LA-UR-12-22485
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Intended for: International Conference on Nonlinear Elastic Materials, 2012-07-02/2012-07-06 (Cefalu, ---, Italy)

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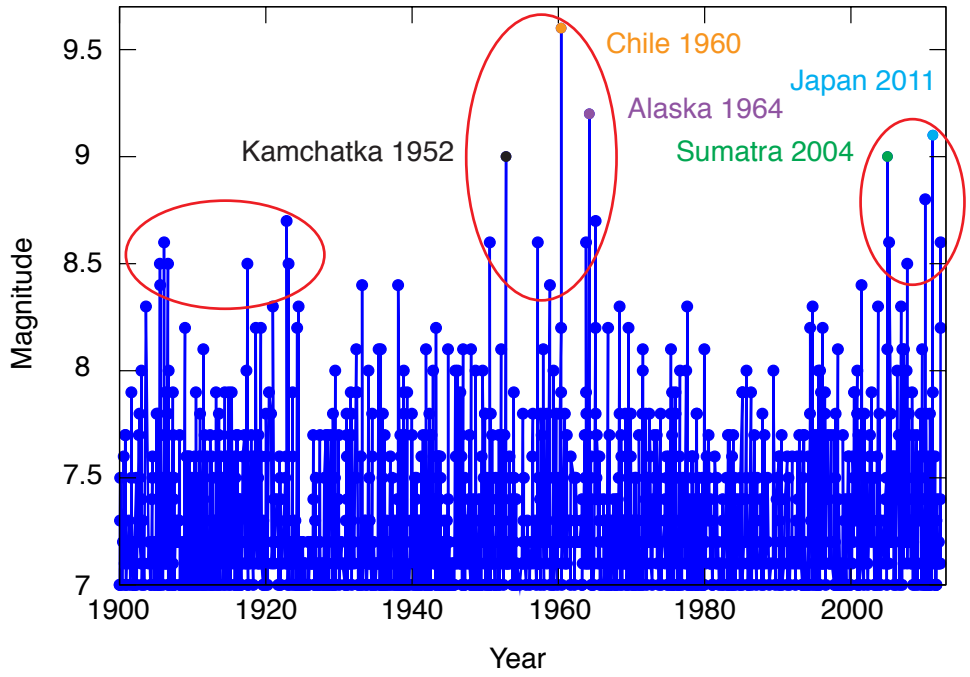
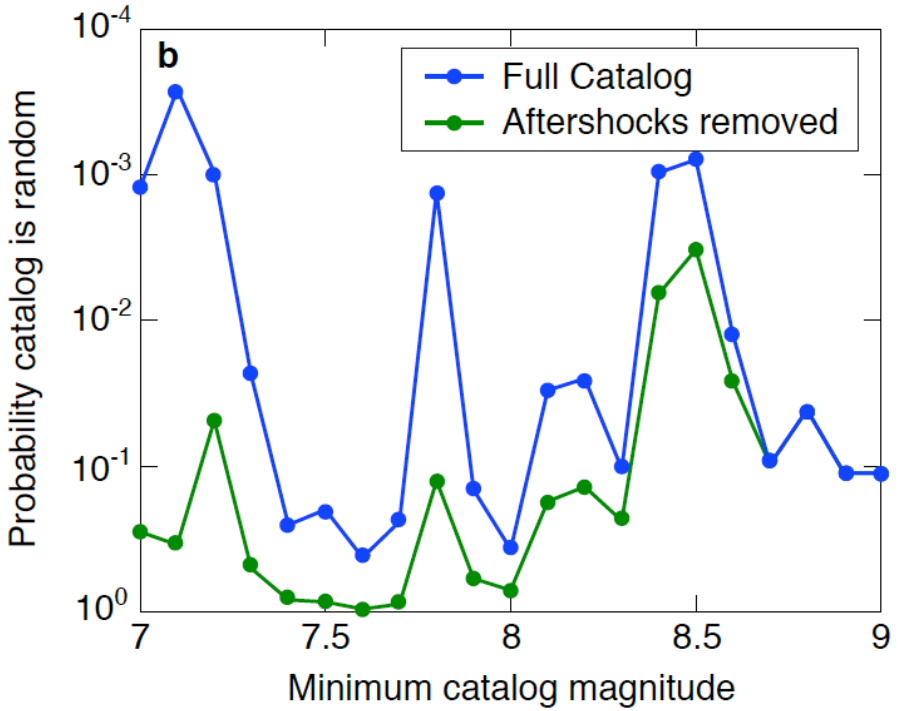
Nonlinear Dynamical Triggering of Great Earthquakes

Eric G. Daub, Eli Ben-Naim, Robert A. Guyer, Paul A. Johnson

Los Alamos National Laboratory

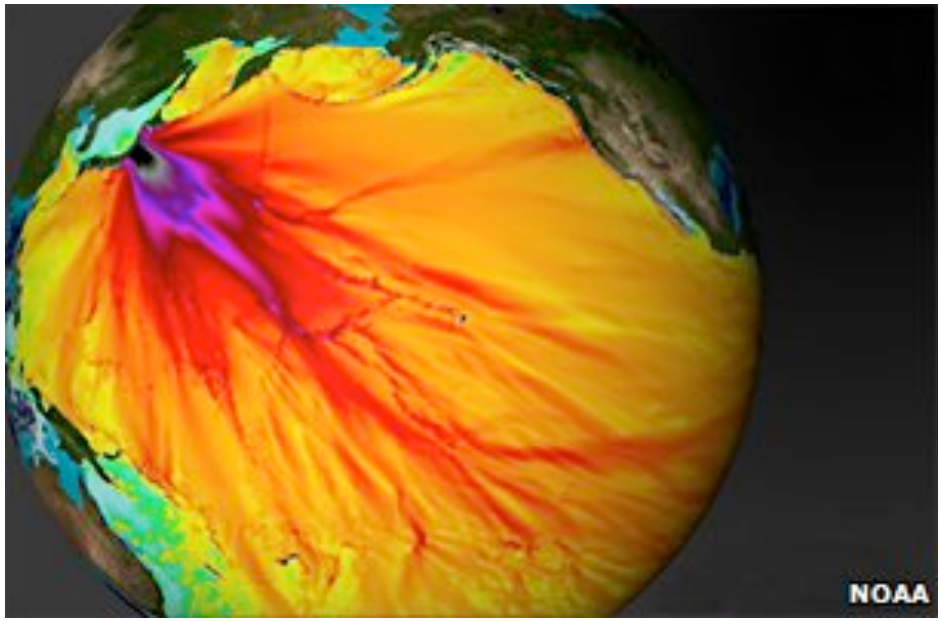




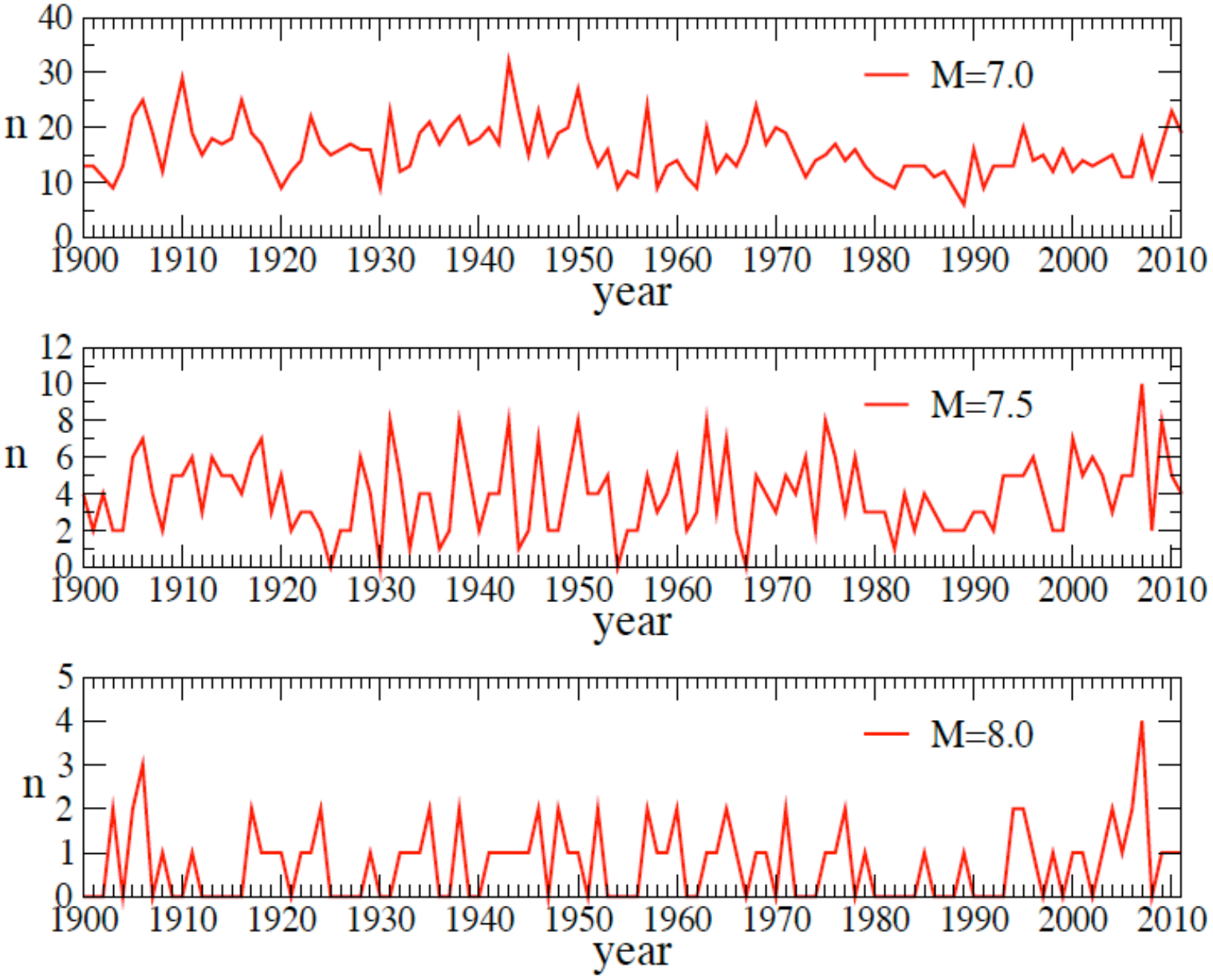
Great Earthquakes

Study largest earthquakes we have on record (“Great Earthquakes”). Rare events (84 with M ≥ 8, 5 with M ≥ 9)

Events are global, cause strong shaking and tsunamis. Don’t know much about their occurrence due to little data.



