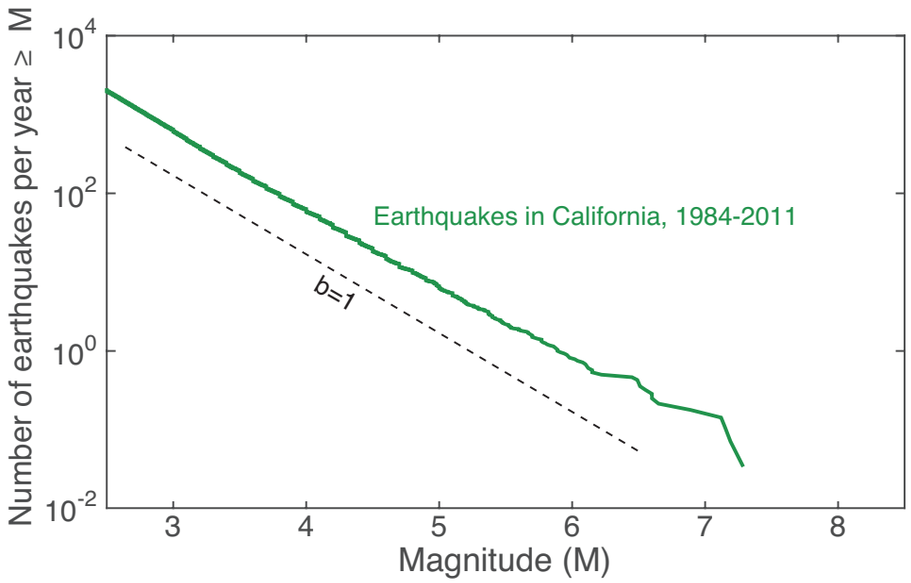
The 2016 Bombay Beach Swarm

Triggering Probabilities for Larger Earthquakes
(on the San Andreas and Elsewhere)

Morgan Page
USGS Pasadena

The Basics of Earthquake Forecasting

The Statistical Seismologist's Approach



Gutenberg-Richter Magnitude Scaling

$$N(M) \propto 10^{(a-bM)}$$

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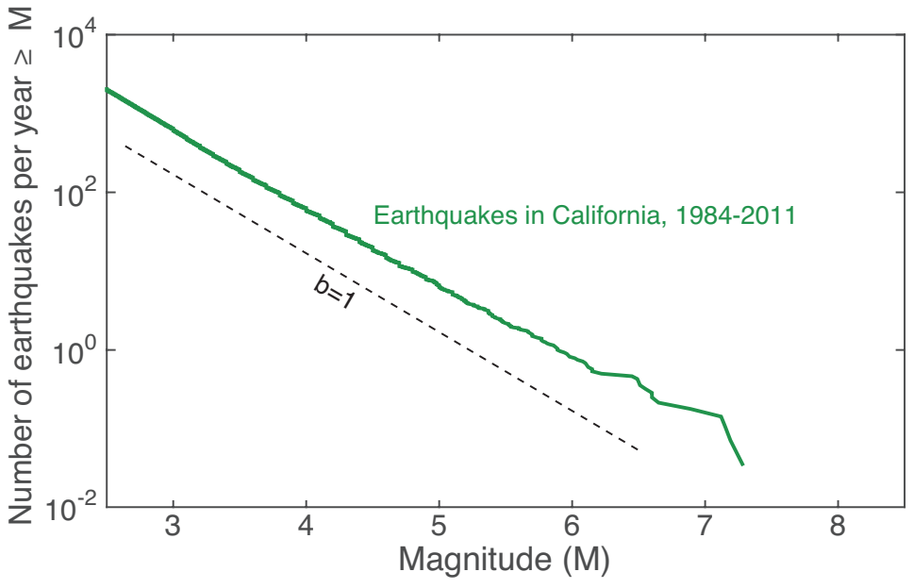

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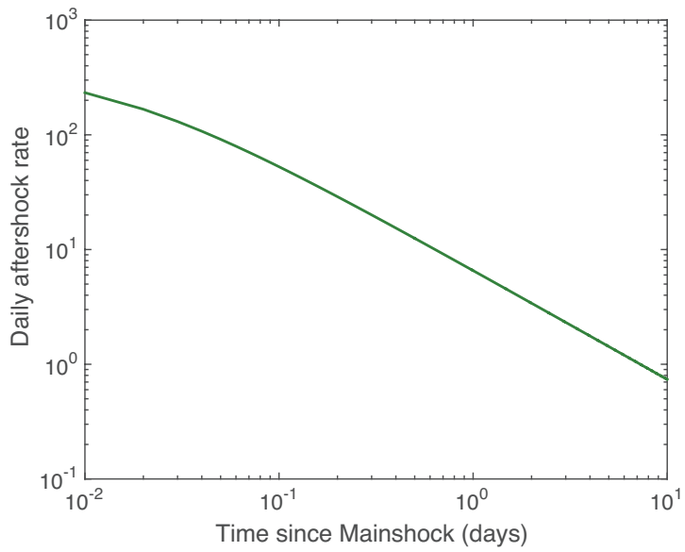

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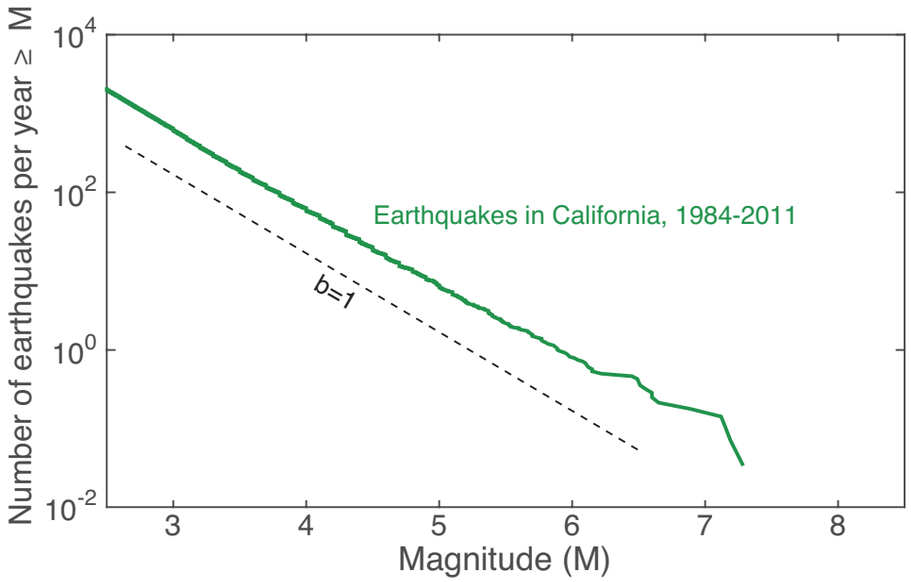

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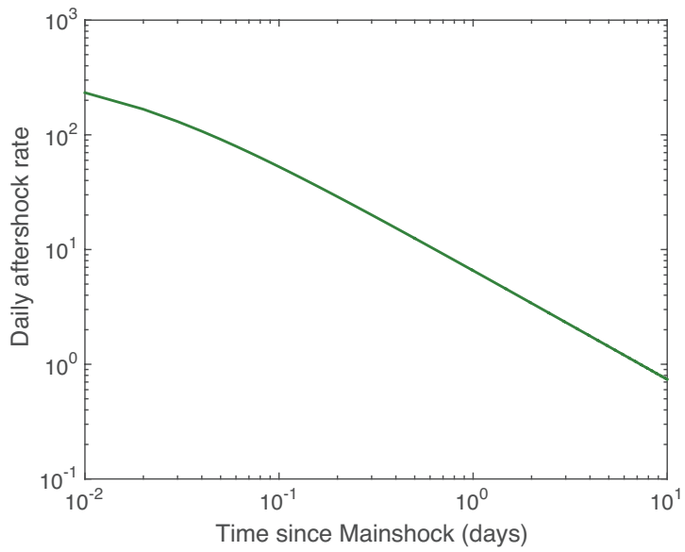

Big earthquakes trigger more aftershocks

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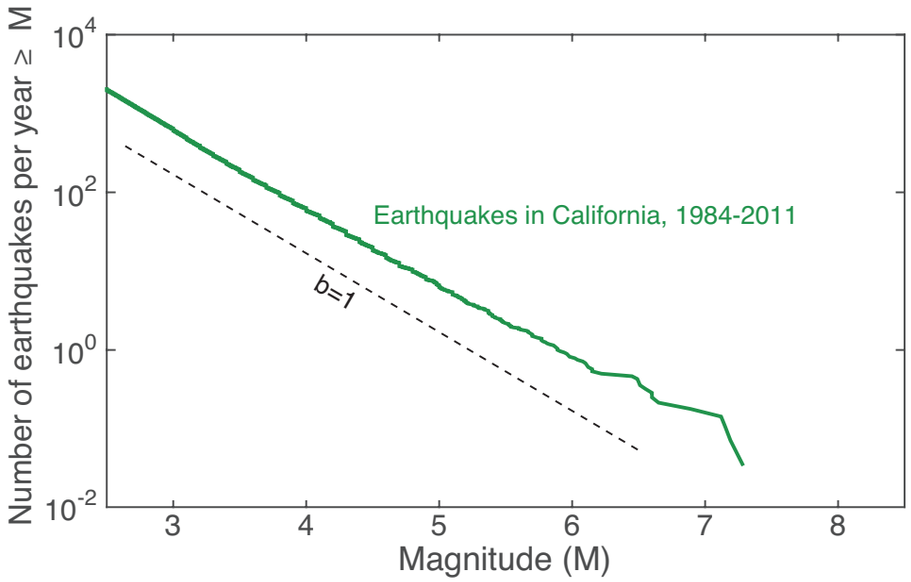

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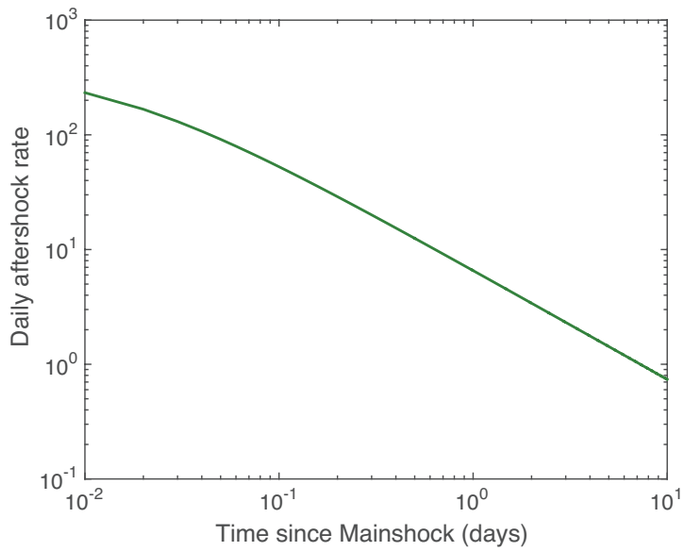

