Benchmarking GEM's 2026 Global Seismic Risk Model through Historical Scenarios

Anirudh Rao[1*], Jovana Borozan[1], Catalina Yepes-Estrada[1], Christopher Brooks[1], Al Mouayed Bellah Nafeh[1], Vitor Silva[1]

[1] GEM Foundation, Pavia, Italy,

[*] anirudh.rao@globalquakemodel.org

The overall model testing framework

Is the model fit for its intended uses and ready for release?

4 – ACCEPTANCE TESTS

external review • user feedback • comparisons with other models

How well does the overall risk model perform as a whole?

3 – SYSTEM TESTS

historical scenarios • historical AAL • historical EP

How well do model components interface with each other?

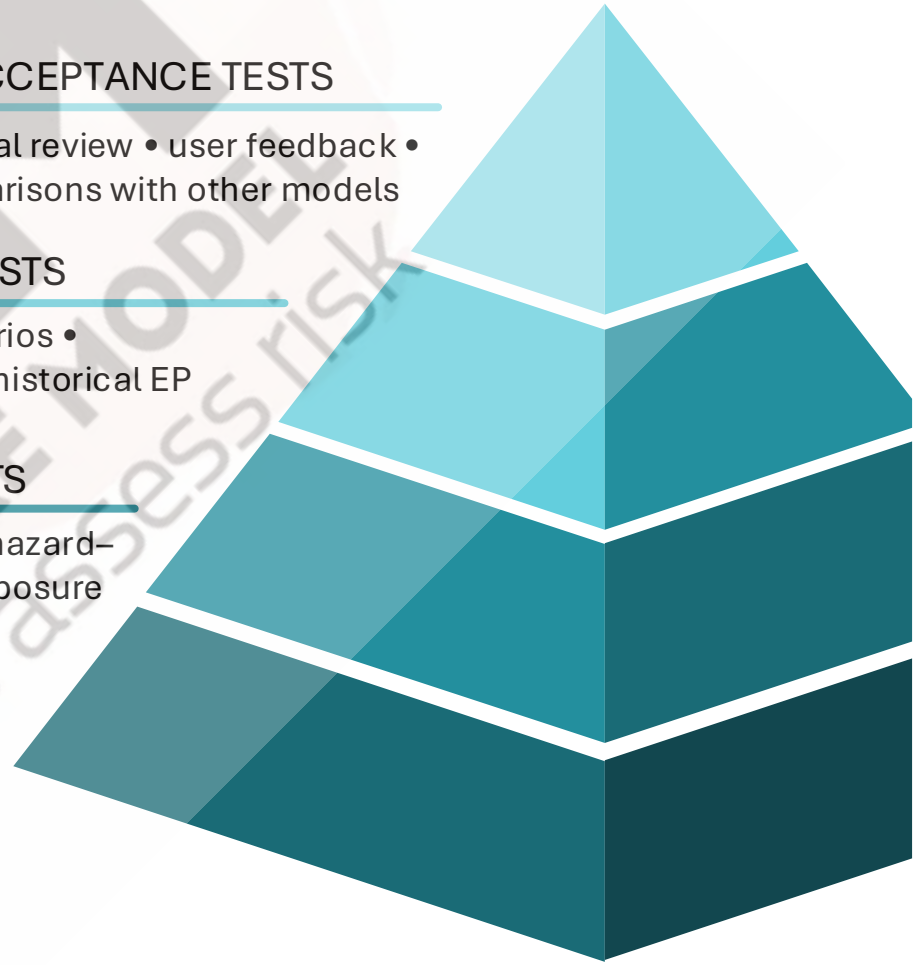
2 – INTEGRATION TESTS

exposure–vulnerability • hazard–vulnerability • hazard–exposure

Does each model component behave correctly on its own?

1 – COMPONENT TESTS

sources • ground motion • exposure • vulnerability



Global scenario inventory

Damaging or potentially damaging earthquakes since 1975, with information about reported impacts.