Global Occurrence of Earthquakes, 1900-Present



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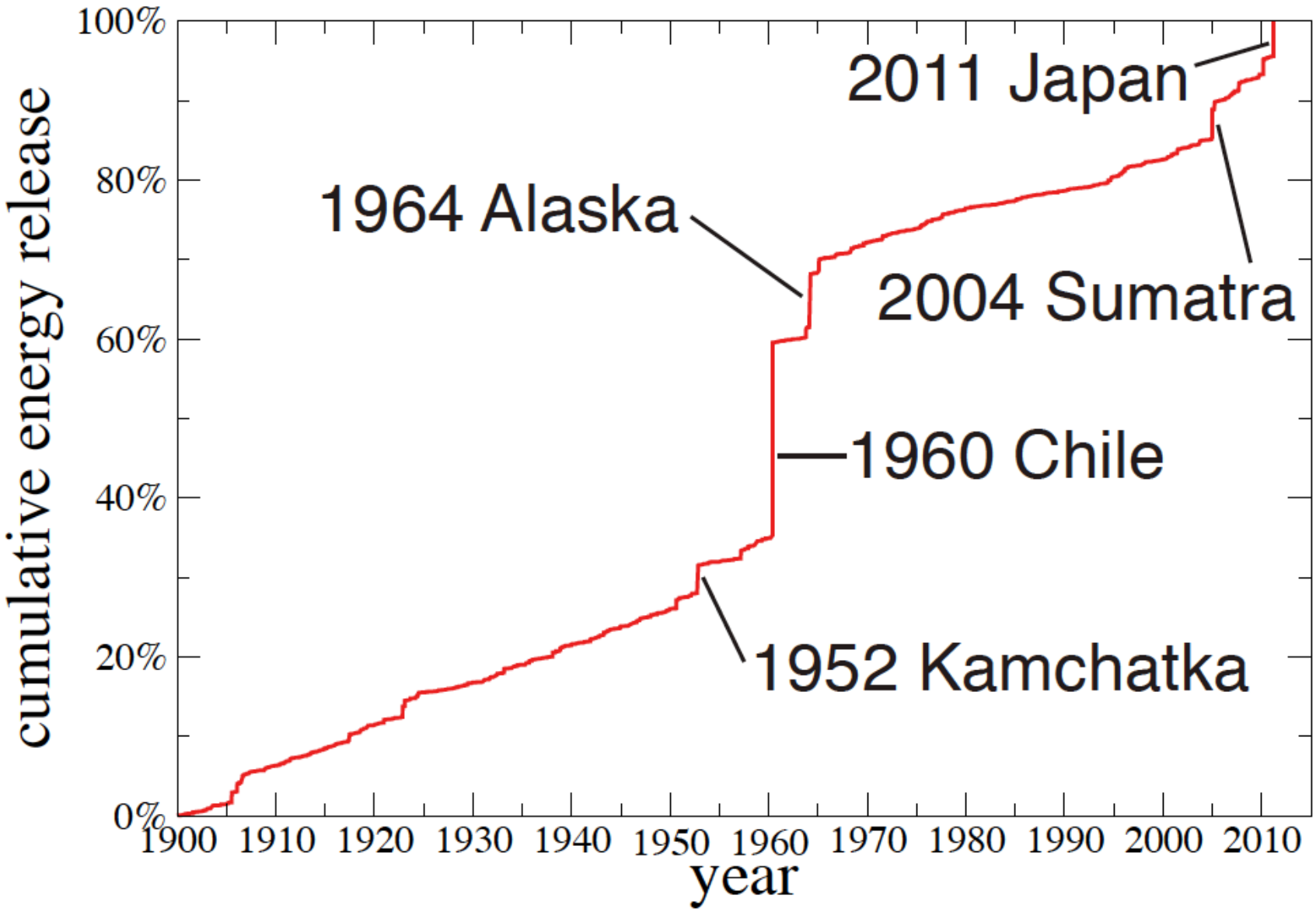
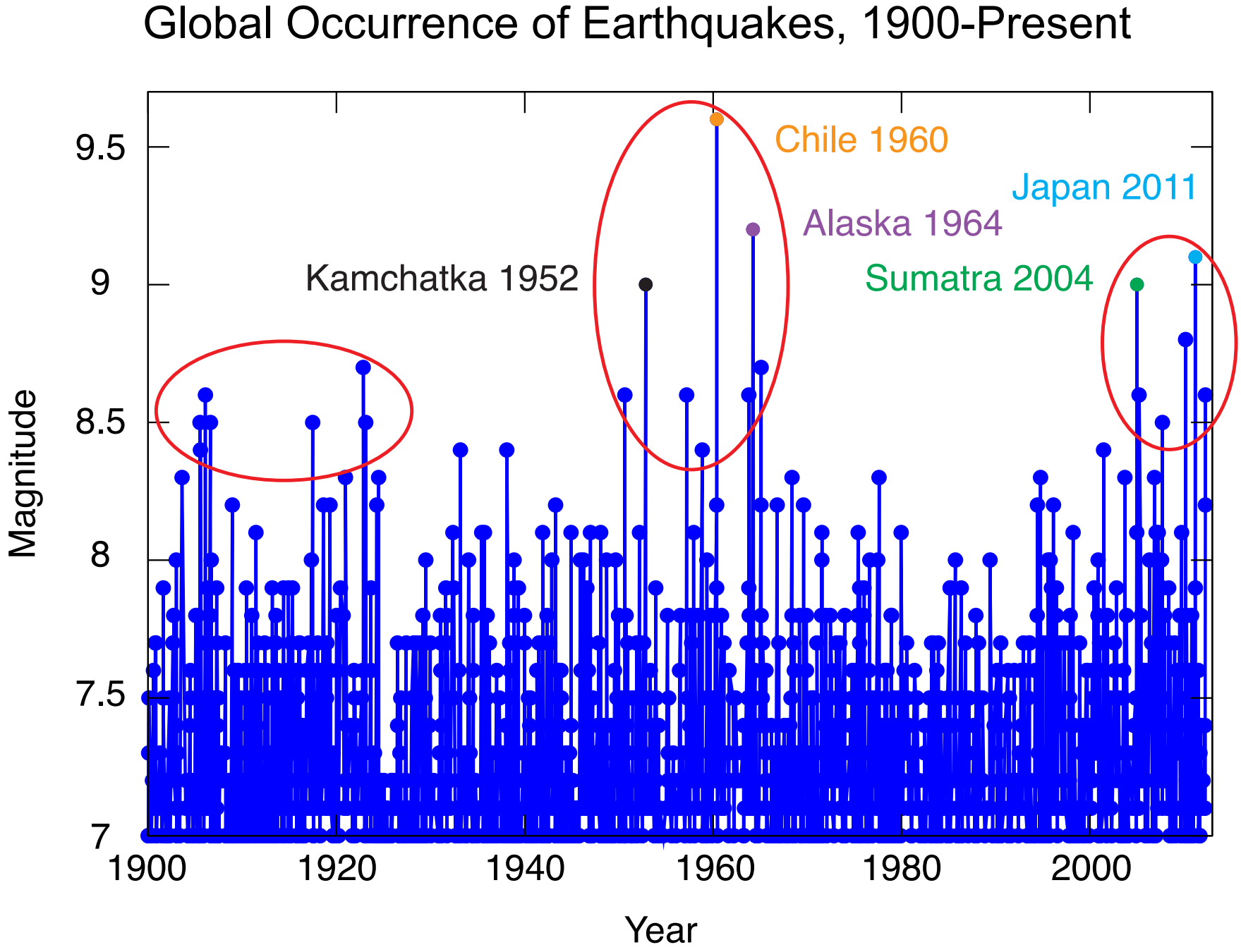



Global Occurrence of Earthquakes, 1900-Present
Chile 1960
Japan 2011
Alaska 1964
Kamchatka 1952
Sumatra 2004
Magnitude
9.5
9
8.5
8
7.5
7
1900
1920
1940
1960
1980
2000
Year

