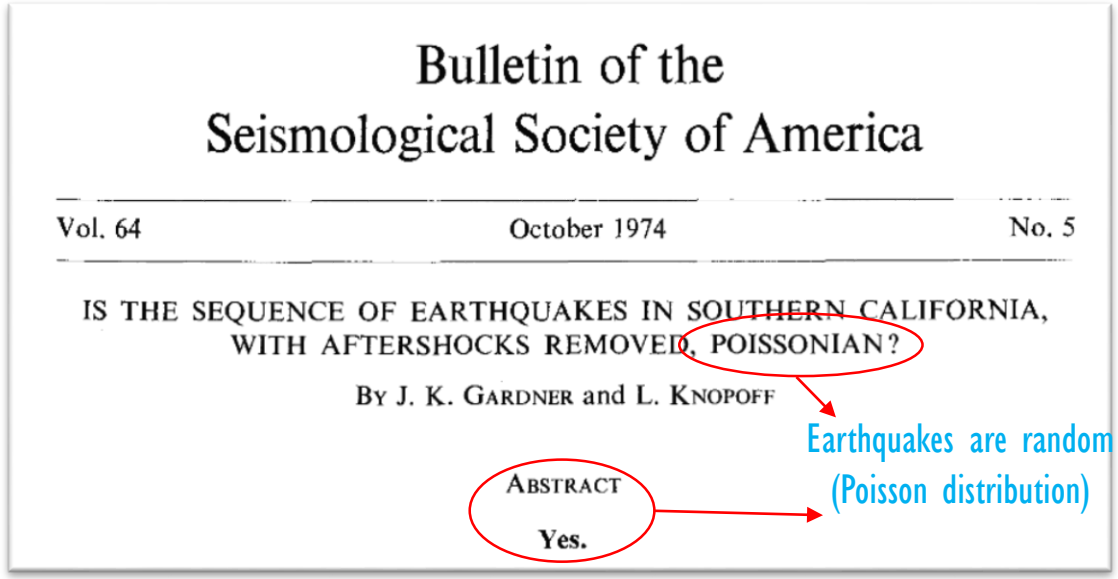
Advances in Earthquake Catastrophe Modelling

OASIS Insight London 2025

MAXIMUM INFORMATION

Most EQ CAT models are mainshock-only…

It's all about simple simulation distributions!



Bulletin of the
Seismological Society of America

Vol. 64 October 1974 No. 5

IS THE SEQUENCE OF EARTHQUAKES IN SOUTHERN CALIFORNIA, WITH AFTERSHOCKS REMOVED, POISSONIAN?

By J. K. Gardner and L. Knopoff

Abstract

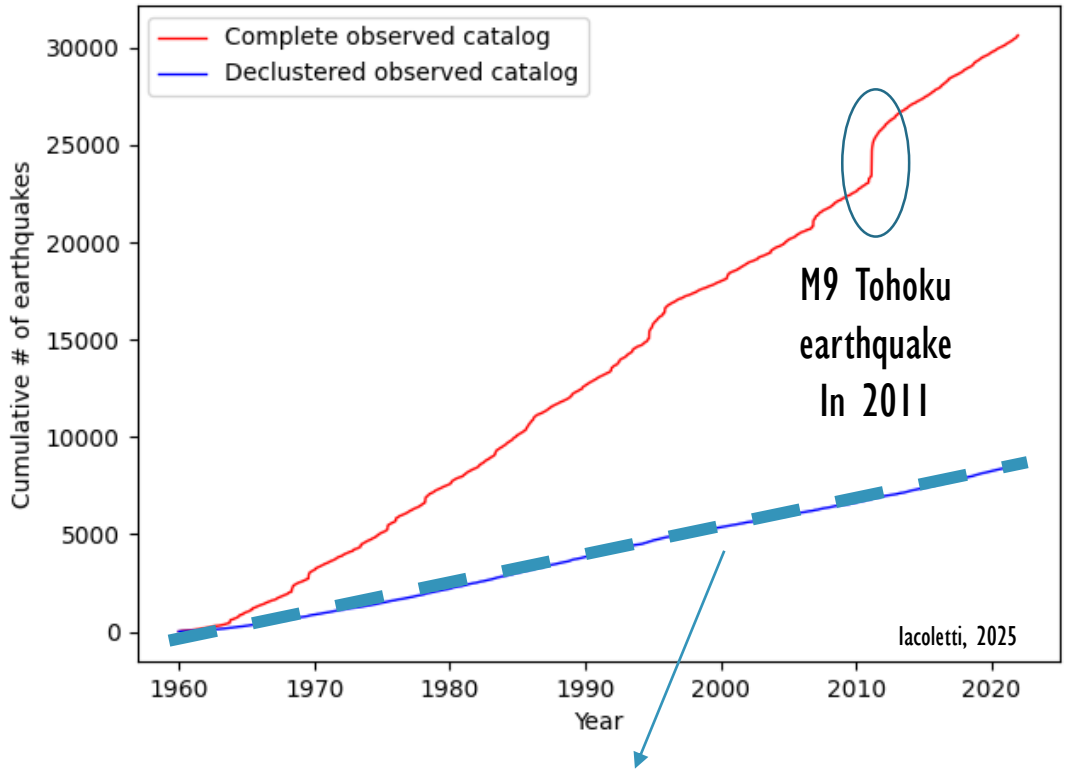
Yes.

Earthquakes are random (Poisson distribution)

Aftershocks

"smaller" earthquakes that follow mainshocks

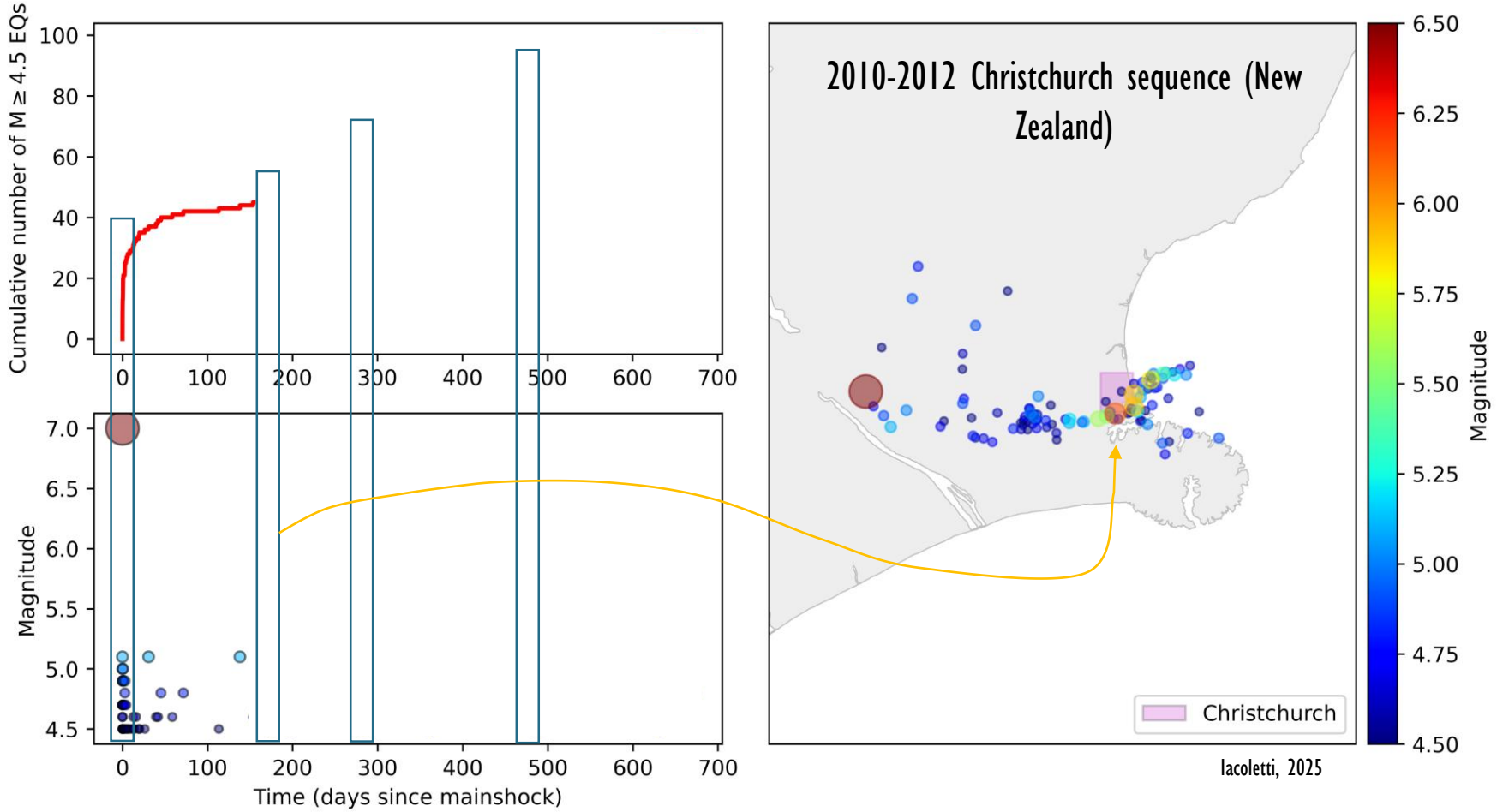
Seismicity in Japan after 1960



The slope of this line is all you need to simulate synthetic earthquakes

. . . but earthquakes are not random at all!

Earthquakes tend to cluster in time and space after large mainshocks



Other notable sequences affecting industry:

- 1994 Northridge, California
- 1995 Hyogo-Kobe, Japan
- 2016 Central Italy
- 2023 Turkey-Syria

Key questions

1. Do mainshock-only CAT models underestimate seismic risk?

2. How can we adjust contemporary CAT models to account for aftershock activity following a large event?

3. What barriers exist to incorporating full earthquake sequences in CAT models?

XL Insurance Reinsurance

Advances in Earthquake Catastrophe Models Clustering

Salvatore Iacoletti | 30 April 2025

CAT lessons learned (?)

2017 Hurricanes Harvey, Irma and Maria (HIM)

Large losses due to Tropical Cyclone Induced Precipitation

Adjustments & model changes

✓

2010-2011 Christchurch earthquake sequence

Large losses due to liquefaction

Adjustments & model changes

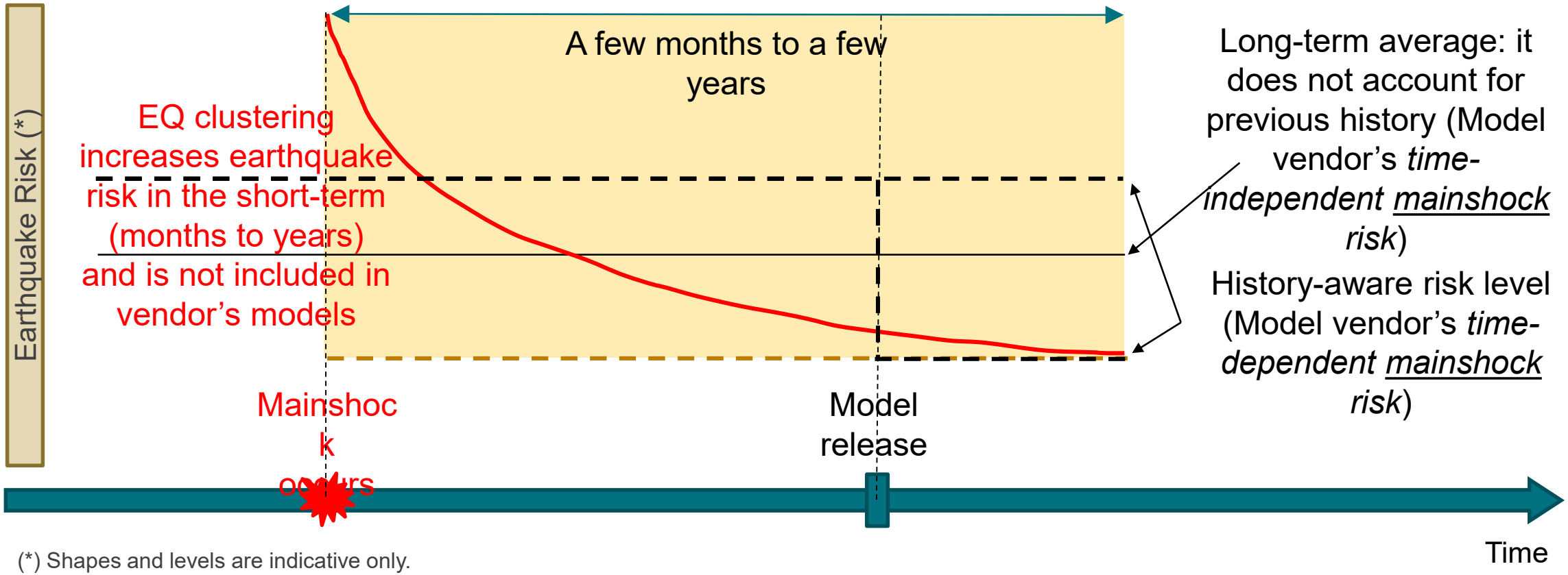
✓

Earthquakes are clustered in space and time (e.g., aftershocks are important for loss calculations)

X

Practical consequences of neglecting EQ clustering

Difference between modeling and reality



(*) Shapes and levels are indicative only.
Model vendors provide the current time-dependent view of risk for mainshocks only, which they need to update at every model release

The pushback on clustering/aftershocks/sequences

Why is this still an outstanding issue?

Incorrect or false statements

Aftershocks have a lower magnitude than mainshocks, so they don't cause losses

Science has not provided a (simple) solution

Events in the sequence could be labeled as mainshocks

Clustering/aftershocks are only a problem in New Zealand

Fair statements to think about

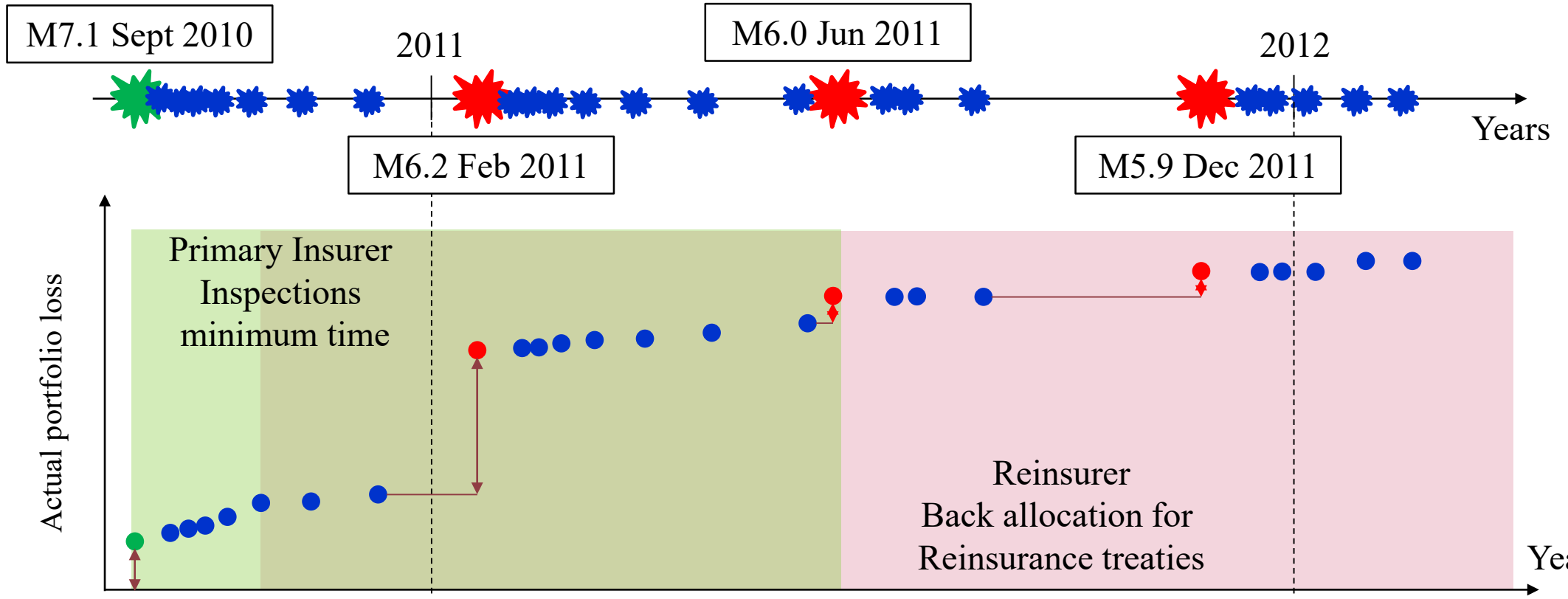
The time delay between incurred and reported loss means claims already implicitly include the impact of aftershocks

Depending on the time between events, separate shocks could be considered as one loss occurrence

Hard to gather claims data to calibrate progressive damage

The dynamics of loss occurrence

The case of the 2010-2011 Christchurch sequence



Apply an extra allowance for situations like Christchurch (not included in the models today) taking the loss dynamics into account

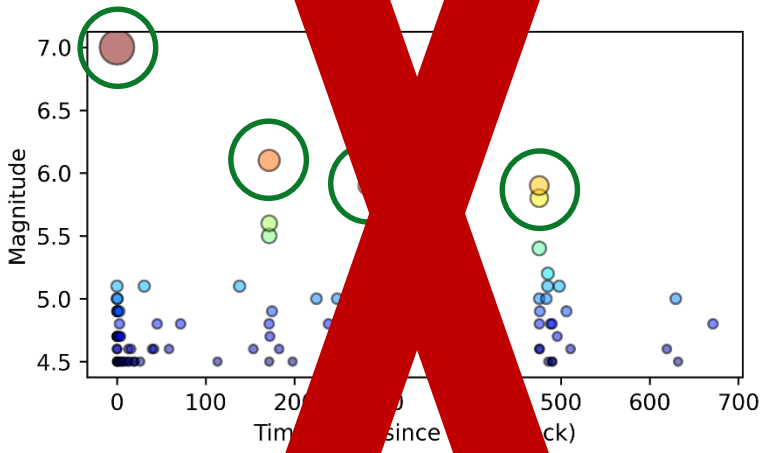
Have a short-term view of how the sequence may progress (capital reserves, contract renewal)

Our needs

What are the options available to us?