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Aftershock rates decay with distance from the mainshock

$$p(r) \propto N(r)\left(r^2 + d^2\right)^{-\gamma/2}$$

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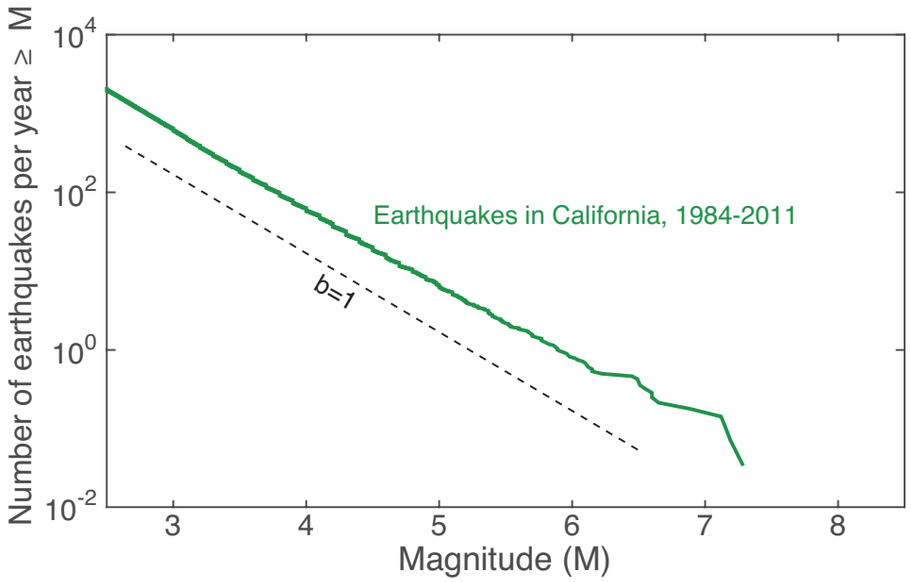

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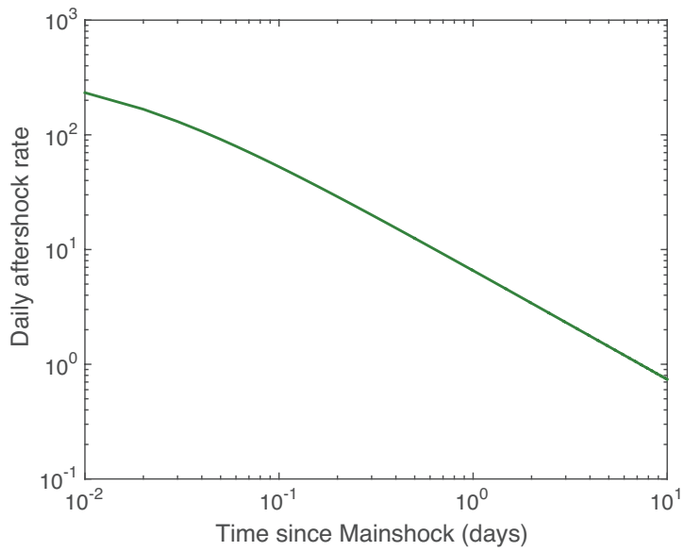

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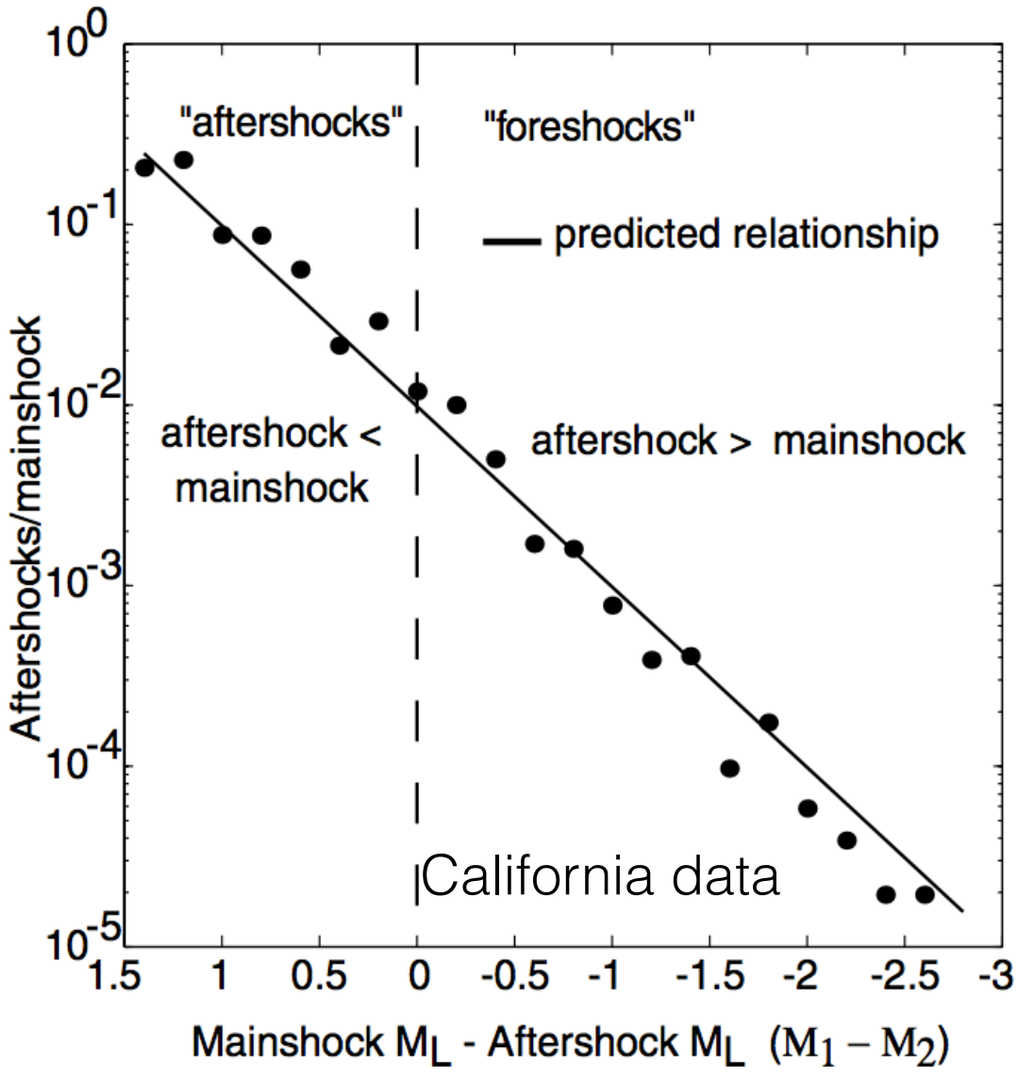
These scaling laws are used in short-term forecasting models like ETAS (Ogata, 1988) and STEP (Gerstenberger et al., 2005)

ETAS Predictions

The foreshock rate and the aftershock rate follow the same trend

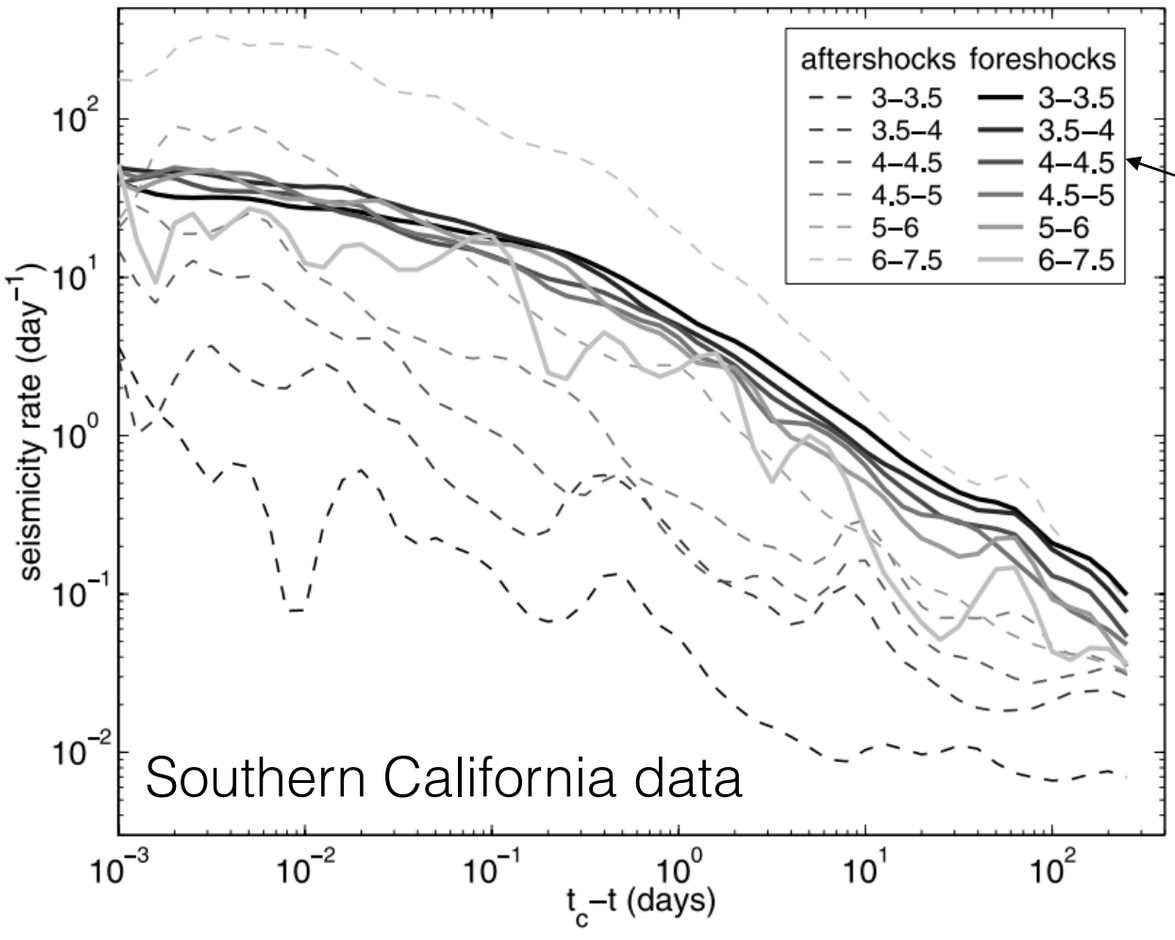


Felzer et al. (2004)

