UPDATE OF THE GLOBAL SEISMIC RISK MODEL

Vitor Silva, Alejandro Calderon, Martina Caruso, Catarina Costa, Maria Camila Hoyos, Luis Martins, Nicole Paul, Anirudh Rao, Michele Simionato, Catalina Yepes, Lana Todorovic, Zarrin Karimzadeh

working together
to assess risk

GEM
GLOBAL EARTHQUAKE MODEL

OQ
OPENQUAKE

AND CREATING!
AND IMPROVING!
AND EXPANDING!
BUT NATIONAL
AND SUB-NATIONAL
AND VULNERABILITY
FRAGILITY
AND EXPOSURE
AND DATA!
AND PROFILES

UPDATE OF THE GLOBAL SEISMIC RISK MODEL /MAPS

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UPDATE OF THE GLOBAL SEISMIC RISK MODEL /MAPS

HELEN Vitor Silva, Alejandro Calderon, Martina Caruso, Catarina Costa, Maria Camila TIEGAN HOBBS CROWLEY Hoyos, Luis Martins, Nicole Paul, Anirudh Rao, Michele Simionato, Catalina SEUGI OZCEBE MARCO PAGANI, EVI RIGA Yepes, Lana Todorovic, Zarrin Karimzadeh KISHOR JAISWAL, TC-PAN MARTA NOVAK, BARBARA BORZI, JOSIP ATALIC, MARIO UROS, GONSALO LOPES, CHRIS BURTON JAMAL DABBEEK, KENDRA JOHNSON, MANUELA VILLANI, JOHN SCHNEIDER, ANTONIO ETTORE RIKKI WEBER, AMIR TAHERIAN, CARLOS SOUSA OLIVEIRA, MICHAEL EWALD, HOSSEIN MOSTAFA ROBIN GEE, MATTHIAS SCHMID, MIGUEL MORA, ANSELM SMOLKA, RUI PINHO, DAVID WALD, GIACOMO LAURENTIU DANCIU, BARBARA POLIDORO, ANA BEATRIZ ACEVEDO, KYRIAZIS PITILAKIS, SAVIERI PAUL HENSHAW, GOKAN TRENDAFILOSKI, SURYA SHRESTHA, DEV KUMAR, AND MUCH MORE....
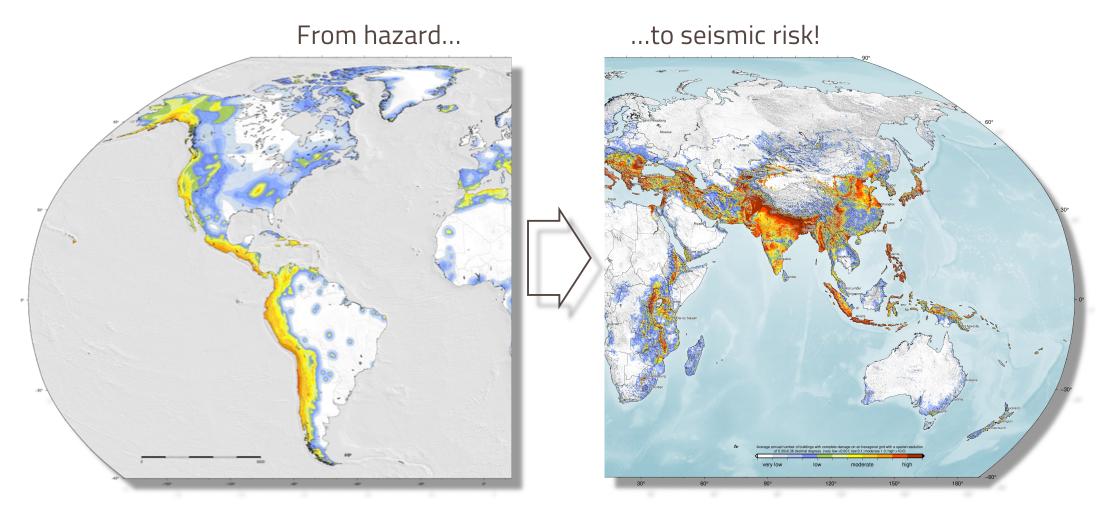
working together to assess risk

GEM
GLOBAL EARTHQUAKE MODEL

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[INSERT LOGOS FROM PUBLIC AND PRIVATE PARTNERS HERE!]

working together to a

YOU + GEM OQ

GLOBAL EARTHQUAKE MODEL   OPENQUAKE

FROM SEISMIC HAZARD TO IMPACT

From hazard...   ...to seismic risk!

Average annual number of buildings with complete damage on an hexagonal grid with a spatial resolution of 0.30x0.36 decimal degrees (very low <0.001; low 0.1; moderate 1.0; high >10.0)

very low   low   moderate   high

GLOBAL EARTHQUAKE MODEL

SOME LESSONS LEARNT

GLOBAL EARTHQUAKE MODEL

SOME APPLICATIONS OF THE RISK MODELS

Dissemination and research

Extension to urban risk assessment

Inclusion in the GAR and World Bank efforts

Porting of models into OASIS and Touchstone

Identification of COVID19 + seismic risk zones

Development of training and teaching material

GLOBAL EARTHQUAKE MODEL

SOME FEEDBACK FROM STAKEHOLDERS

Dr Claudia Pinto,
City hall of Lisbon, Portugal

"...vulnerability of the housing and cultural heritage (...) infrastructure networks (..) as a way to evacuate and access critical facilities."

Mr Dražen Štajduhar,
Civil Protection Dictorate, Croatia

"...vulnerability of the building stock (...) evaluate the number of collapses, fatalities and injured citizens."

GLOBAL EARTHQUAKE MODEL
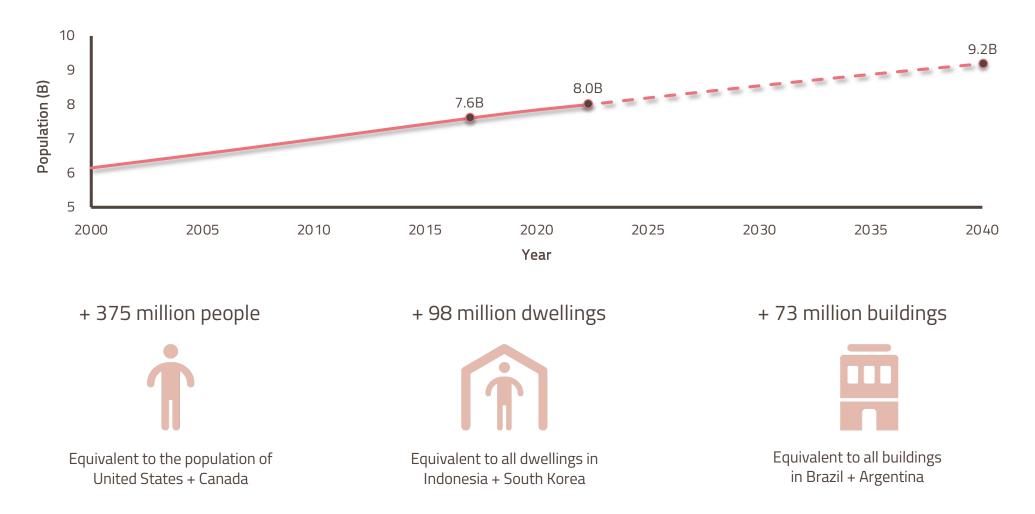
UPDATING AND UPGRADING EXPOSURE

GLOBAL EARTHQUAKE MODEL
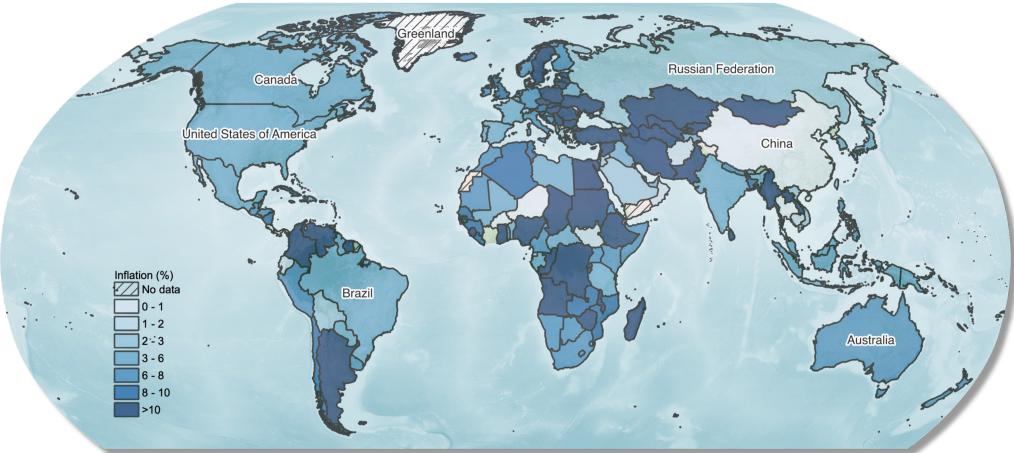
SINCE 2018, A LOT HAS HAPPENED

Population (B) vs Year

- 2015: 7.6B
- ~2022: 8.0B
- 2040: 9.2B

+ 375 million people

Equivalent to the population of
United States + Canada

+ 98 million dwellings

Equivalent to all dwellings in
Indonesia + South Korea

+ 73 million buildings

Equivalent to all buildings
in Brazil + Argentina

GLOBAL EARTHQUAKE MODEL

INFLATION AND CONSTRUCTION COSTS

More than 54 countries currently have inflation above 10%, which tends to be 50% higher for the construction sector