Please don't do this

Pick the 4 biggest events and calculate EQ uencies

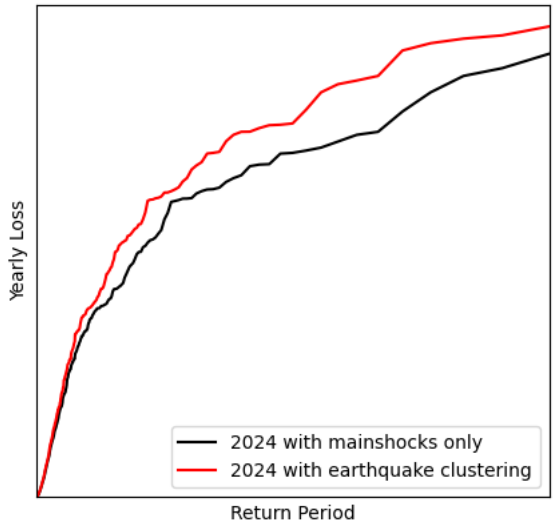


These events are part of a sequence (i.e., connected to each other)

One sequence occurred in the region in the last 180 years

Option 1

Adjust the legacy models



Assess what's included in the data and avoid double counting

Option 2

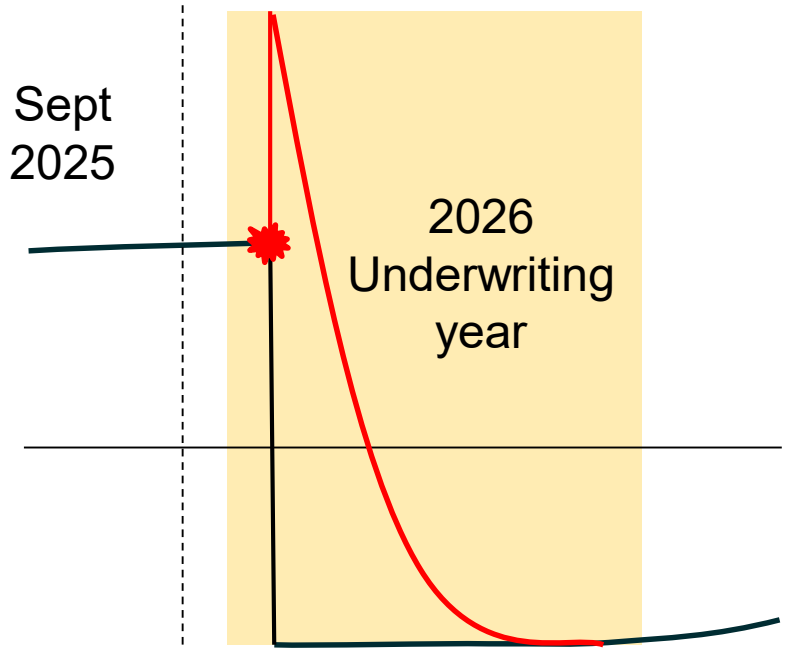
If your company has decent data, **license** a model including

Difficult to validate without deep data cleaning

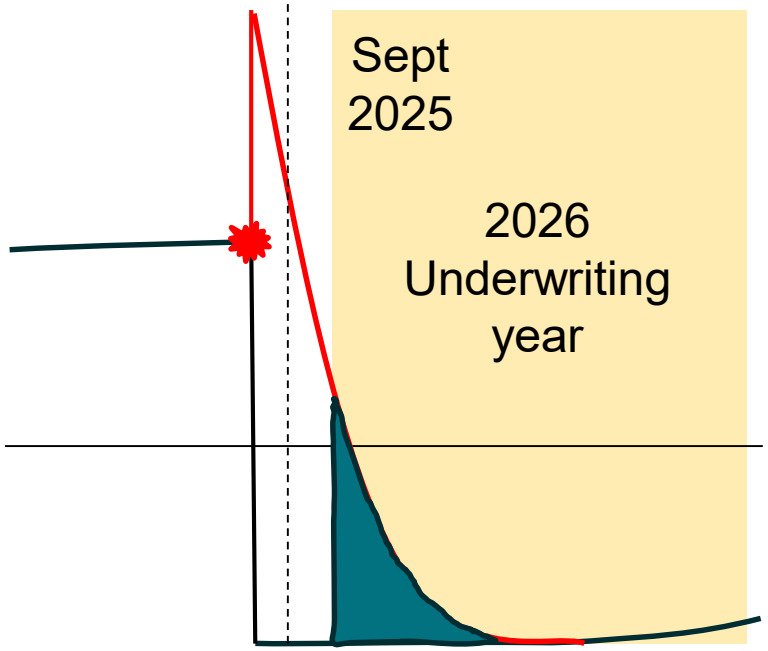
The adjustment approach

And how it ties to our needs

Aftershock sequence of future mainshocks



Aftershock sequence of earthquakes that already occurred



Apply an extra allowance for situations like Christchurch (not included in the models today)

Have a short-term view of how the sequence may progress (capital reserves, contract renewal)

How do we adjust the legacy models?

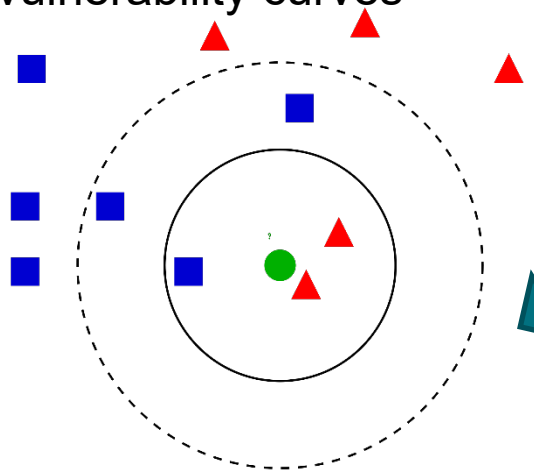
AXA XL

Input
Mainshock catalog

Pre-calibrated aftershock simulator

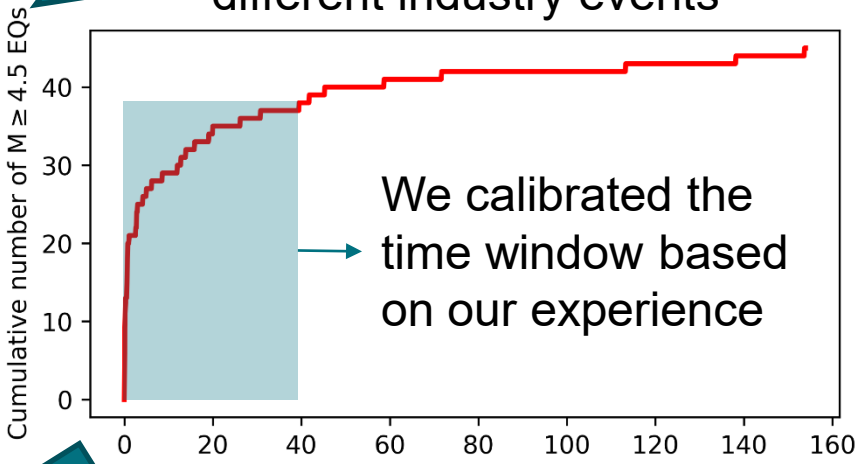
Output
Mainshock + aftershock catalog

Risk of double counting Losses from earthquakes falling within the technical time delay are **implicitly included** in vulnerability curves



Calculate a loss value for each of the considered aftershocks

Consider events viewed as different industry events



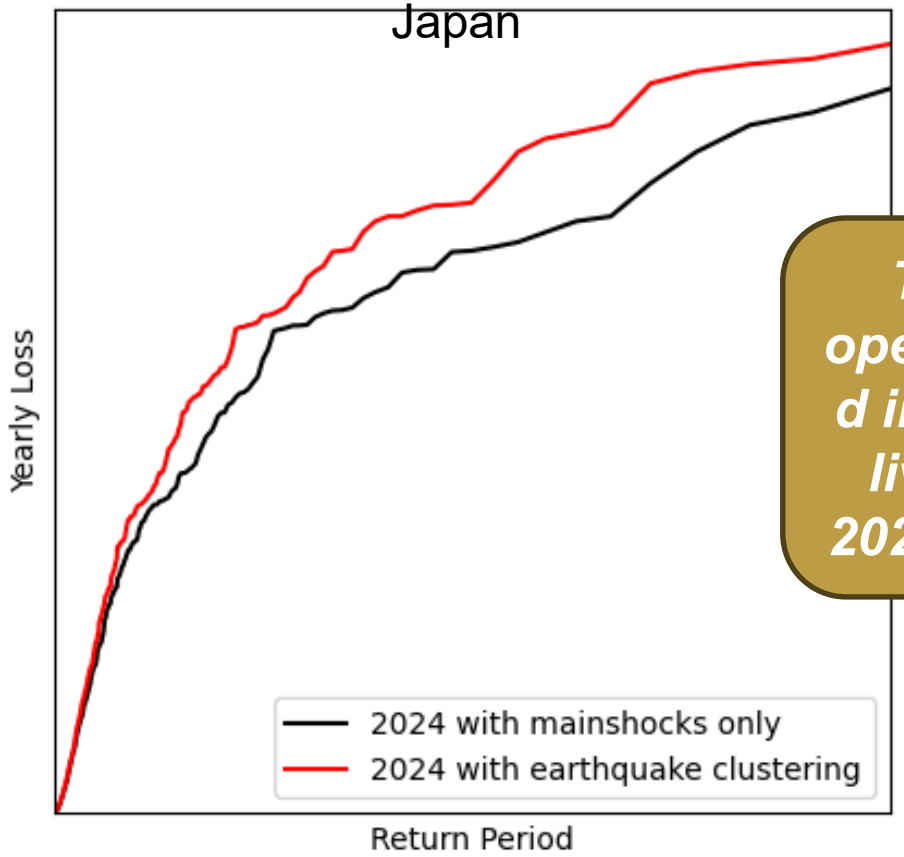
We calibrated the time window based on our experience

Modify the EP curve (frequency or loss adjustments)

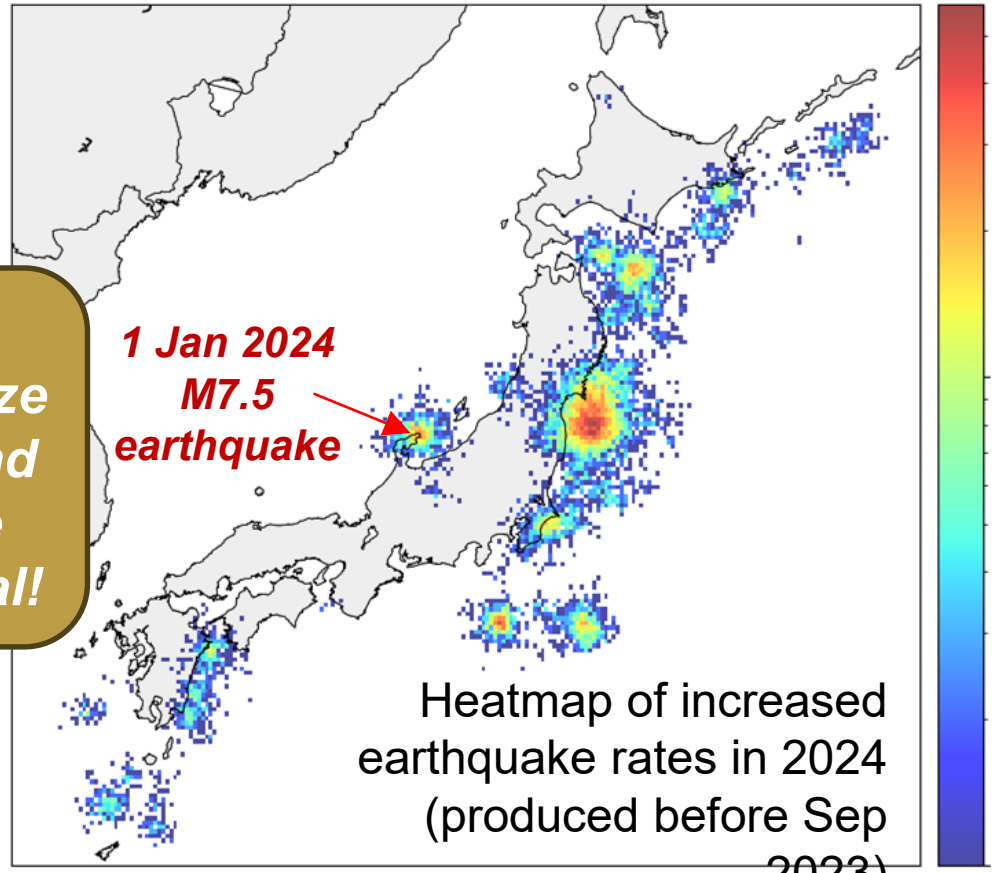
Example for Japan

Impact of clustering

Impact on the EP Loss Curve in Japan



This was operationalized in 2023 and live for the 2024 renewal!



Heatmap of increased earthquake rates in 2024 (produced before Sep 2023)

Apply an extra allowance for situations like Christchurch (not included in the models today)

Have a short-term view of how the sequence may progress (capital reserves, contract renewal)

Let's learn our lesson…

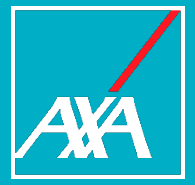
"There are only a few certainties in life: death, taxes and aftershocks"

- Traditional CAT models do not include sequences, but they are calibrated on data that might implicitly consider sequences
- Given the available claims data, adjusting traditional CAT models can be difficult, but not impossible, our objective is:

Apply an extra allowance for situations like Christchurch (not included in the models today)

Have a short-term view of how the sequence may progress (capital reserves, contract renewal)

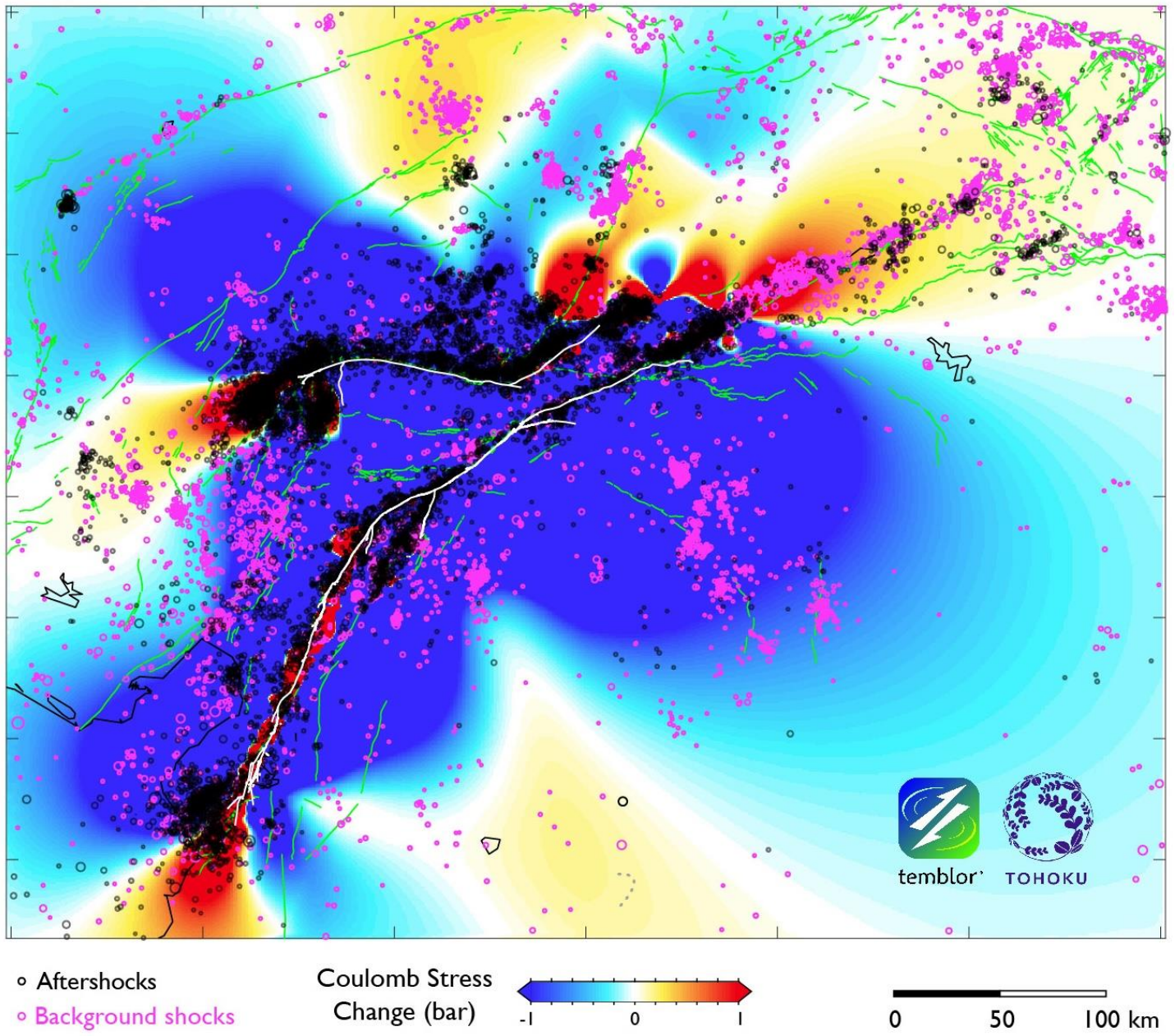
- The scientific community has done their part, now it's up to us to apply…
- Most tools/data/methodologies we use are publicly available: pysimulator, simpIETAS, WCEE, Time-dependent seismic risk modeling, Effect of sequences on hazard