Given the aftershock rate, you can predict the foreshock rate, suggesting they represent the same process

ETAS Predictions

No significant correlation between number of foreshocks and mainshock size



size of mainshocks

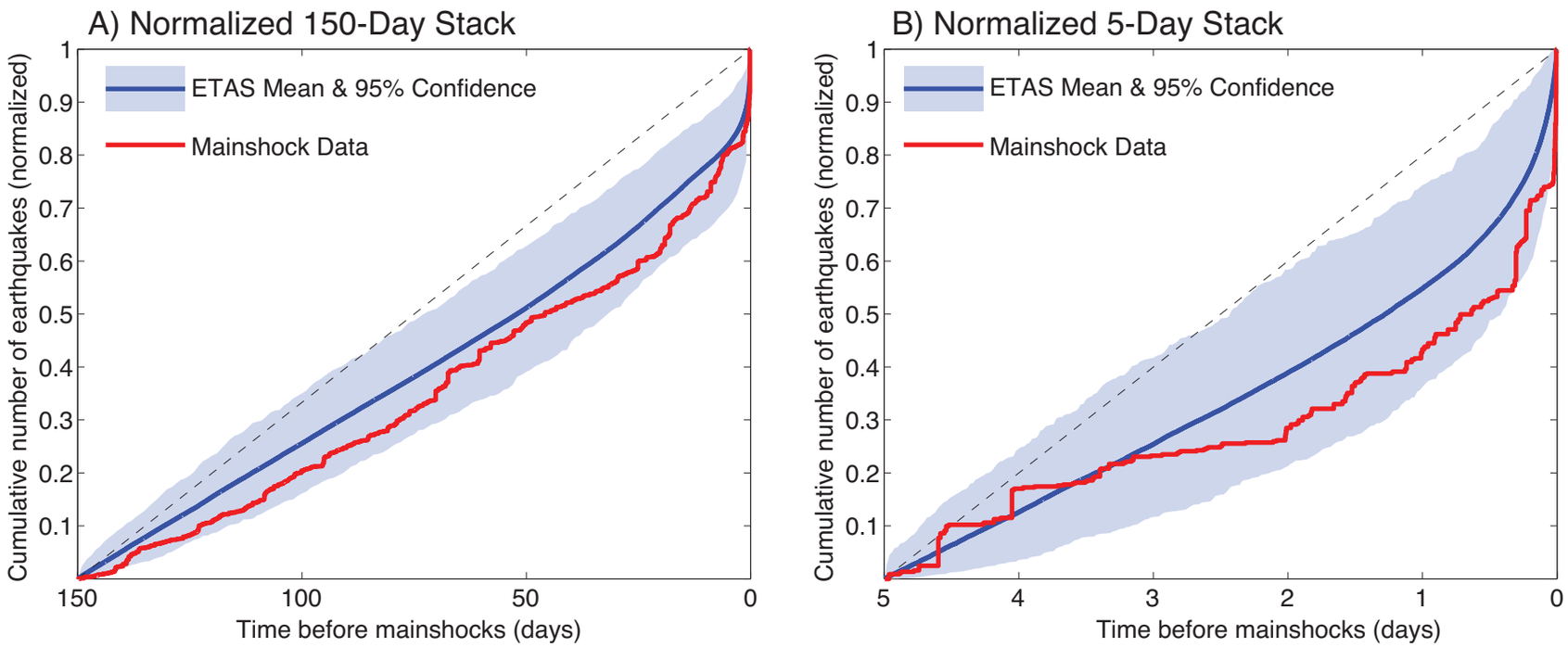
dashed lines - aftershock rates for different mainshock sizes

solid lines - foreshock rates for different mainshock sizes

Helmstetter and Sornette (2003)

Inverse Omori Acceleration

ETAS models can match the acceleration seen in Bouchon et al. (2014) dataset



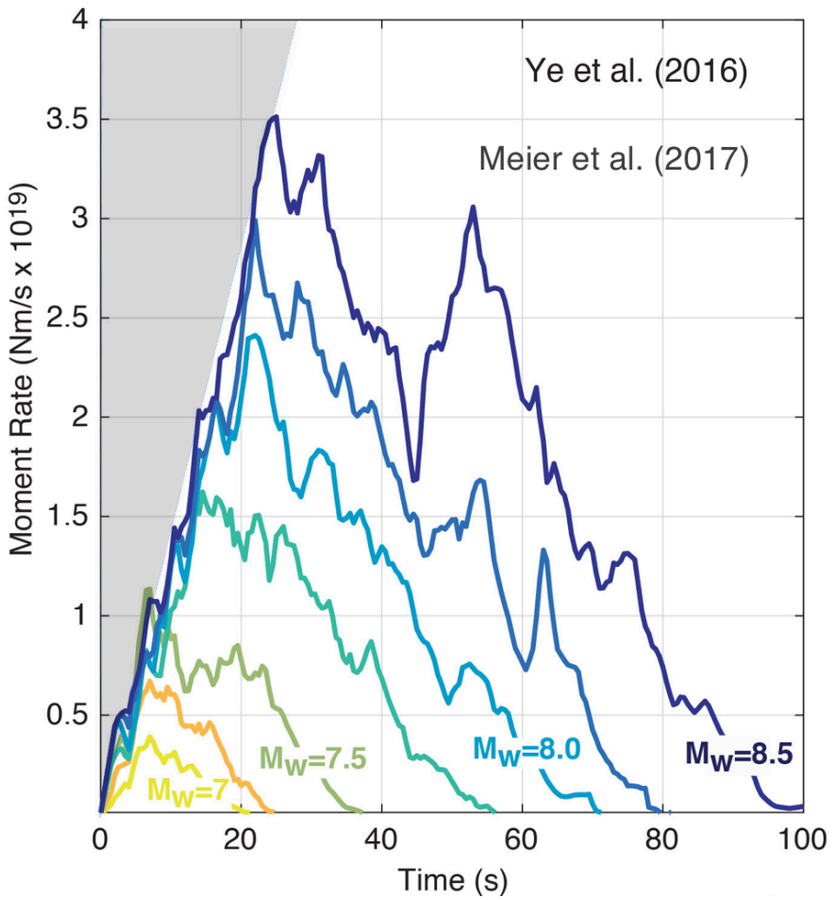
Felzer, Page and Michael (2015)

Foreshocks are not predictive of mainshock size

Science Home News Journals Topics Careers

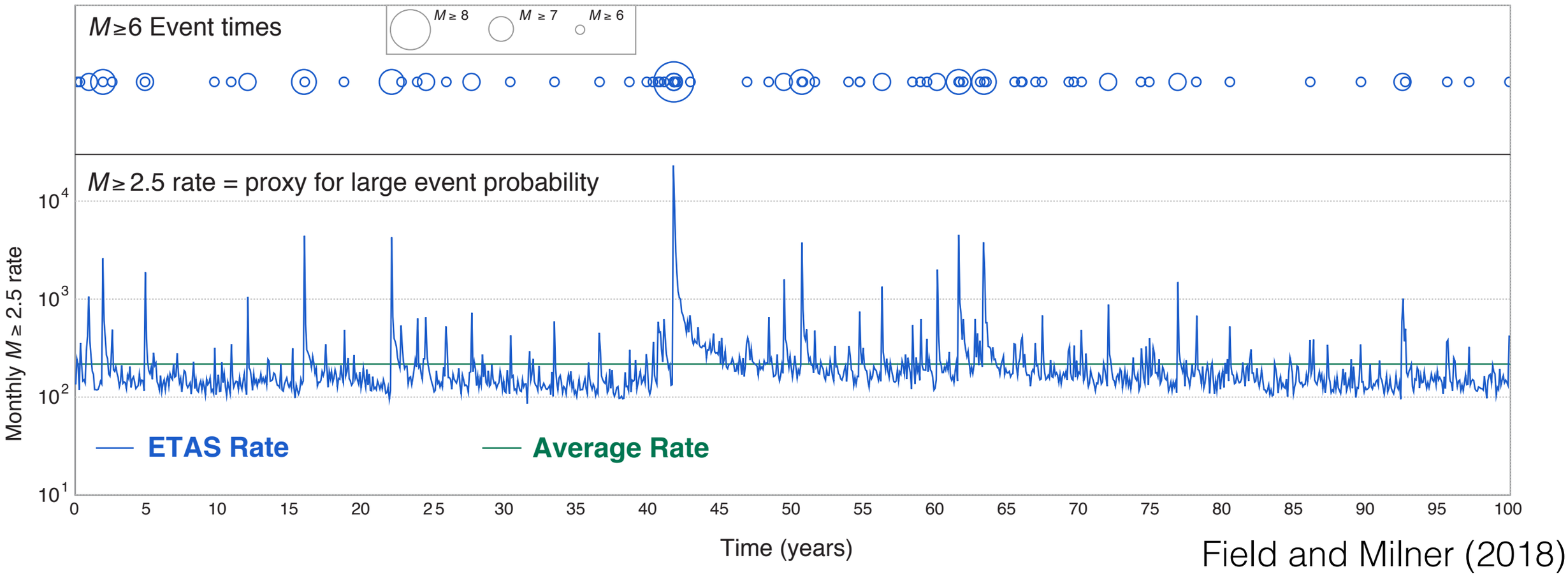
The hidden simplicity of subduction megathrust earthquakes

M.-A. Meier,* J. P. Ampuero, T. H. Heaton



Moment rate functions all start out the same, which suggests the earthquake doesn't "know" its final size

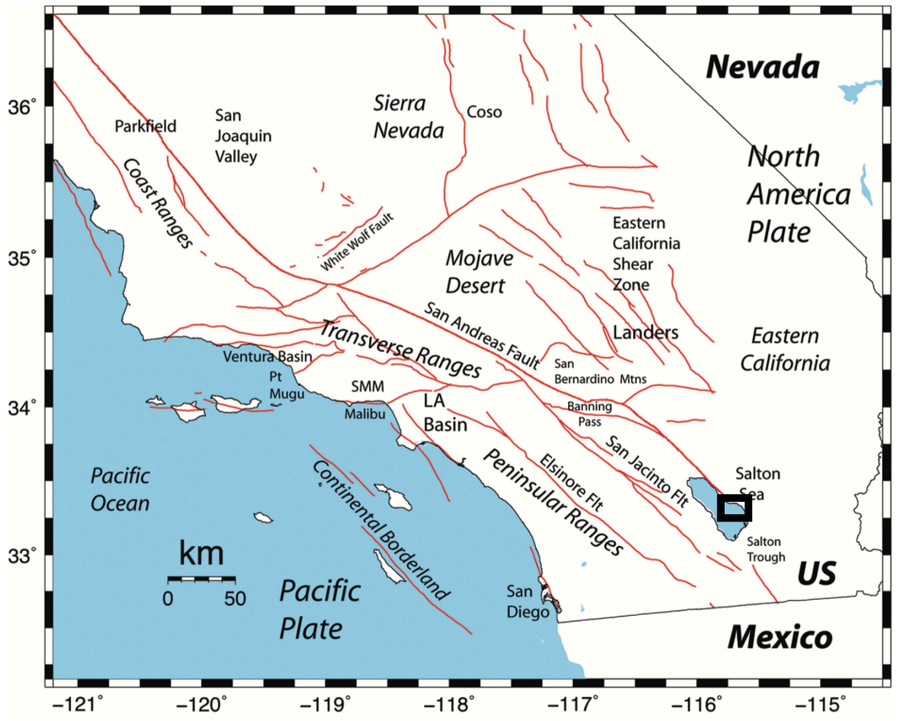
What do changing earthquake probabilities look like in time?