Existing databases used to create an initial longlist of events for consideration:

- GEM Earthquake Consequences Database (**GEMECD**): So et al. (2014)
- **USGS AtlasCat 4.0**: Marano et al. (2024)
- **EM-DAT**: Delforge et al. (2025)
- NGDC/WDS **Global Significant Earthquake Database**. NOAA (last accessed July 2026)
- GEM Global Earthquake Impact Database (**GEID**): Karim Zadeh et al. (2026)

Global scenario inventory

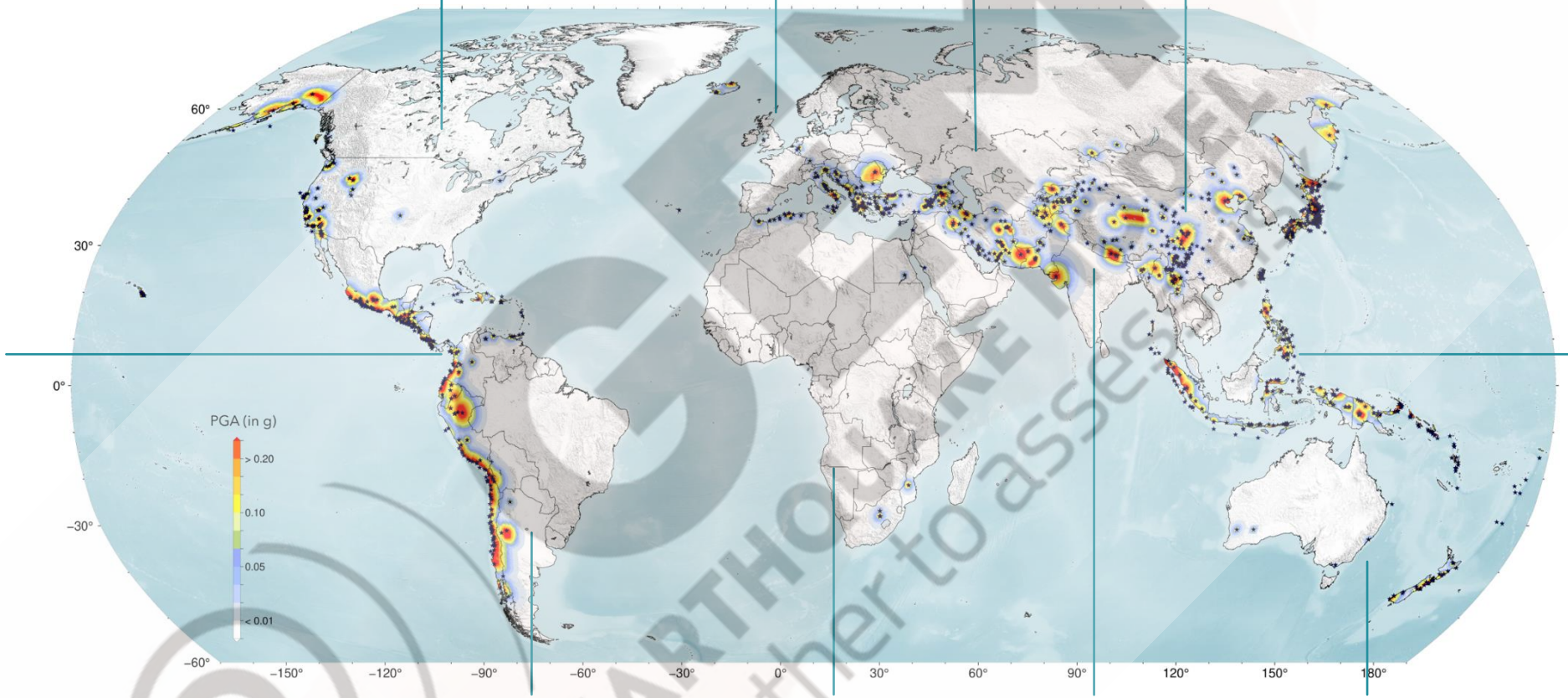
NORTH AMERICA
113 events

EUROPE
184 events

MIDDLE EAST
81 events

EAST ASIA
412 events

CENTRAL AMERICA
97 events



SOUTHEAST ASIA
144 events

SOUTH AMERICA
110 events

AFRICA
21 events

SOUTH ASIA
44 events

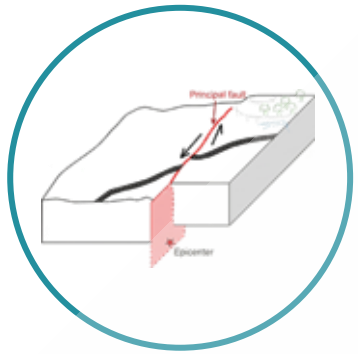
OCEANIA
105 events

Scenario calculations

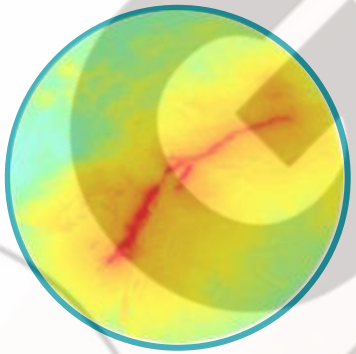
1,335
earthquakes since 1975

79
countries represented

86
high-constraint events



→



→



→



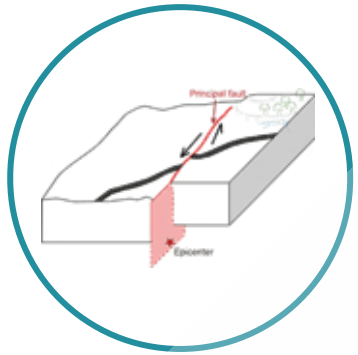
RUPTURE
event geometry

SHAKING
ground motion fields

ASSETS
exposure + vulnerability