Know You Can

Here's what we're doing

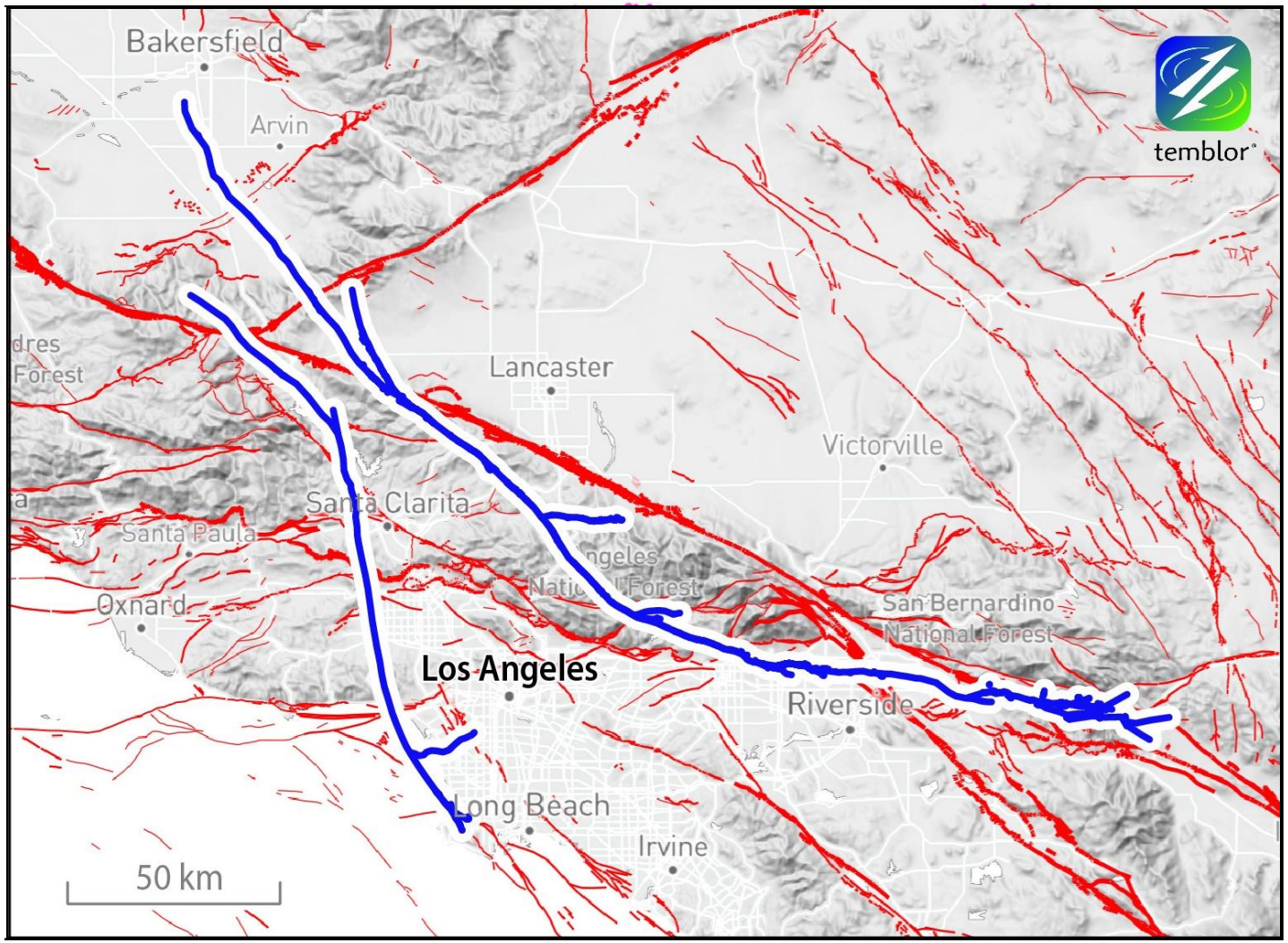
2023 Kahramanmaras sequence: M 7.8 and M 7.7 shocks, 9 hours apart



Here's what we're doing

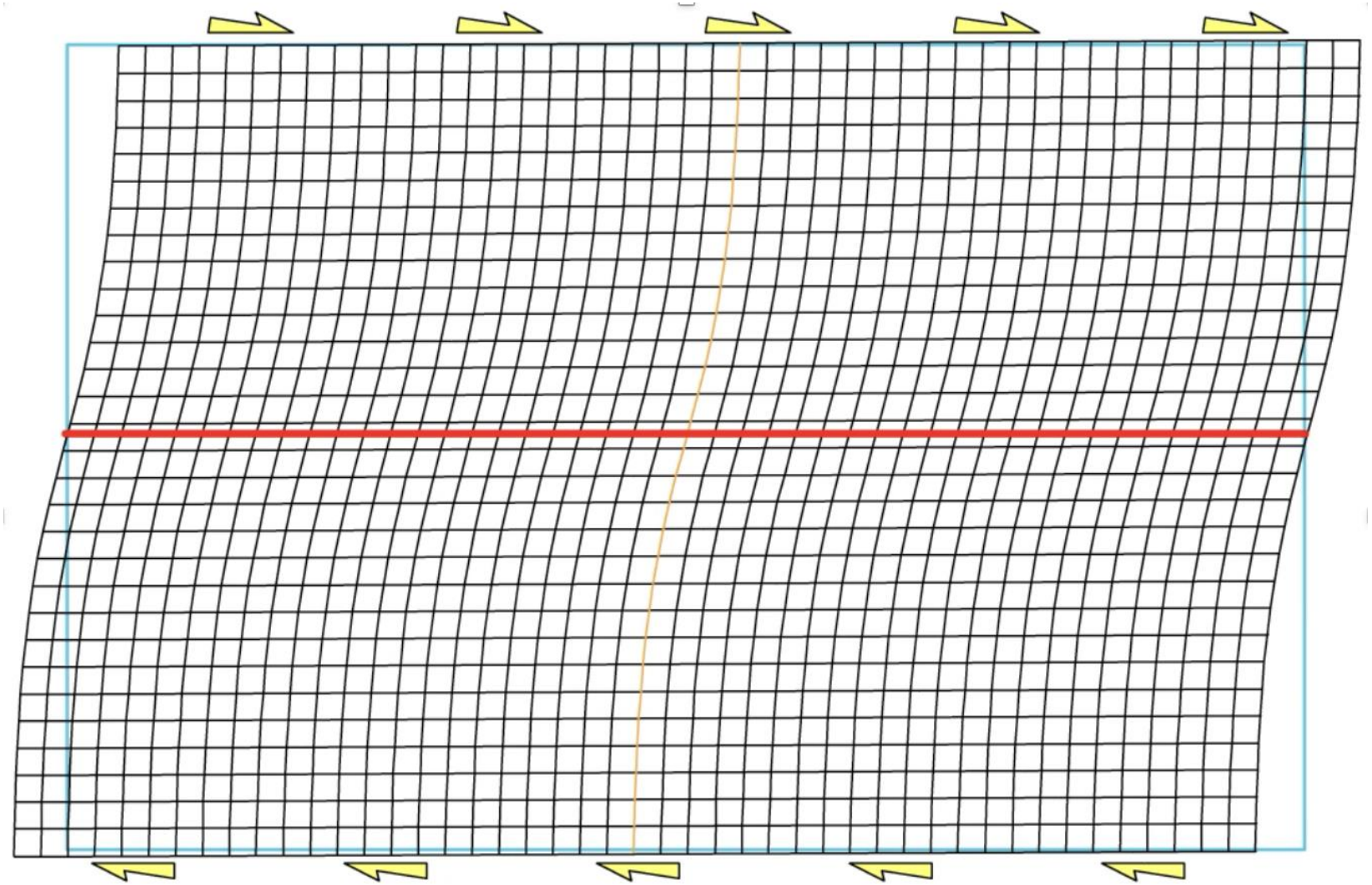
Here's why it matters

2023 Kahramanmaras sequence: M 7.8 and M 7.7 shocks, 9 hours apart



2023 Kahramanmaras ruptures (*blue*) rotated to loosely align with southern California faults (*red*), at the same scale

What's the Coulomb stress change, anyway?



Stress accumulation over 200 years

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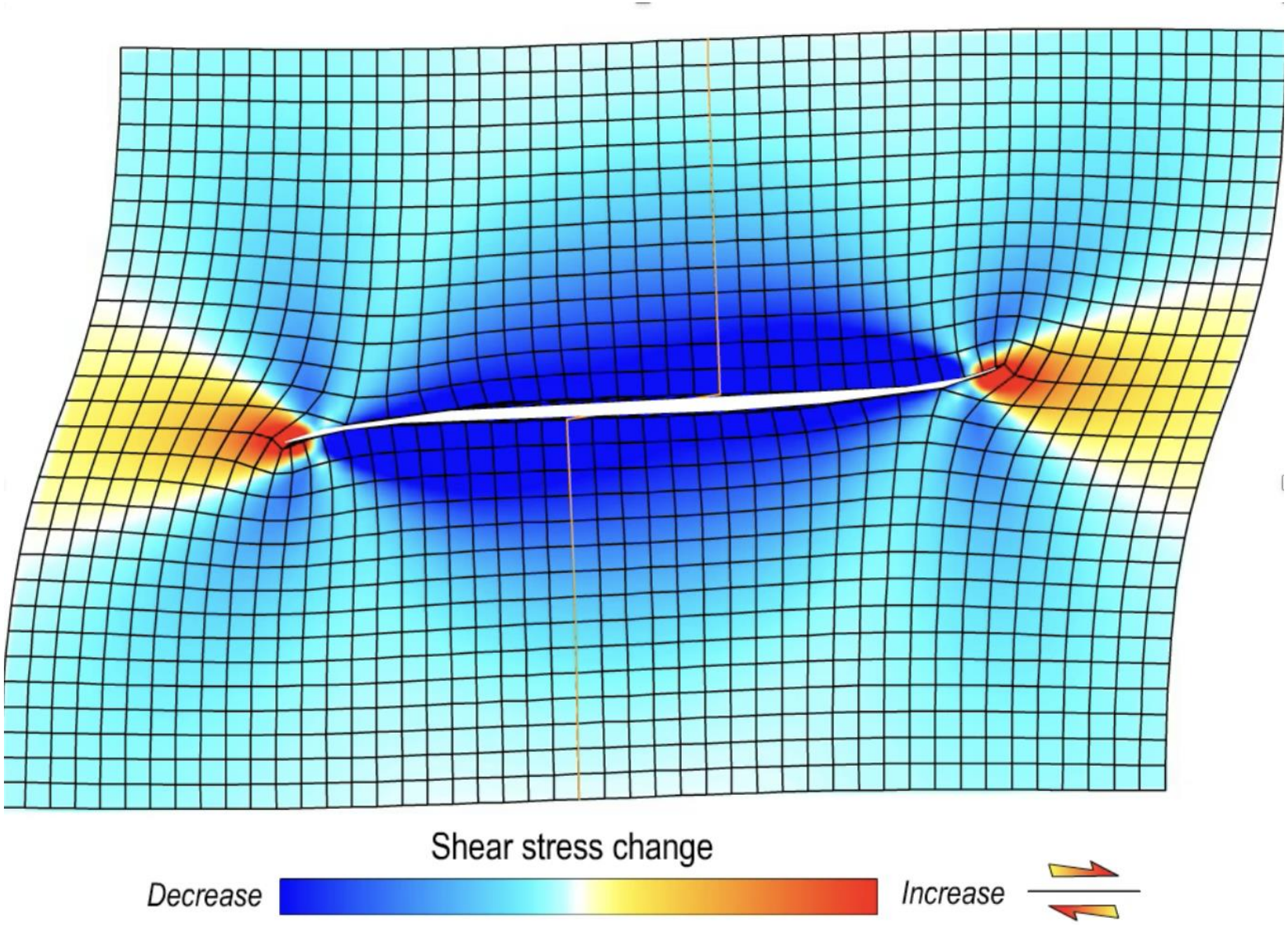

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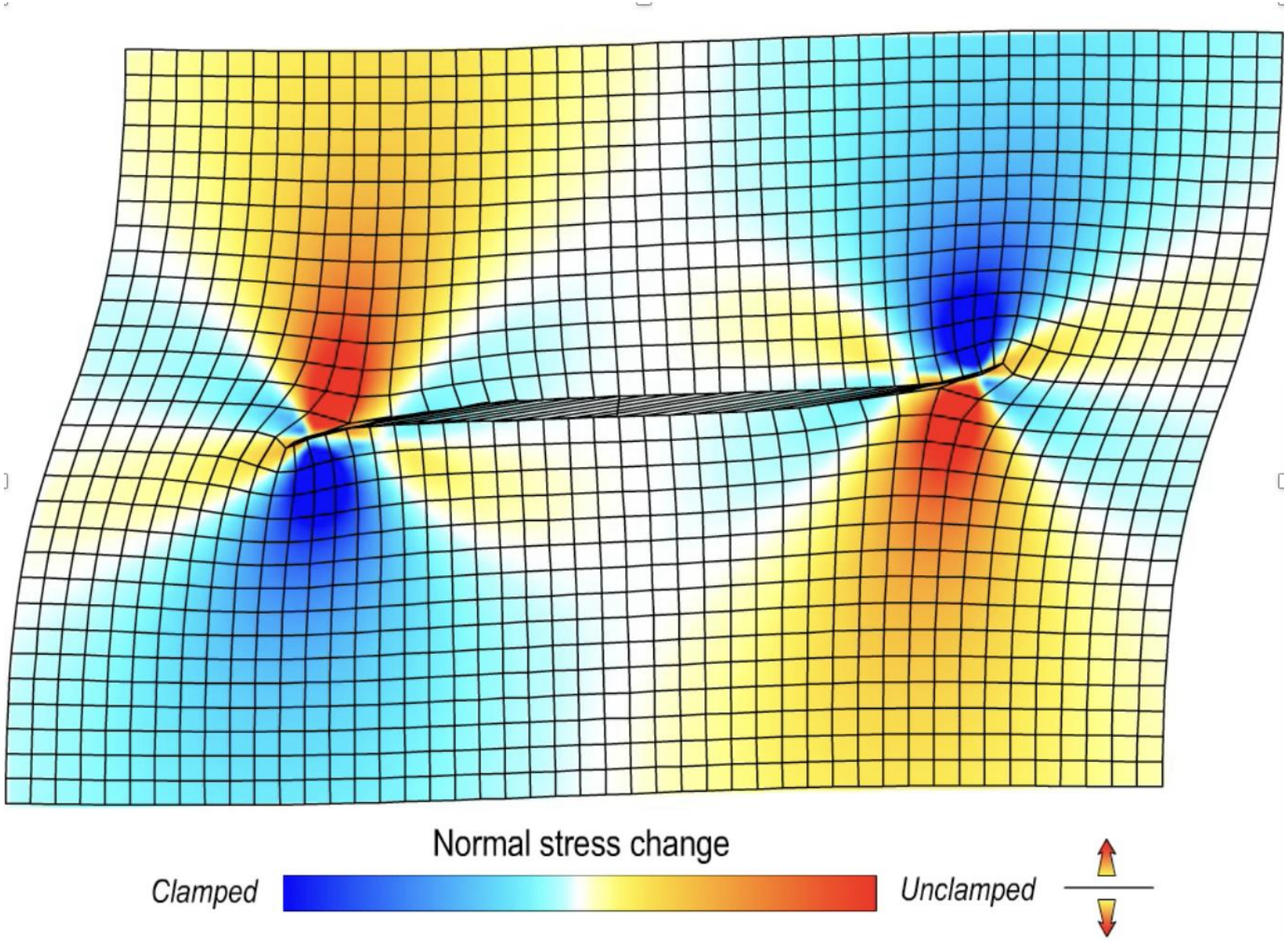