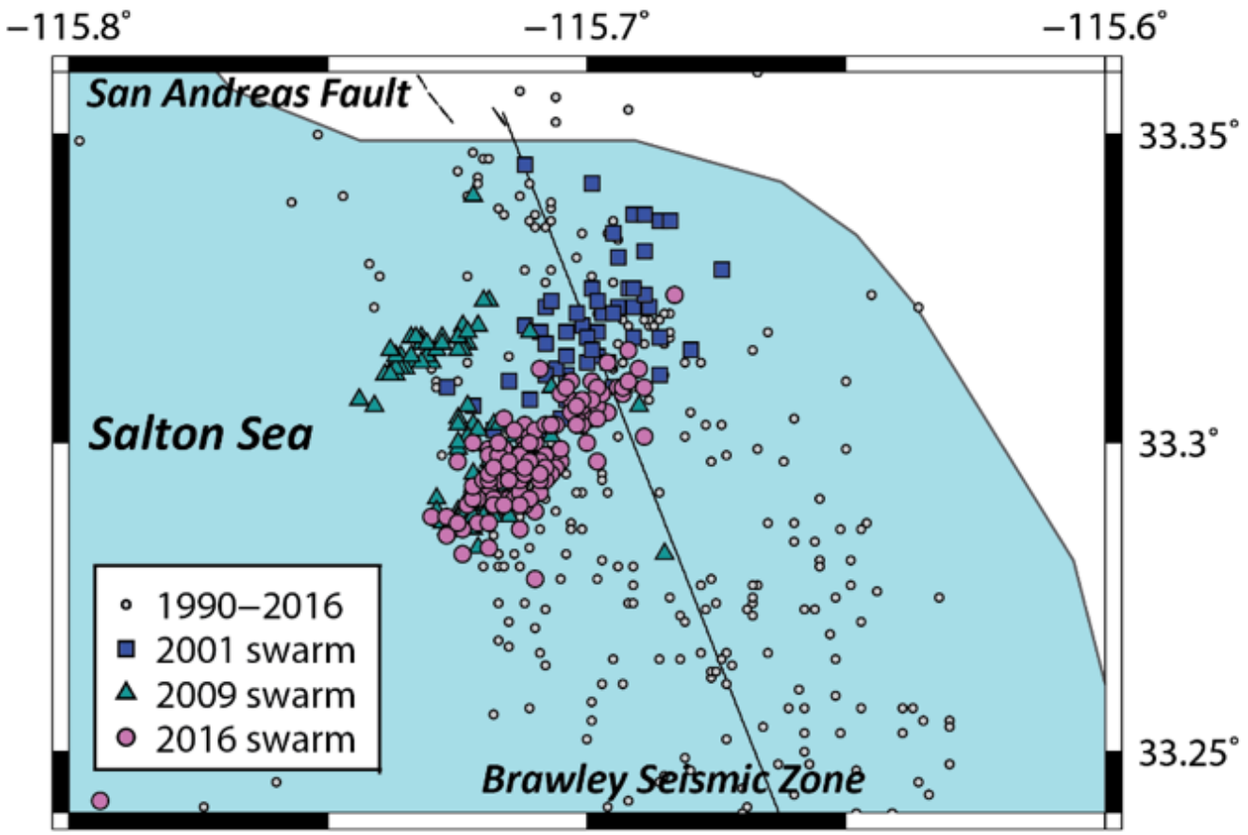


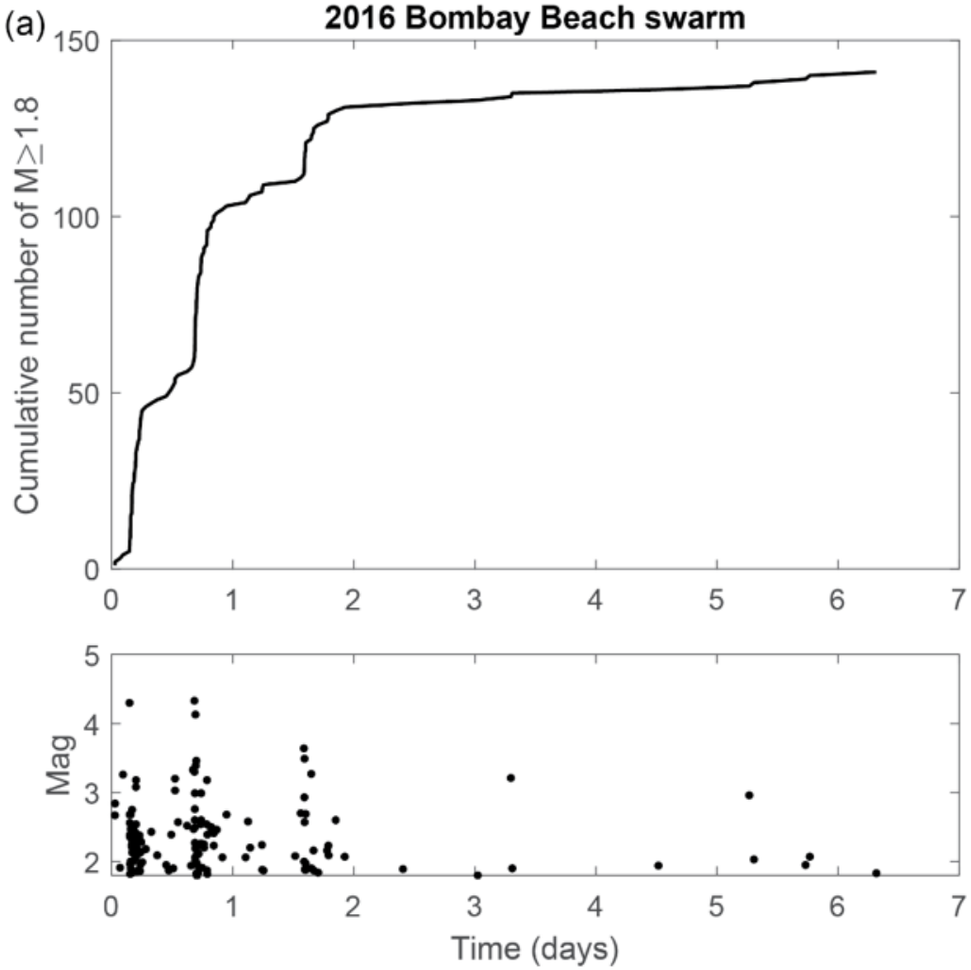
Field and Milner (2018)

Even though foreshocks are not predictive of earthquake size, foreshock/aftershock statistics can give orders of magnitude changes in the probabilities for future earthquakes of all sizes.