Inflation (%)
- No data
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 6
- 6 - 8
- 8 - 10
- >10
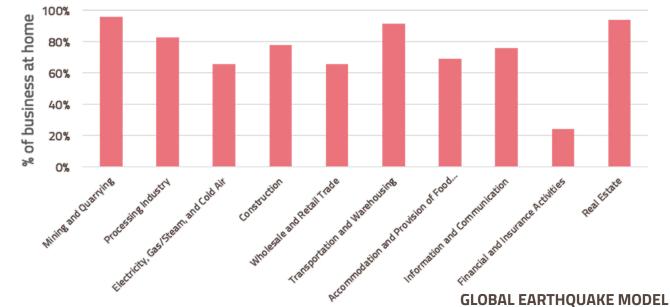
GLOBAL EARTHQUAKE MODEL
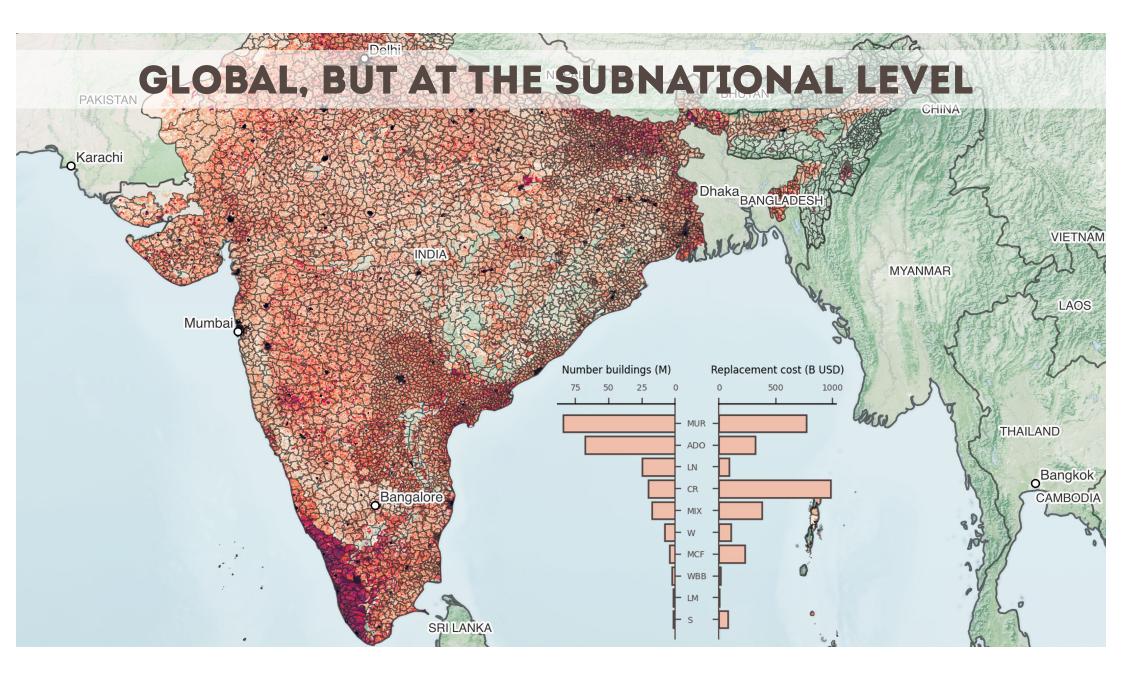
BETTER UNDERSTANDING OF NONRESIDENTIAL ASSETS
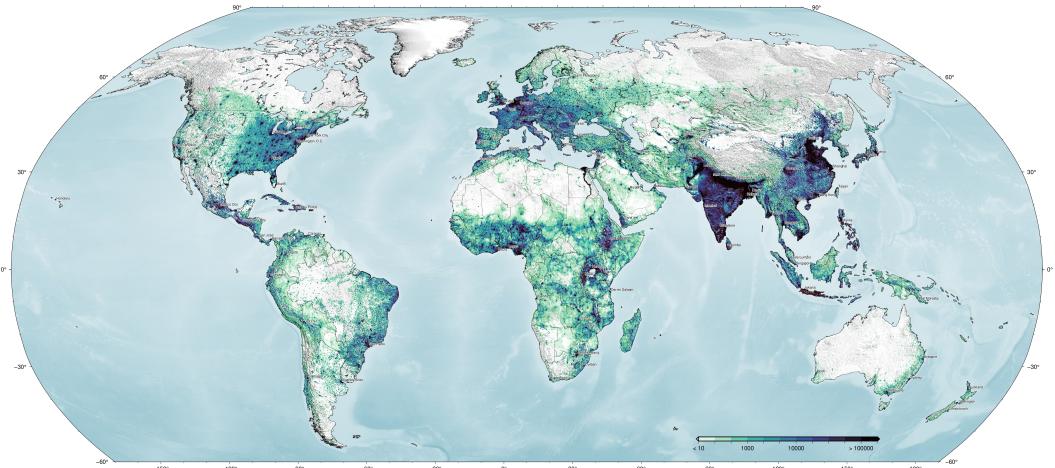
In several countries (in particular in South East), several business are established in the owenrs house, thus reducing the number of (exclusive) commercial buildings.
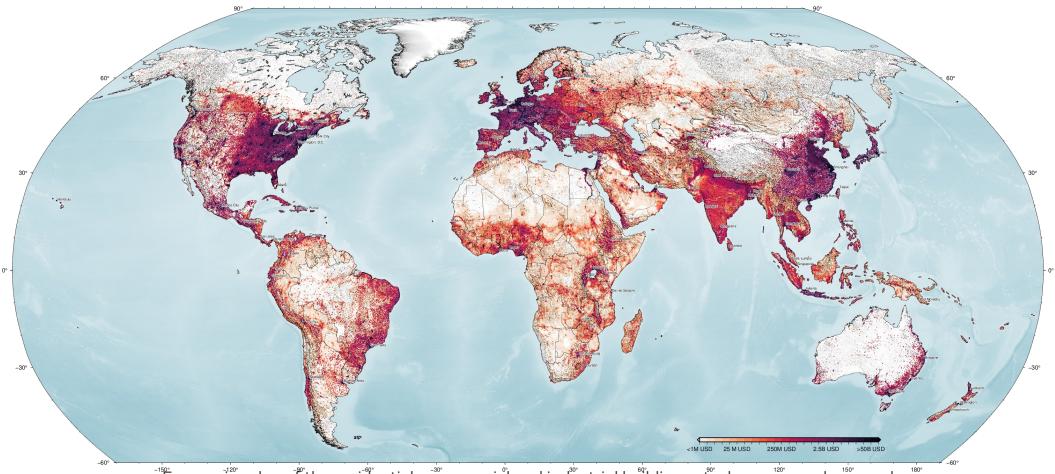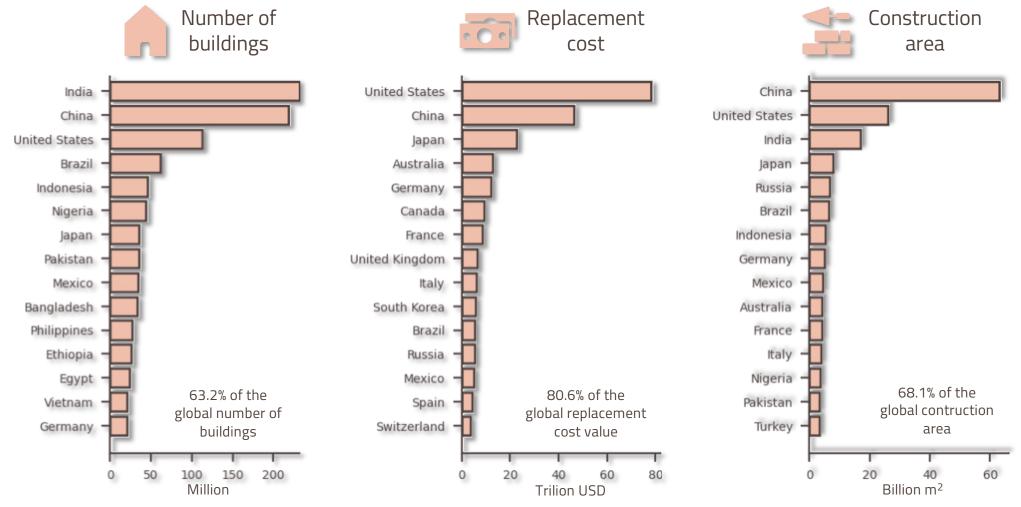
% of businesses at home in Indonesia

GLOBAL EARTHQUAKE MODEL

GLOBAL, BUT AT THE SUBNATIONAL LEVEL

THE 2023 GEM'S GLOBAL EXPOSURE MODEL

Number of residential, commercial and industrial buildings on an evenly spaced hexagon grid with a constant spatial resolution of 0.30x0.36 decimal degrees.

GLOBAL EARTHQUAKE MODEL

THE 2023 GEM'S GLOBAL EXPOSURE MODEL

Legend: <1M USD · 25 M USD · 250M USD · 2.5B USD · >50B USD

Economic value of the residential, commercial and industrial buildings stock on an evenly spaced hexagon grid with a constant spatial resolution of 0.30x0.36 decimal degrees.

GLOBAL EARTHQUAKE MODEL

THE 2023 GEM'S GLOBAL EXPOSURE MODEL

	Residential	Commercial	Industrial	Total
🚶	7.87B	-	-	**7.87B**
🏠	1.39B	0.10B	0.03B	**1.52 B**
🧱 (m2)	193B	29B	20B	**242B**
💵 (USD)	202T	57T	28T	**287T**
	components	components		

GLOBAL EARTHQUAKE MODEL

THE 2023 GEM'S GLOBAL EXPOSURE MODEL

Number of buildings

Country	
India	
China	
United States	
Brazil	
Indonesia	
Nigeria	
Japan	
Pakistan	
Mexico	
Bangladesh	
Philippines	
Ethiopia	
Egypt	
Vietnam	
Germany	

63.2% of the global number of buildings

0 50 100 150 200
Million

Replacement cost

Country	
United States	
China	
Japan	
Australia	
Germany	
Canada	
France	
United Kingdom	
Italy	
South Korea	
Brazil	
Russia	
Mexico	
Spain	
Switzerland	

80.6% of the global replacement cost value

0 20 40 60 80
Trilion USD

Construction area

Country	
China	
United States	
India	
Japan	
Russia	
Brazil	
Indonesia	
Germany	
Mexico	
Australia	
France	
Italy	
Nigeria	
Pakistan	
Turkey	

68.1% of the global contruction area

0 20 40 60
Billion m²

GLOBAL EARTHQUAKE MODEL

EXPANDING THE VULNERABILITY DATABASE

GLOBAL EARTHQUAKE MODEL

EXPANDING THE GLOBAL VULNERABILITY MODEL

We have expanded the vulnerability database from **544** functions to **1201** functions (times 3 occupancy types – for a total of **3603** functions)

