Models for Economic and Human losses caused by earthquakes

Philippe Guéguen

Underlying probabilistic framework for risk assessment

Insurance prolicies: used by private individuals and asset owners to protect their assets against financial damage caused by earthquakes in exchange of a regular and known payment called **premium**.

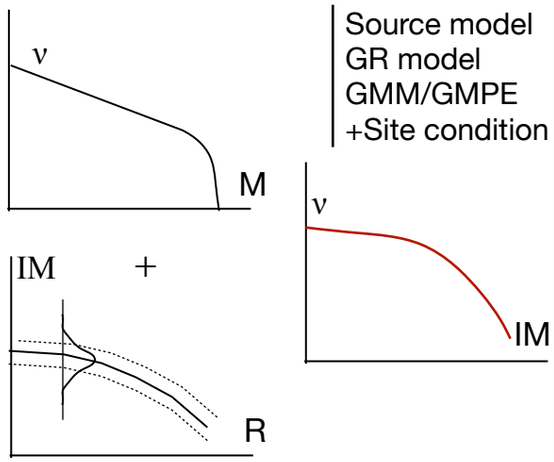
Cat bonds: used by insurance companies, governments or financial institutions to transfer part, or the full financial risk, to the capital market (high rates of return /low time to maturity (typically, 3 to 5 years)):

Cat bond price=Interest rate model, pay-off model, aggregate loss model

$$F(D,T) = \sum_{n=0}^{\infty} e^{-\lambda T} \frac{(\lambda T)^n}{n!} F^n(D)$$

Hazard Module

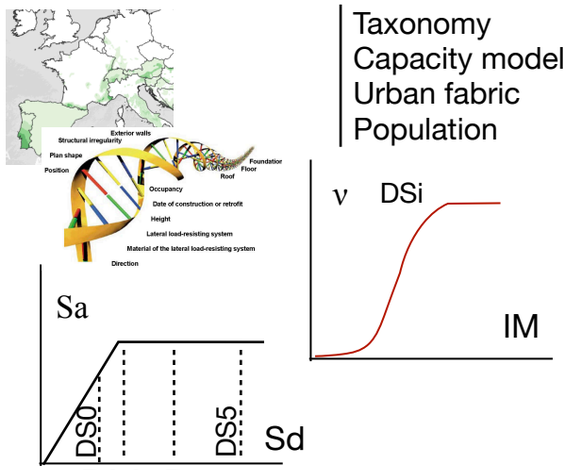
How often? How big? Where?



IM: intensity measure
p[IM|O,D(T)]

Exposure Module

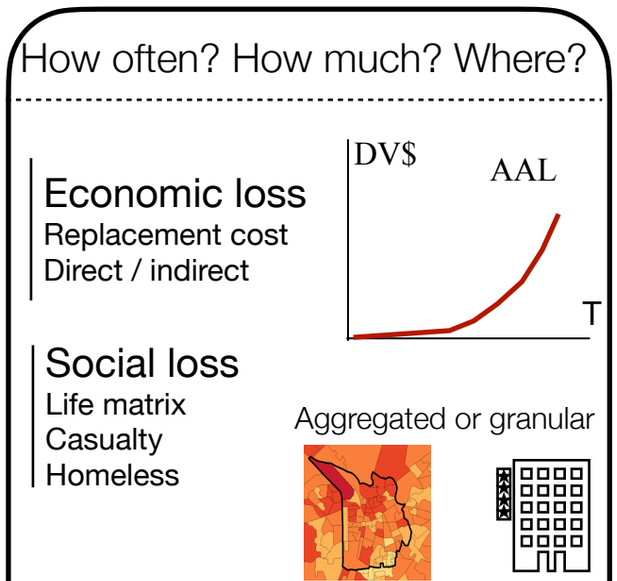
Where? What? How much?



DM: Damage measure
p[DM|IM,Ta]

Risk Module - CAT risk

How often? How much? Where?