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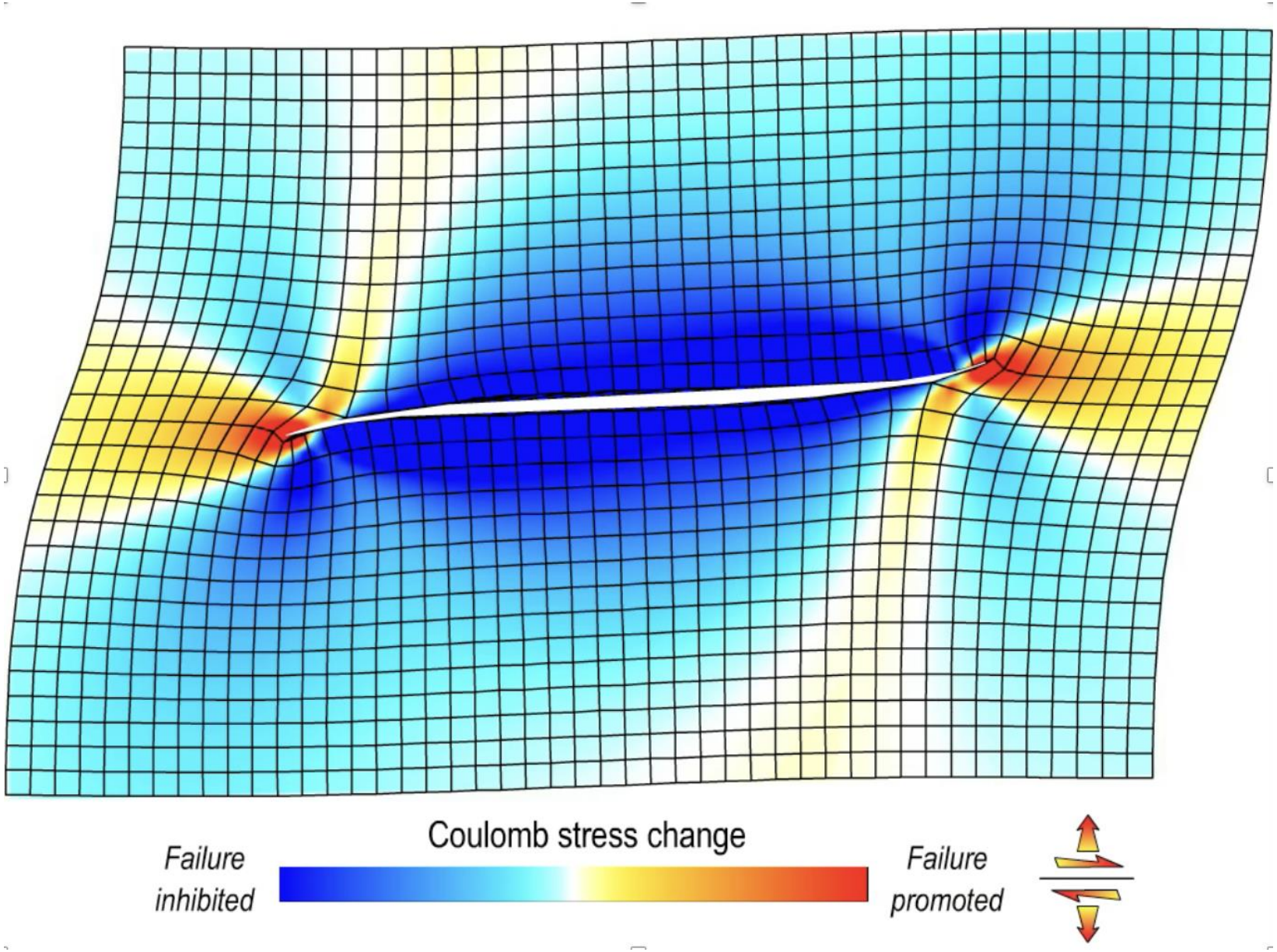
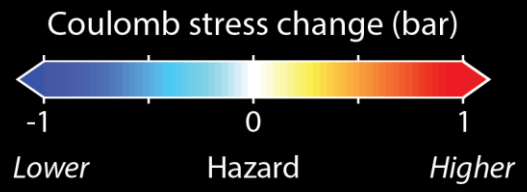
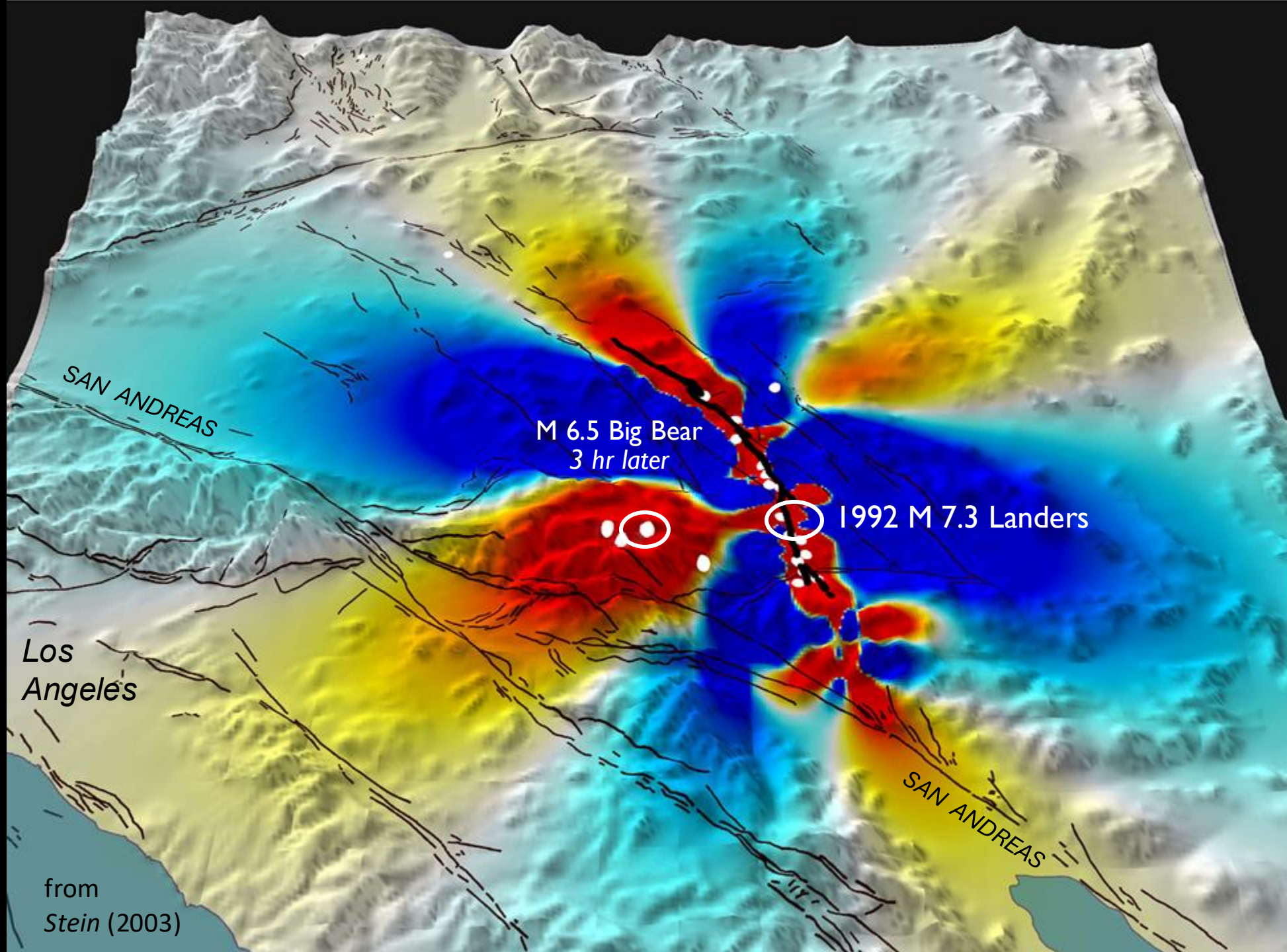


Stress transfer acts over minutes to decades



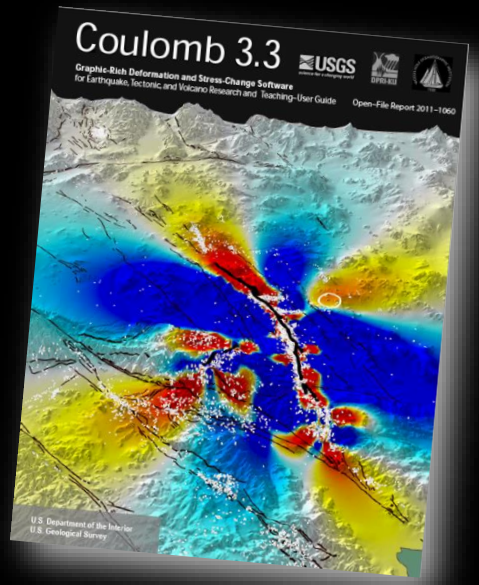


Stress transfer acts over minutes to decades

Coulomb stress change (bar)

-1 0 1

Lower Hazard *Higher*



3,000 pubs since 1992

2019 M 7.1 Ridgecrest
27 years later

M 7.1 Hector Mine
7 years later

M 6.5 Big Bear
3 hr later

1992 M 7.3 Landers

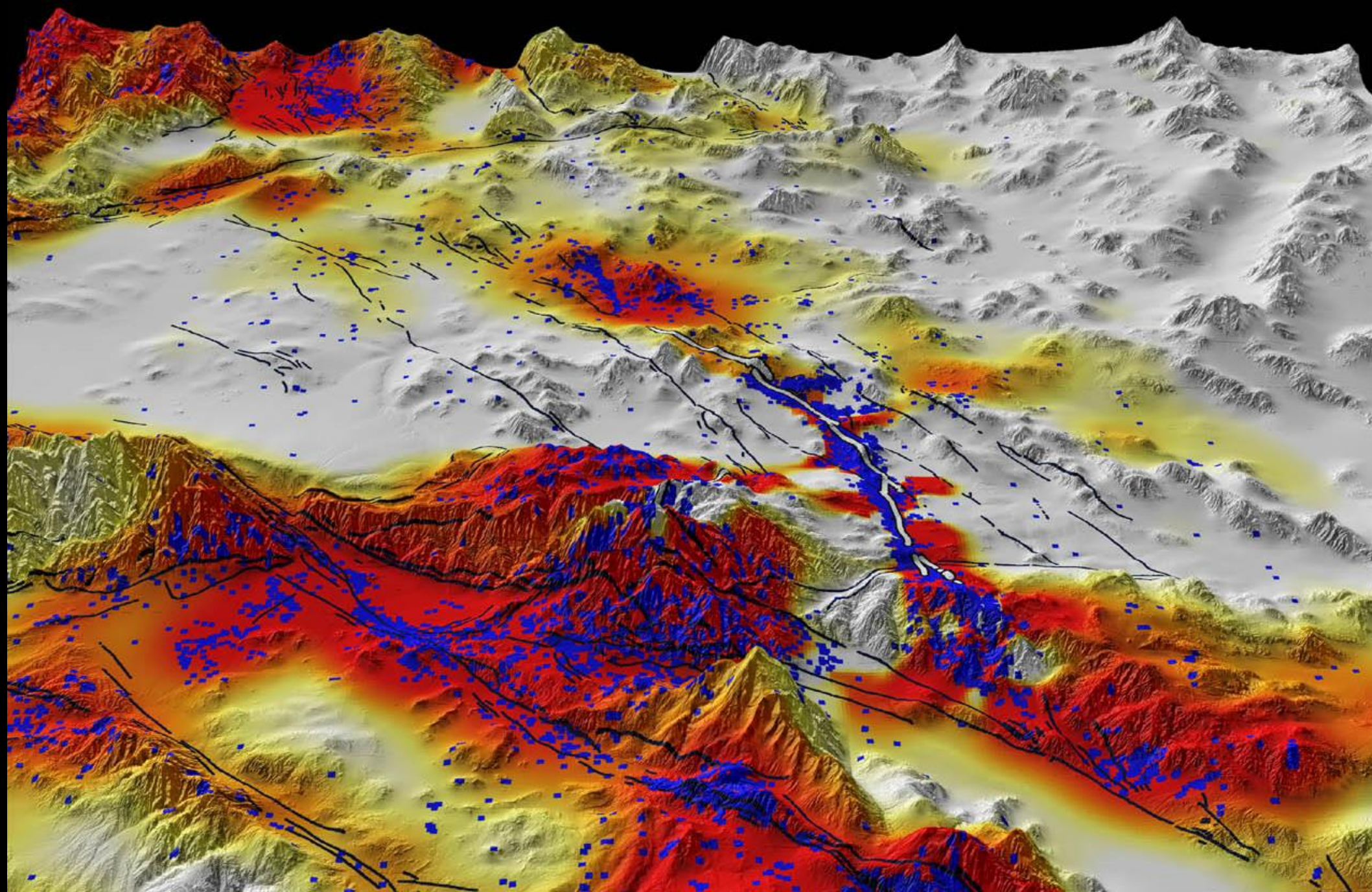
SAN ANDREAS

SAN ANDREAS

Los Angeles

from *Stein* (2003)

When combined with ‘rate/state friction’ theory, model resembles observed seismicity



Expected rate increase

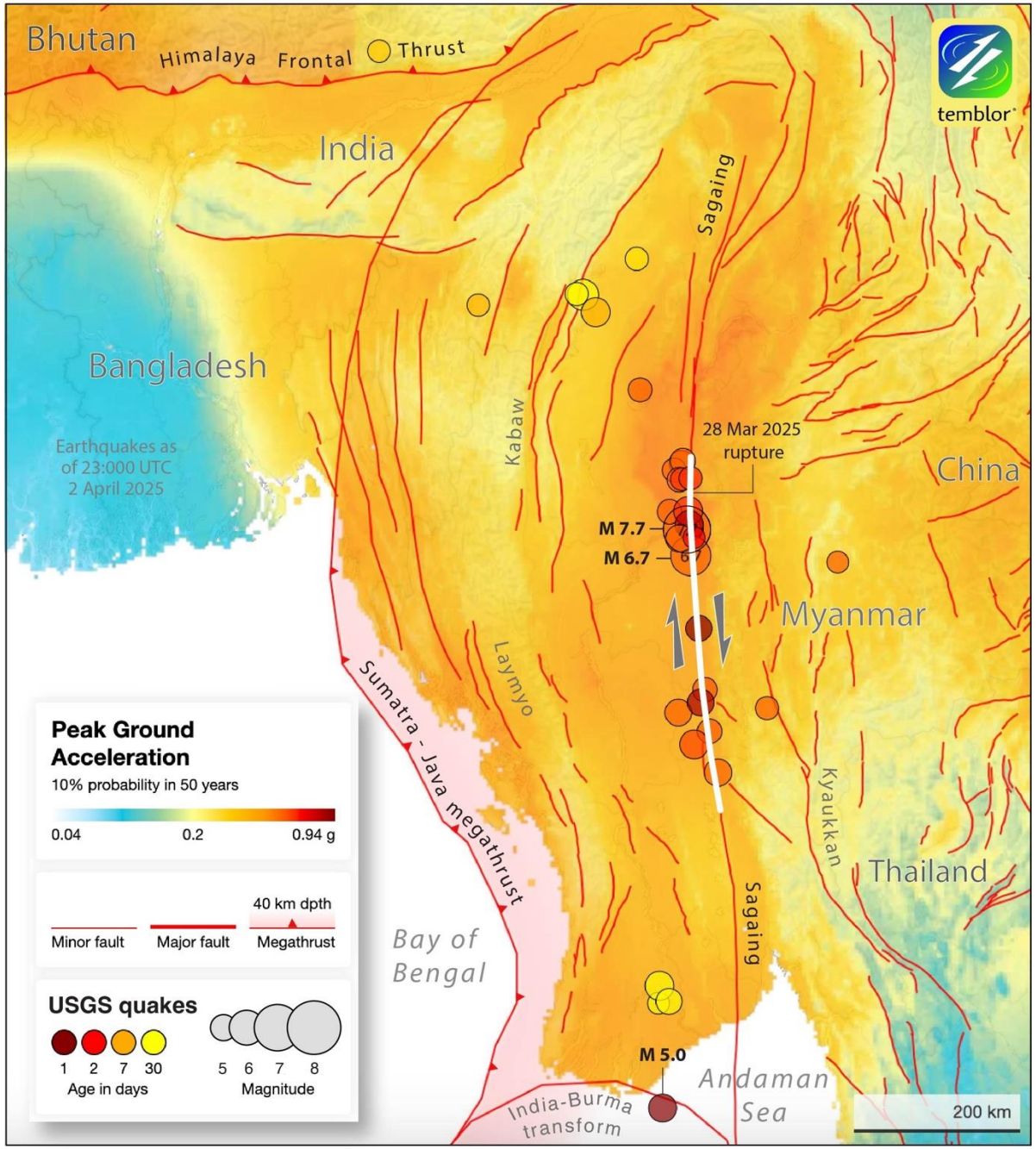
Observed quakes in 1996-1999

Toda et al. (2005)