Bamboo houses

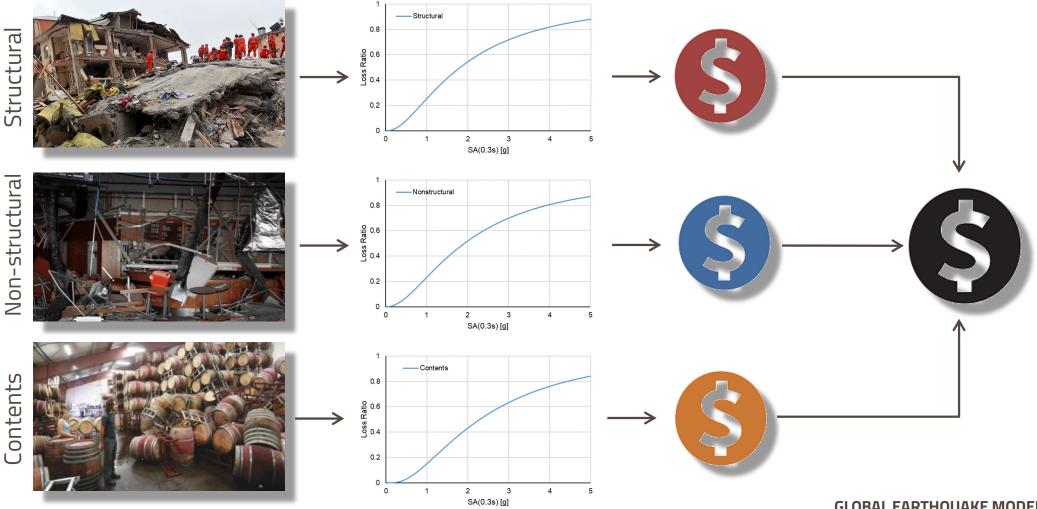Large panel buildings
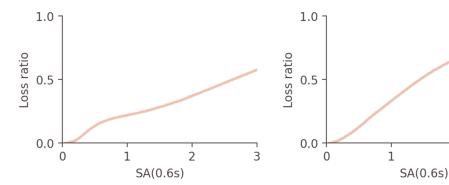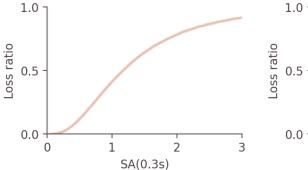
Ruble stone masonry
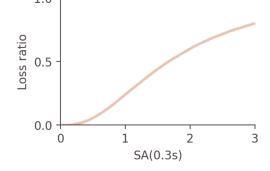
Concrete bricks masonry

EXPANDING THE GLOBAL VULNERABILITY MODEL

GLOBAL EARTHQUAKE MODEL
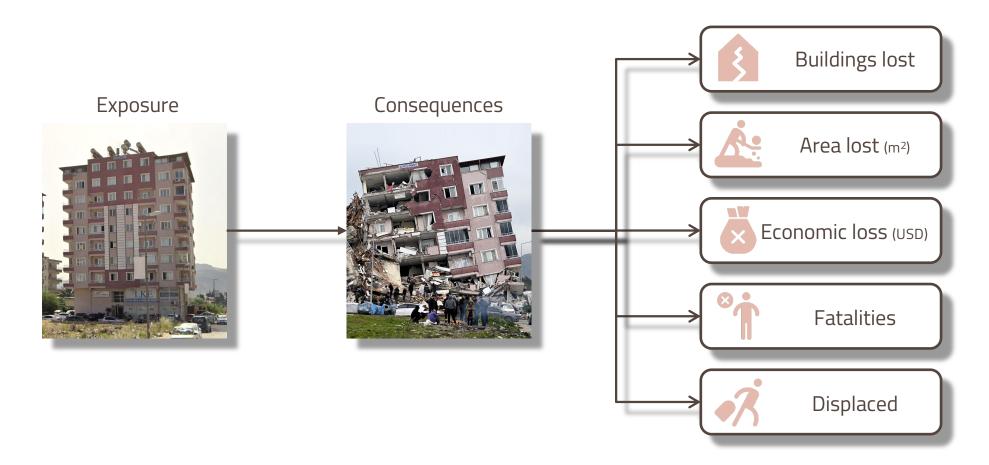
EXPANDING THE GLOBAL VULNERABILITY MODEL

The vulnerability model currently covers five main risk metrics

Exposure

Consequences

Buildings lost

Area lost (m²)

Economic loss (USD)

Fatalities

Displaced
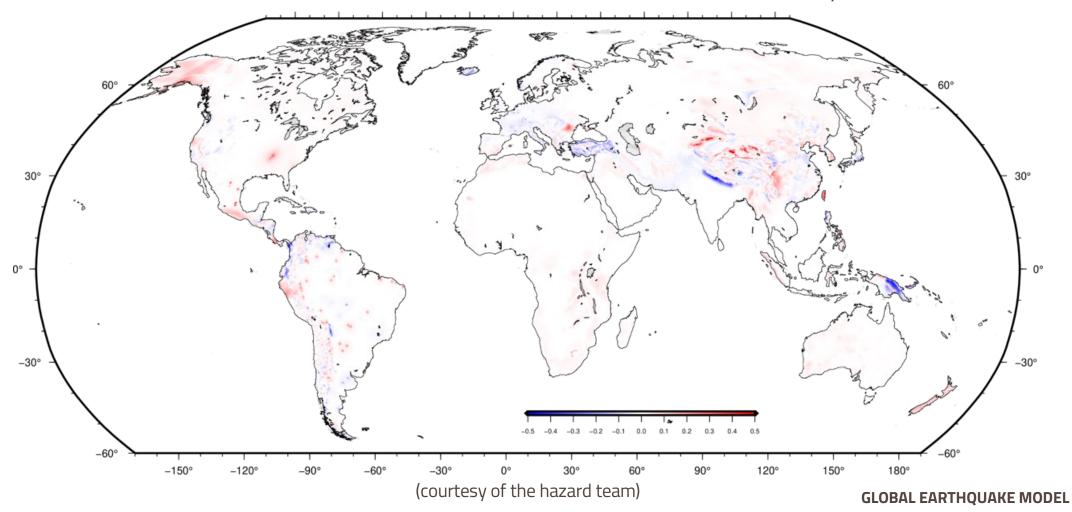
IMPACT OF THE SEISMIC HAZARD

GLOBAL EARTHQUAKE MODEL
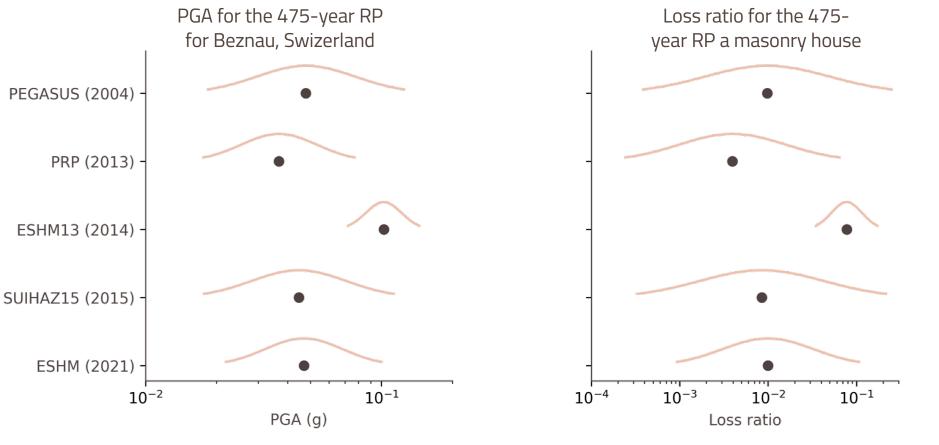
DIFFERENCES ON THE SEISMIC HAZARD

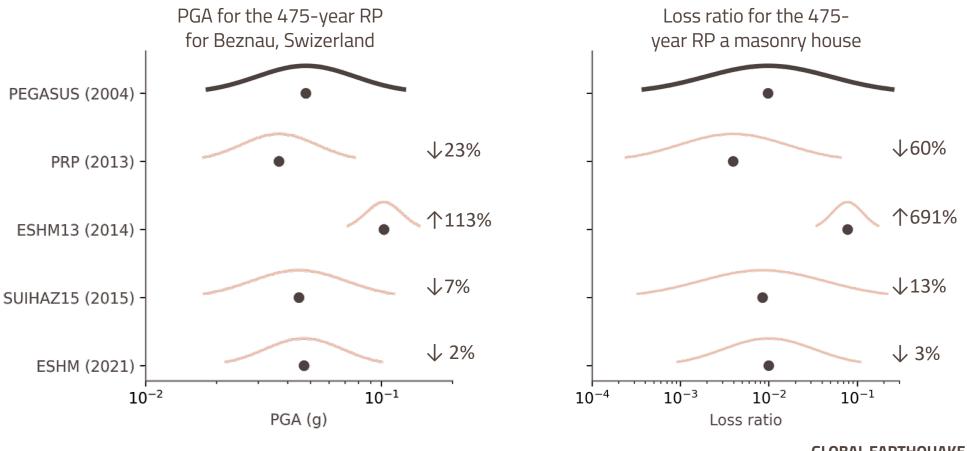Differences in the seismic hazard between 2018 and 2023 (PGA for the 475year RP on rock).

(courtesy of the hazard team)

DIFFERENCES ON THE SEISMIC HAZARD

One small step for hazard, one giant leap for risk

PGA for the 475-year RP for Beznau, Swizerland

Loss ratio for the 475-year RP a masonry house

GLOBAL EARTHQUAKE MODEL

DIFFERENCES ON THE SEISMIC HAZARD

One small step for hazard, one giant leap for risk

PGA for the 475-year RP for Beznau, Swizerland

Loss ratio for the 475-year RP a masonry house

PEGASUS (2004)

PRP (2013) ↓23% ↓60%

ESHM13 (2014) ↑113% ↑691%

SUIHAZ15 (2015) ↓7% ↓13%

ESHM (2021) ↓2% ↓3%

PGA (g)