The 2016 Bombay Beach Swarm

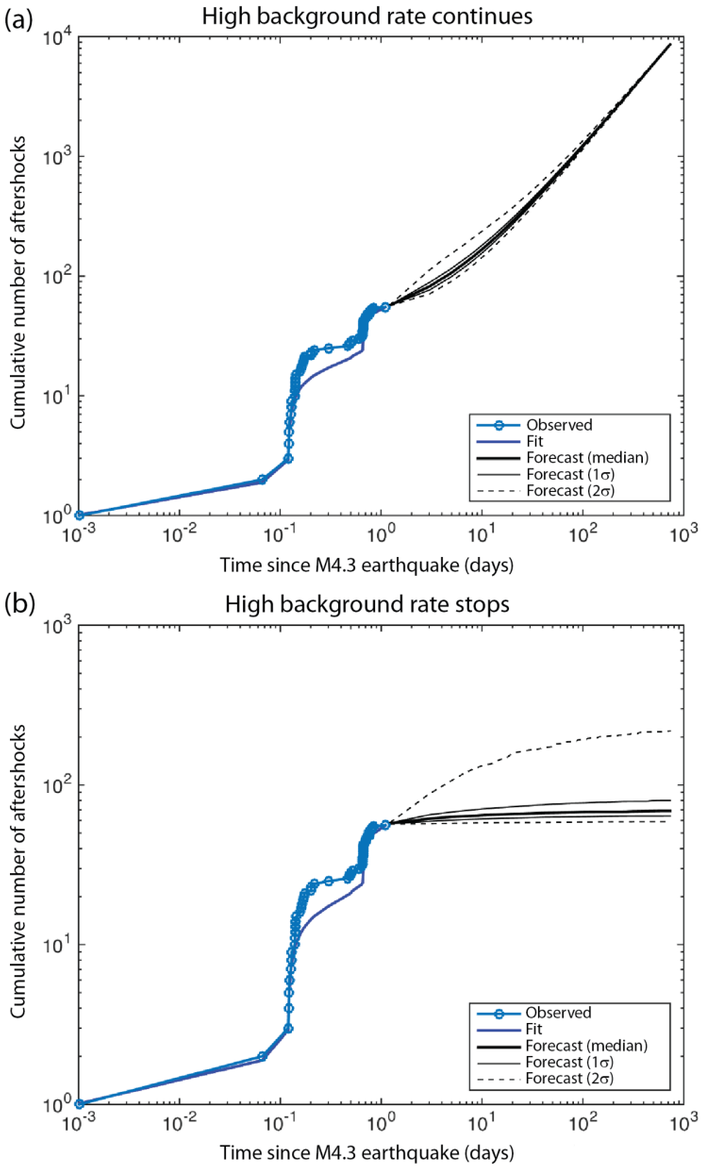




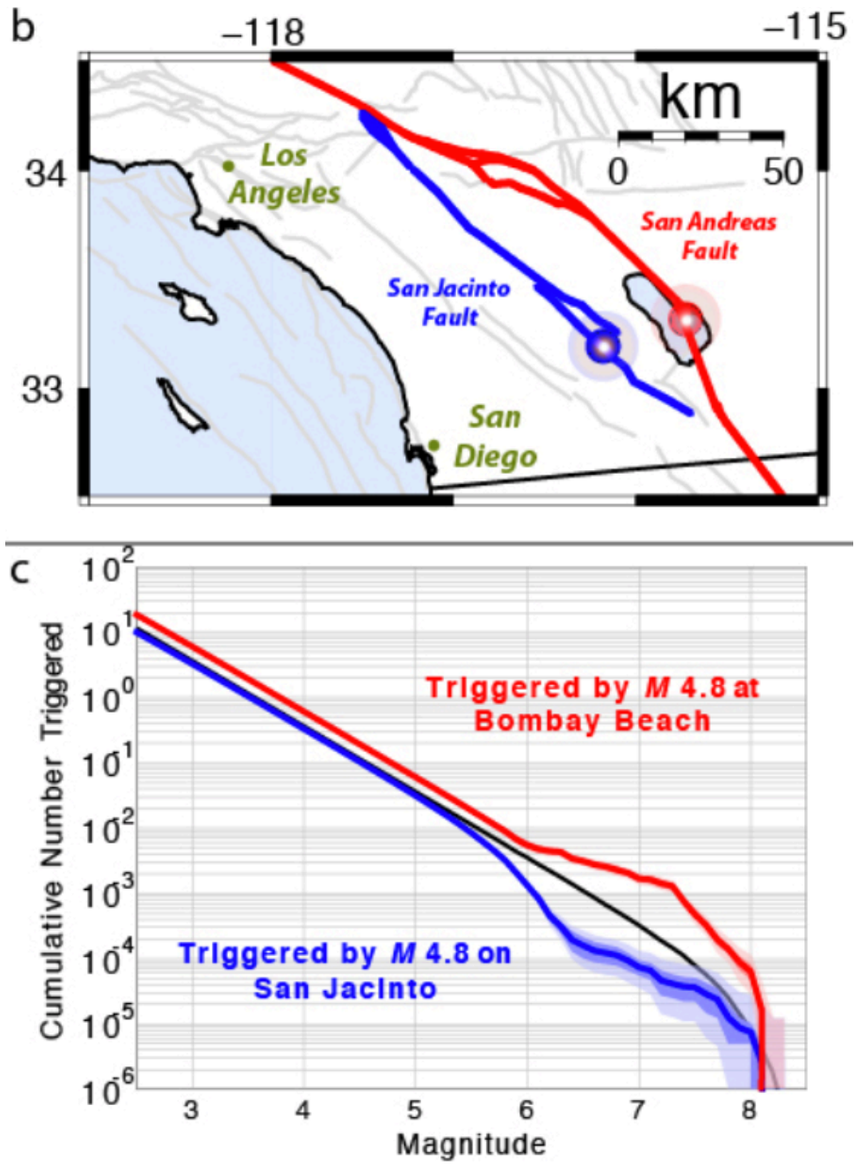


McBride, Llenos, Page, and van der Elst (submitted)

Major forecast uncertainties

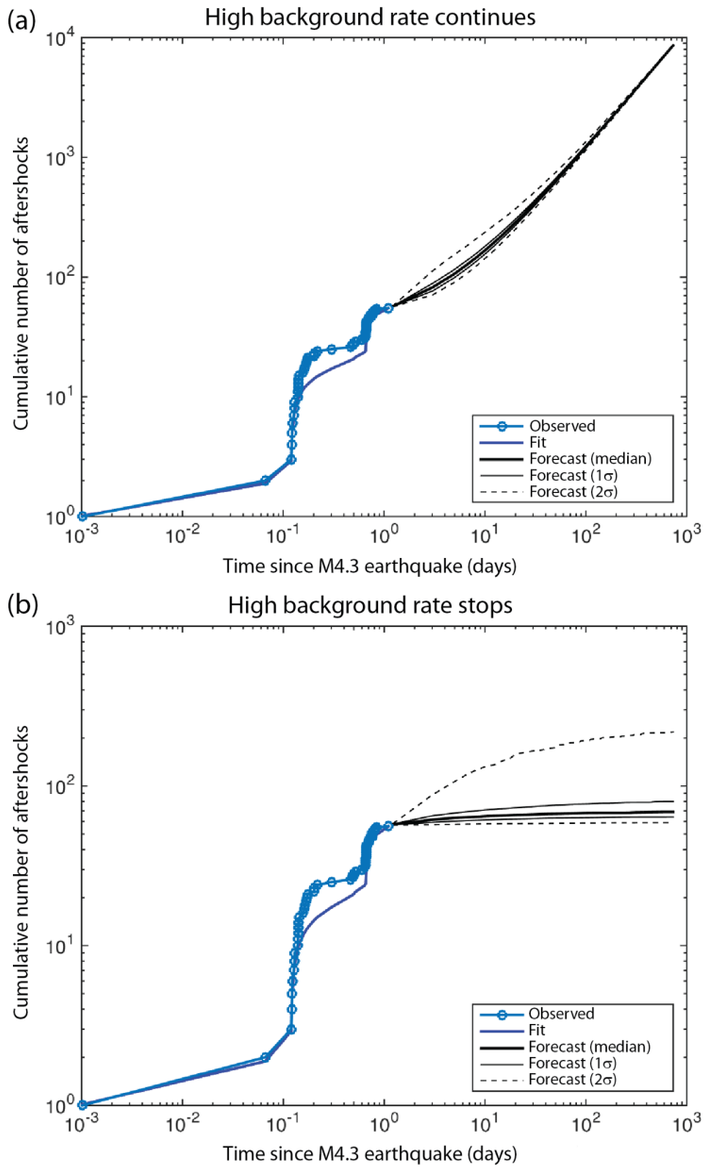


How long will increased rate of earthquakes last?



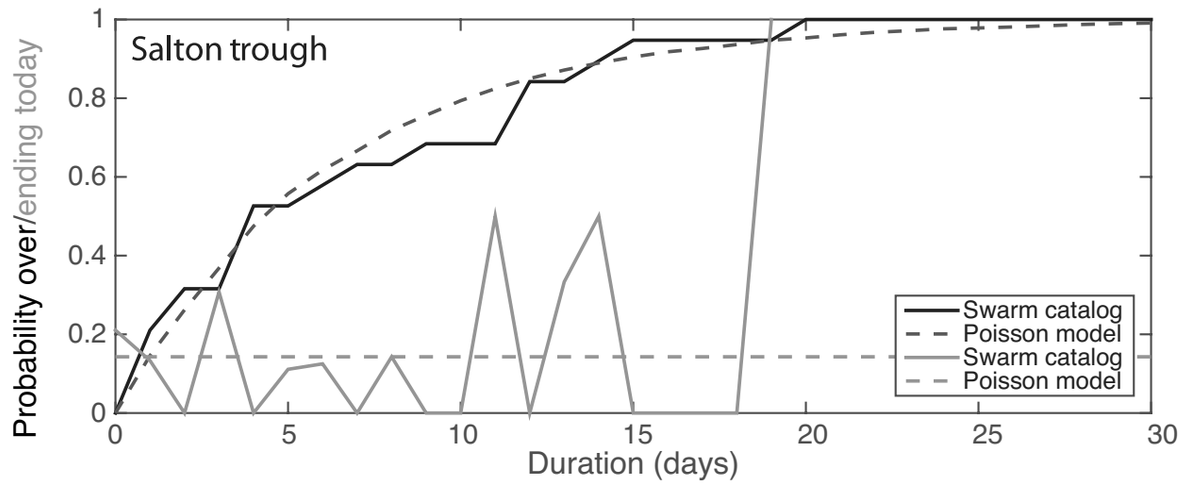
What is the appropriate magnitude distribution for the Southern San Andreas?

Major forecast uncertainties



How long will increased rate of earthquakes last?

