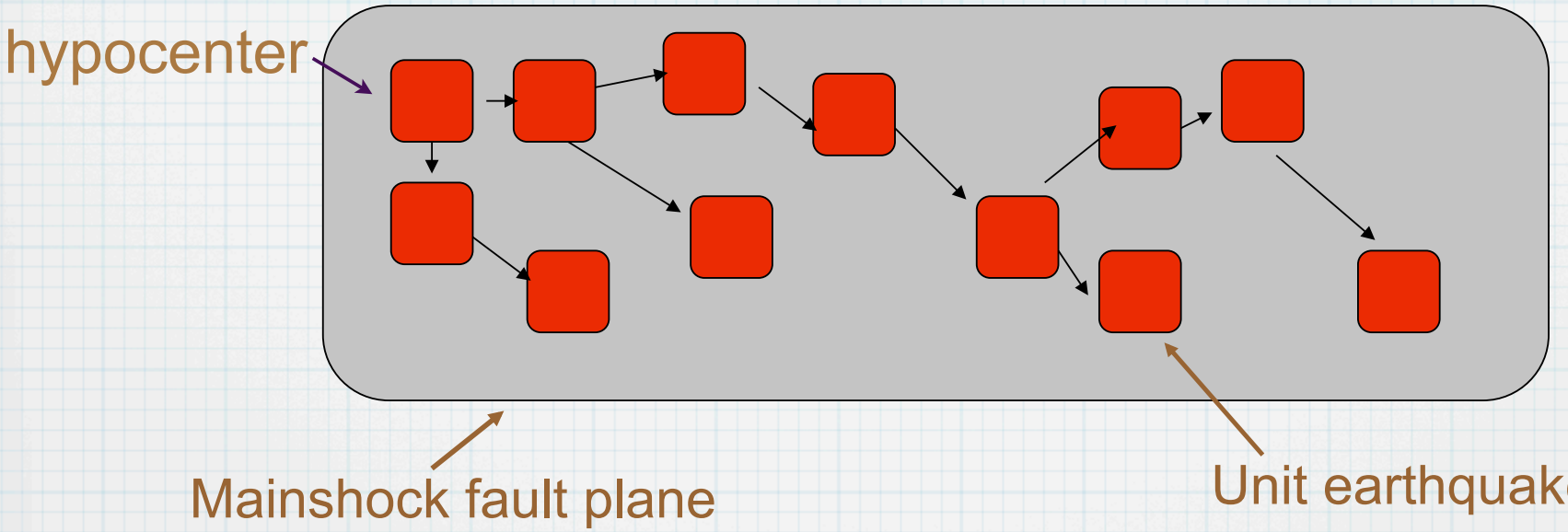
Why I think earthquake prediction is impossible

All earthquakes start at small points, called hypocenters, and propagate over the fault plane at the same velocity