Loss ratio

GLOBAL EARTHQUAKE MODEL

GLOBAL SEISMIC RISK ASSESSMENT
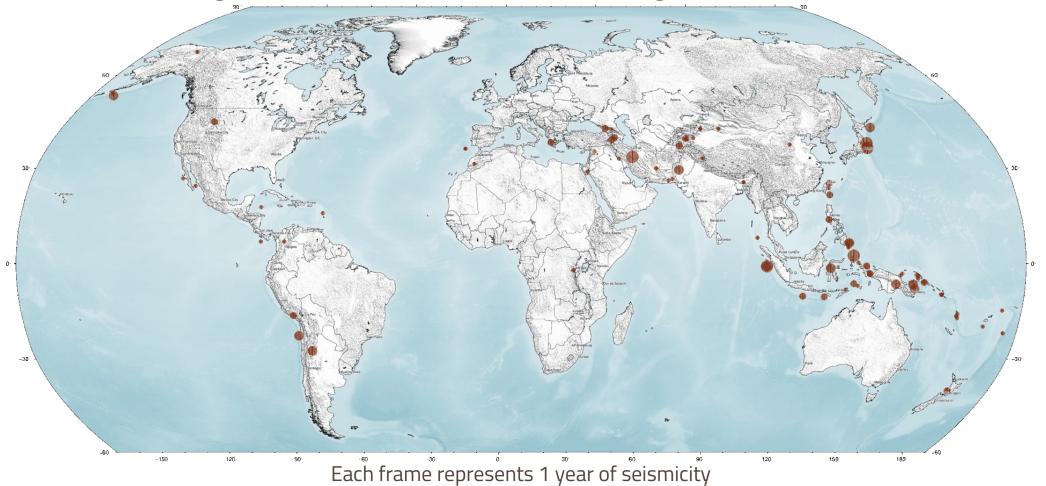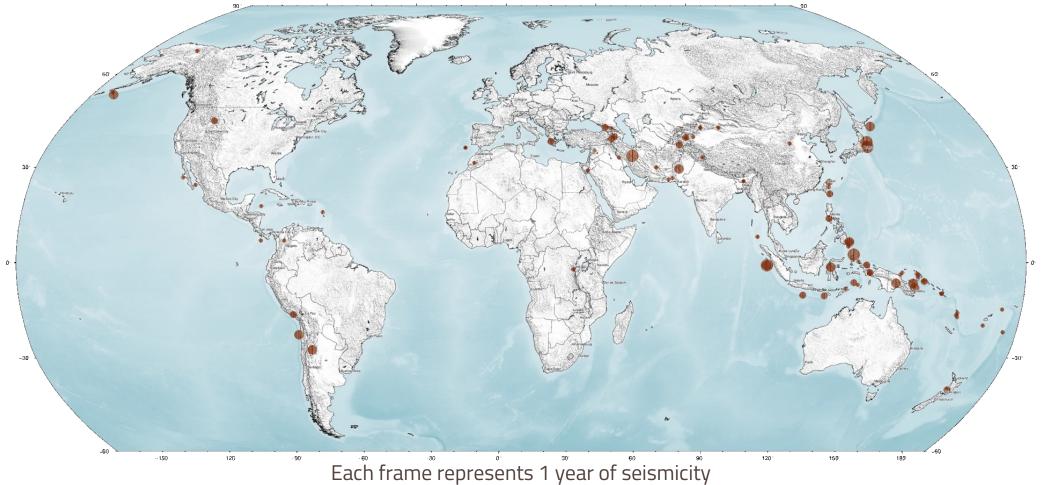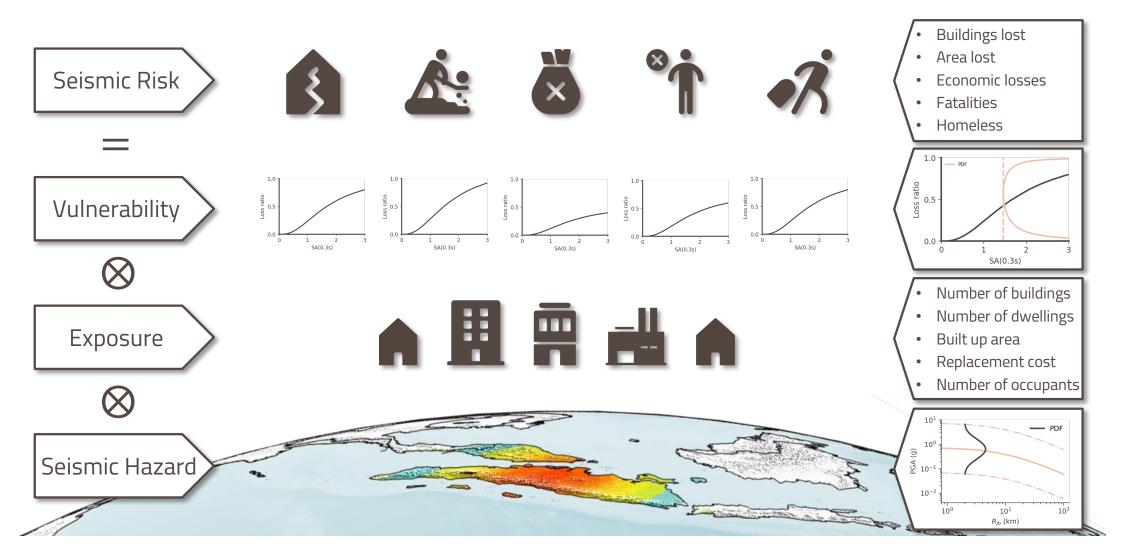
GLOBAL SEISMIC RISK ASSESSMENT

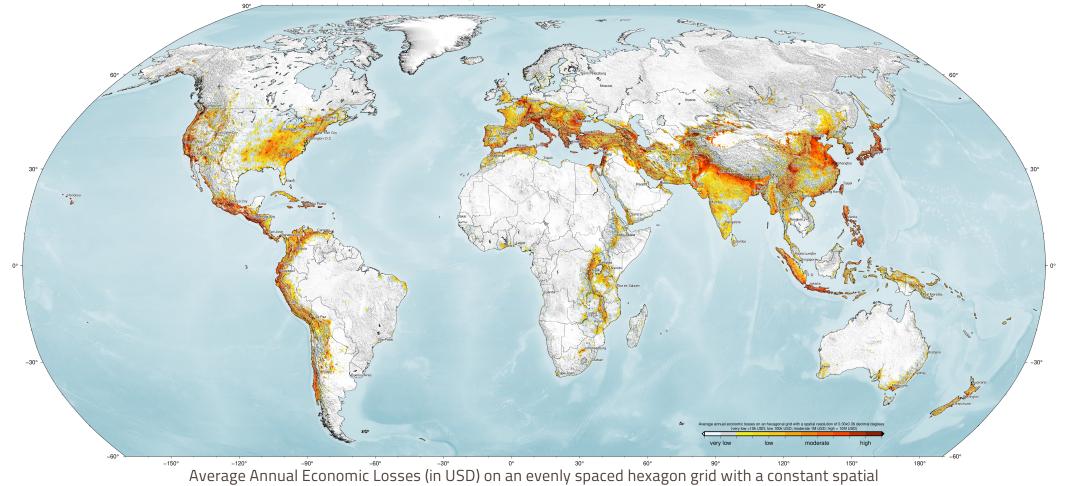Stochastic generation of million of seismic events using the seismic hazard mosaic

Each frame represents 1 year of seismicity

GLOBAL SEISMIC RISK ASSESSMENT

Generation of ground motion fields for each stochastically generated seismic event

Each frame represents 1 year of seismicity

GLOBAL EARTHQUAKE MODEL

GLOBAL SEISMIC RISK ASSESSMENT

GLOBAL SEISMIC RISK ASSESSMENT

Global Average Annual Economic Losses

Average annual economic losses on an hexagonal grid with a spatial resolution of 0.30x0.36 decimal degrees
(very low <10k USD; low 100k USD; moderate 1M USD; high > 10M USD)

very low   low   moderate   high

Average Annual Economic Losses (in USD) on an evenly spaced hexagon grid with a constant spatial
resolution of 0.30x0.36 decimal degrees.

GLOBAL EARTHQUAKE MODEL

GLOBAL SEISMIC RISK ASSESSMENT

Southeast Asia represent
44.1% of the Global AAL

84.1B USD / 0.029%

AAL (B USD)

Country	
Japan	
United States	
China	
Italy	
Turkey	
Mexico	
Taiwan	
Iran	
Indonesia	
Pakistan	
Peru	
Ecuador	
India	
Greece	
Chile	

Represents 77.8% of the global AAL

AALR (%)

Country	
Solomon Islands	
Afghanistan	
Vanuatu	
Nicaragua	
El Salvador	
Guatemala	
Armenia	
Philippines	
Ecuador	
Azerbaijan	
Nepal	
Turkey	
Pakistan	
Taiwan	
Peru	

GLOBAL SEISMIC RISK ASSESSMENT

Let's put 84.1 billion USD in perspective...

2023 M7.8 Türkiye-Syria
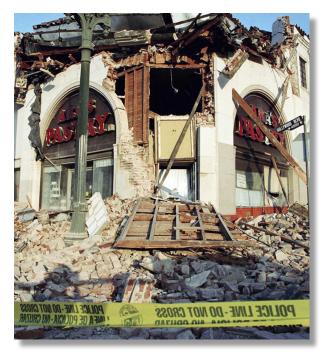
*"The cost of the disaster of the century to our country is approximately 2 trillion Turkish lira (**$ 103.6 billion**)" – Türkiye's Ministry of Finance*

2008 M7.9 Sichuan, China

*"The overall direct economic loss was estimated to be RMB 845 billion (**$ 130 billion**) "– Vivian Bernal, World Bank*

1994 M6.7 Northridge, USA

*"In addition, Dr. Grossi says that based on RMS data, a repeat of the Northridge earthquake would result in up to **$155 billion** in total economic loss."*

GLOBAL EARTHQUAKE MODEL

POST LOSS AMPLIFICATION

The impact of destructive earthquakes might exceed the local capacity to cope with disasters, and lead to an increase in the reconstruction costs
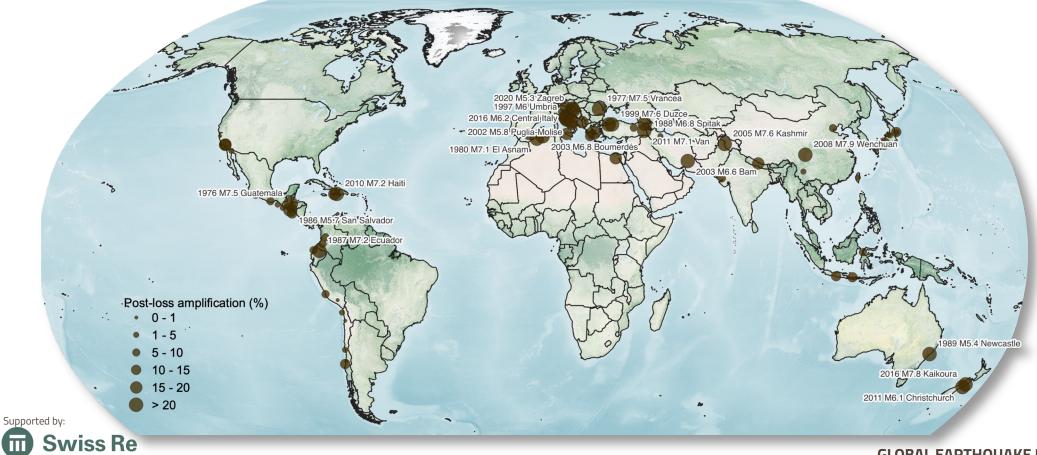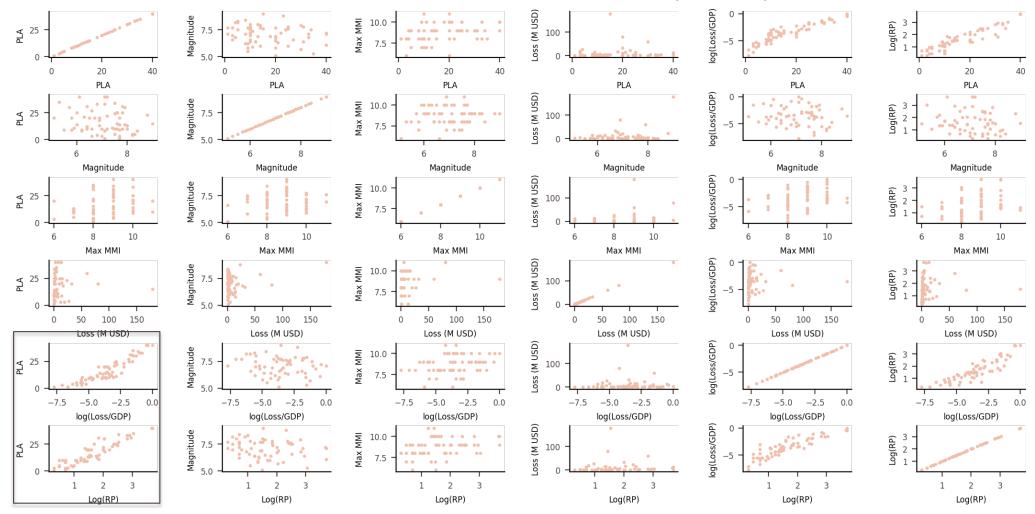
1994 M 6.7 Northridge (USA) earthquake