Swarm duration in Salton trough are well-fit by a Poisson model

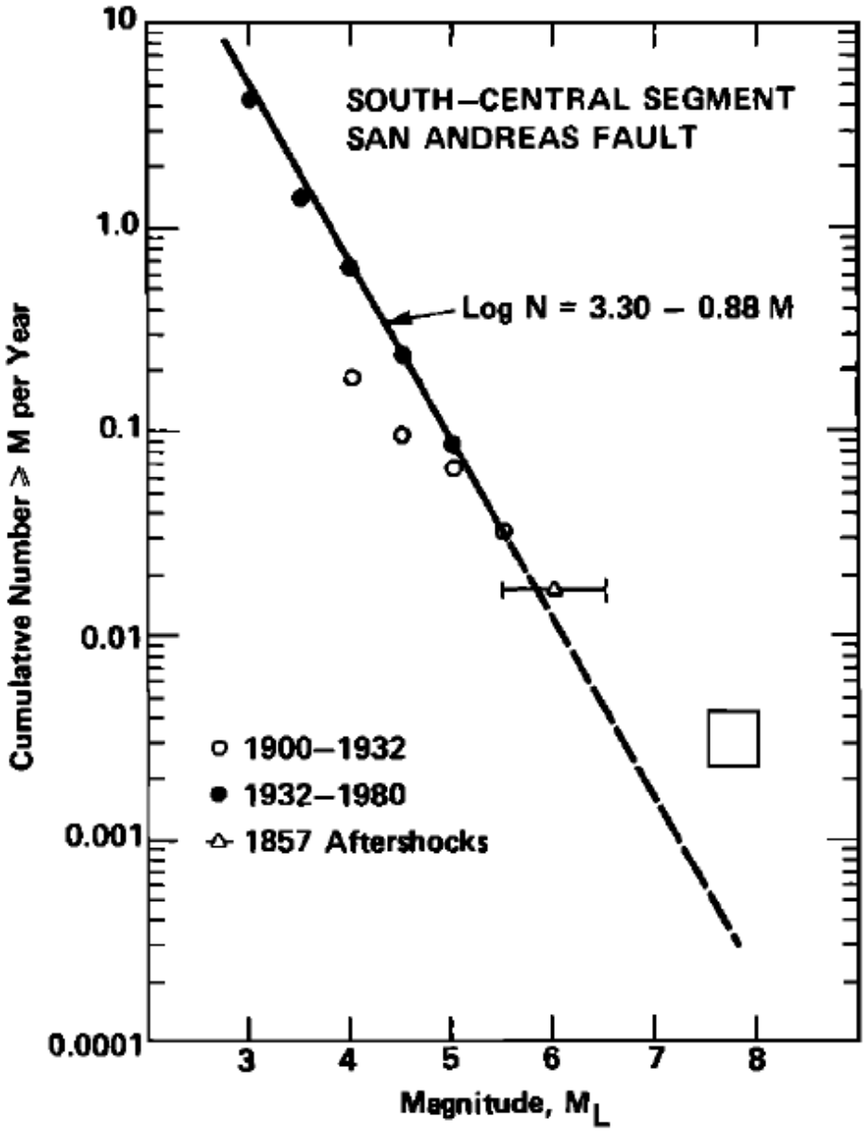


15% chance of terminating each day

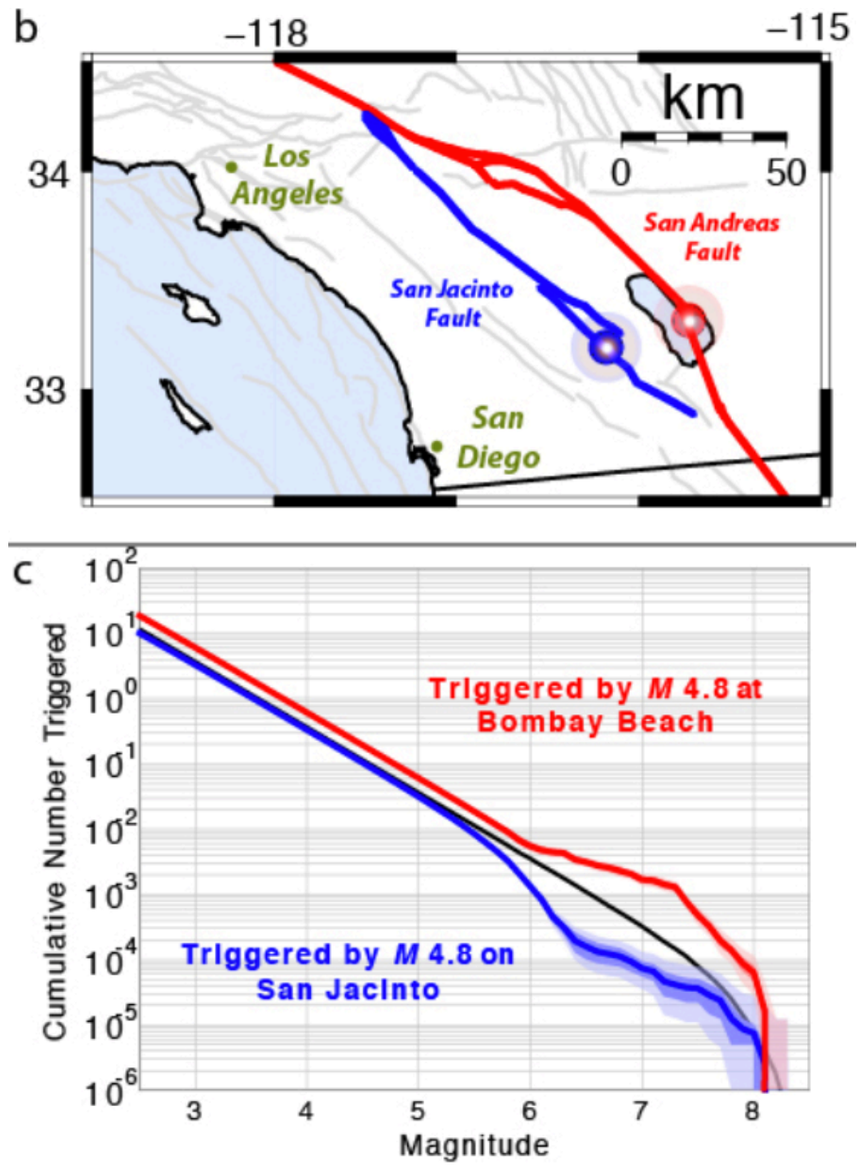
Average length of 7 days

Llenos and van der Elst, 2019

Major forecast uncertainties



Schwartz and Coppersmith (1984)
20 km from South-Central SAF
(Aftershocks of 1952 Kern country and 1971 San Fernando earthquakes removed)



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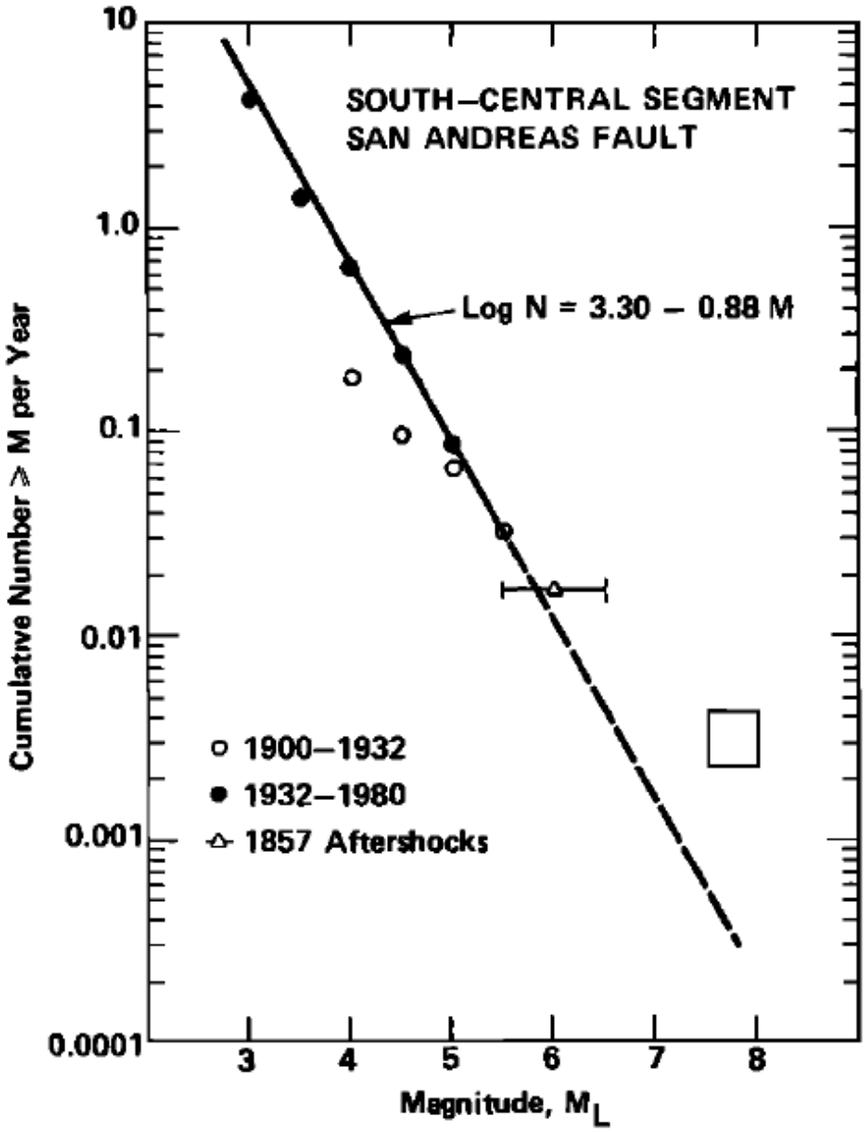

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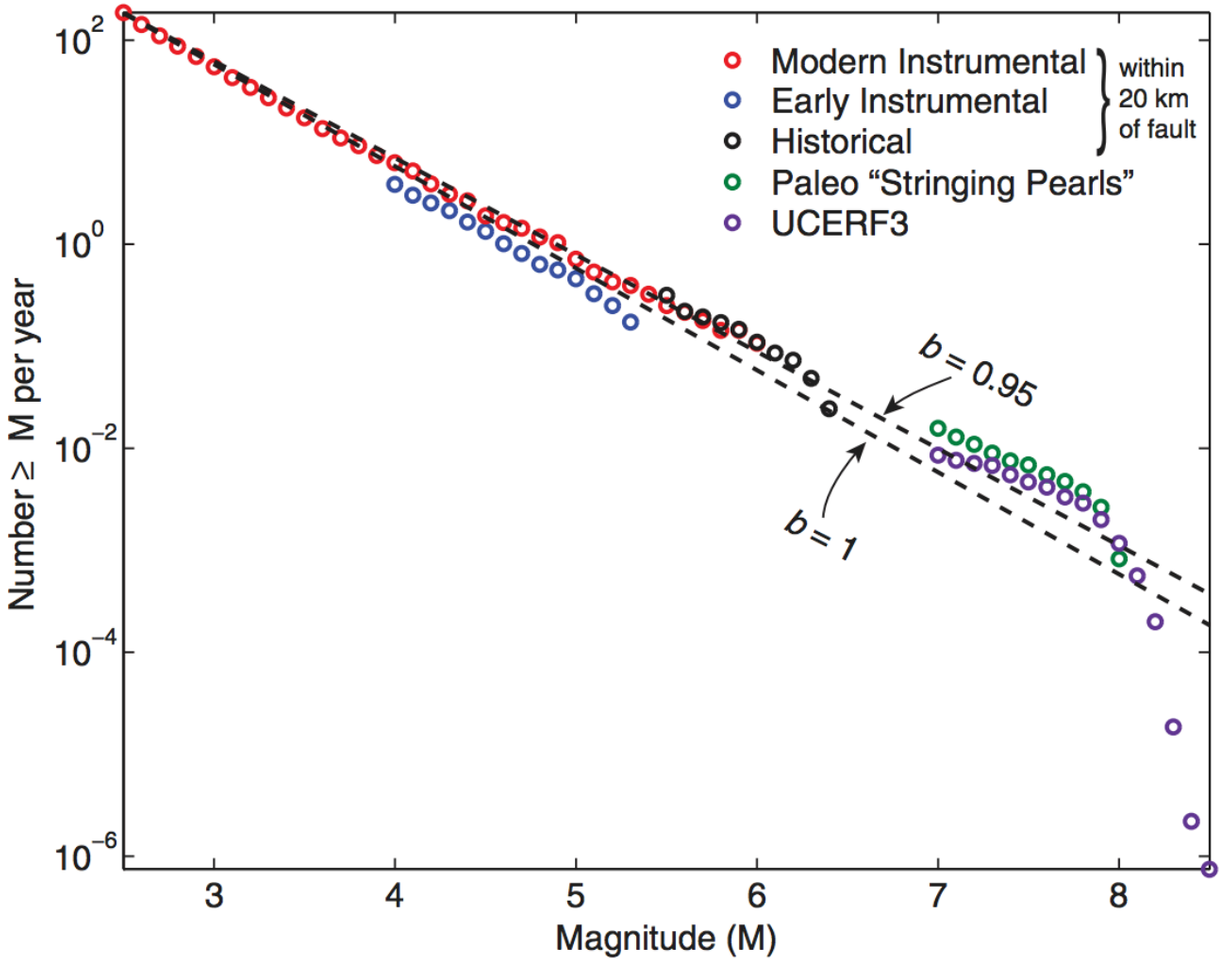


Page and Felzer (2015)