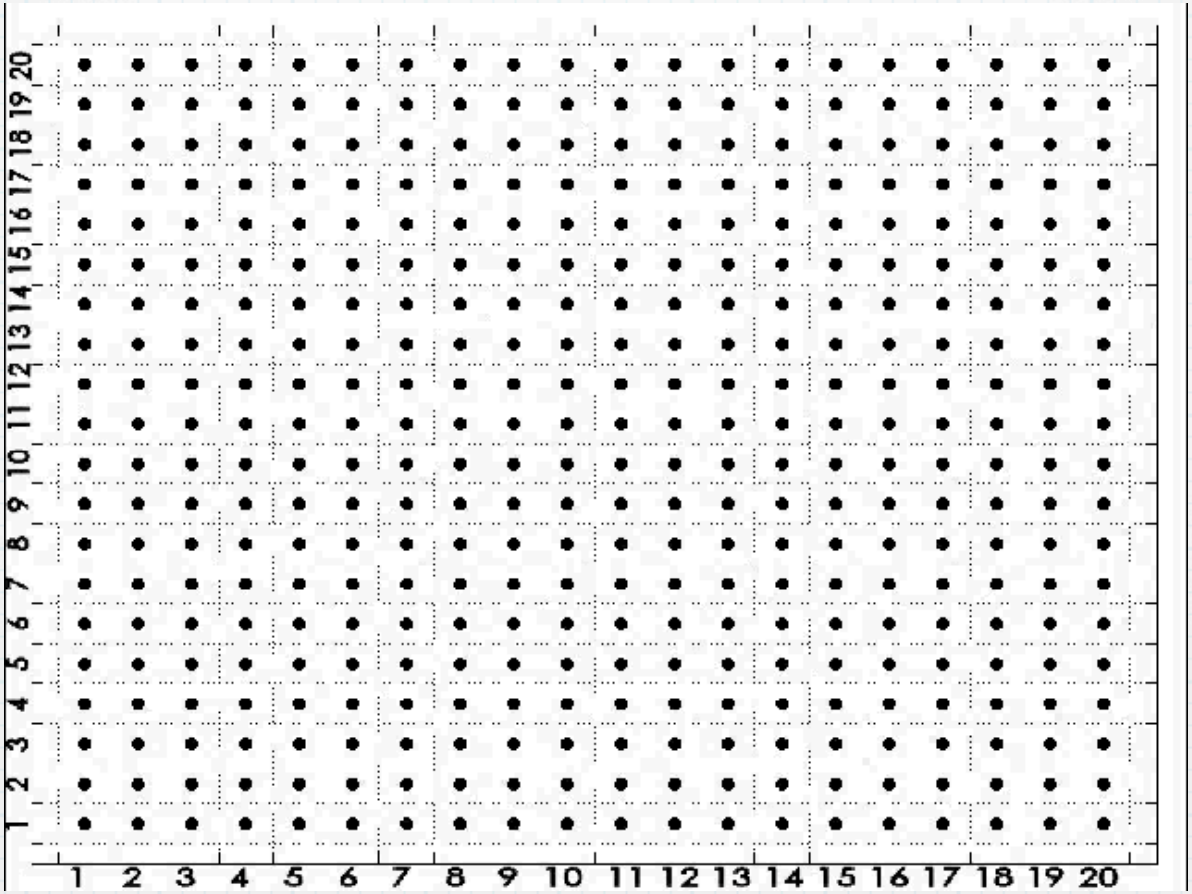
Small earthquakes stop after a small rupture; large earthquakes continue to rupture a large area

This observation, and many others, inspired the Cascade Model



- Propagation is stochastic
- Points have a constant prob. of rupturing if stressed
- Magnitude is undetermined until earthquake is over