"After the Northridge earthquake, a 20% PLA was observed, mostly related to the lack of labor in the area. This added cost combined with issues in handling insurance claims almost led to the bankruptcy of the 20th Century Insurance Company" - Olsen and Porter (2010)
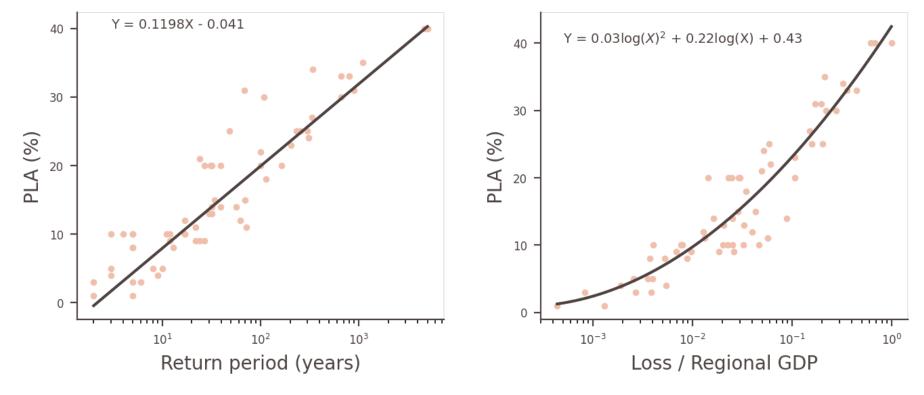
GLOBAL EARTHQUAKE MODEL

POST LOSS AMPLIFICATION

Development of a database with 68 past events with information regarding post loss amplification and other impact parameters

2020 M5.3 Zagreb
1997 M6 Umbria
2016 M6.2 Central Italy
2002 M5.8 Puglia-Molise
1980 M7.1 El Asnam
1977 M7.5 Vrancea
1999 M7.6 Duzce
1988 M6.8 Spitak
2011 M7.1 Van
2003 M6.8 Boumerdés
2005 M7.6 Kashmir
2008 M7.9 Wenchuan
2003 M6.6 Bam
2010 M7.2 Haiti
1976 M7.5 Guatemala
1986 M5.7 San Salvador
1987 M7.2 Ecuador
1989 M5.4 Newcastle
2016 M7.8 Kaikoura
2011 M6.1 Christchurch

Post-loss amplification (%)
- 0 - 1
- 1 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- > 20

Supported by:
Swiss Re

GLOBAL EARTHQUAKE MODEL

POST LOSS AMPLIFICATION

Evaluation of correlations between PLA and all explanatory variables

POST LOSS AMPLIFICATION
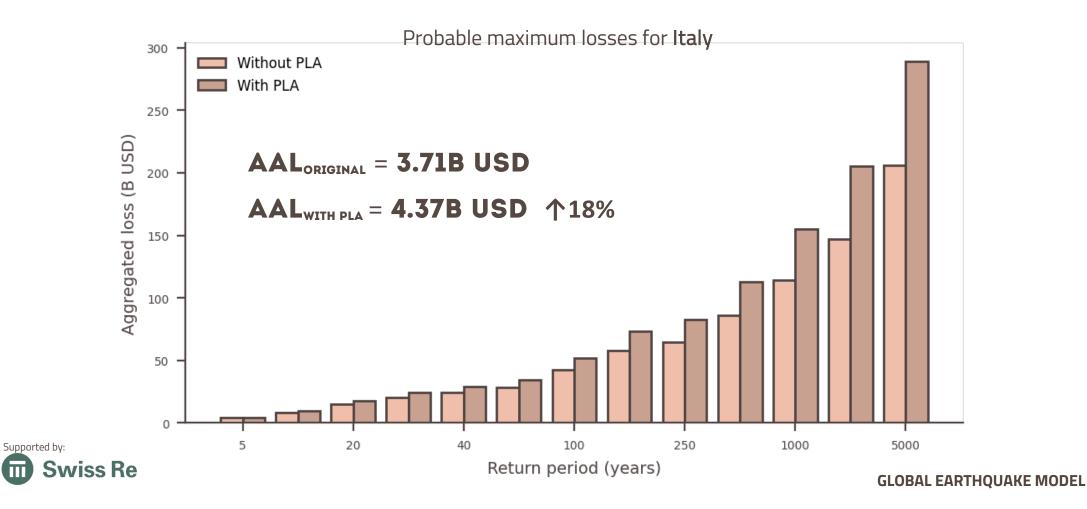
A relatively good correlation between the RP of the loss and the loss divided by the local GDP

Left plot: PLA (%) vs Return period (years), with equation $Y = 0.1198X - 0.041$

Right plot: PLA (%) vs Loss / Regional GDP, with equation $Y = 0.03\log(X)^2 + 0.22\log(X) + 0.43$

POST LOSS AMPLIFICATION

Swiss Re
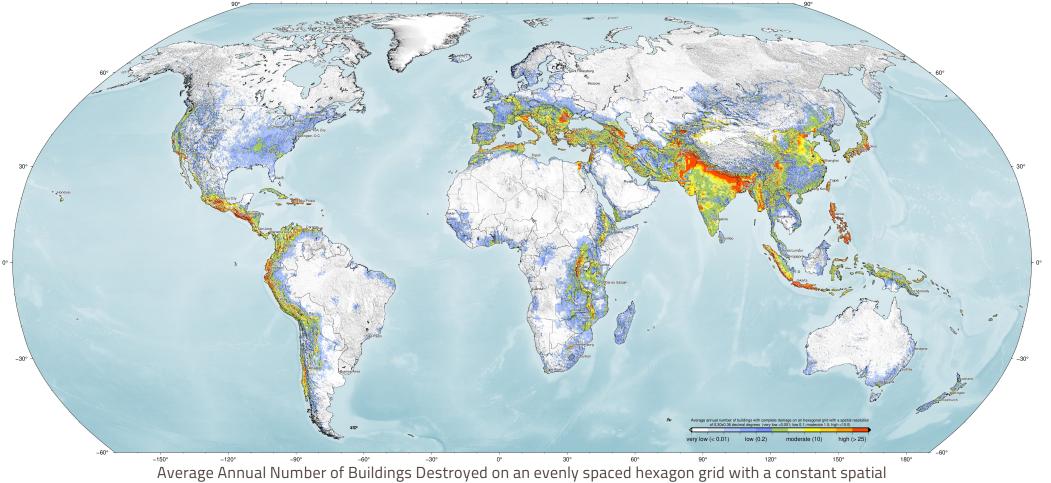
Application of the PLA model to probabilistic risk results

Probable maximum losses for Italy

$AAL_{ORIGINAL}$ = **3.71B USD**

$AAL_{WITH\ PLA}$ = **4.37B USD** ↑18%

Legend:
- Without PLA
- With PLA

Y-axis: Aggregated loss (B USD)
X-axis: Return period (years)

GLOBAL EARTHQUAKE MODEL

GLOBAL SEISMIC RISK ASSESSMENT

Global Average Annual Number of Buildings Destroyed

Average annual number of buildings with complete damage on an hexagonal grid with a spatial resolution of 0.30x0.36 decimal degrees (very low <0.001; low 0.1; moderate 1.0; high >10.0)

very low (< 0.01)　　low (0.2)　　moderate (10)　　high (> 25)

Average Annual Number of Buildings Destroyed on an evenly spaced hexagon grid with a constant spatial resolution of 0.30x0.36 decimal degrees.

GLOBAL EARTHQUAKE MODEL

GLOBAL SEISMIC RISK ASSESSMENT

Average Annual Number of
Buildings Destroyed

🏚 **379K**   🧑 **109M M²**

AA buildings lost (K)

Country	
India	
Pakistan	
Philippines	
China	
Indonesia	
Iran	
Japan	
Peru	
Mexico	
Turkey	
Bangladesh	
Afghanistan	
Guatemala	
Myanmar	
Algeria	

Represents 73.2%
of the global loss

0 10 20 30 40

AA area lost (M m²)

Country	
China	
Pakistan	
India	
Turkey	
Japan	
Iran	
Indonesia	
Philippines	
United States	
Mexico	
Taiwan	
Colombia	
Italy	
Peru	
Bangladesh	

Represents 74.4%
of the global loss

0 10 20 30 40

GLOBAL SEISMIC RISK ASSESSMENT

Let's put 379k buildings in perspective...

1990 M7.4 Manjil, Iran
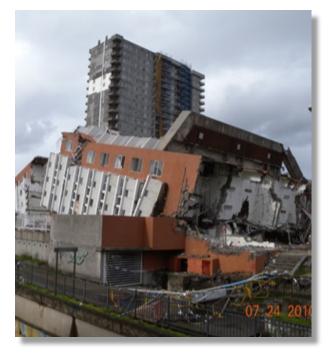
"(...) left more than 500,000 homeless and destroyed *314,000 residential houses* (...)" – Tavakoli and Tavakoli (1992).