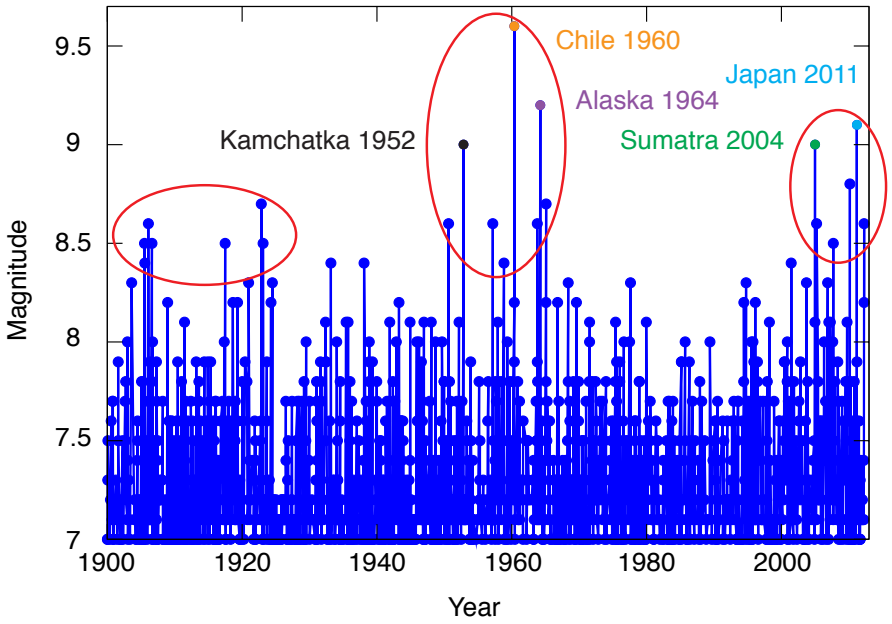
Global Occurrence of Earthquakes, 1900-Present

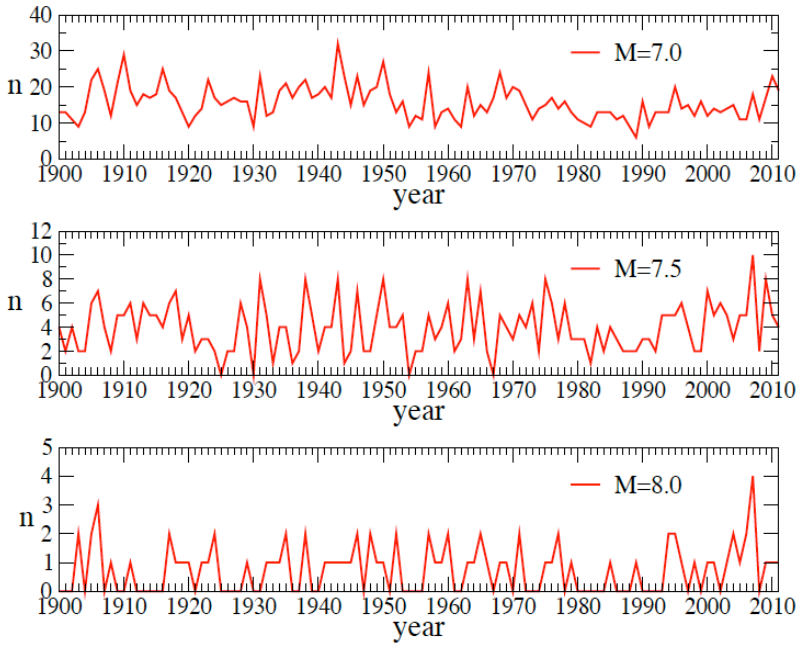
What do we make of this?

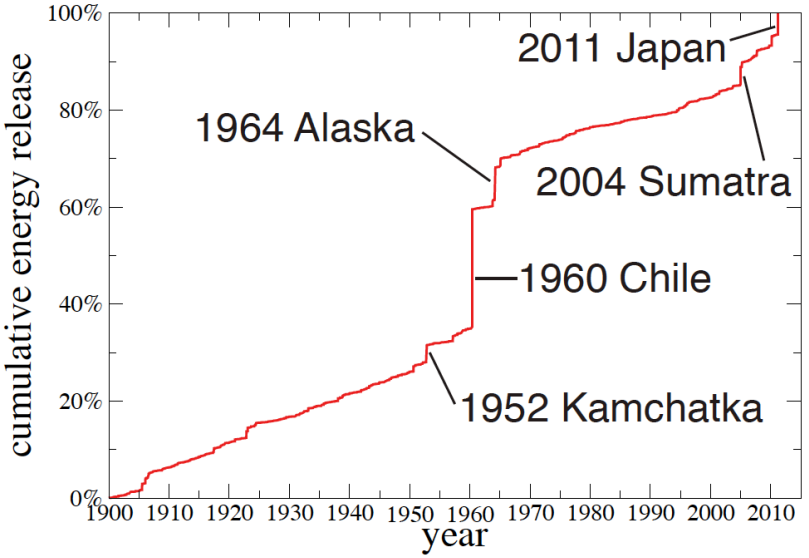
Do events cluster? Coincidence? Artifact of short record?

In other words: what is the chance of observing the earthquake record if events are random (i.e. event times completely uncorrelated)?

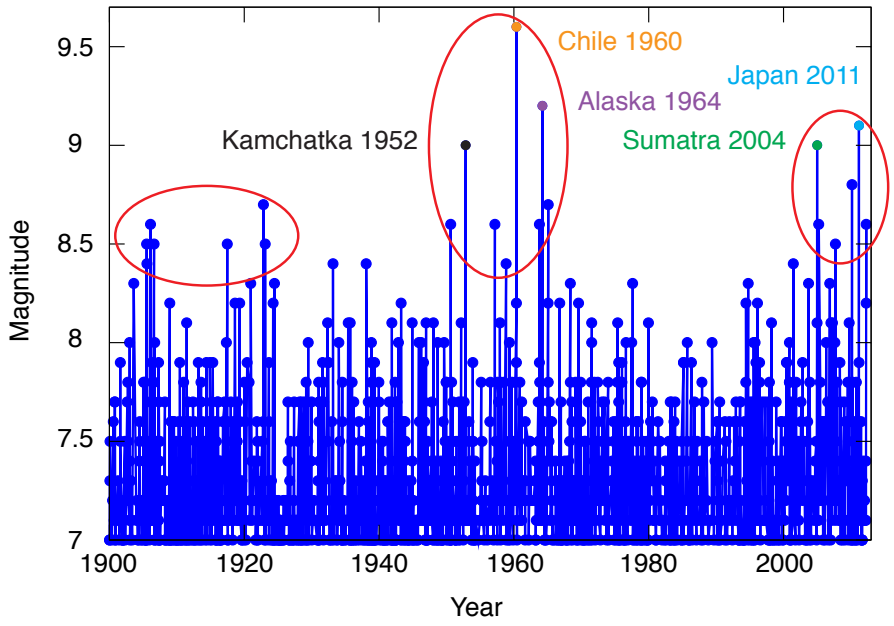
Implications for physics?