Cellular automata approximation of cascade model: 20 random simulations

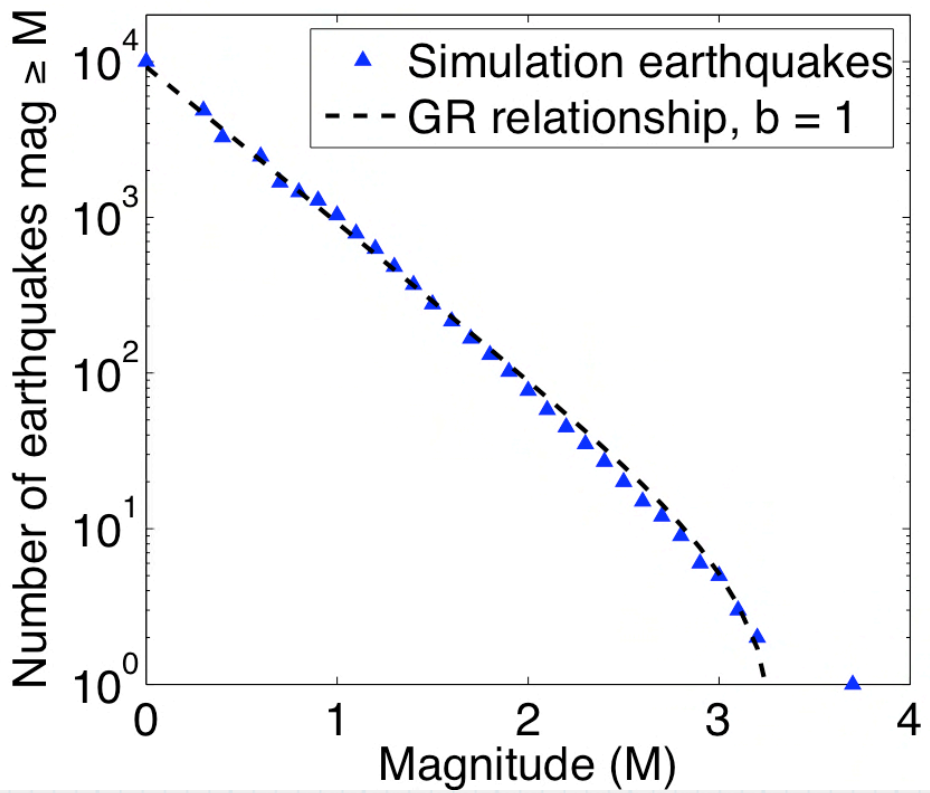


Animation by Mike Harrington

Each point has a 75% chance of triggering a neighbor

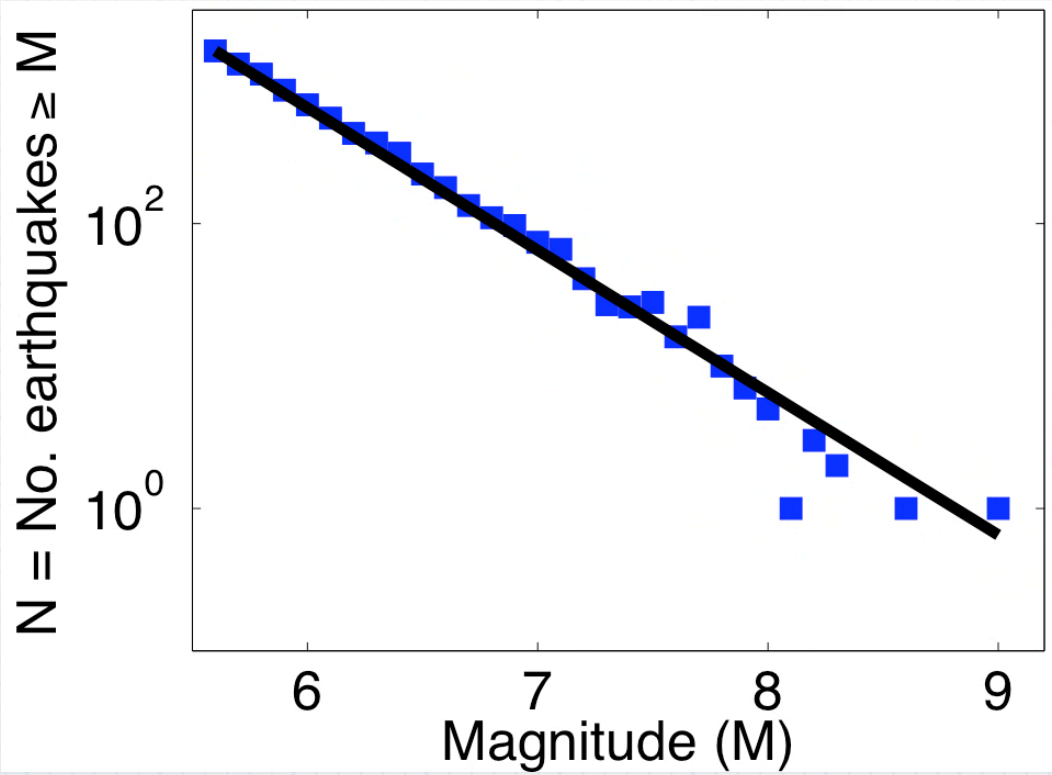
The cascade model is consistent with empirical earthquake statistical laws