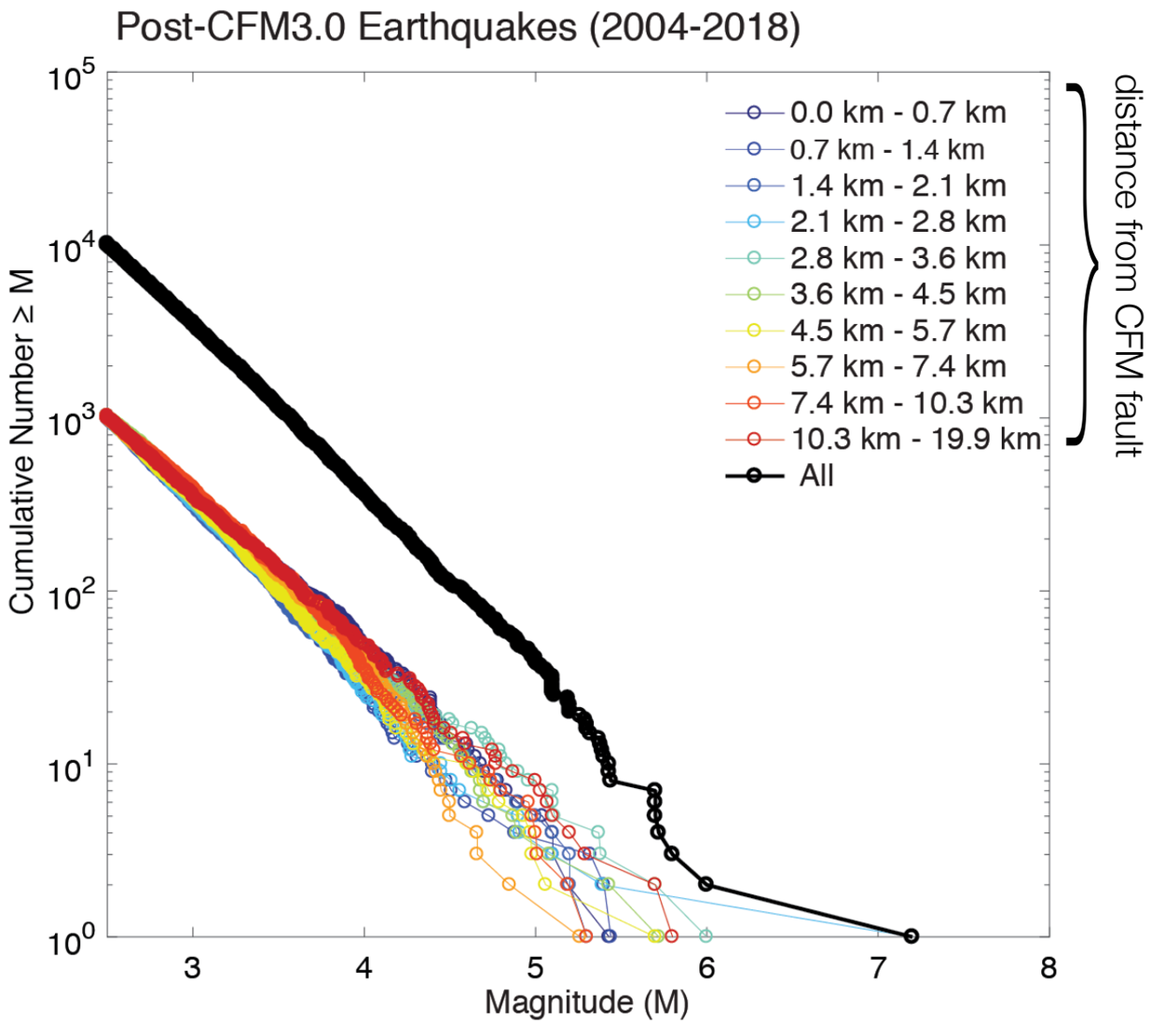
What is the appropriate magnitude distribution for the Southern San Andreas?

Major forecast uncertainties

effect of proximity to San Andreas

In the instrumental catalog, we do **not** see that earthquakes near major faults are larger.

We also do **not** see that earthquakes near faults produce more aftershocks or are more likely to be a foreshock to a larger event.



Page and van der Elst, 2018

Major forecast uncertainties

lead to factor of 30 difference in hazard estimate

U.S. Geological Survey (USGS)
September 27, 2016 ·

Earthquake Swarm Activity Near Bombay Beach

An earthquake swarm near Bombay Beach, California, started on 2016 Sept. 26 at 4:03 am (PDT) in the Brawley Seismic Zone, which lies near the southern terminus of the San Andreas Fault.

The swarm includes 142 events so far (as of 26 Sep 2016, 11:31PM PDT) in the magnitude range M1.4 to M4.3. Relocations of these events show that they are occurring in the depth range 4 to 9 km.

The earthquakes are occurring near a set of north-northeast trending cross-faults in the Salton Sea. The cross-faults are part of a fault network that connect the southernmost end of the San Andreas fault with the Imperial fault. Some of the cross-faults are oriented such that they add stress to the San Andreas fault and the San Jacinto fault system when they rupture in small earthquakes like those in the ongoing swarm.

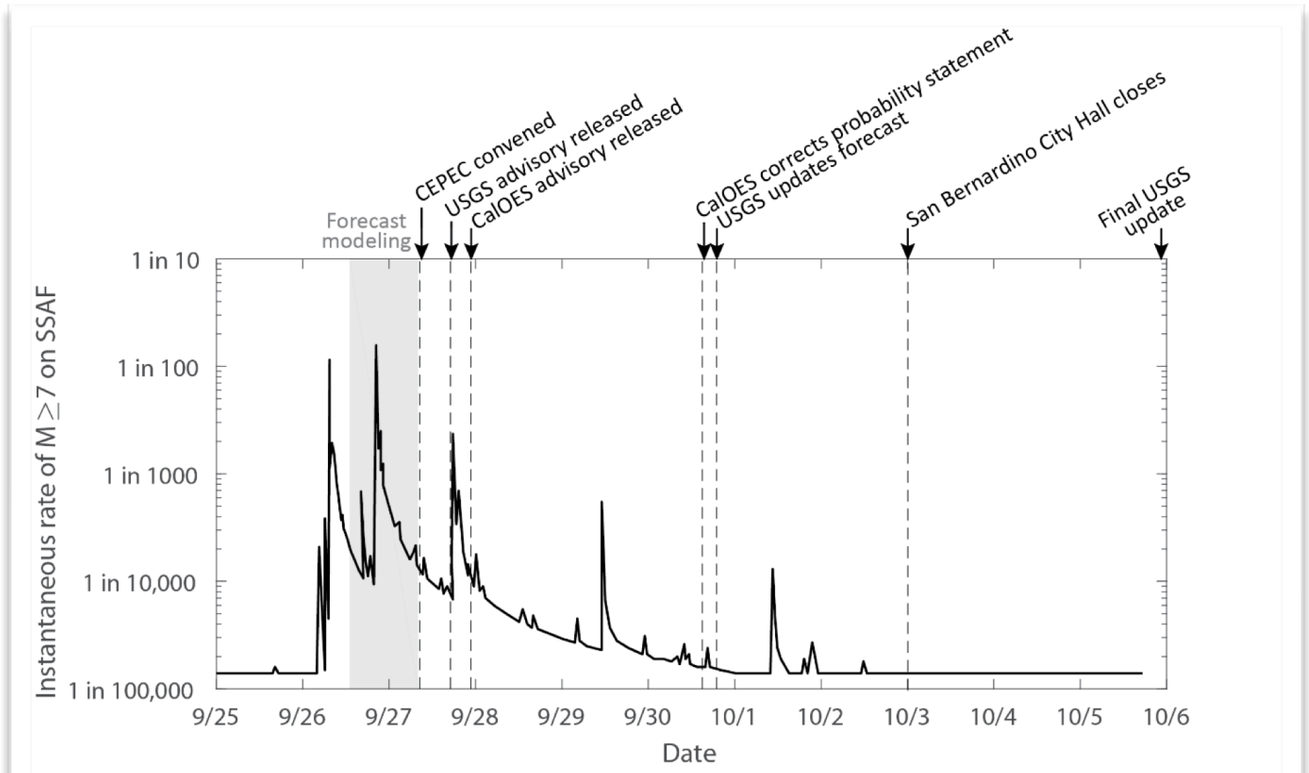
Earthquake Swarms & Probabilities

Swarm-like activity in this region has occurred in the past, so this week's activity, in and of itself, is not necessarily cause for alarm.

Preliminary calculations indicate that, as of 10:00 am (PDT) Sept. 27, 2016, there is a 0.03%-1% chance (1 in 3000 to 1 in 100) of a magnitude 7 or greater earthquake being triggered on the Southern San Andreas fault within the next next seven days through October 4, with the likelihood decreasing over time. This probability range is estimated using several models developed in California to assess foreshock/aftershock probabilities.

Learn more at: http://earthquake.usgs.gov/

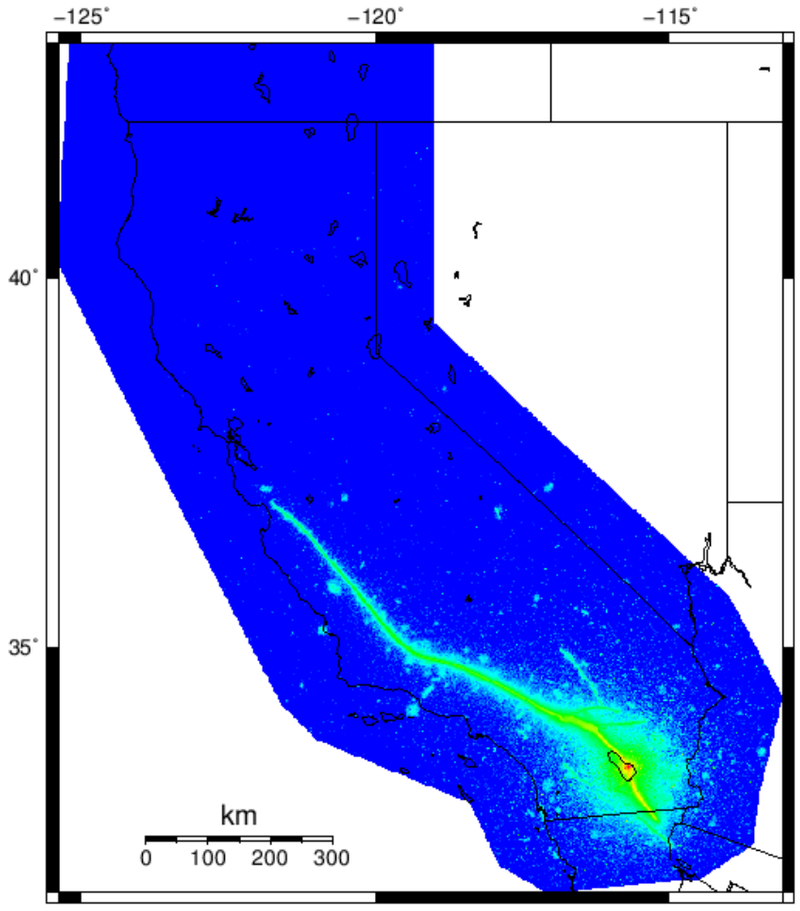
0.03% to 1% chance of M≥7 earthquake next 7 days