M 7.7 Mandalay earthquake produced a 400-km-long rupture

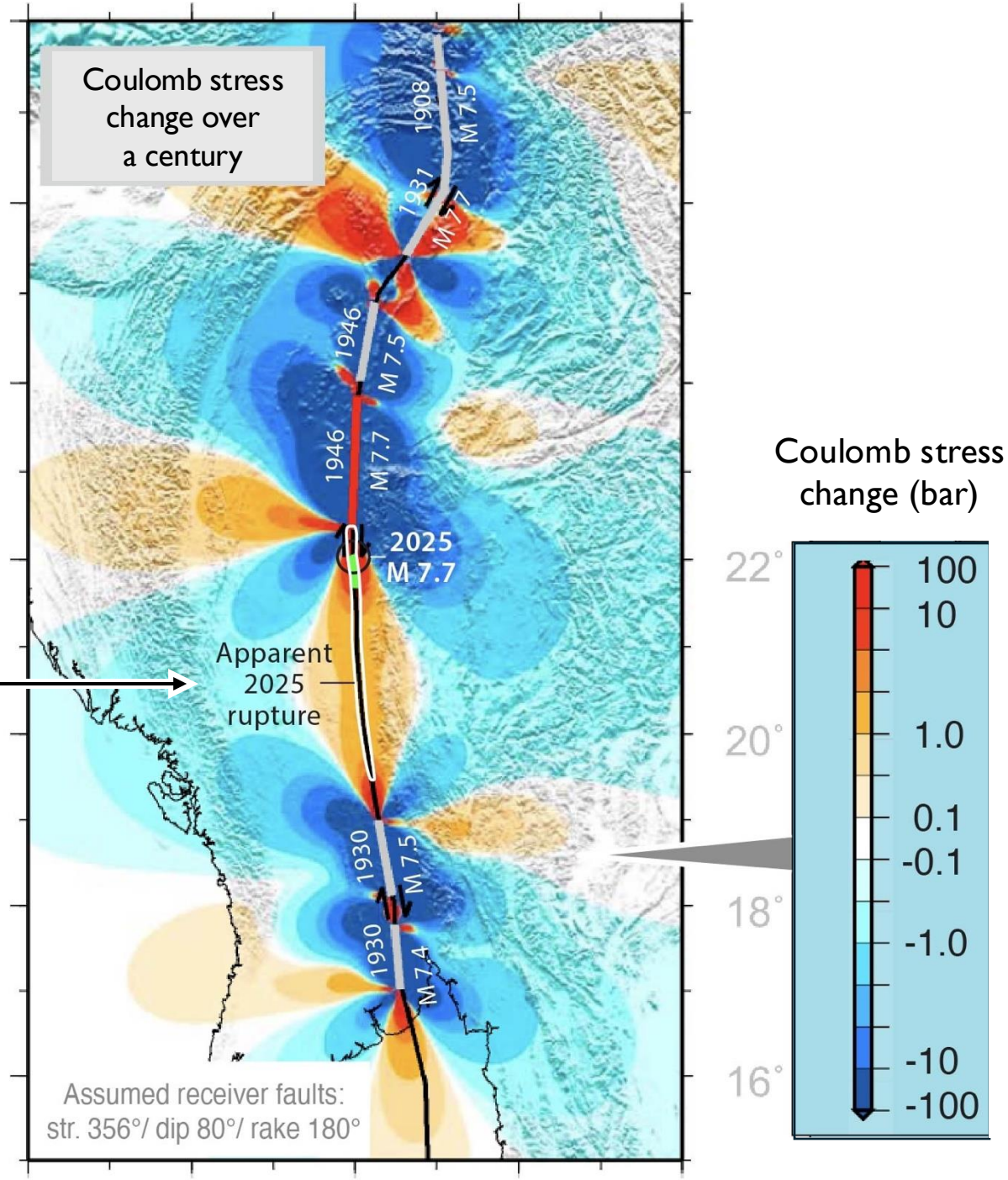
Temblor's free risk app
app.temblor.net/

The Sagaing and San Andreas share the same length, slip rate, and quake histories



Xiong et al. (2017) calculated the Coulomb stress from the ten M≥6.5 shocks along the Sagaing fault since 1906

The section of the Sagaing that ruptured on Mar 28 was closest to failure

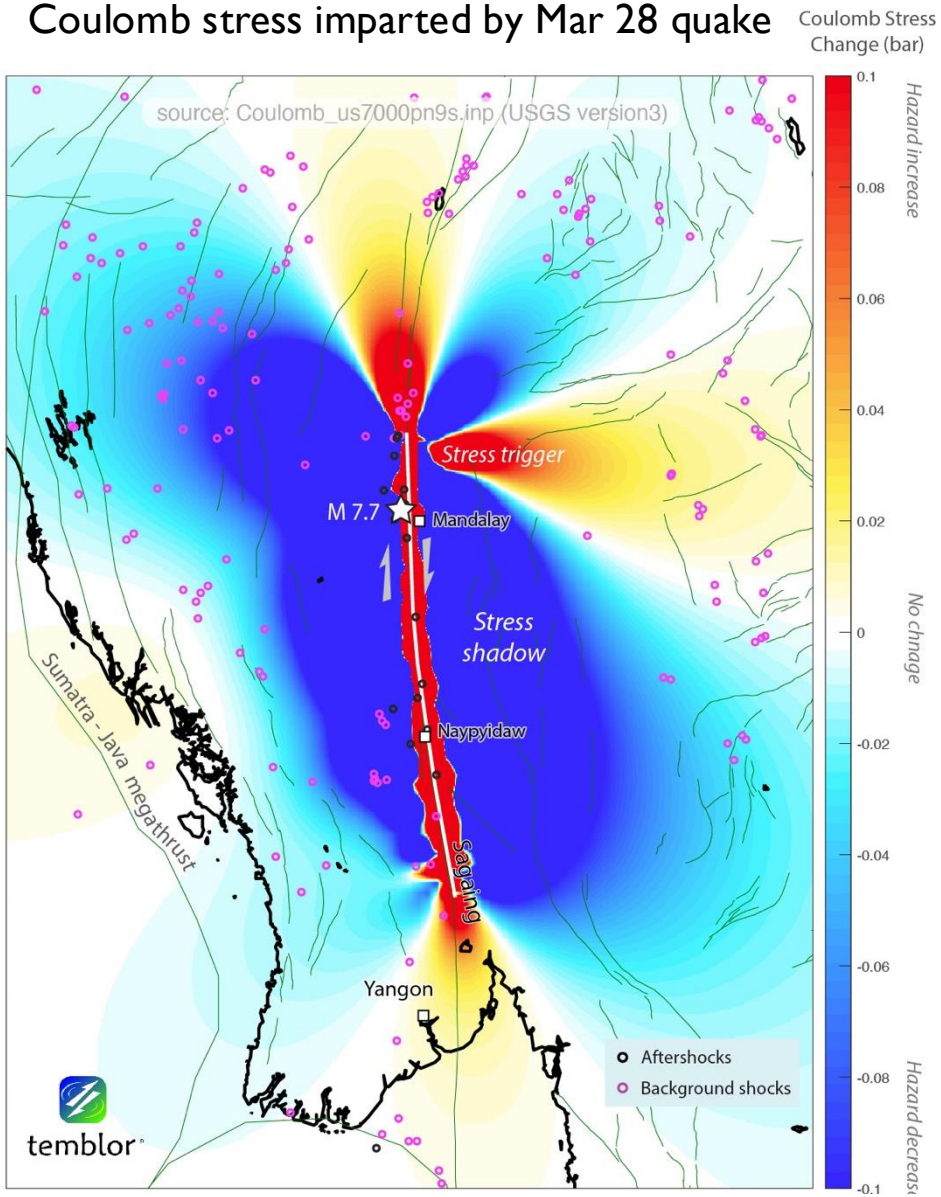


Coulomb stress used to build aftershock forecast

Temblor

Realtime Risk

Coulomb stress imparted by Mar 28 quake



Toda and Stein (2025)

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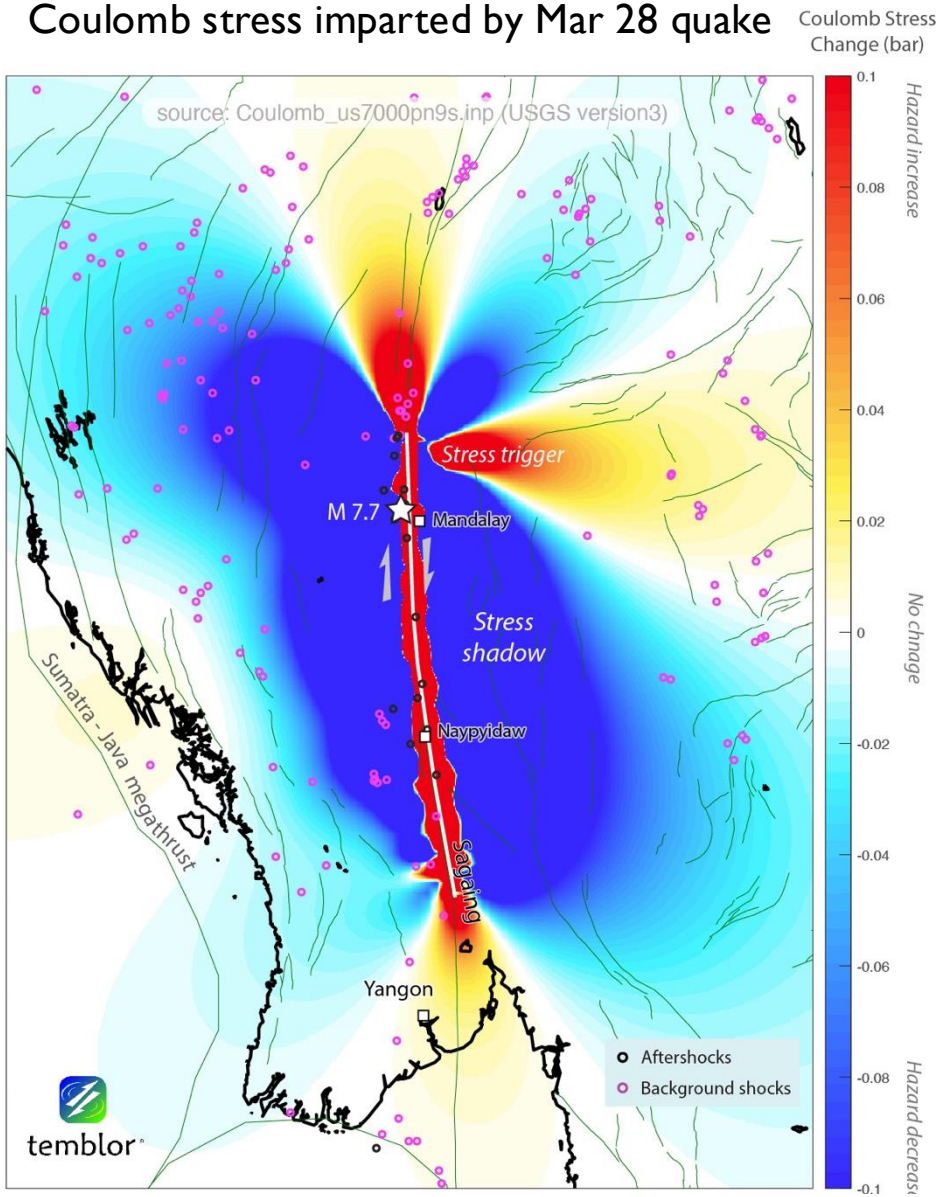
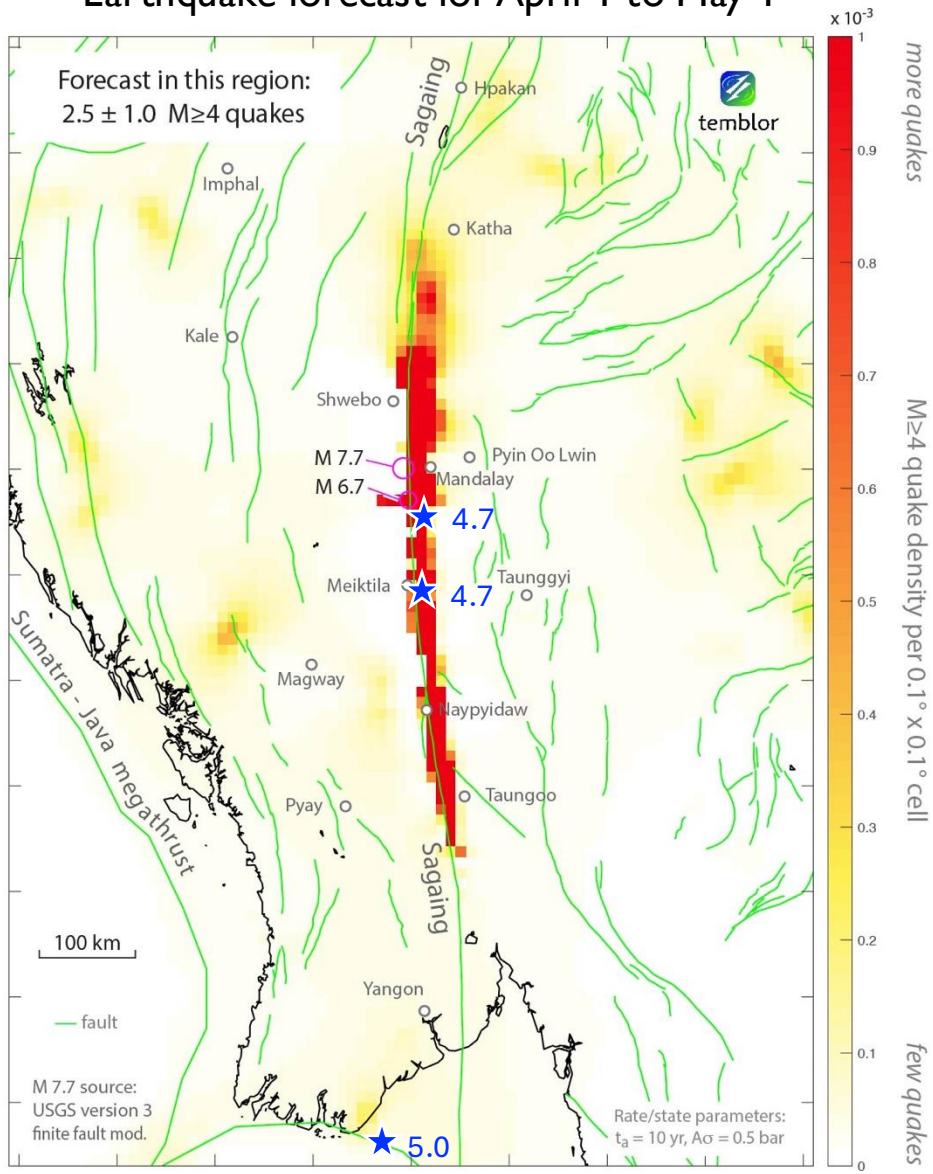


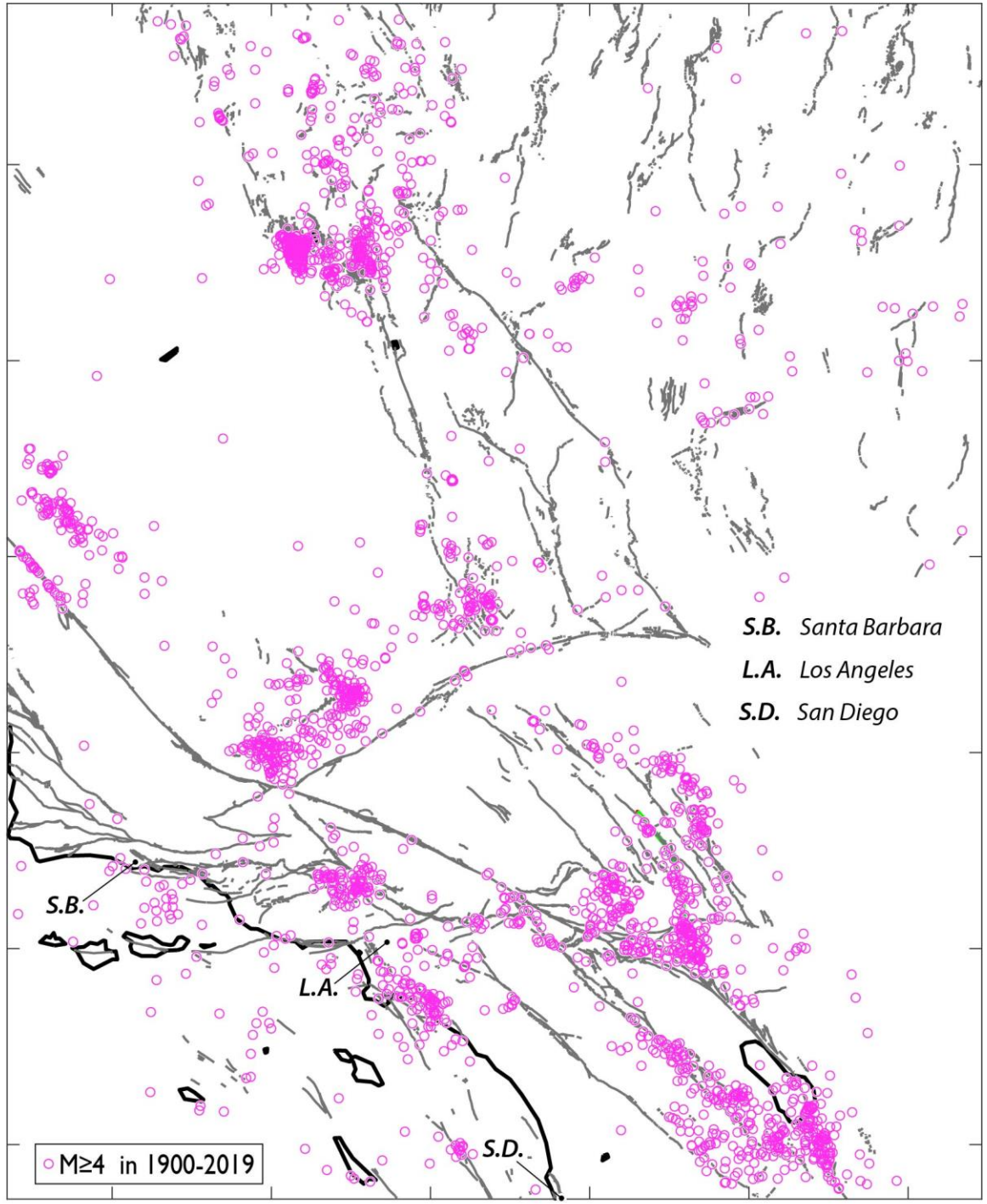
Earthquake forecast for April 1 to May 1