Magnitude-Frequency stats produced by cascade model: inverse power law



Magnitude-frequency statistics seen in data: Inverse power law

1976-2005 Global CMT catalog



The Ishimoto-Iida/ Gutenberg-Richter law

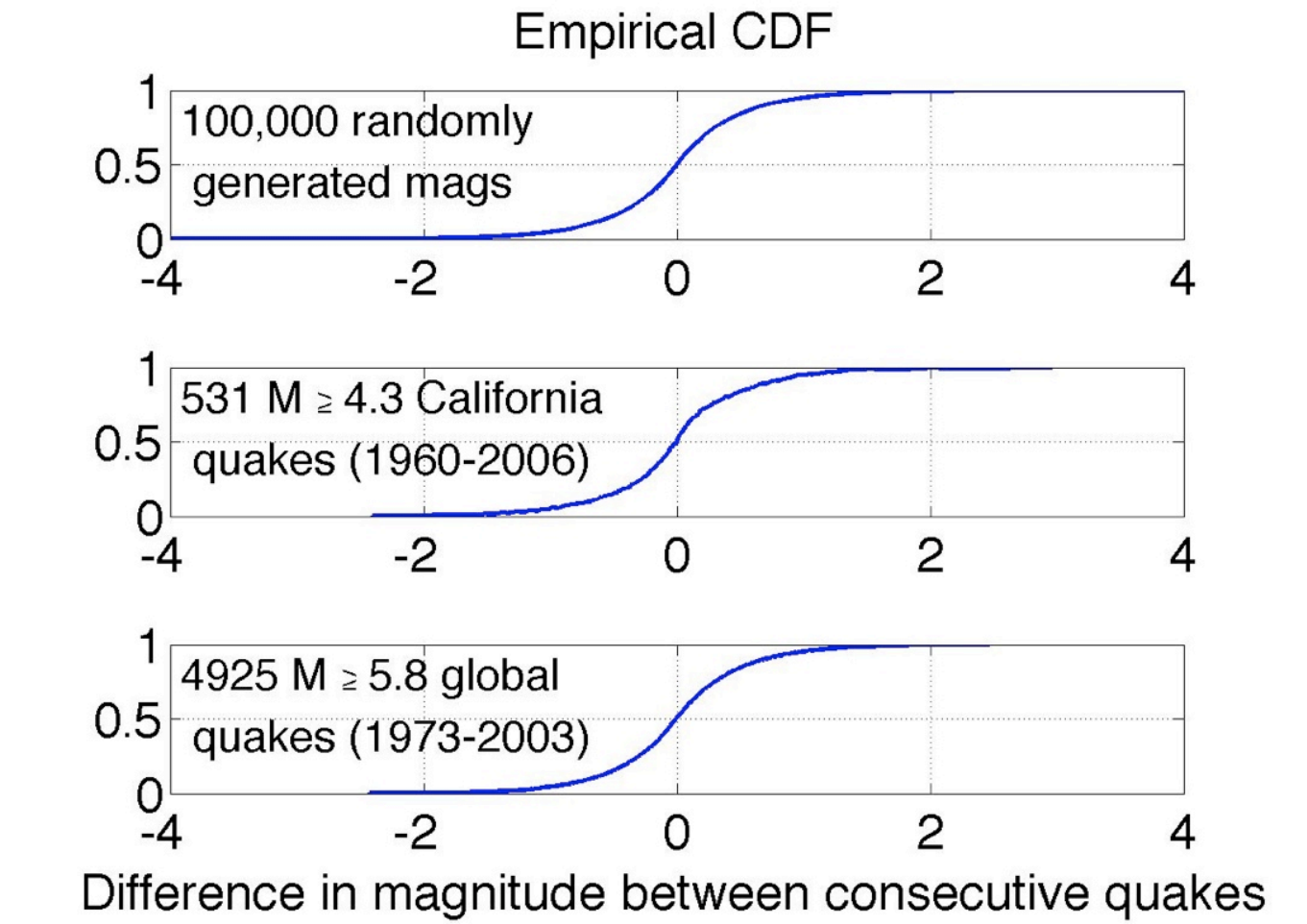
$N(A) \sim 1/A$

In the cascade model the magnitude of each earthquake should be random