DV: Decision variable
p[DV|DM,T,O]

EU SolvabilityII
CatNat

Decision-making module

- Insurance products
- Earthquake-resistant designs
- Early warning

Seismology
Observation
Research
Data

Engineering
EC8
PPRS

Education
Information
Governance

UN mitigation programmes - Sendai 2015-2030

Example operational (real-time) system:

M7.8 Central Turkey - 06/02/2023

PAGER (USGS)

Fatalities
P(0.35) 10 000 /100 000
P(0.87) 1 000 >100 000

09/2023: 59 000 fatalities

Economic USD (million)
P(0.35) 10 000 /100 000
P(0.91) 1 000 >100 000

09/2023: 40 $bn

USGS science for a changing world

Earthquake Shaking — Red Alert

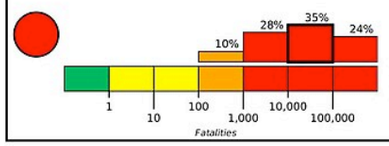
USAID FROM THE AMERICAN PEOPLE

GSN ANSS

M 7.8, Central Turkey
Origin Time: 2023-02-06 01:17:35 UTC (Mon 04:17:35 local)
Location: 37.1736° N 37.0320° E Depth: 17.9 km

PAGER Version 8
Created: 4 days, 3 hours after earthquake

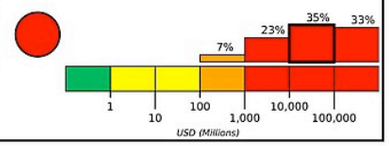
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 1-10% GDP of Turkey.

Estimated Economic Losses

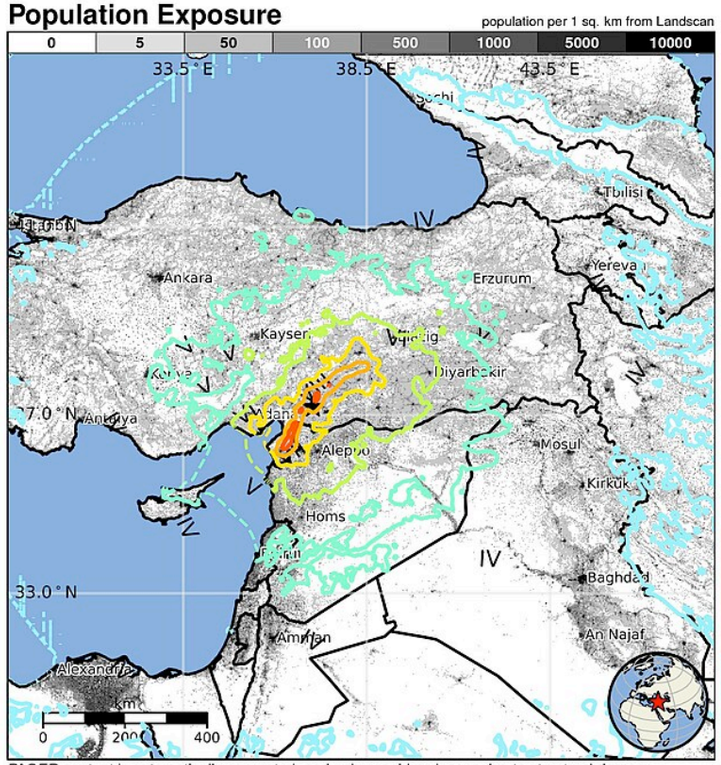


Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k=x1000)		–*	12,744k*	240,897k	22,861k	12,841k	7,574k	1,191k	657k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	None	None	None	V. Light	Light	Moderate	Mod./Heavy	Heavy	V. Heavy
	Vulnerable Structures	None	None	None	Light	Moderate	Mod./Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure



Structures
Overall, the population in this region resides in structures that are extremely vulnerable to earthquake shaking, though some resistant structures exist. The predominant vulnerable building types are unreinforced brick masonry and low-rise nonductile concrete frame with infill construction.

Historical Earthquakes

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2001-06-25	72	5.4	V(26k)	0
1992-03-13	361	6.6	IX(151k)	498
1975-09-06	359	6.7	VIII(1k)	2k

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure
from GeoNames.org

MMI	City	Population
IX	Asagi Karafakili	1k
IX	Hassa	10k
IX	Narli	<1k
IX	Aktepe	<1k
IX	Buyuk Dalyan	2k
IX	Kirikhan	61k
IV	**Cairo**	**7,735k**
IV	**Baghdad**	**7,216k**
IV	**Alexandria**	**3,812k**
IV	**Istanbul**	**11,174k**
III	**Ankara**	**3,517k**

bold cities appear on map. (k=x1000)