Toda and Stein (2025)

California seismicity is also a product of a century of stress transfer

Earthquakes are in a chain reaction, promoting and inhibiting each other



Toda and Stein (BSSA, 2020)

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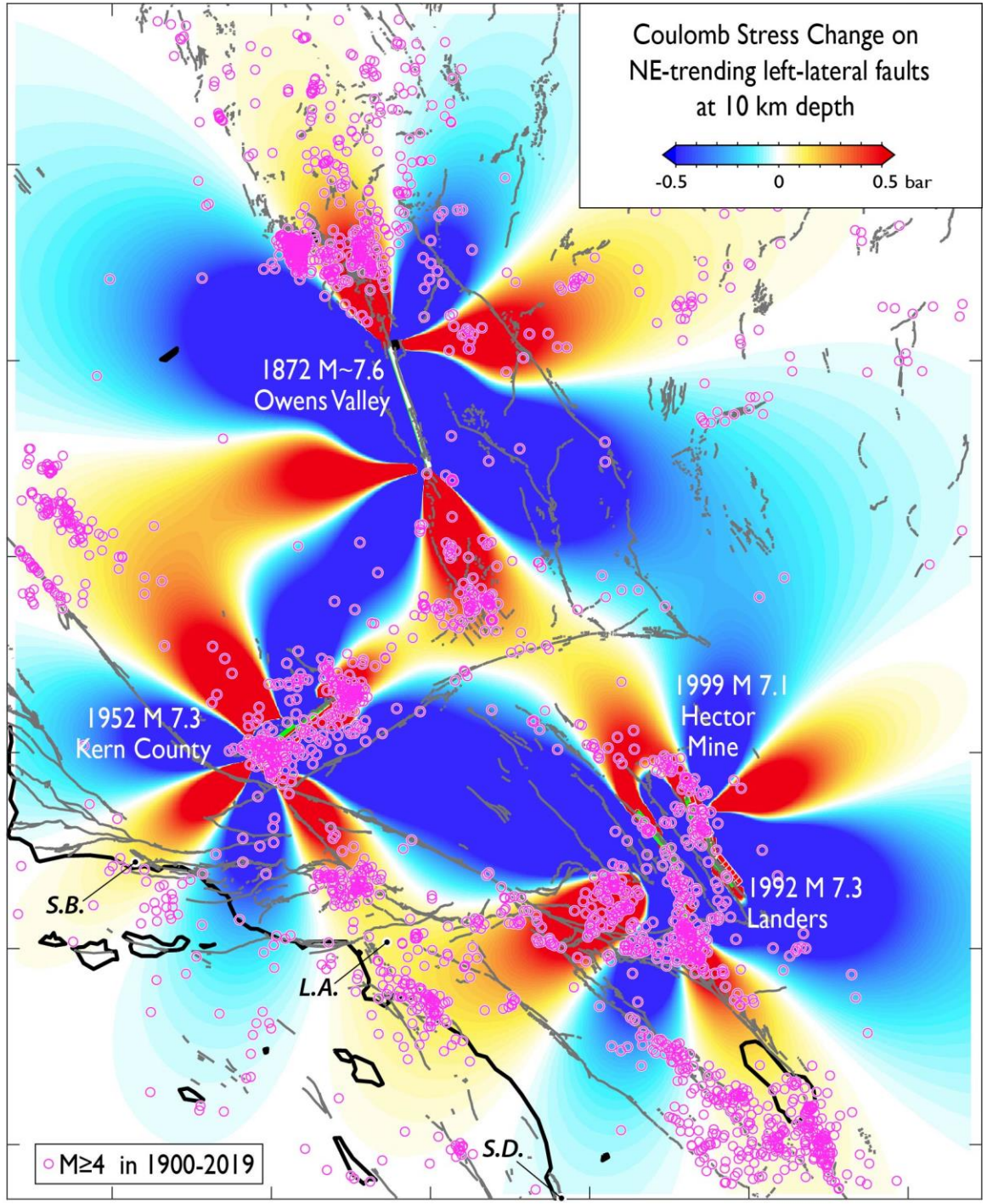
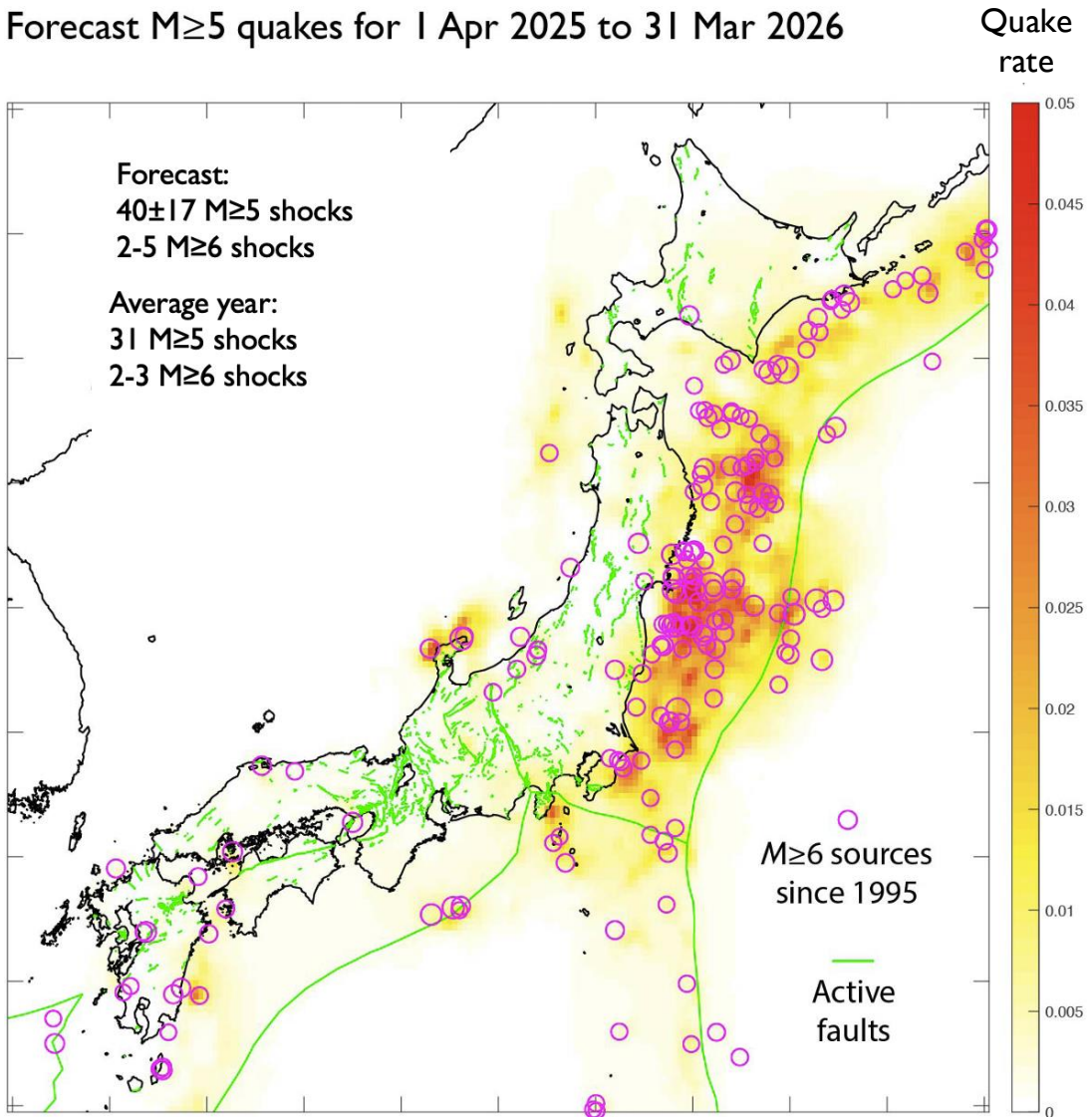
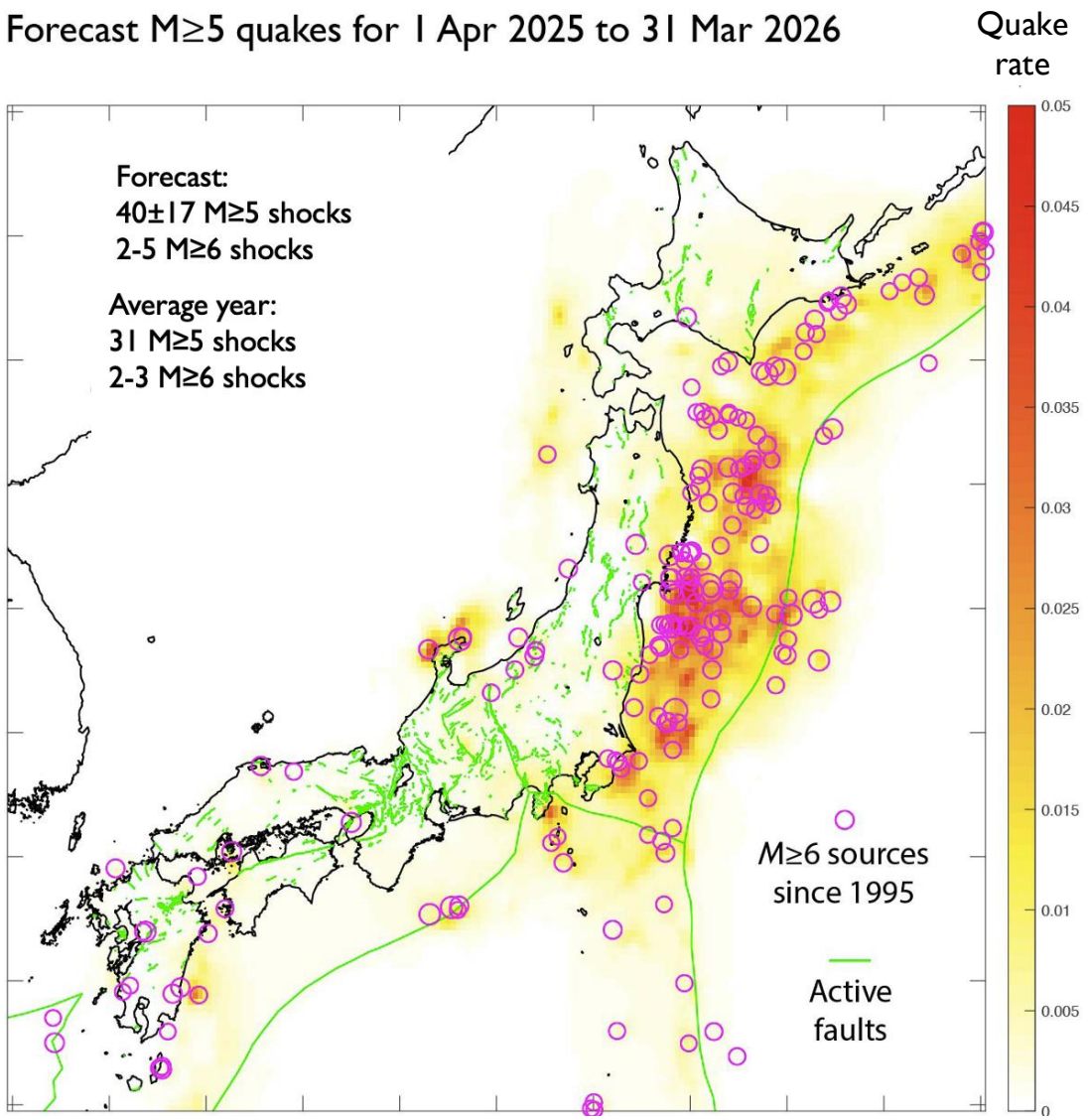


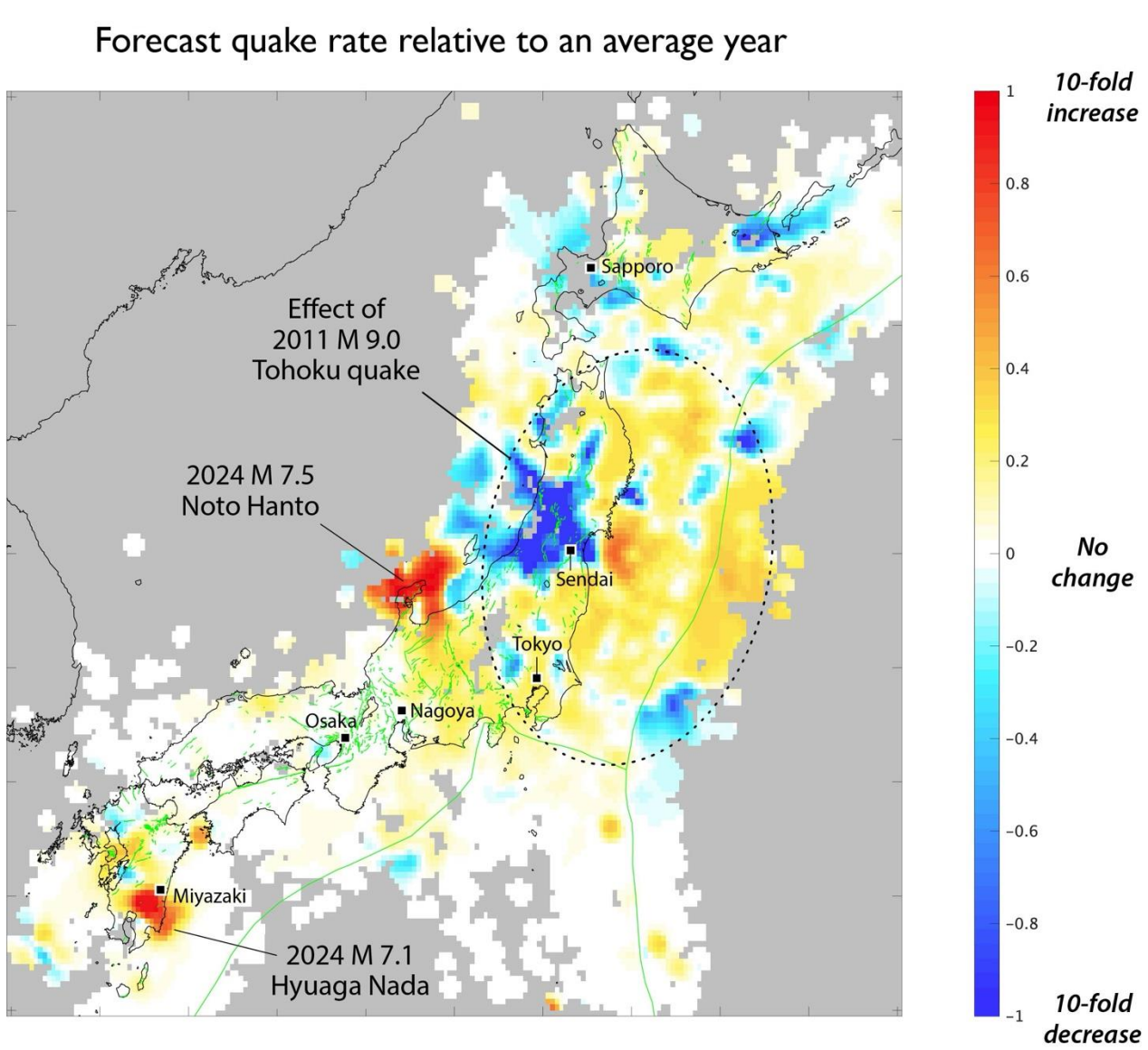
Toda and Stein
(BSSA, 2020)

Temblor's Japan renewal year forecast for Gallagher Re: Quake rate 25% higher rate than normal