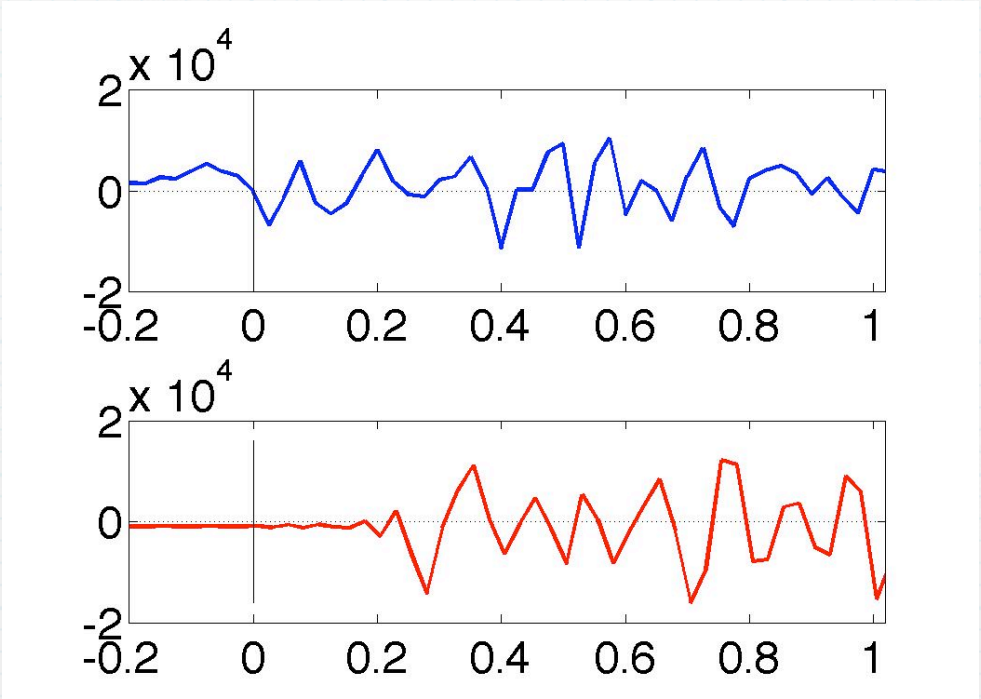
Test for magnitude randomness

* Take magnitudes, above the completeness threshold, from the California and Global catalog.
* Take the difference between consecutive magnitudes.
* Compare to the differences between a randomly generated set of magnitudes.