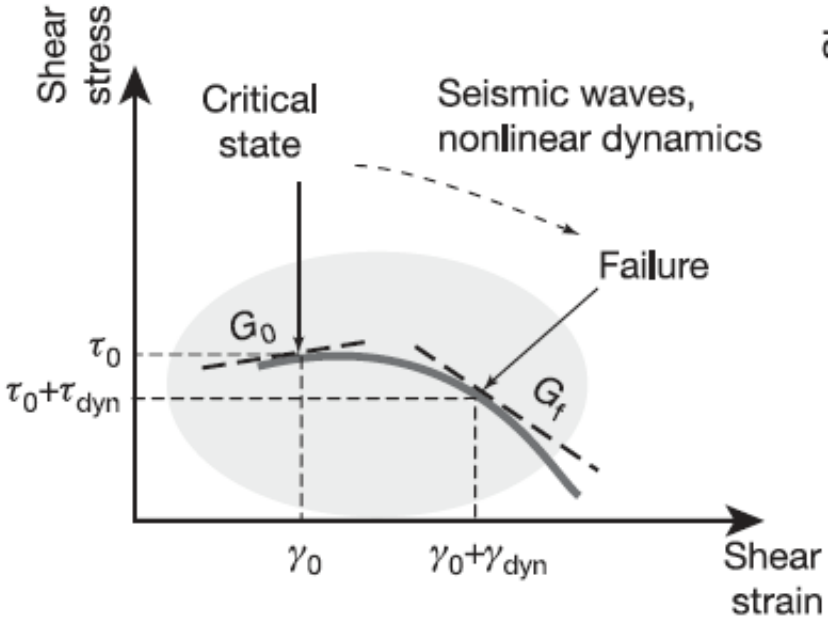




Part 1: Testing for clustering



Part 2: Physics of triggering



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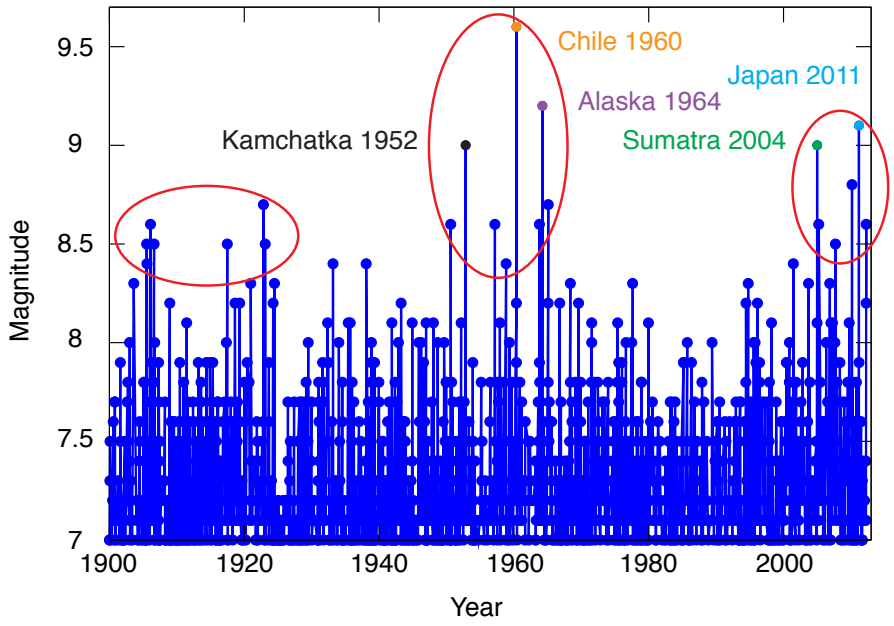
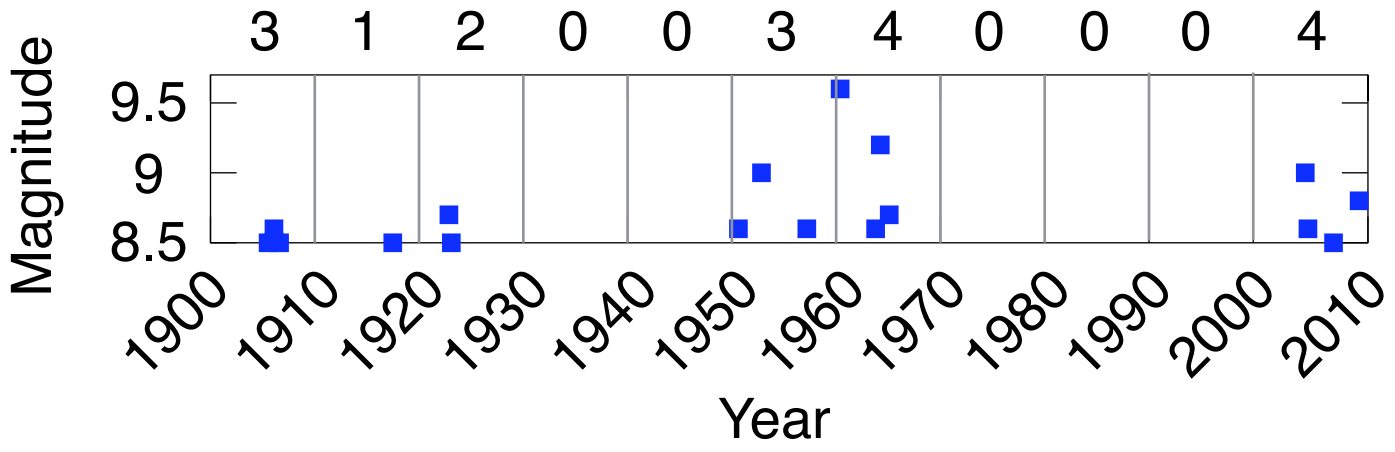


Is this spike unexpected?

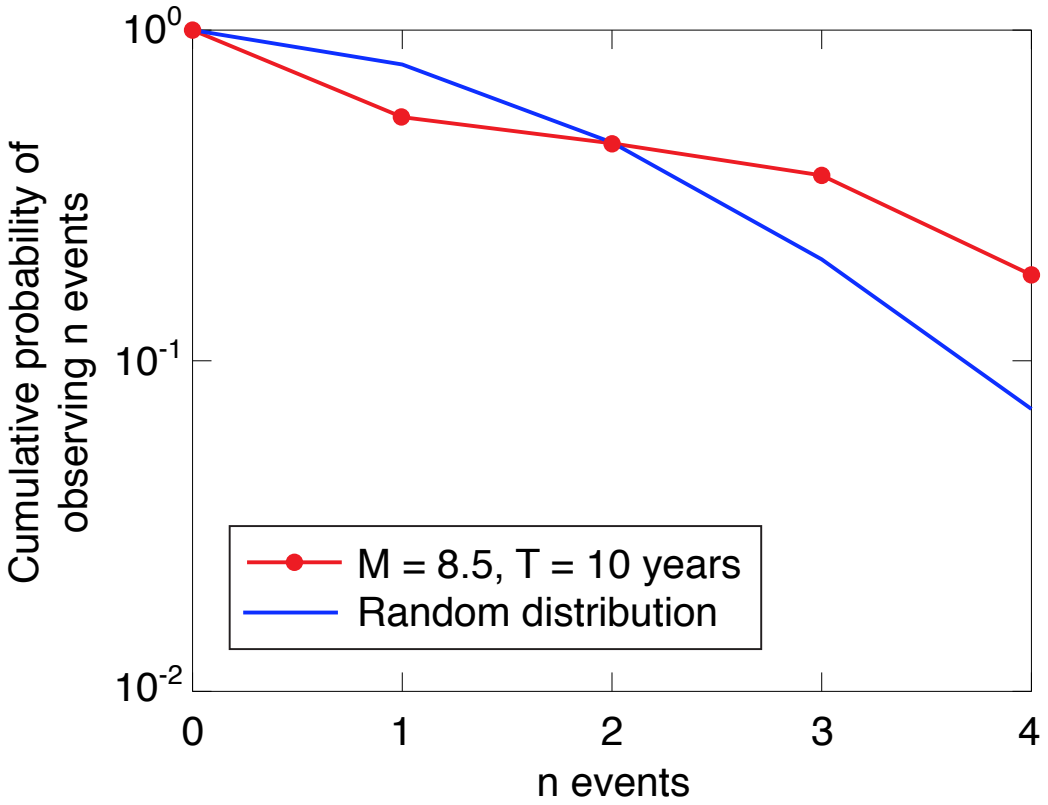


Choose magnitude threshold M

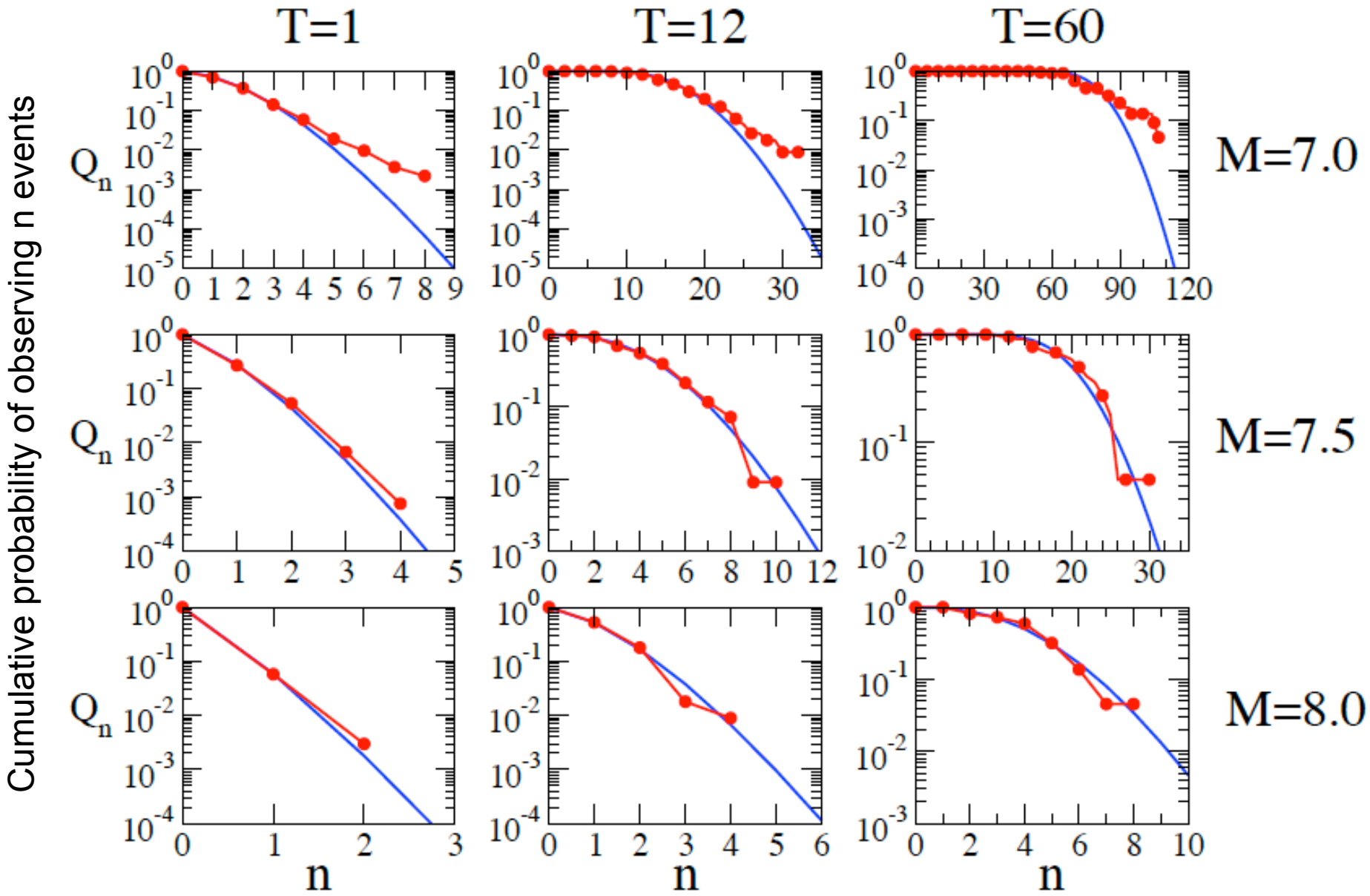
Divide catalog into bin size T

Count up number of events in each bin, and compare with expected distribution for a Poisson process.

