# Advances in Earthquake Catastrophe Modelling

OASIS Insight London 2025



# Most EQ CAT models are mainshock-only...

(Poisson distribution)

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 Earthquakes are random

Abstract

Yes.

**Aftershocks** "smaller" earthquakes that follow mainshocks



to simulate synthetic earthquakes

# ...but earthquakes are not random at all!

Earthquakes tend to cluster in time and space after large mainshocks



# Key questions

- I. 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?





X<sup>L</sup> Insurance Reinsurance

# Advances in Earthquake Catastrophe Models Clustering



Salvatore lacoletti | 30 April 2025

# CAT lessons learned (?)



### Practical consequences of neglecting EQ clustering

Difference between modeling and reality



(\*) Shapes and levels are indicative only.

Model vendors provide the <u>current</u> 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		Fair
Aftershocks have a lo magnitude than mainsh so they don't cause lo	ower nocks, sses	
	Science has not provided a (simple) solution	Dependi events,
Events in the sequence could be labeled as mainshocks		be col
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



=

### What are the options available to us?



One sequence occurred in the region in the last 180 years



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



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



AXÁ

## **Example for Japan**

Impact of clustering



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)

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### Let's learn our lesson...

*"There are only a few certainties in life: death, taxes and <u>aftershocks</u>"* 

- 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: <u>pysimulator</u>, <u>simplETAS</u>, <u>WCEE</u>, <u>Time-dependent seismic risk modeling</u>, <u>Effect of sequences on hazard</u>



### **Know You Can**

AXA

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

What's the Coulomb stress change anyway?

#### Stress transfer acts over minutes to decades





#### Stress transfer acts over minutes to decades



SAN

Los

Angeles

from

Stein (2003)

ANDREA



3,000 pubs since 1992

2019 M 7.1 Ridgecrest 27 years later

> M 6.5 Big Bear 3 hr later

M 7.1 Hector Mine 7 years later

1992 M 7.3 Landers

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





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

Toda and Stein (2025)

Southern 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)

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



#### M 7.8 rupture brought the M 7.7 fault closer to failure



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

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



Toda & Stein (2024)



Where have we done it?

California Japan Turkey Chile Mexico Taiwan

New Zealand

What periods can it cover?

Hours clause

Renewal year

Next decade

How do we deliver it?

Grid of quake rate changes to modify legacy model losses

Modified stochastic event set to run losses

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### Extras

#### The Bay Area fell under the stress shadow of the 1906 earthquake

75 years before the 1906 earthquake



75 years after the 1906 earthquake



Earthquakes from *Bakun* [1999] and *Ellsworth* [1990]

1911 M=6.2 shock from Bakun [BSSA, 1999]

Coulomb stress change calculations capture this earthquake interaction

Our retrospective forecast since 20 Feb is consistent with locations of subsequent aftershocks



Our retrospective forecast since 20 Feb is consistent with locations of subsequent aftershocks





# **COSS** INSIGHT

# Advances in earthquake catastrophe modelling

Earthquake sequences: why should you care?

Speaker: Prof. Dr. Paolo Bazzurro

Advisor | Earthquake risk RED Risk Engineering + Development



April 30<sup>th</sup>, 2025



# Earthquakes come in clusters and have no labels

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







Kahramanmaraş 2023 sequence

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# **'Mainshock for modelling**



# Earthquakes come in clusters and have no labels The mainshock-only view of seismicity was dictated by statistical convenience





# Mainshock-only view: two issues



**Underestimate** & **mischaracterize** risk

After October

Ancona

Fermo

Ascoli Piceno

L'Aquila

Teramo

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#### After entire sequence





Pescara



# Mainshock-only view is now obsolete

### We can simulate **stochastic catalogs that include sequences** with realistic spatiotemporal characteristics





ETAS=Epidemic Type Aftershock Sequence

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# Damage accumulation: tougher nut to crack

Updating of fragility models to account for the loss of capacity







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Earthquake Engineering **Structural Dynamics** 

The Journal of the International Association for **Earthquake Engineeri** 

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



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

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