2015 M7.8 Gorkha, Nepal

"Over **500,000 houses** were destroyed and another 269,000 damaged (...)" – PreventionWeb.
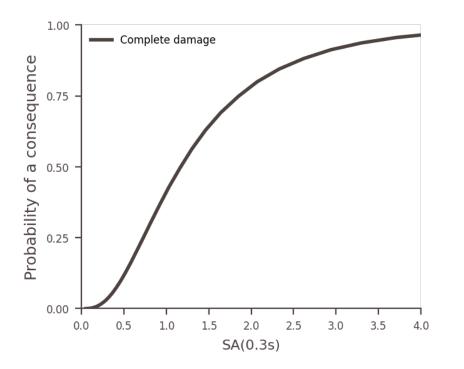
2010 M8.8 Maule, Chile
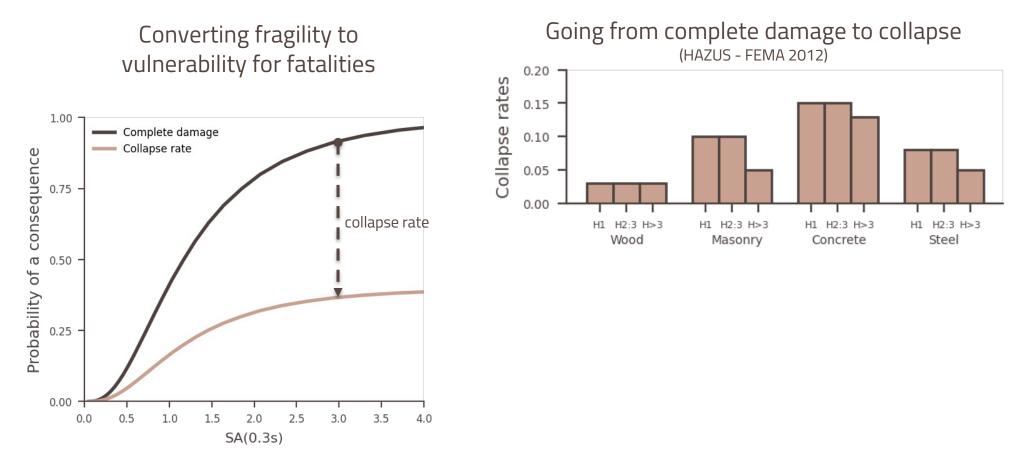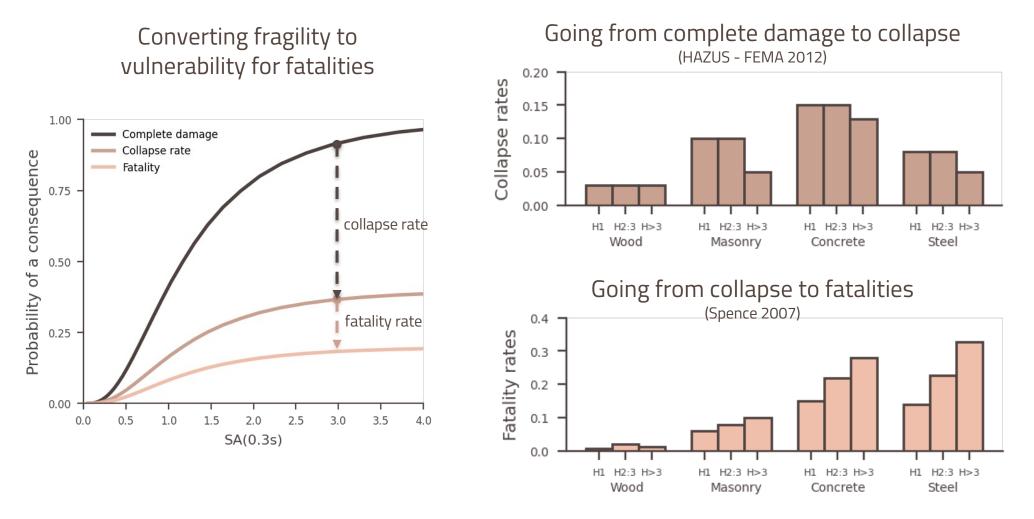
"According to Government reports, some. *441,000 houses* have been severely damaged or completely destroyed." - ECLAC (United Nations)

GLOBAL EARTHQUAKE MODEL

WHAT ABOUT HUMAN IMPACT?

High fatality rates
(Concrete)

Moderate fatality
rates (Masonry)

Low fatality rates
(Wood)

WHAT ABOUT HUMAN IMPACT?

Converting fragility to
vulnerability for fatalities

WHAT ABOUT HUMAN IMPACT?

Converting fragility to vulnerability for fatalities

Going from complete damage to collapse
(HAZUS - FEMA 2012)

WHAT ABOUT HUMAN IMPACT?

Converting fragility to vulnerability for fatalities

Going from complete damage to collapse
(HAZUS - FEMA 2012)

Going from collapse to fatalities
(Spence 2007)

GLOBAL EARTHQUAKE MODEL

WHAT ABOUT HUMAN IMPACT?

How can we calibrate these

collapse and fatality rates?

Going from complete damage to collapse
(HAZUS - FEMA 2012)

Going from collapse to fatalities
(Spence 2007)

GLOBAL EARTHQUAKE MODEL

DATA REGARDING FATALITIES SINCE 1950

Total fatalities = 2045

GLOBAL EARTHQUAKE MODEL

EMPIRICAL AVERAGE ANNUAL FATALITIES

AAL = 9831 fatalities

GLOBAL EARTHQUAKE MODEL

WHAT IF PAST EARTHQUAKES WERE TO OCCUR TODAY?

THE NEW YORK TIMES, WEDNESDAY, MARCH 2, 1960.

1,000 Feared Dead as Quakes Hit Moroccan Port

AGADIR IS TURNED INTO RUBBLE HEAP

Tidal Wave and Fire Wreak Havoc in Beach Resort— Americans Are Missing

HIT BY EARTHQUAKES AND TIDAL WAVE: An aerial view of damaged buildings in Moroccan port of Agadir

Two earthquakes and a tidal wave struck Agadir (cross)

The 1960 M5.8 Agadir (Morocco) earthquake caused more than ~**13,000 fatalities** (approximately one third of the population of the city at the time). Since then, Agadir has increased tenfold, with a metropolitan area of almost 1 million people. If one assumes that the seismic vulnerability of the building stock remained exactly the same, a death toll of **130,000 people** could be expected if the same event were to happen today.

GLOBAL EARTHQUAKE MODEL

EMPIRICAL AVERAGE ANNUAL FATALITIES

AAL = 9940 fatalities

GLOBAL EARTHQUAKE MODEL

INCORPORATING BUILDING VULNERABILITY

Country	Low code		Moderate code		High code	
	Year	Enforcement	Year	Enforcement	Year	Enforcement
Afghanistan						
Albania						
Algeria						
Argentina						
Azerbaijan						
Bolivia						
Canada						
Chile						
China						
Colombia						
Costa Rica						
Croatia						

INCORPORATING BUILDING VULNERABILITY
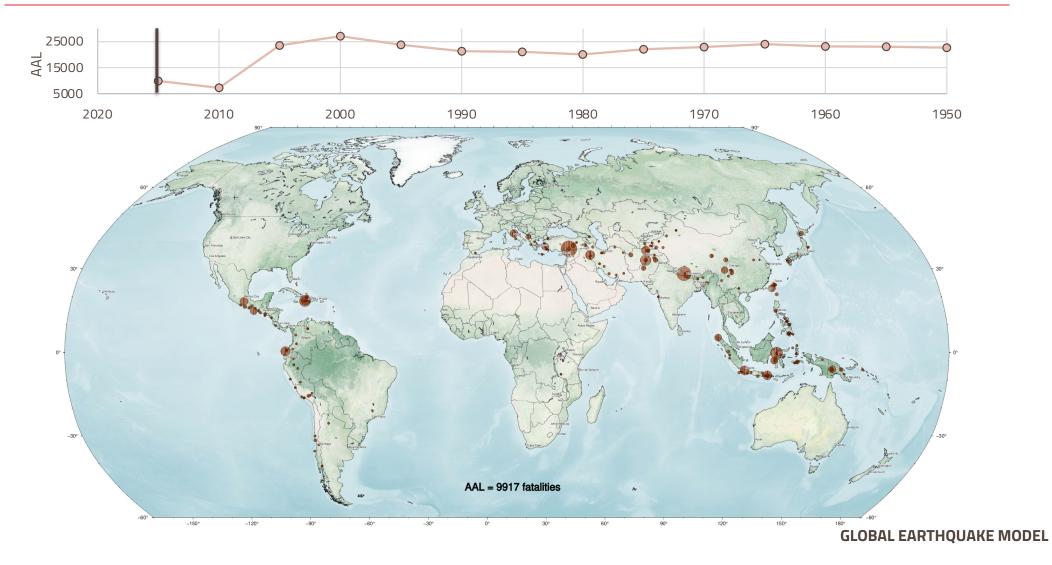
Country	Low code		Moderate code		High code	
	Year	Enforcement	Year	Enforcement	Year	Enforcement
Afghanistan	-		2012		-	
Albania	1978		1989		-	
Algeria	1980		2003		-	
Argentina	1972		1983		1998	
Azerbaijan	-		2009		-	
Bolivia	-		2006		2020	
Canada	1960		1980		2010	
Chile	1935		1972		1993	
China	1960		1980		2010	
Colombia	1984		1998		2010	
Costa Rica	1986				2002	
Croatia	1964		1981		2006	

GLOBAL EARTHQUAKE MODEL

INCORPORATING BUILDING VULNERABILITY

Country	Low code		Moderate code		High code	
	Year	Enforcement	Year	Enforcement	Year	Enforcement
Afghanistan	-	E	2012	D	-	E
Albania	1978	C	1989	B	-	E
Algeria	1980	D	2003	C	-	E
Argentina	1972	C	1983	B	1998	B
Azerbaijan	-	E	2009	B	-	E
Bolivia	-	E	2006	C	2020	C
Canada	1960	C	1980	B	2010	A
Chile	1935	C	1972	B	1993	A
China	1960	D	1980	C	2010	B
Colombia	1984	C	1998	B	2010	B
Costa Rica	1986	B			2002	B
Croatia	1964	C	1981	C	2006	B

A – Fully enforced	B – Mostly enforced	C – Partially enforced	D– Poorly enforced	E – Not enforced

EMPIRICAL AVERAGE ANNUAL FATALITIES

AAL = 9917 fatalities

GLOBAL EARTHQUAKE MODEL
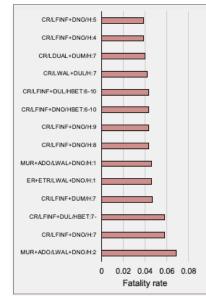
CALIBRATING FATALITY AND COLLAPSE RATES

Step 1
We compute the number of people in buildings that might collapse

Step 3
We compute annual human losses

Average Annual Occupants in complete damaged buildings

Fatality rate

Average Annual Fatalities (2018)