CONSEQUENCES
direct loss distribution

Rupture models



RUPTURE

event
geometry

1 Published finite-fault geometry

Detailed event studies, SRCMOD or USGS finite-fault models
Typically large, significant earthquakes

2 GEESE rupture matching

Best matching rupture from GEM's regional seismic source model
Brooks et al. (2025)

3 Alternative geometry approaches

No suitable match in tiers 1–2 and outside the point-rupture range

Worden et al. (2026)	Geometry ensembles and ground-motion uncertainty
Salgado-Gálvez et al. (2020)	Fault-plane selection using regional source information
Akkar et al. (2021)	Sampling of alternative fault-plane solutions

4 Point ruptures for M5.0–5.5

Small-event point source approximation for rupture-to-site distances

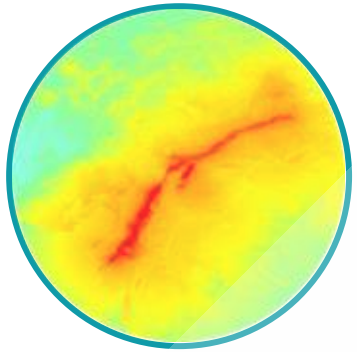
Ground motion

TRT: Infer or assign a tectonic region type

GMMs: Use GEM's ground motion characterization logic tree

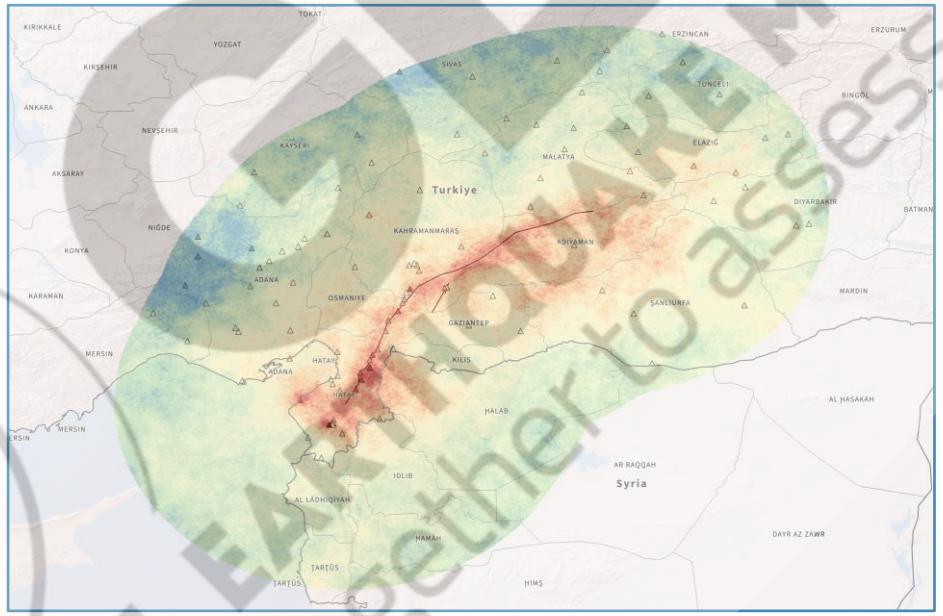
Stations: Use seismic station data to condition GMFs if available