Example shown for M=8.5, T = 10 years



PAGER Catalog Analysis

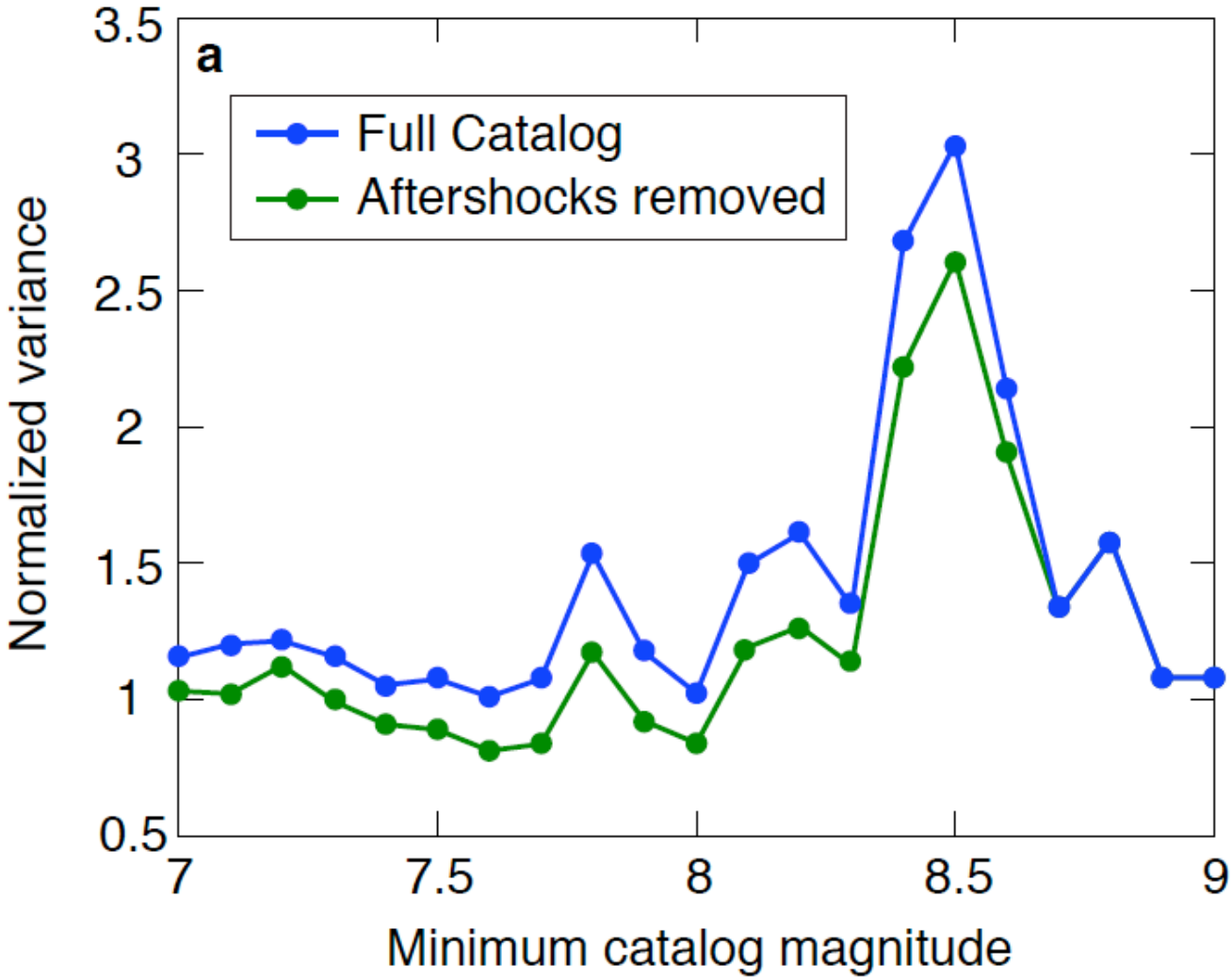


Alternative statistical tests?

Calculate normalized variance based on recurrence time:

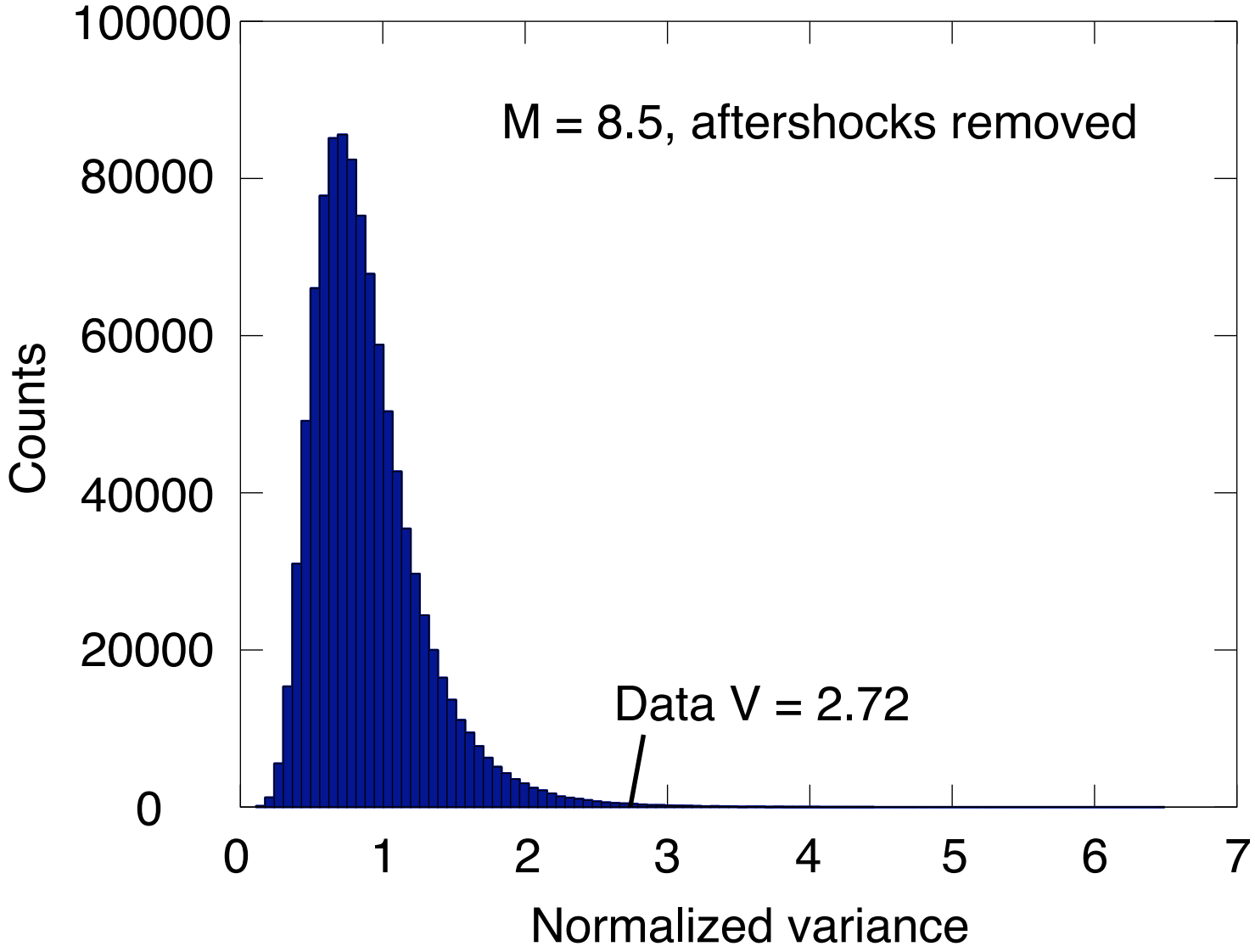
$$V = \frac{\langle t^2 \rangle - \langle t \rangle^2}{\langle t \rangle^2}$$

Should be close to 1 for a random catalog.



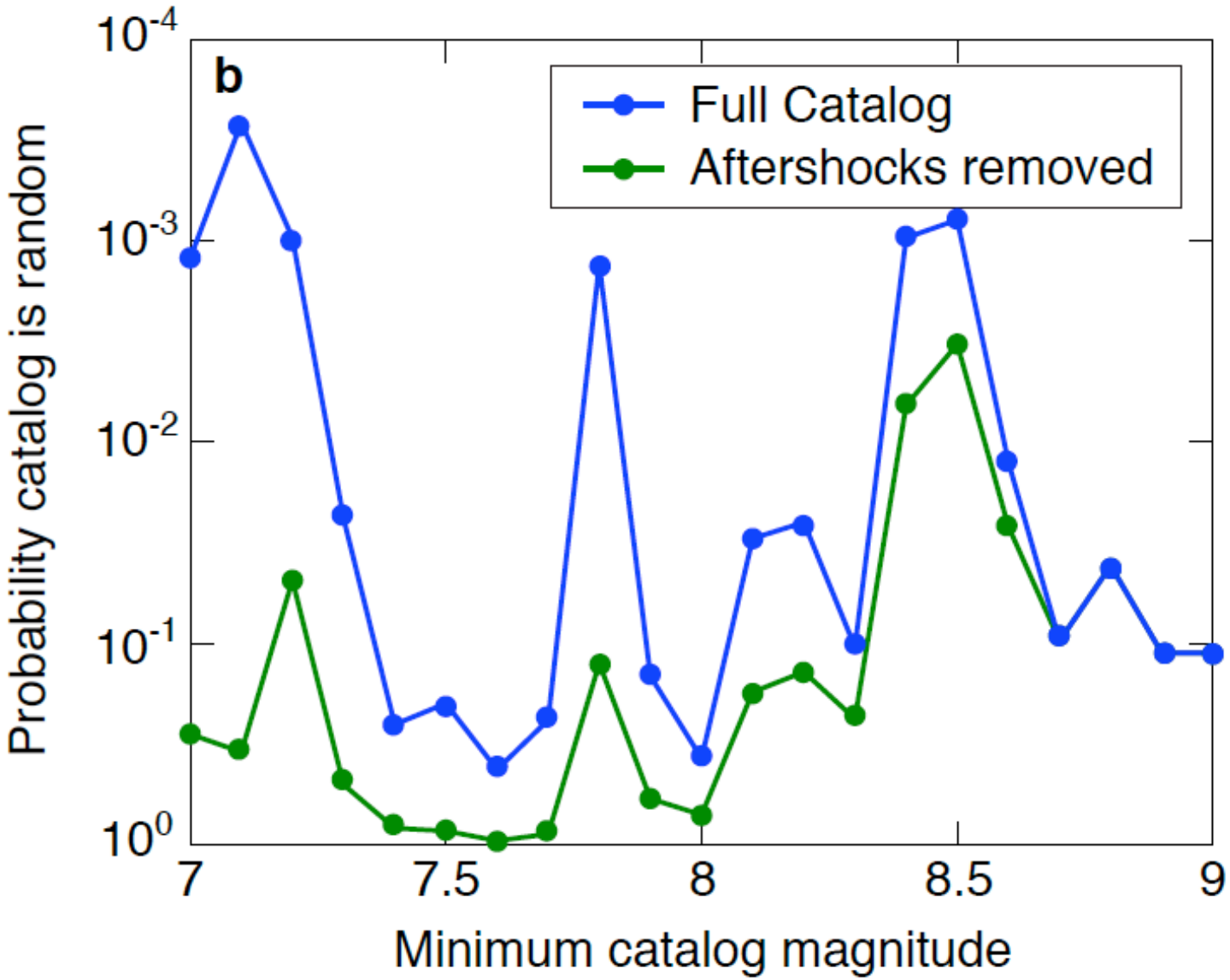
Recurrence Statistics

Calculate V for 10^6 random synthetic catalogs for comparison with data:

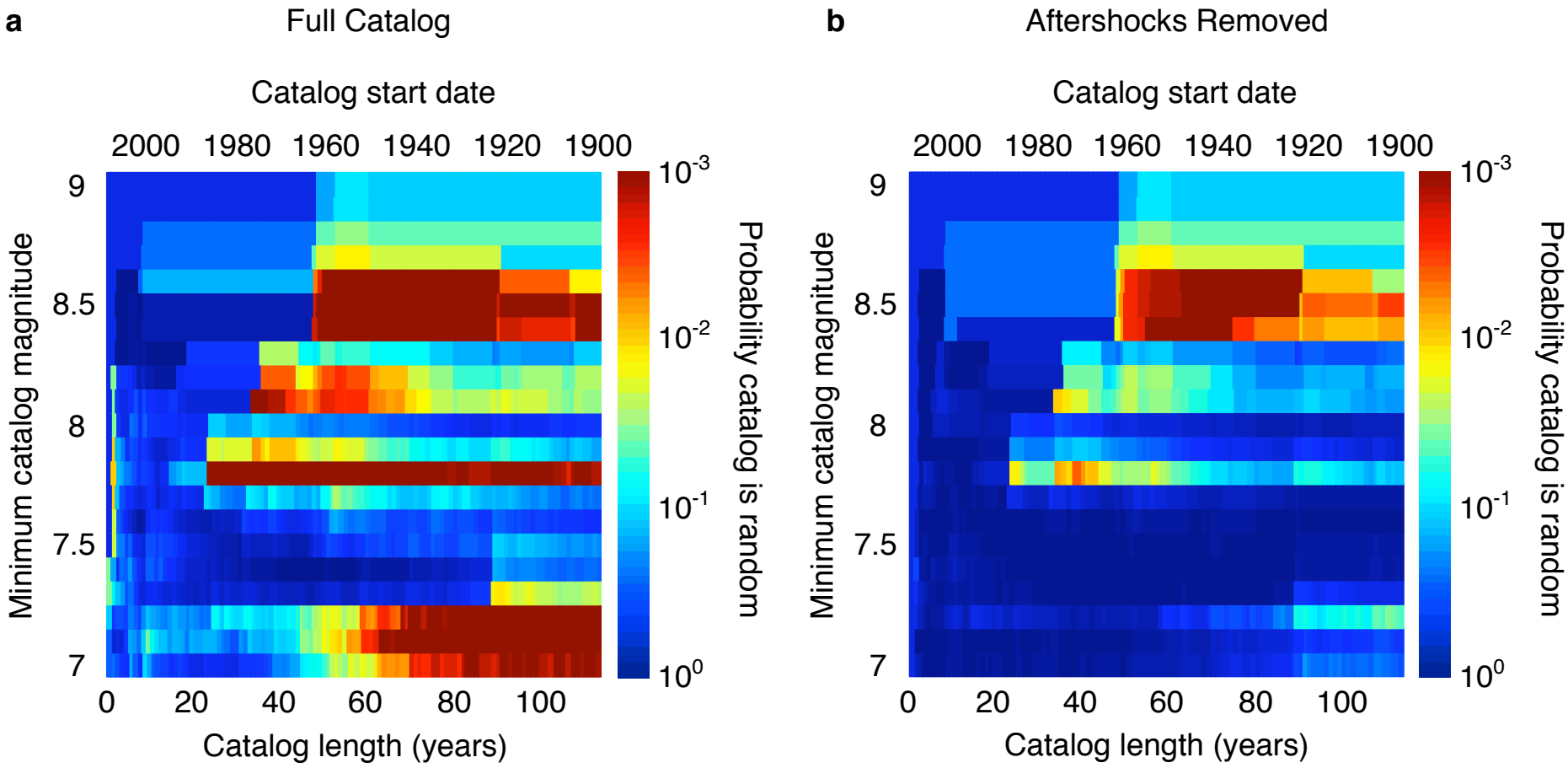


Probabilities

Calculate probability catalog produces V larger than in data. See clustering!



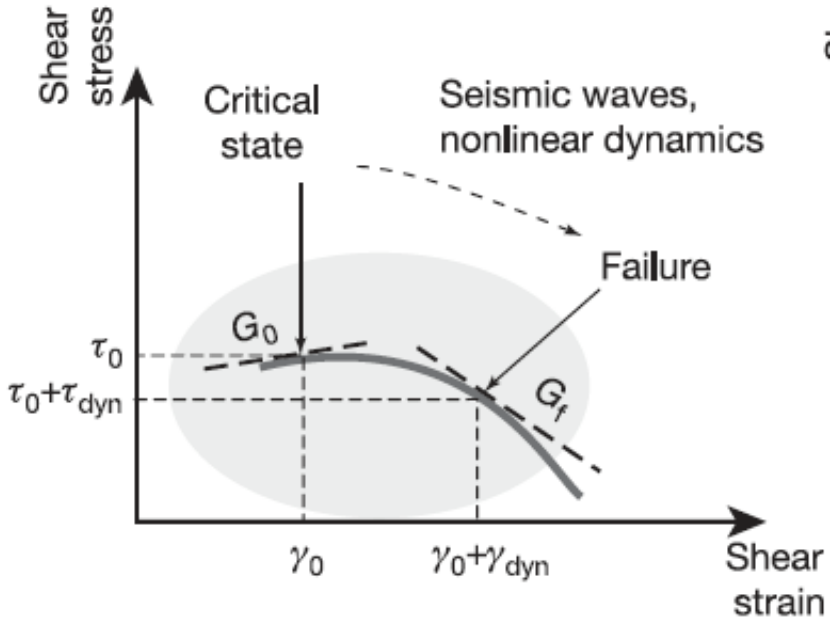
What if we don't trust early data?



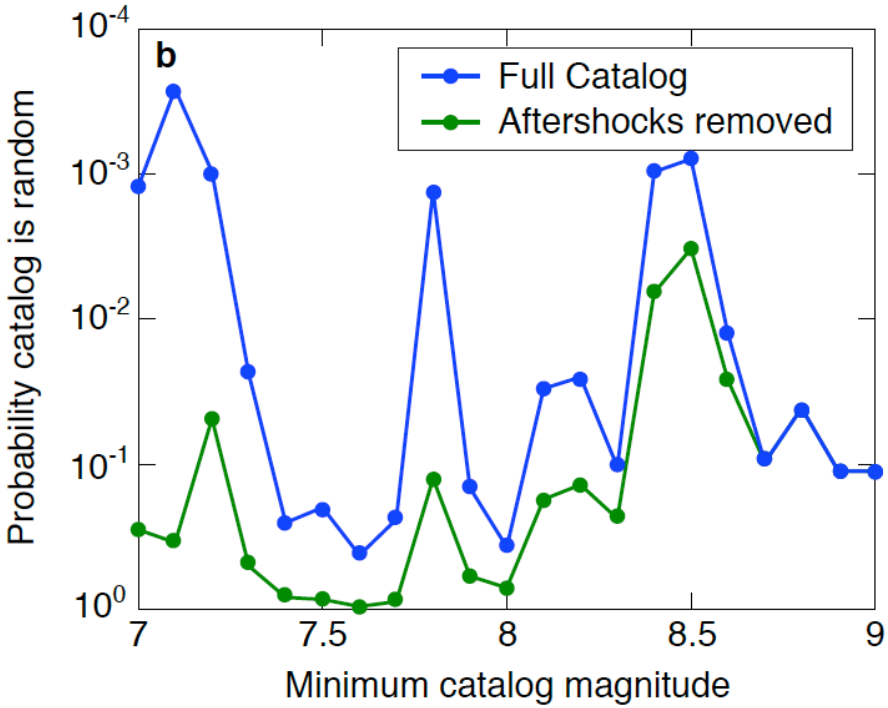
Removing early data makes clustering more likely!

Have established clustering, implications for physics?

Part 2: Physics of triggering



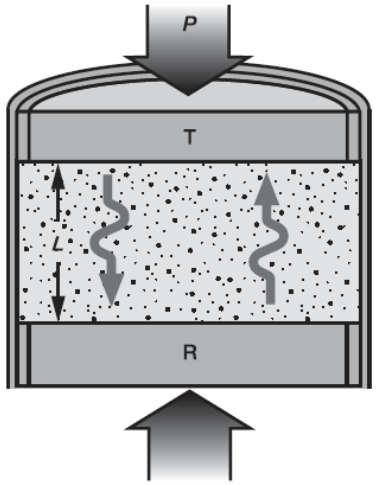
Why only at M = 8.4-8.5?