Empirical Average Annual Fatalities (from 1970 to 2020)
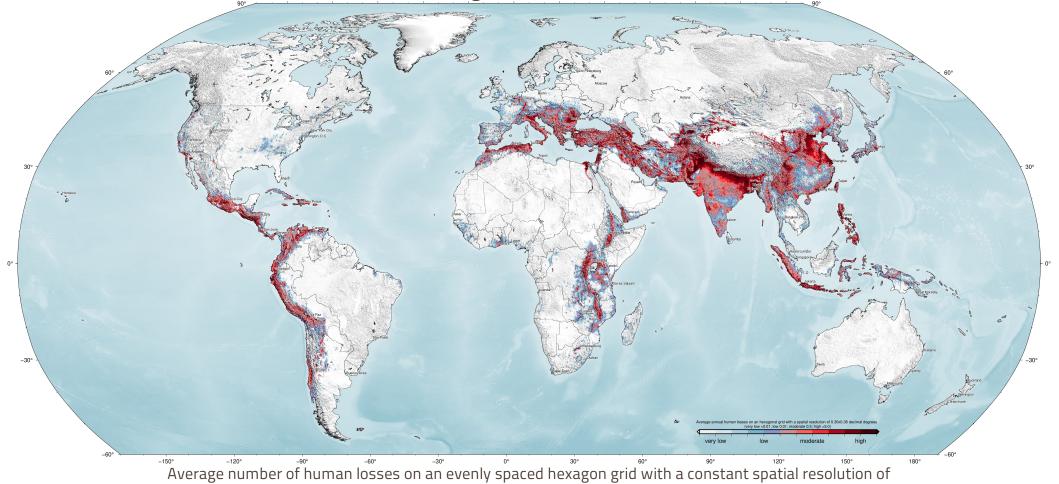
Step 2
We assume collapse and fatality rates

Step 4
We compare the estimations with observations

Step 5
We update the collapse and fatality rates

GLOBAL EARTHQUAKE MODEL

GLOBAL EARTHQUAKE FATALITY MODEL

Global Average Annual Human Losses

Average annual human losses on an hexagonal grid with a spatial resolution of 0.30x0.36 decimal degrees
(very low <0.01; low 0.01; moderate 0.5, high >5.0)

very low   low   moderate   high

Average number of human losses on an evenly spaced hexagon grid with a constant spatial resolution of
0.30x0.36 decimal degrees.

GLOBAL EARTHQUAKE MODEL
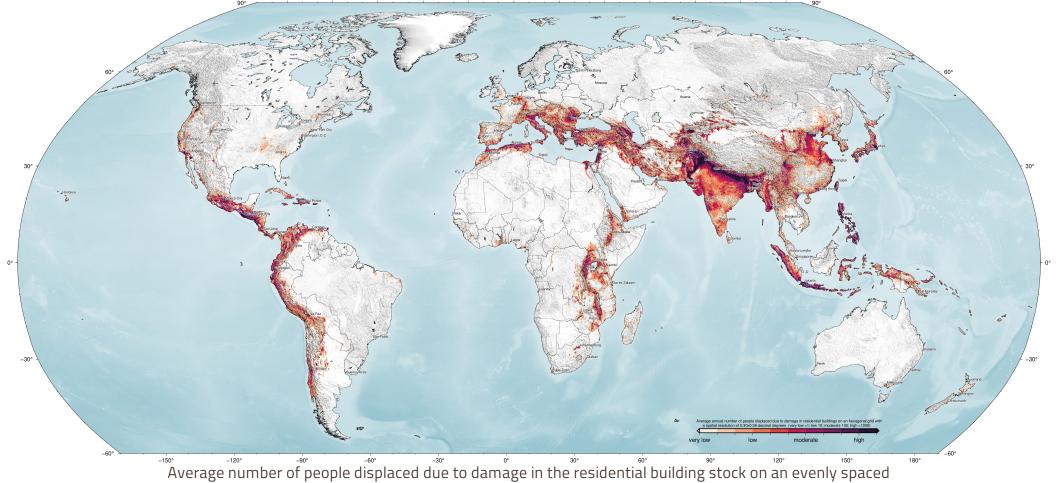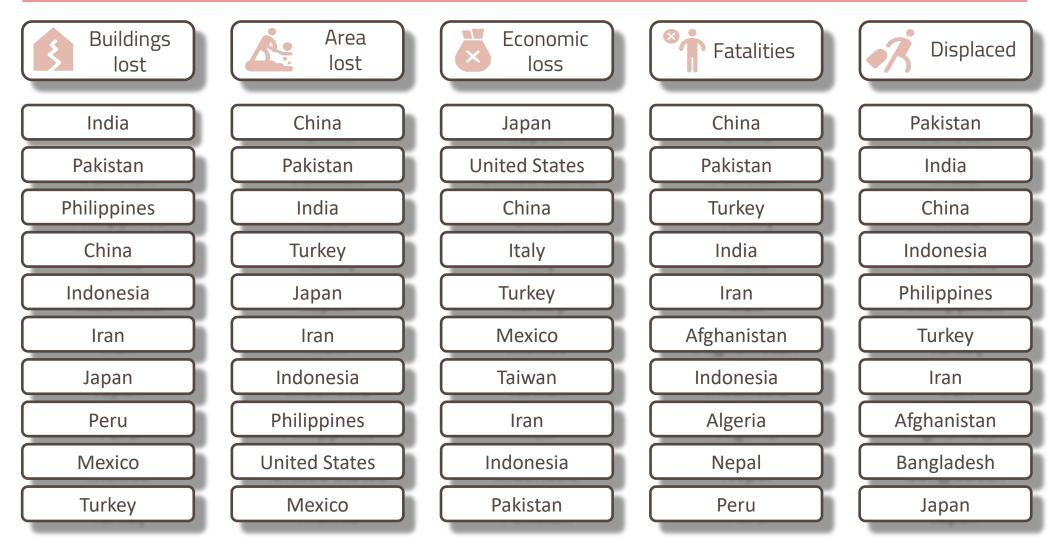
GLOBAL EARTHQUAKE DISPLACED MODEL

Global Average Number of Displaced

Average annual number of people displaced due to damage in residential buildings on an hexagonal grid with a spatial resolution of 0.30x0.36 decimal degrees (very low <1; low 10; moderate 100; high >1000)

very low   low   moderate   high

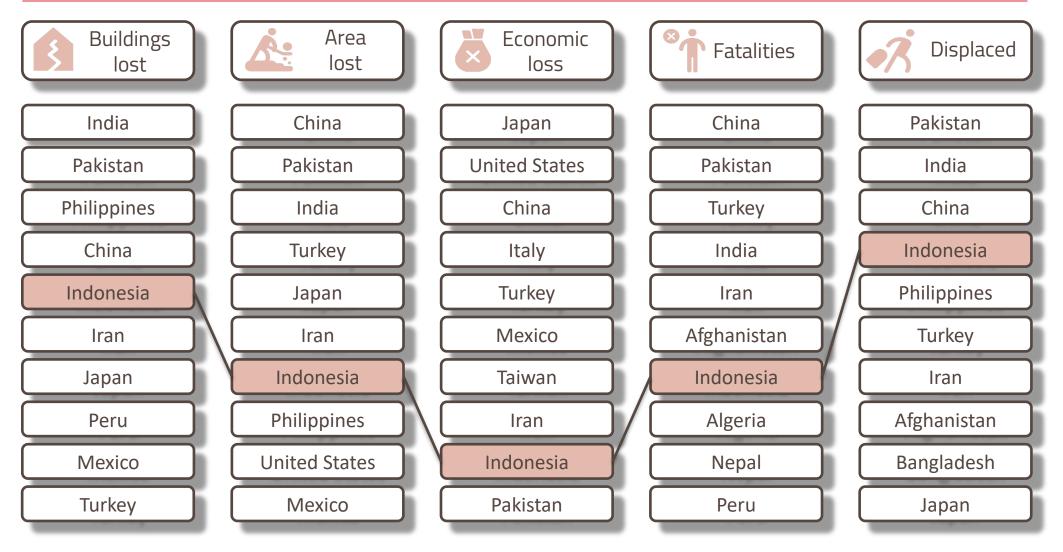Average number of people displaced due to damage in the residential building stock on an evenly spaced hexagon grid with a constant spatial resolution of 0.30x0.36 decimal degrees.

GLOBAL EARTHQUAKE MODEL

TOP 10 COUNTRIES PER RISK METRIC
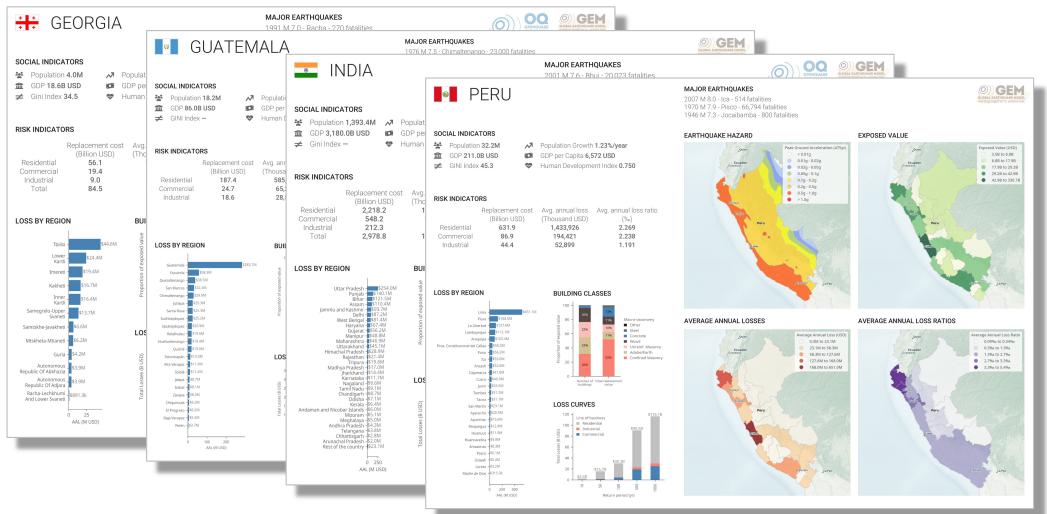
Buildings lost	Area lost	Economic loss	Fatalities	Displaced
India	China	Japan	China	Pakistan
Pakistan	Pakistan	United States	Pakistan	India
Philippines	India	China	Turkey	China
China	Turkey	Italy	India	Indonesia
Indonesia	Japan	Turkey	Iran	Philippines
Iran	Iran	Mexico	Afghanistan	Turkey
Japan	Indonesia	Taiwan	Indonesia	Iran
Peru	Philippines	Iran	Algeria	Afghanistan
Mexico	United States	Indonesia	Nepal	Bangladesh
Turkey	Mexico	Pakistan	Peru	Japan