Vs30: Use USGS global Vs30 mosaic unless local data is available



SHAKING

ground motion fields



500 spatially-cross-correlated ground motion fields to propagate uncertainty

Exposure and vulnerability



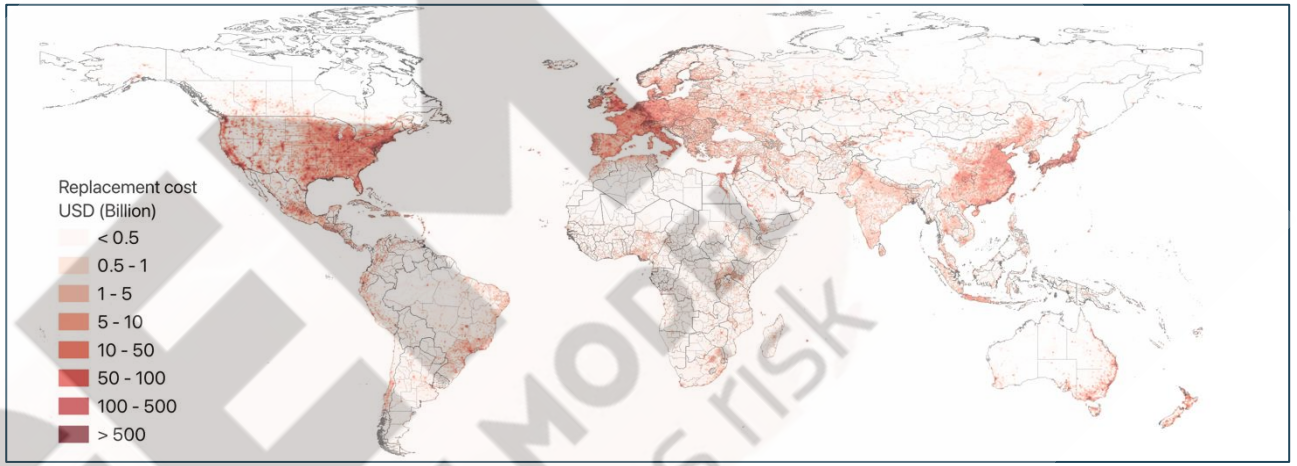
ASSETS

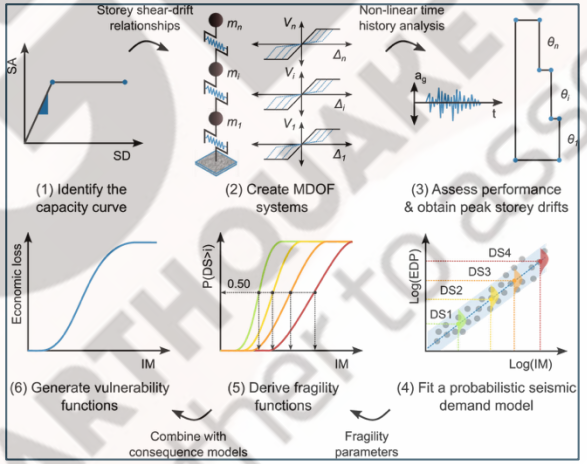
exposure + vulnerability

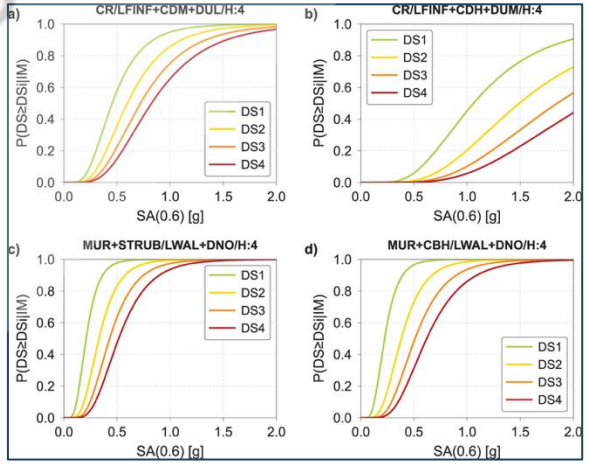
Exposure to vulnerability mapping

GEM's Global Exposure Model

Yepes-Estrada et al. (2026)







GEM's Global Vulnerability Model

Aljawhari et al. (2026) and Nafeh et al. (2026)

Making historical losses comparable

Adjusting past losses to current conditions: Karim Zadeh et al. (under review)



Reported historical loss

Event-year loss estimate

×



Cost factor

Inflation and exchange rates

×



Built-up growth

Growth in built-up surface area

×



Vulnerability factor

Seismic codes and enforcement

=



Adjusted 2026 loss

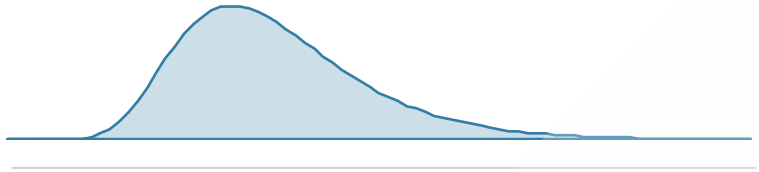
Contemporary reference basis

Uncertainty in the reported loss and each adjustment carries through to the result.

What can we compare?