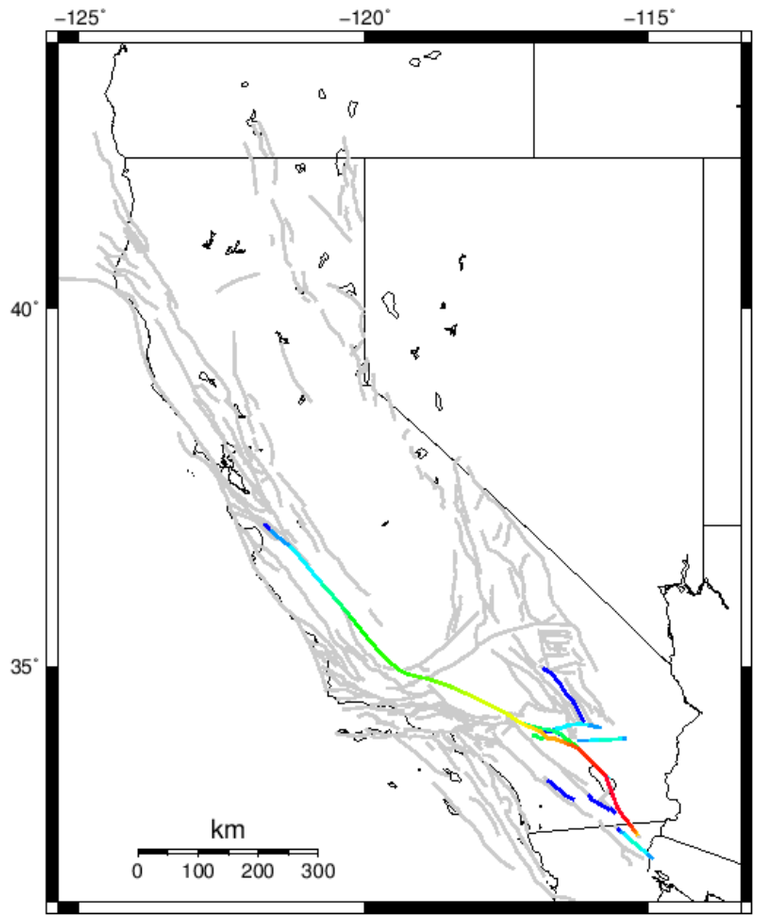


Probabilities decay very quickly

UCERF3 Forecast following Bombay Swarm

What faults are likely to be triggered?



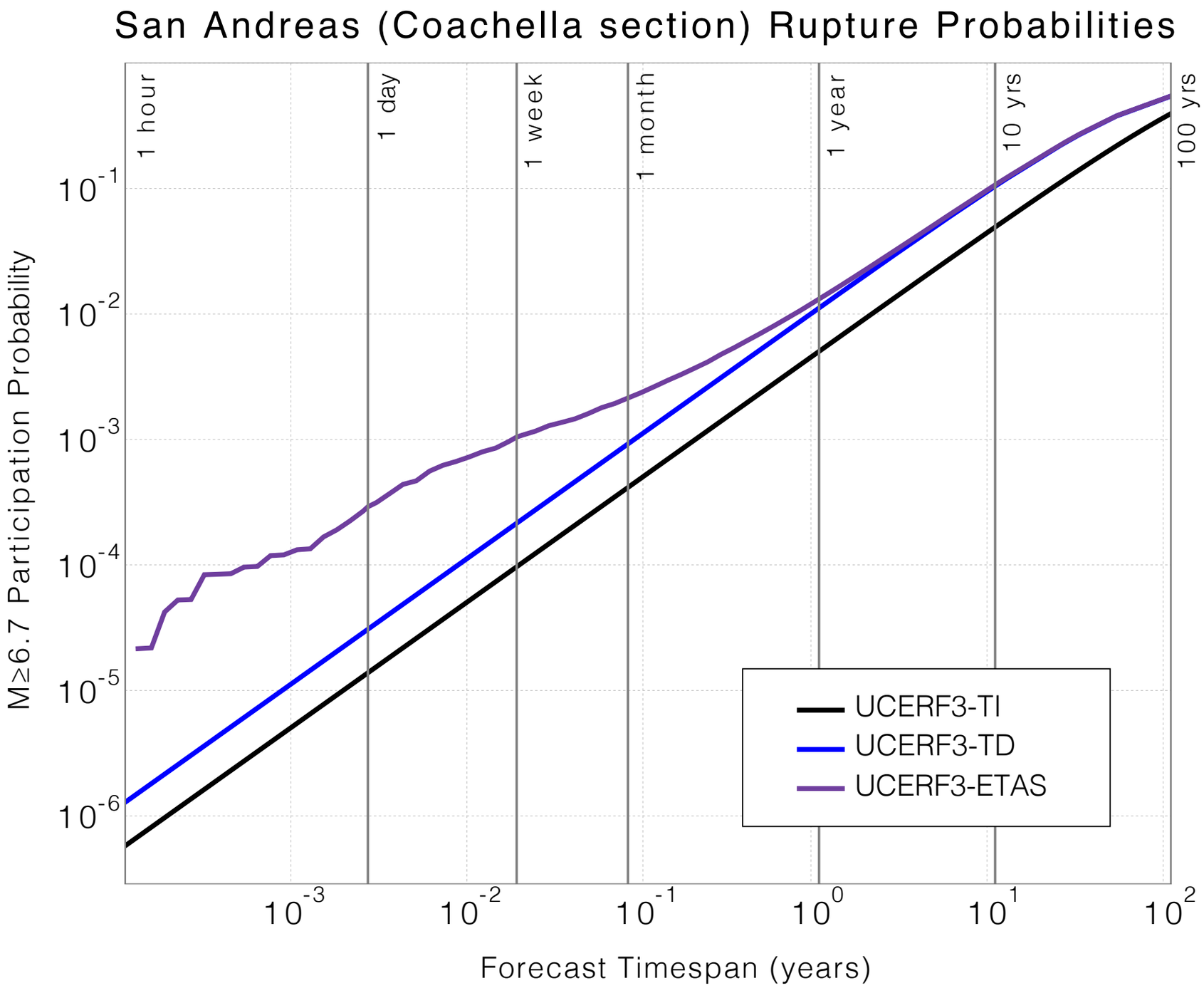


Aftershock forecast following Bombay Beach swarm

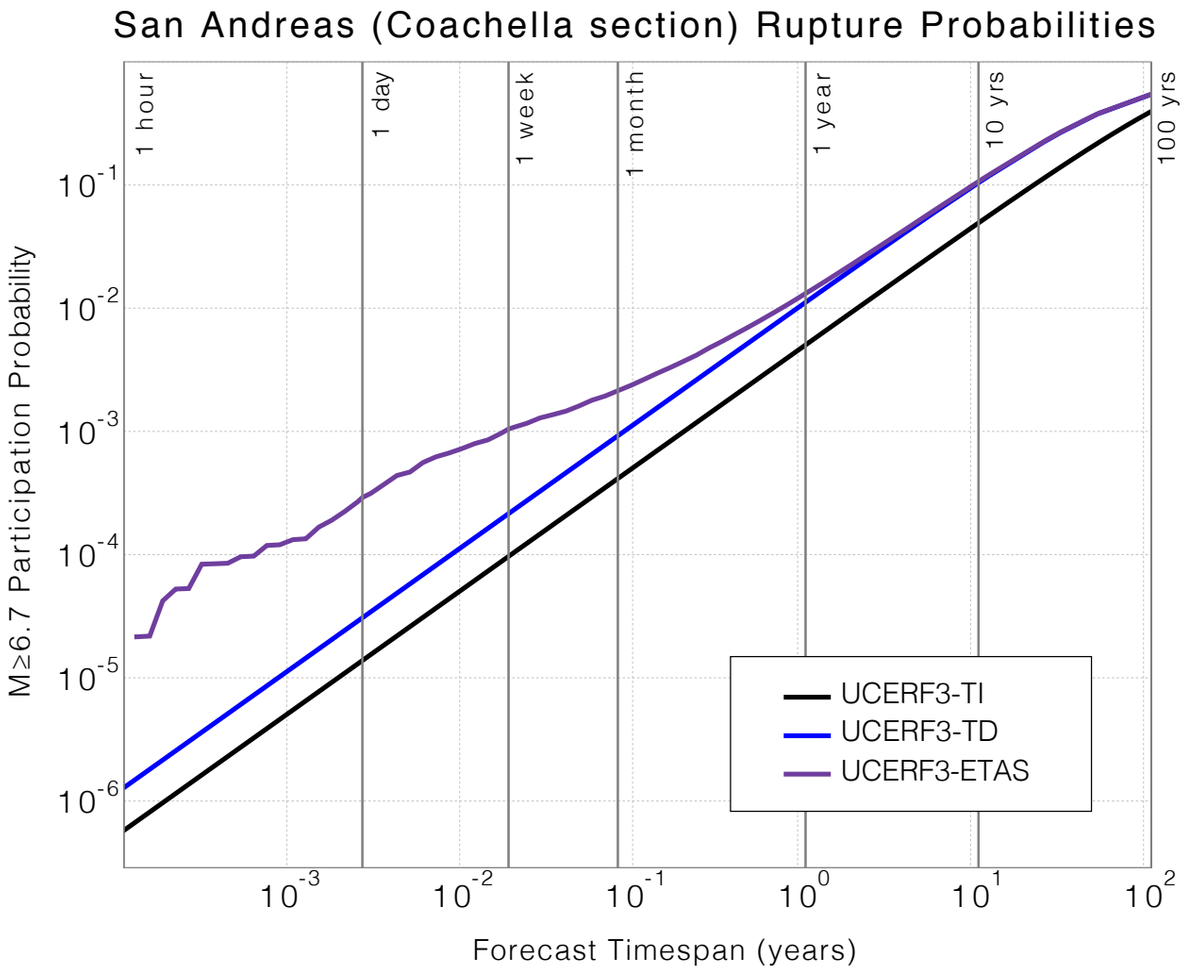
Average of 100,000 simulations

UCERF3 Forecast following Bombay Swarm

How are probabilities elevated compared to long-term rate?



Conclusions



During seismic swarms, the chance of a large earthquake can change by orders of magnitude

These elevated probabilities decay quickly

Proximity to major faults is a concern

(but it is not proven that proximity to major faults elevates foreshock probability)

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