A Kolmogorov-Smirnoff test indicates that each magnitude is chosen randomly

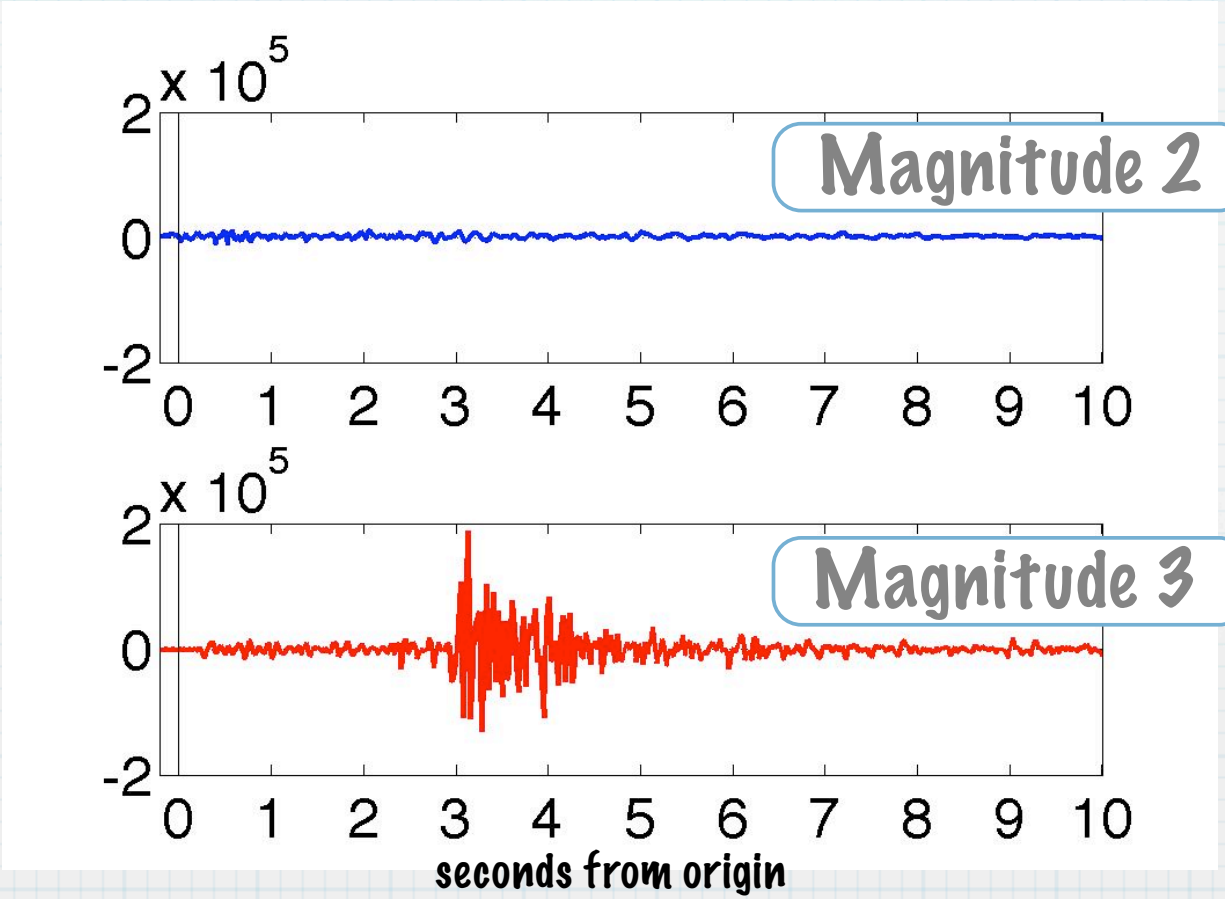


The cascade model is supported by the similar starts of small & large earthquakes



The 1st second of two quakes. Which will be larger?

10 seconds of record, same earthquakes



Cascade Model Summary

* In the cascade model earthquake growth is stochastic and self similar.
* Earthquakes of any magnitude may be generated from the same starting conditions.
* Earthquake magnitude evolves as the earthquake grows => cannot be predicted beforehand.

Conclusions

* Average earthquake rates and increased rates during aftershock sequences can be empirically forecast.
* More precise earthquake prediction requires pre-determined earthquake magnitude.
* Observation indicates that earthquake magnitude is random, and that all quakes start the same.
* => Earthquake "prediction" is impossible.

And some parting thoughts from a USGS interview with Charles Richter

Q: What are your thoughts on the possibility of predicting earthquakes in the next two decades.
A: None.