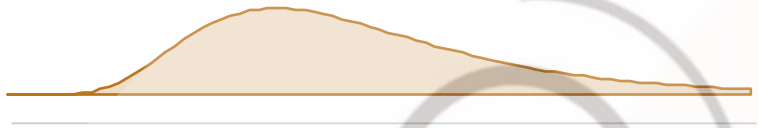
Both loss estimates carry uncertainty

Simulated losses



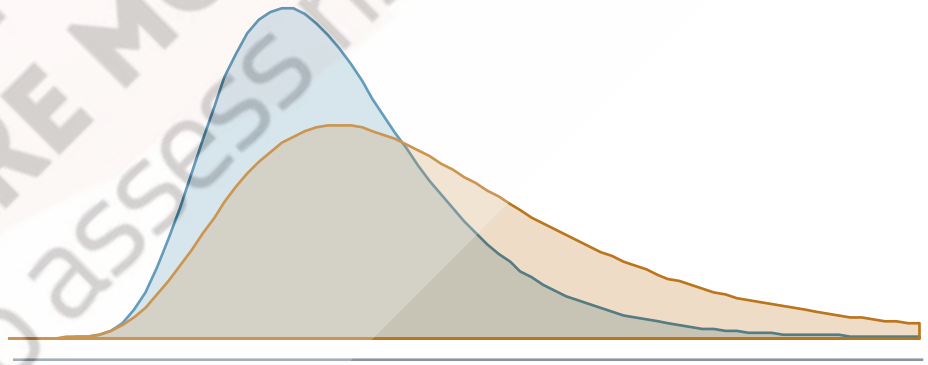
Uncertainties in modelling and analysis

Adjusted historical losses



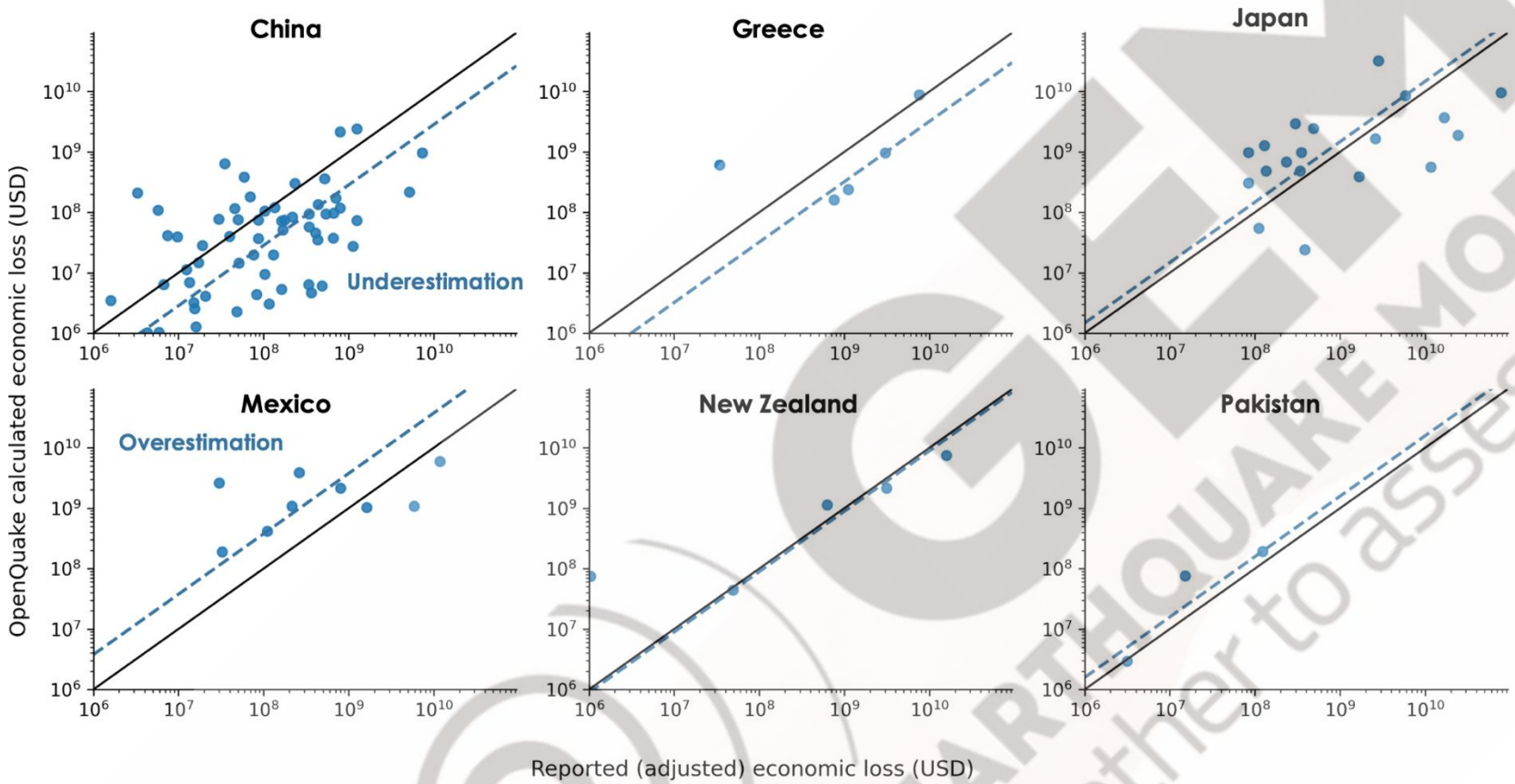
Uncertainties in reported losses and adjustment factors

Compare the distributions



Ensure same loss scope on both sides —
direct building and contents loss from ground shaking

Preliminary country patterns



- China and Greece tend to underestimate losses. Mexico tends to overestimate.
- Japan shows substantial event-to-event variation.
- Small samples limit conclusions for New Zealand and Pakistan.
- Patterns guide investigation. A single global correction would be inappropriate.