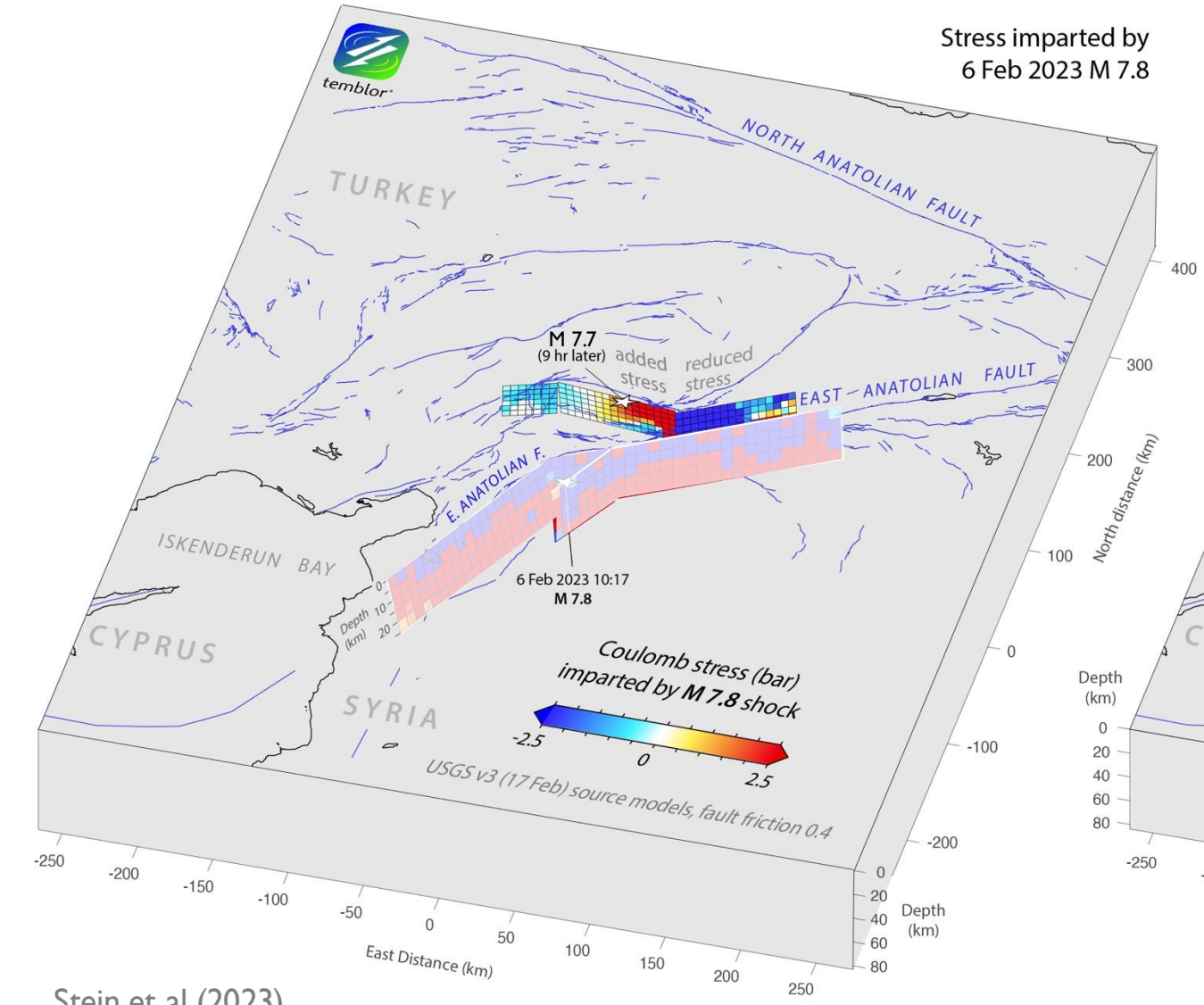


Temblor's Japan renewal year forecast for Gallagher Re: Quake rate 25% higher rate than normal

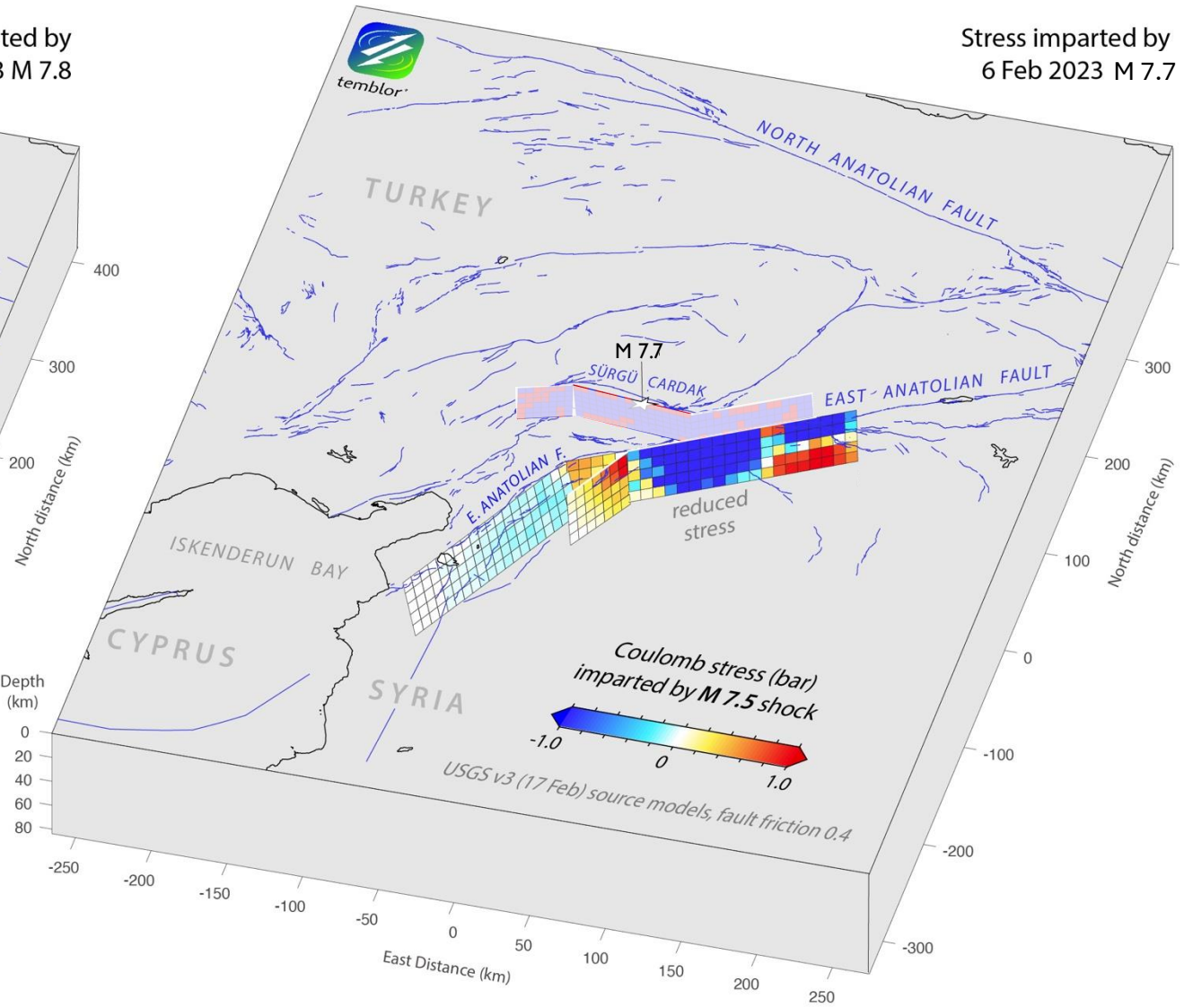




2023 M 7.8 brought the second fault closer to failure



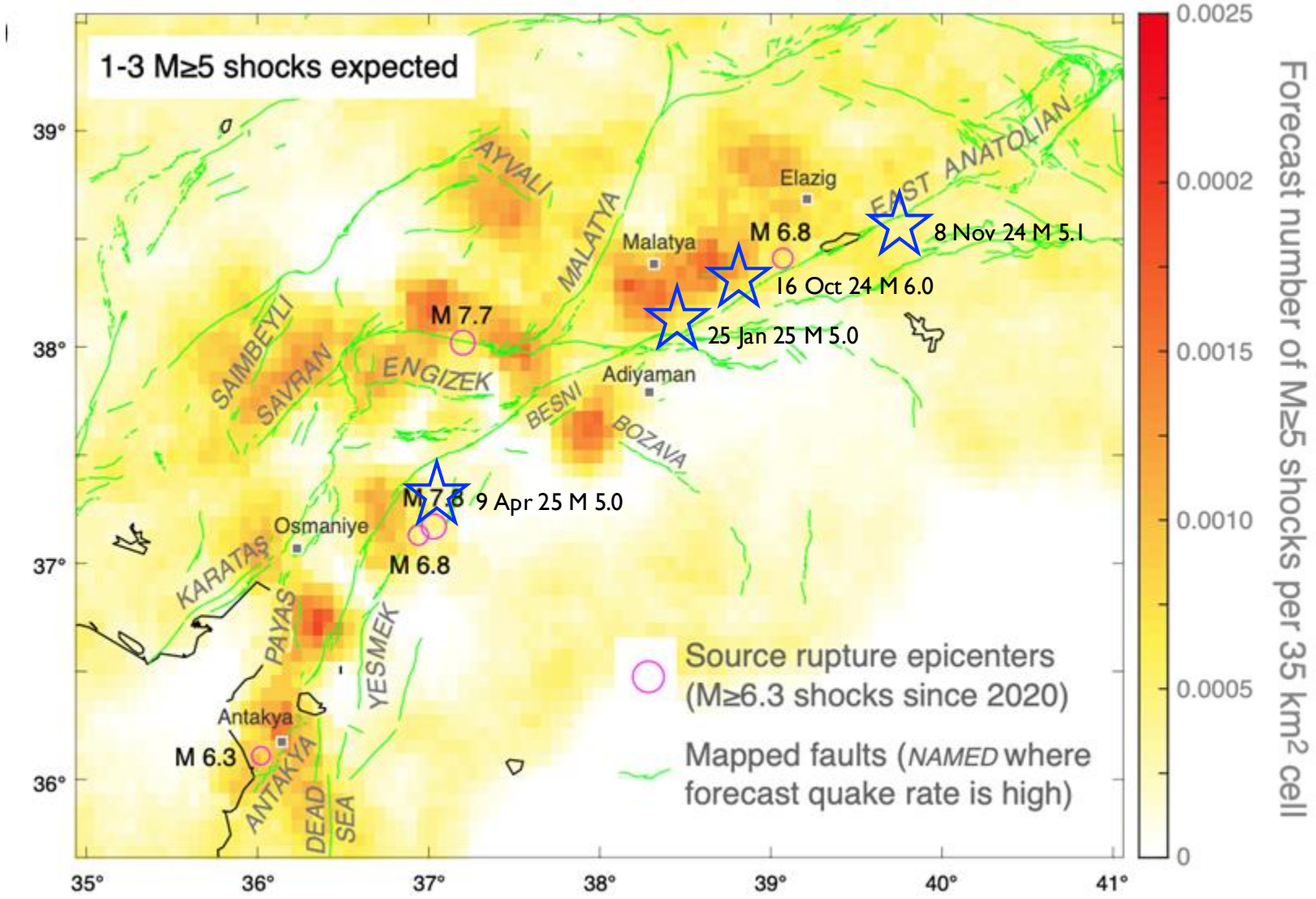
M 7.7 then shut down central M 7.8 aftershocks



Stein et al (2023)

We forecast 1-3 M≥5 earthquakes during 1 Dec 2023 – 1 Dec 2024

The blind forecast is slightly lower than observed (four M≥5 shocks)



Toda & Stein (*2024*)

Temblor Realtime Risk

Where have we done it?	What periods can it cover?	How do we deliver it?
California	Hours clause	Grid of quake rate changes to modify legacy model losses
Japan		
Turkey	Renewal year	
Chile		
Mexico	Next decade	Modified stochastic event set to run losses
Taiwan		
New Zealand		

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Advances in earthquake catastrophe modelling

Earthquake sequences: why should you care?

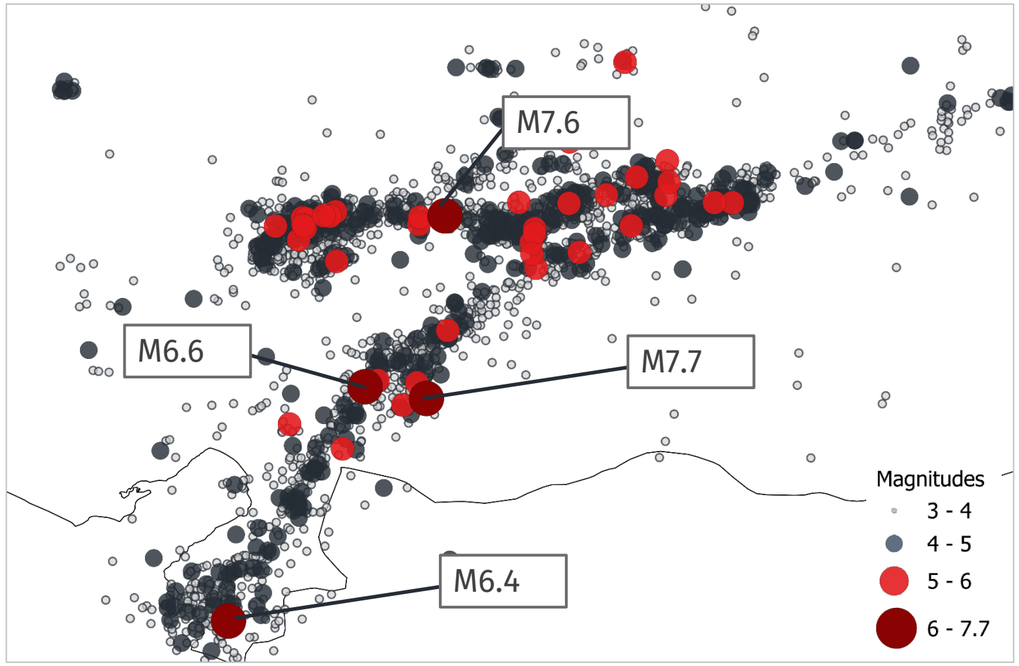
Speaker: Prof. Dr. Paolo Bazzurro
Advisor | Earthquake risk
RED Risk Engineering + Development

April 30th, 2025

Earthquakes come in clusters and have no labels

The mainshock–only view of seismicity was dictated mainly by convenience

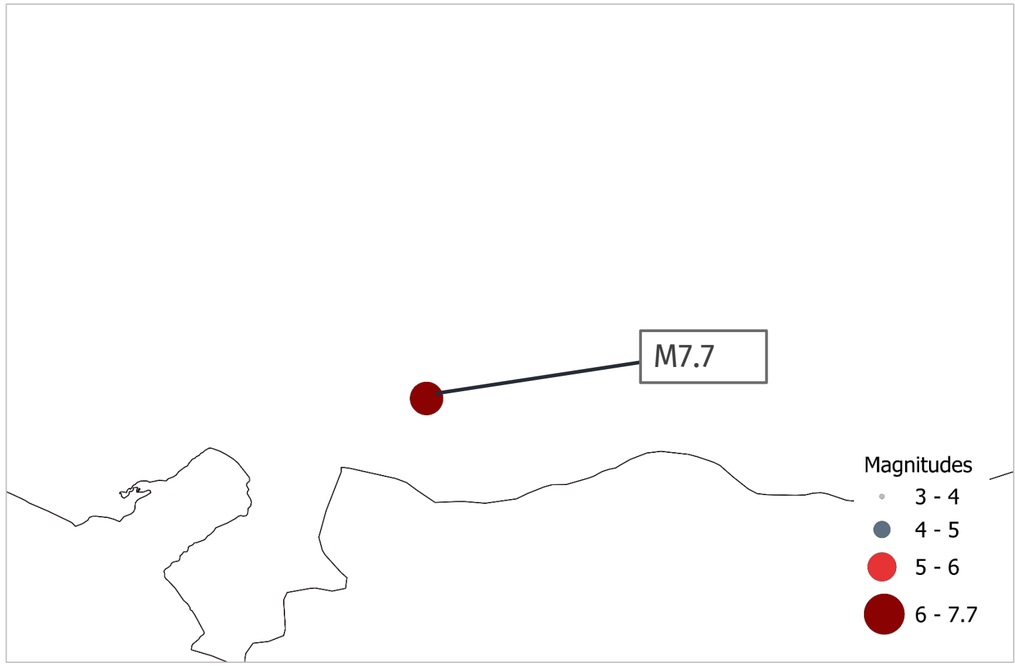
1 Observed Sequence



Kahramanmaraş 2023 sequence

After ‘seismicity declustering’