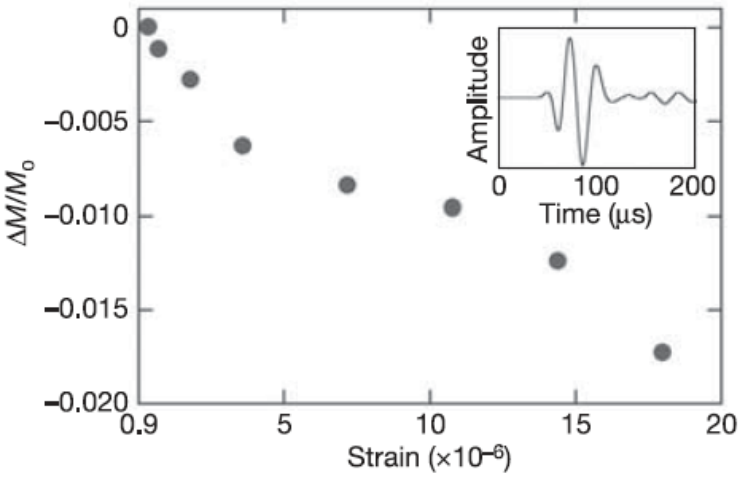


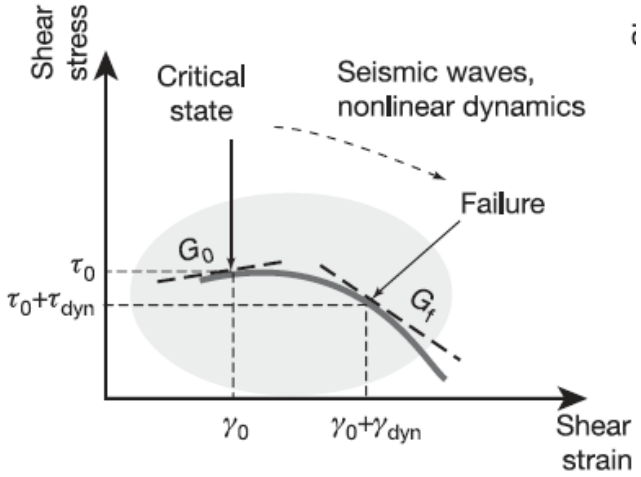
Why do we see triggering at high magnitudes, but not lower magnitudes?

May give us clues to the physics of earthquake triggering (maybe nonlinear elasticity?)

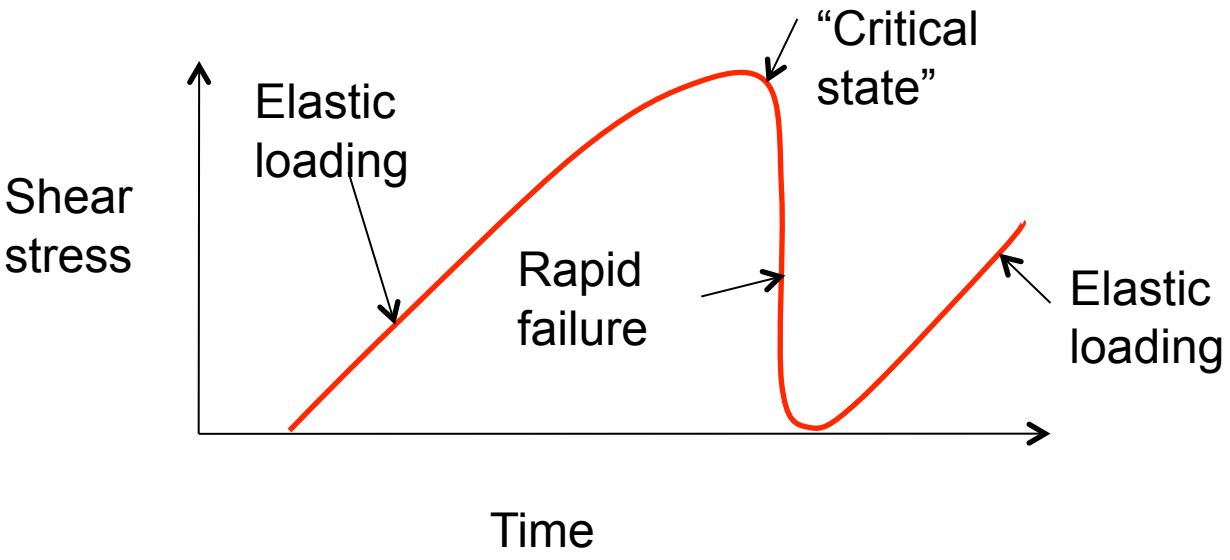
Johnson and Jia, 2005







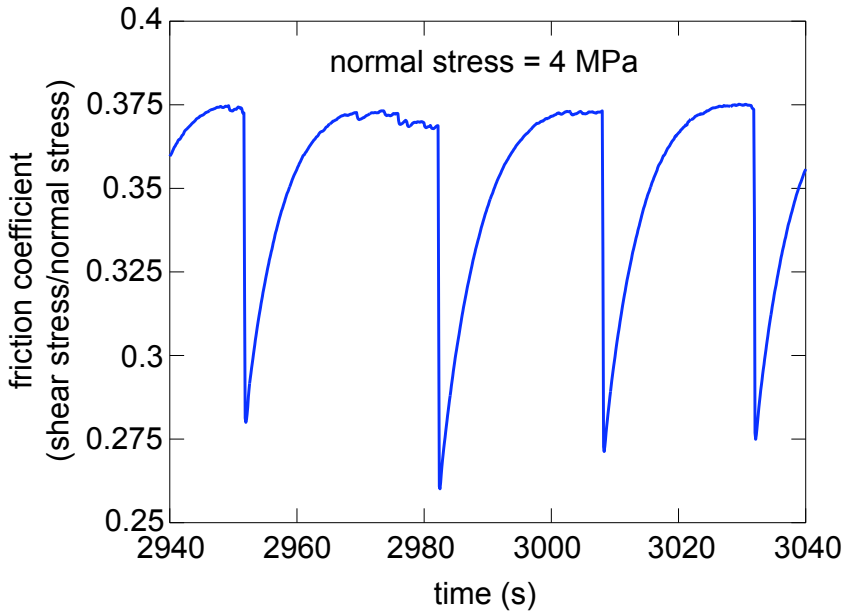
Physics of Triggering



How are earthquakes triggered?

Idea: faults can be triggered when in a "critical state" that is very close to failure.

See this in lab experiments. (Johnson et al., 2008)