Investigating a discrepancy

We check each part of the calculation against the available evidence

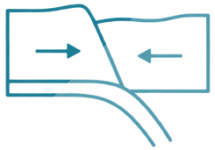
1



Rupture representation

Geometry and source parameters

2



Tectonic region

Appropriate regional ground-motion models

3



Ground shaking

Agreement with station recordings

4



Exposure

Locations, stock, code levels and costs

5



Vulnerability mapping

Functions assigned to each building class

6



Historical benchmark

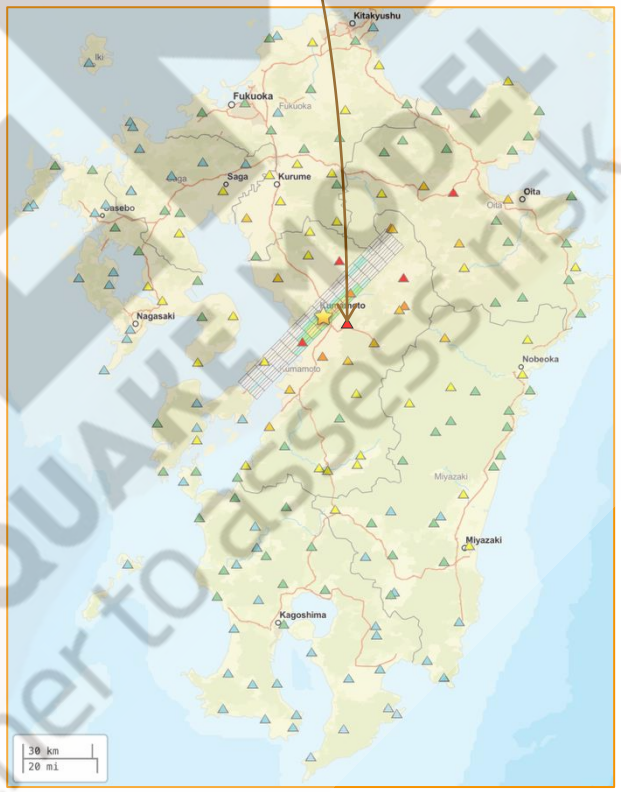
Loss scope, reporting and adjustment factors

A loss mismatch identifies a question. Independent evidence identifies the change.

Evidence required for a model update

- Station recordings constrained shaking in the heavily damaged towns.
- Surveys highlighted collapses and fatalities in pre-1950, pre-code heavy wood buildings.
- We added this previously missing class to the exposure model.
- Collapse rates by structural type and construction era guided vulnerability assignments.
- We reviewed other Japanese events before updating Japan's exposure and vulnerability mapping.

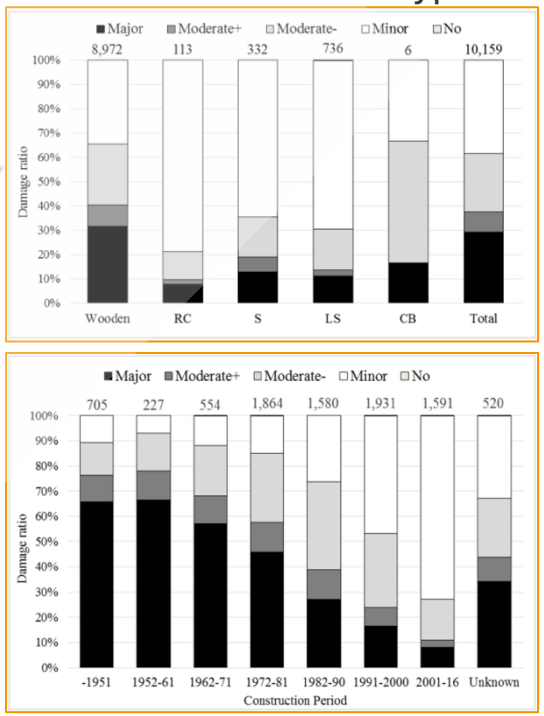
KiK-net station KMM016 ▲
Mashiki town
PGA 1.34g



2016 M7.0 Kumamoto earthquake

Mashiki town

Damage ratios for different structural types



Damage ratios for wooden structures by construction period

Conclusions and ongoing work

Conclusions

- Historical scenarios test the complete rupture-to-loss calculation.
- Loss scope and uncertainty on both sides matter when interpreting agreement.
- Event evidence can identify specific improvements to exposure and vulnerability.

Ongoing and future work

- Extend scenario coverage and detailed reviews of well-constrained events.
- Quantify uncertainty in reported losses and historical adjustments.
- Complete testing of the 2026 release candidate and report performance by region and evidence quality.

Model changes need independent evidence and checks across multiple events!