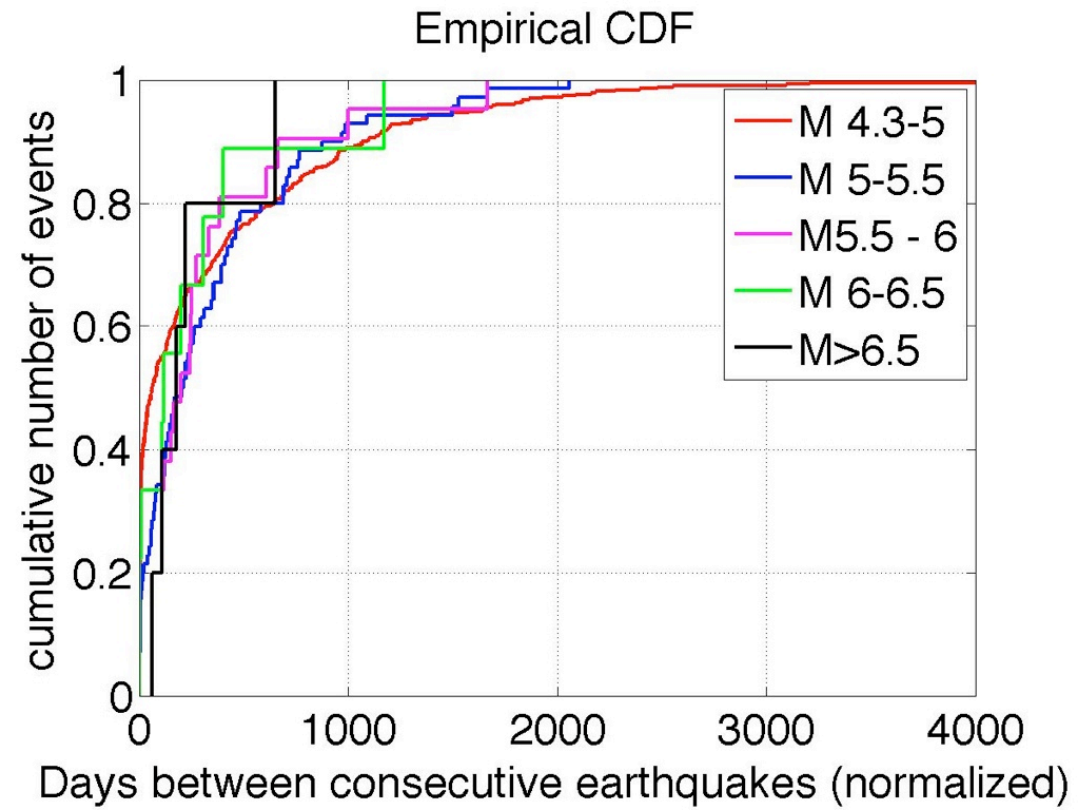
Q: How can the study of United States earthquakes be improved?
A: By continuous earnest efforts to find out what is going on, without running after prediction.

Q: If the building you are in now started to shake and you knew an earthquake was occurring, what would you do?
A: I would walk - not run - to the nearest seismograph.

Acknowledgements

* Alan Felzer, my dad, for years of high quality editing, commentary, and incredible support.
* Mike and Emmet Harrington, husband & 12 mo. old son, for giving me the gift of time to write this talk!
* Laura Felzer and Andee Harrington, mom and mom-in-law extraordinaire, for taking care of everyone!

The difference in time between consecutive earthquakes does not vary with magnitude range



California earthquakes, 1960-2007

* Even if magnitude is completely random a sudden increase in the seismicity rate would increase the odds of a large earthquake.

* But we rarely see larger rate increases than during aftershock sequences => aftershock forecasts are the best "predicting" we can do!

* Important! -- if the magnitude of each earthquake is truly random there is no way to predict earthquake magnitude unless there is some signal right before/after the earthquake starts.
* But it has never been demonstrated that earthquakes of different magnitudes show any differentiation until the small one stops and large one keeps going.