TOP 10 COUNTRIES PER RISK METRIC

Buildings lost	Area lost	Economic loss	Fatalities	Displaced
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Philippines	India	China	Turkey	China
China	Turkey	Italy	India	Indonesia
Indonesia	Japan	Turkey	Iran	Philippines
Iran	Iran	Mexico	Afghanistan	Turkey
Japan	Indonesia	Taiwan	Indonesia	Iran
Peru	Philippines	Iran	Algeria	Afghanistan
Mexico	United States	Indonesia	Nepal	Bangladesh
Turkey	Mexico	Pakistan	Peru	Japan

DEVELOPMENT OF COUNTRY PROFILES
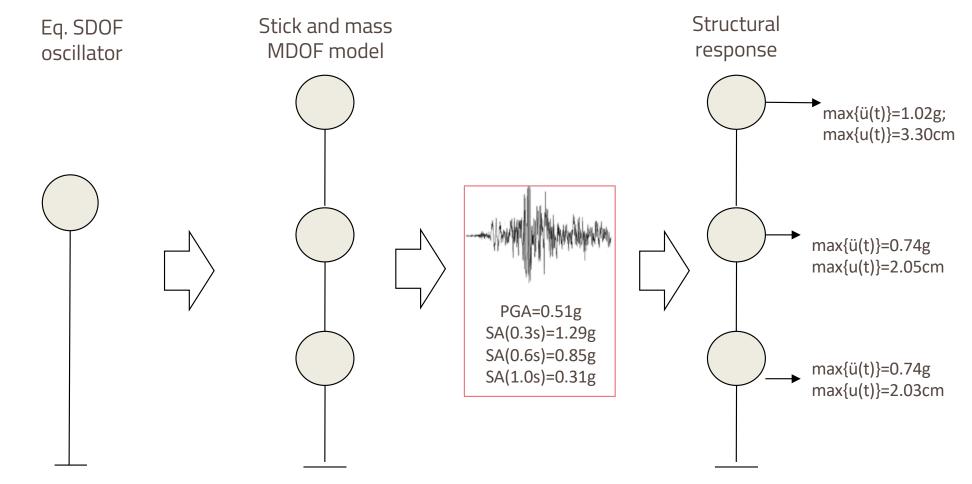
GLOBAL EARTHQUAKE MODEL

FUTURE DEVELOPMENTS
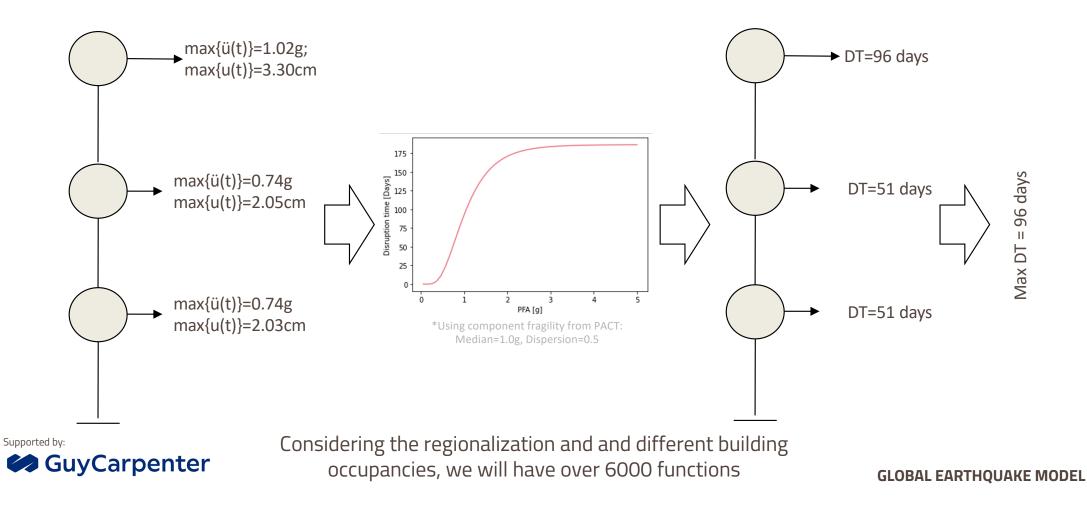
NEW VULNERABILITY MODELLING APPROACH

Eq. SDOF oscillator

Stick and mass MDOF model

PGA=0.51g
SA(0.3s)=1.29g
SA(0.6s)=0.85g
SA(1.0s)=0.31g

Structural response

max{ü(t)}=1.02g;
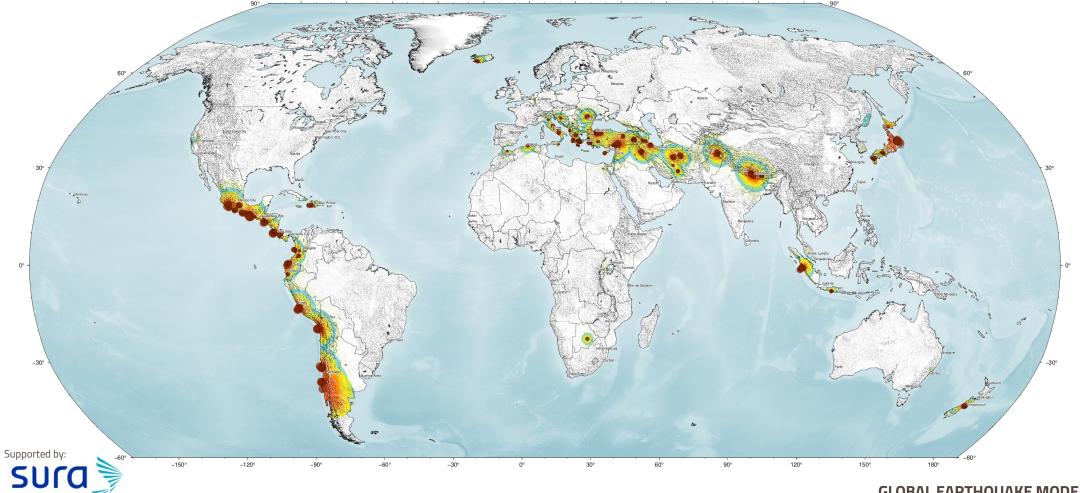max{u(t)}=3.30cm

max{ü(t)}=0.74g
max{u(t)}=2.05cm

max{ü(t)}=0.74g
max{u(t)}=2.03cm

NEW VULNERABILITY MODELLING APPROACH

Example of business interruption estimation based on one content (computer equipment)

max{ü(t)}=1.02g;
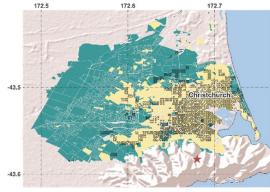max{u(t)}=3.30cm

max{ü(t)}=0.74g
max{u(t)}=2.05cm

max{ü(t)}=0.74g
max{u(t)}=2.03cm

DT=96 days

DT=51 days

DT=51 days

Max DT = 96 days

*Using component fragility from PACT:
Median=1.0g, Dispersion=0.5

Considering the regionalization and and different building occupancies, we will have over 6000 functions

GLOBAL EARTHQUAKE MODEL

TESTING, CALIBRATION, AND VALIDATION

Development of a global testing framework (initial set of 100 past events)

Supported by:
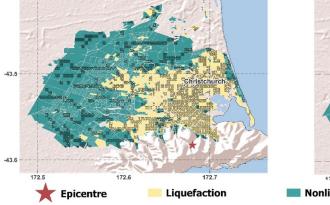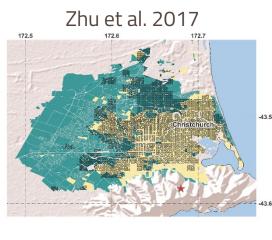sura

GLOBAL EARTHQUAKE MODEL

STILL MUCH TO BE DONE

It is fundamental to go beyond the impact of ground shaking, and explore current or new methodologies to account for **secondary hazards**
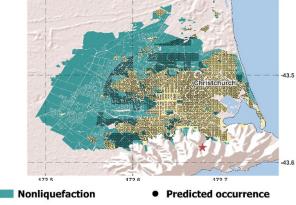

Zhu et al. 2015

Zhu et al. 2017

Bozzoni et al. 2020

Todorovic and Silva 2022

★ Epicentre   Liquefaction   Nonliquefaction   • Predicted occurrence
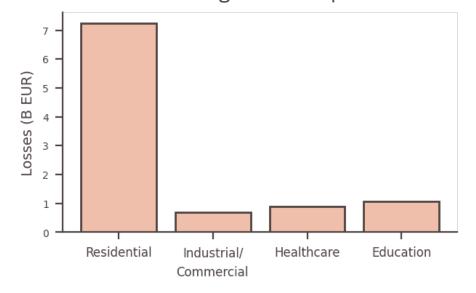
Some existing models already predict with a reasonable level of accuracy liquefaction occurrence, but the estimation of ground deformation is still challeging.

Todorovic L, Silva V (2022). A Liquefaction Occurrence Model for Regional Analysis. Soil Dynamics and Earthquake Engineering, 161:107430.
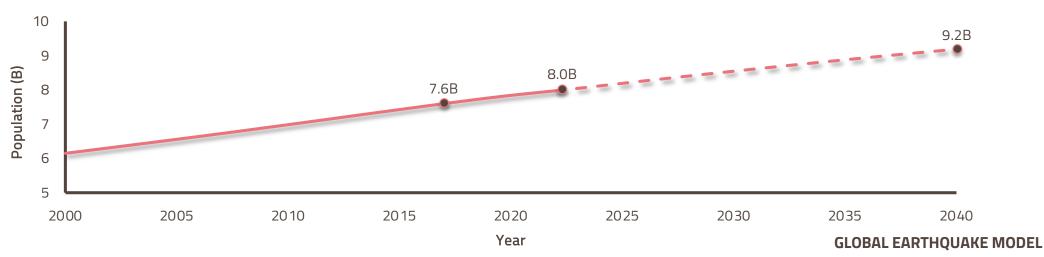
GLOBAL EARTHQUAKE MODEL

STILL MUCH TO BE DONE

o It is fundamental to go beyond the impact of ground shaking, and explore current or new methodologies to account for **secondary hazards**.

o The current Global Seismic Risk Model covers the impact on residential, commercial and industrial building stock, but **governmental, healthcare and educational** facilities can also contribute significantly to the impact.

Direct economic losses due to the 2020
M5.5 Zagreb earthquake

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We need your support to reach a global seismic risk model that covers all current and future facets of earthquake impact!

GLOBAL EARTHQUAKE MODEL

THANK YOU

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