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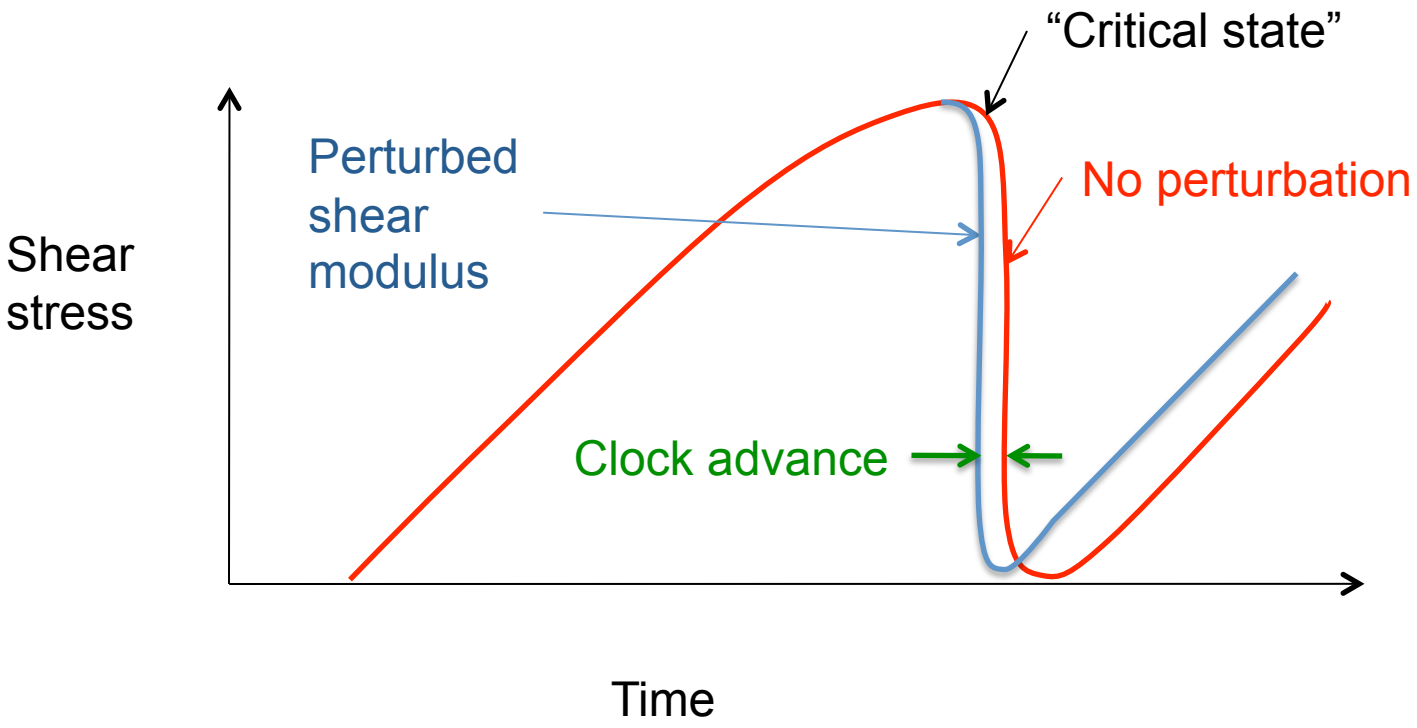
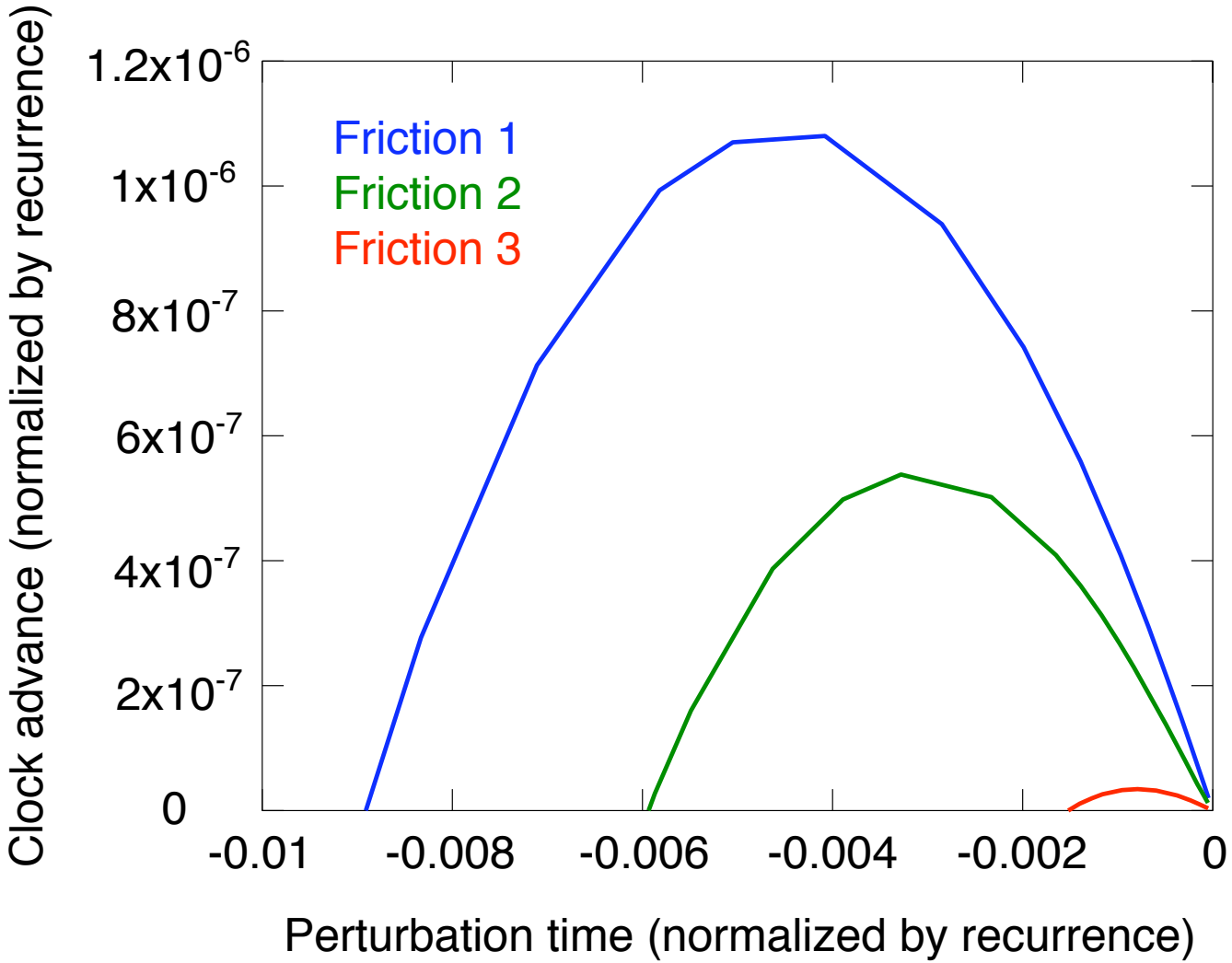


Idea: perturb shear modulus while in a critical state, and failure time advances

Physics of Triggering

Clock advance grows nonlinearly with duration of critical state. Long critical state, much more dramatic triggering effect!



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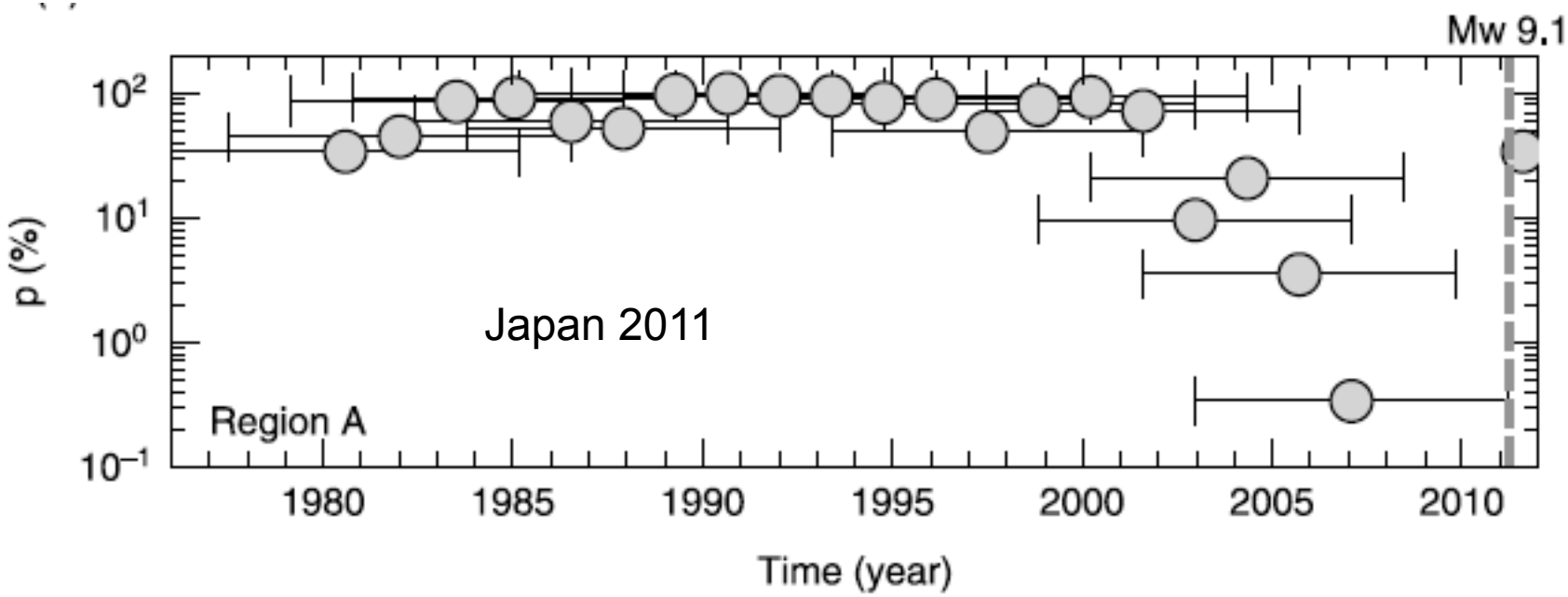

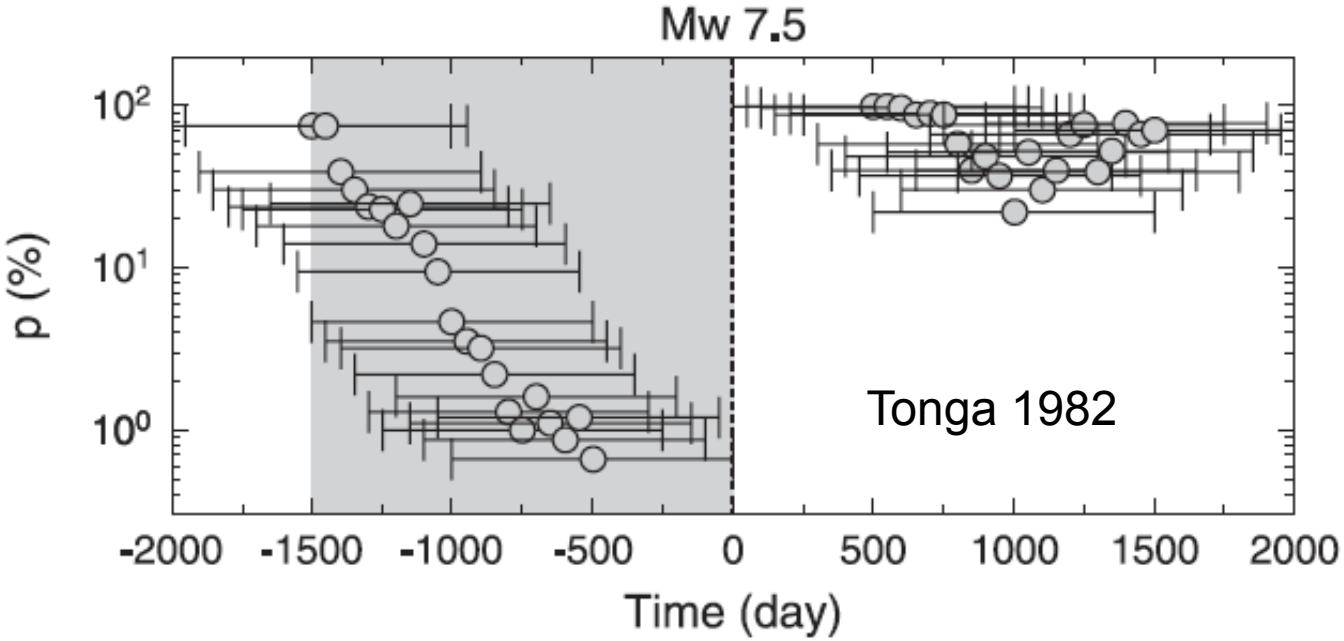

Tidal triggering studies suggest great earthquakes may have longer periods at a critical state before failure

Tanaka et al. 2002
Tanaka 2012