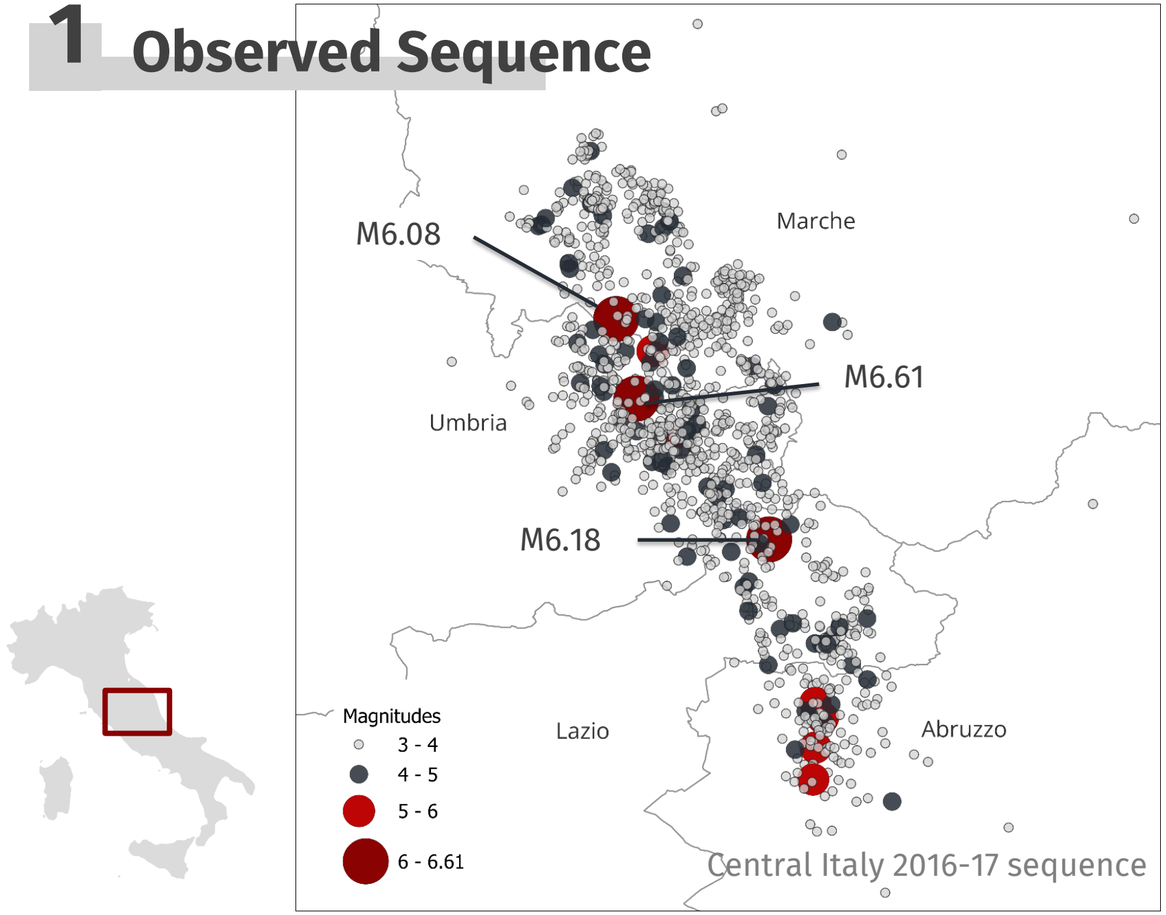
2 ‘Mainshock for modelling



Earthquakes come in clusters and have no labels

The mainshock–only view of seismicity was dictated by statistical convenience

1 Observed Sequence



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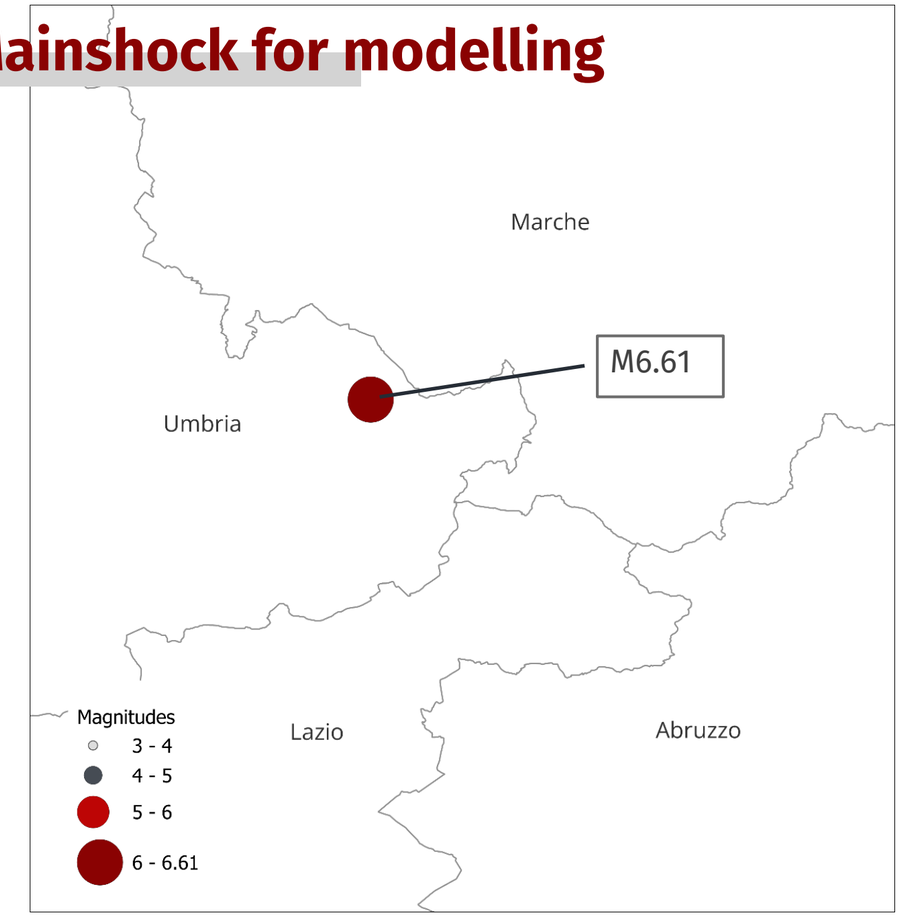


Mainshock-only view: two issues

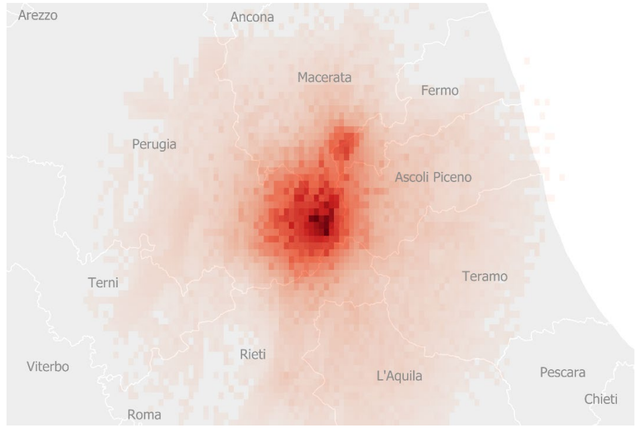
01
Underrepresent hazard
(seismicity declustering)

+

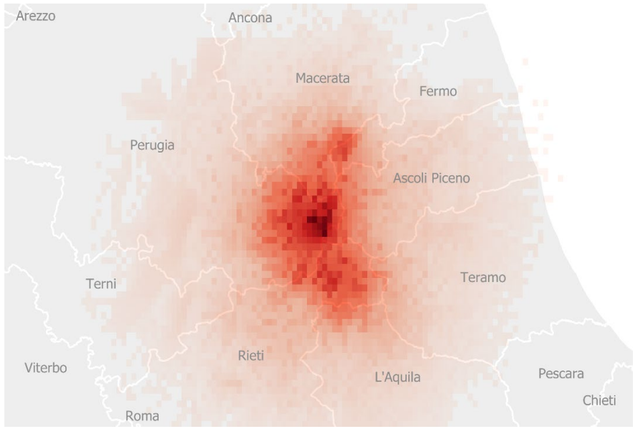
02
Ignore damage accumulation

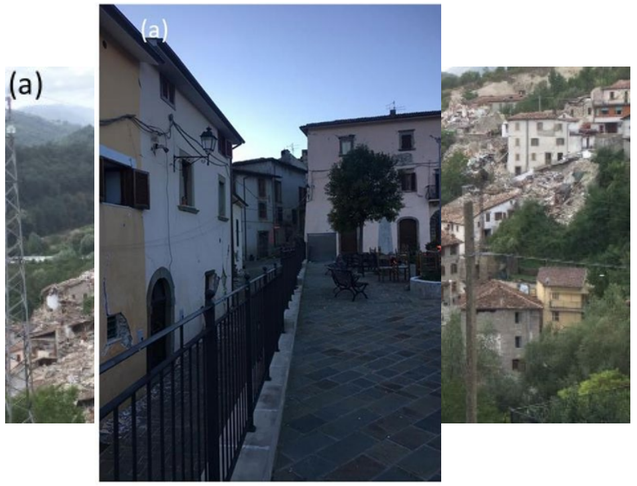
=

After October 2016 event



After entire sequence

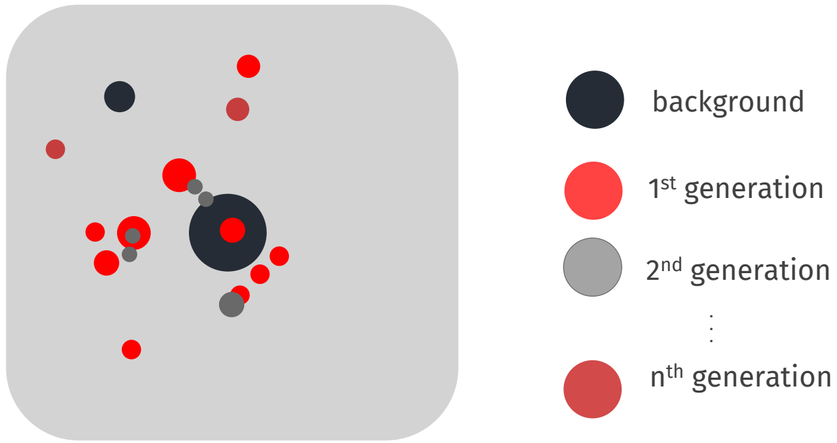


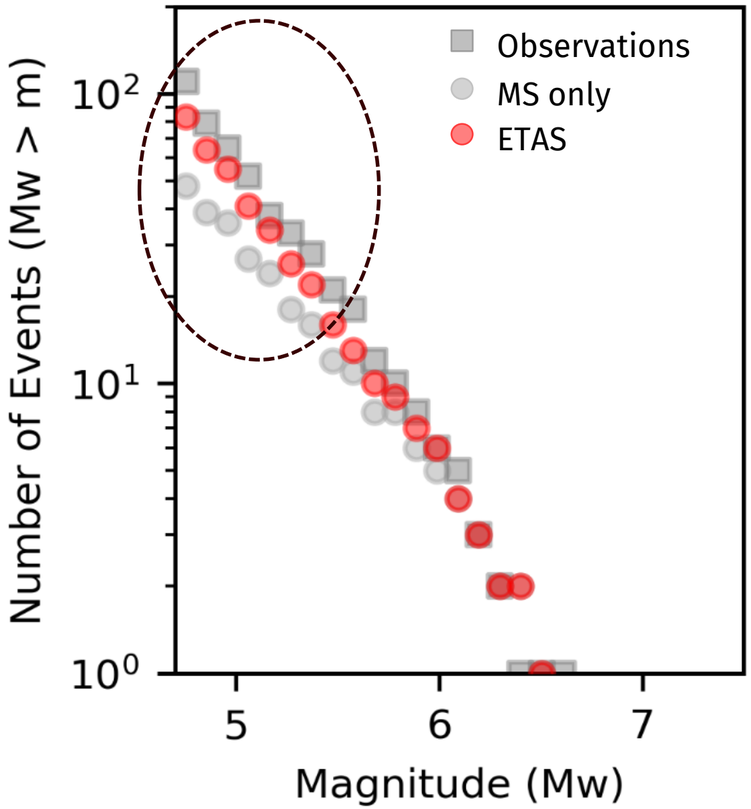


Underestimate & mischaracterize risk

Mainshock-only view is now obsolete

We can simulate **stochastic catalogs that include sequences** with realistic spatio-temporal characteristics

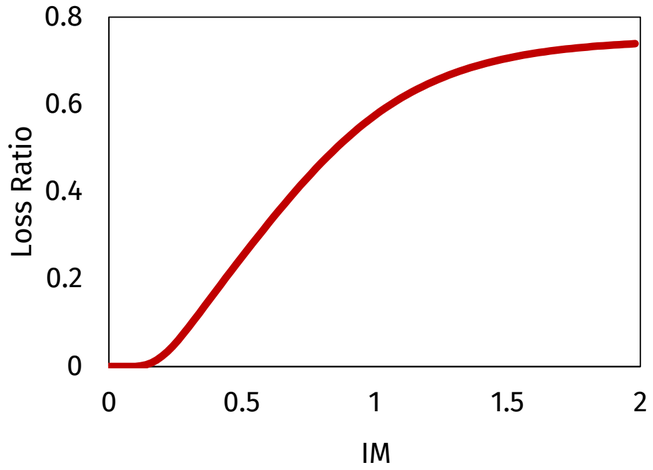


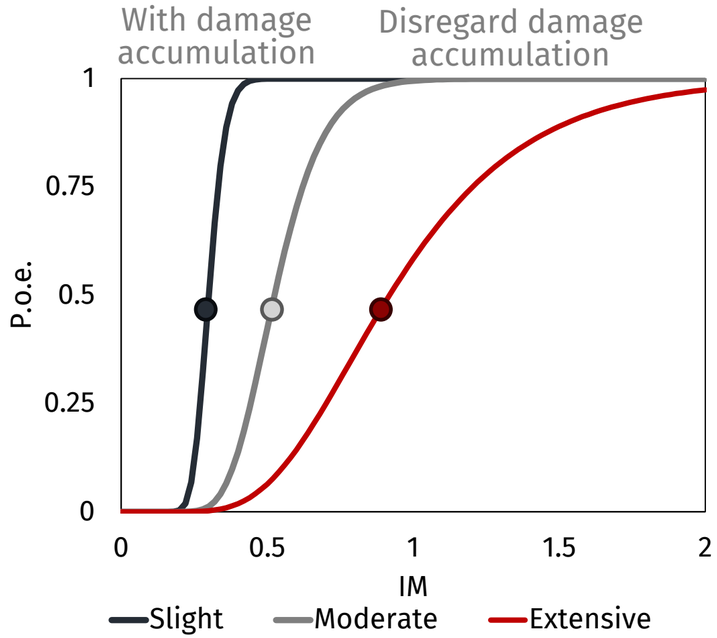


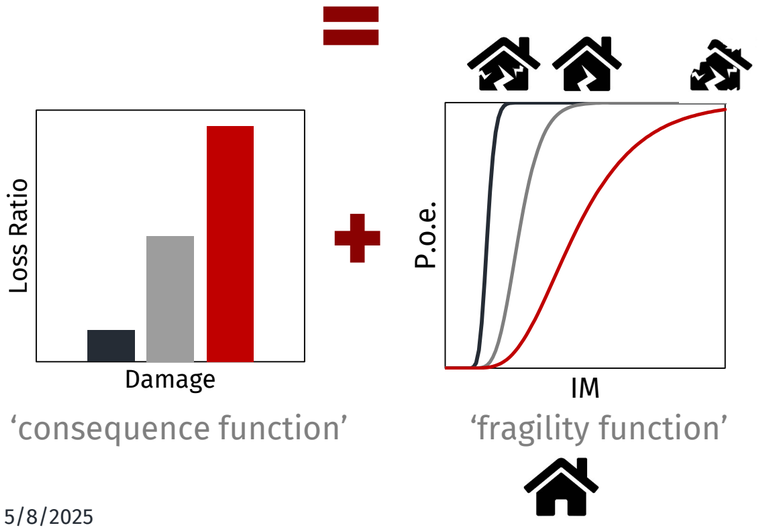
ETAS=Epidemic Type Aftershock Sequence

Damage accumulation: tougher nut to crack

Updating of fragility models to account for the loss of capacity







‘consequence function’

‘fragility function’

Already slightly damaged

Worsening initial conditions

Earthquake Engineering & Structural Dynamics
The Journal of the International Association for Earthquake Engineering

RESEARCH ARTICLE

Considering Cumulative Damage in URM Buildings for Clustered Seismicity Risk Assessment

Pablo Garcia de Quevedo Inarritu, Mohsen Kohrangi, Serena Cattari, Sergio Lagomarsino, Paolo Bazzurro

First published: 10 January 2025 | https://doi.org/10.1002/eqe.4304

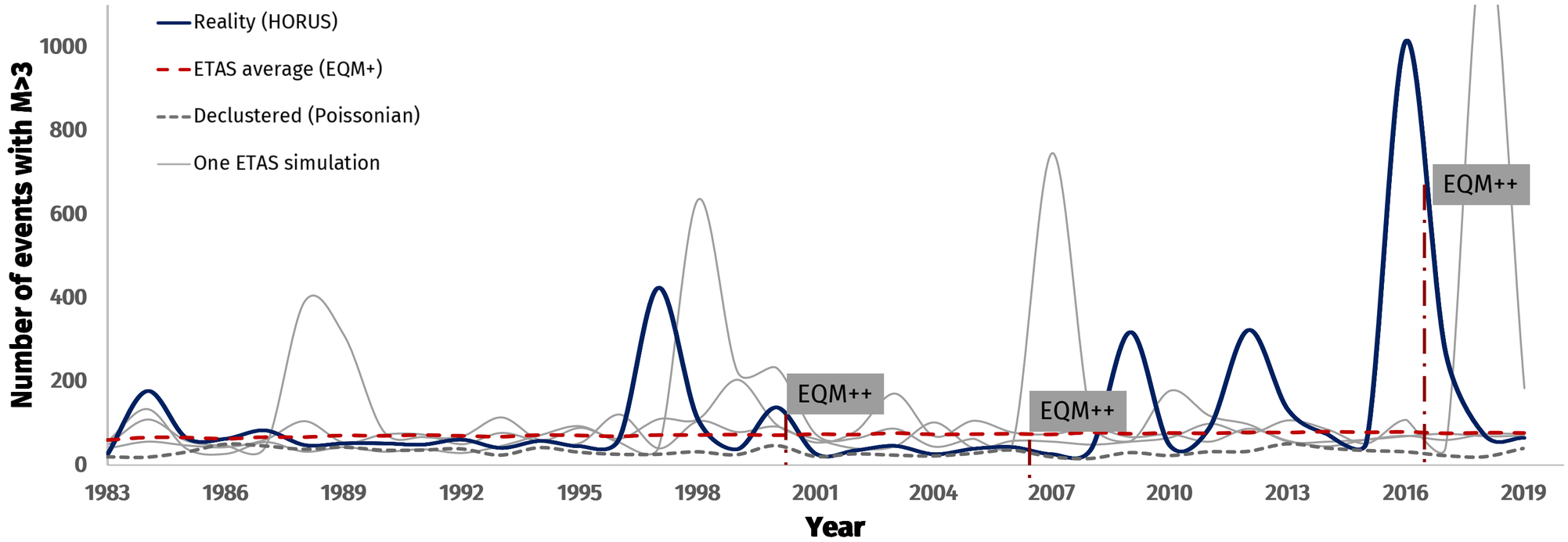
Engineering Demand Parameters for Cumulative Damage Estimation in URM and RC Buildings

Conference paper | First Online: 24 June 2023
pp 57–71 | Cite this conference paper

P. García de Quevedo Iñarritu, N. Šipčić & P. Bazzurro

Part of the book series: Lecture Notes in Civil Engineering ((LNCE,volume 236))

Next generation models offer superior flexibility



Q&A

Do stop by **RED's booth** for more info on
our next generation EQ models for Europe!

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