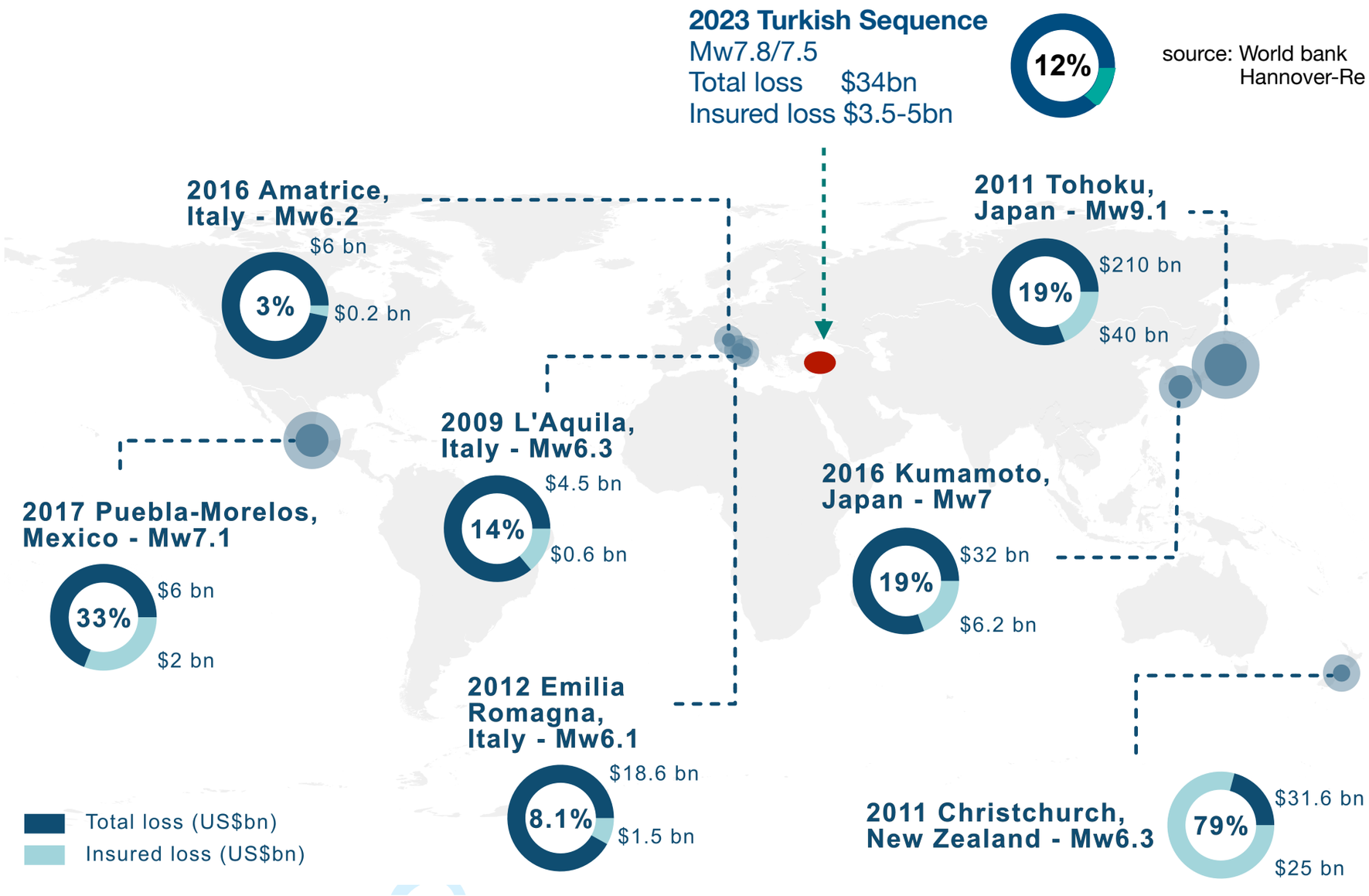
PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
https://earthquake.usgs.gov/earthquakes/eventpage/us6000jllz#pager

Event ID: us6000jllz

Cost of some earthquake disasters

Pothon et al., NHESS, 2019 - Mistry, Hernandez, Guéguen, Lombardi, Risk Analysis 2024

Protection gap: the cost of catastrophe to society



Reasons of low insurance penetration are **uncertainties** when pricing insurance policies and cat bonds, **low risk perception**, household and income **demographics and affordability**

Global earthquakes losses

LEQ445 flat file (Dollet and Guéguen, 2022): all earthquakes

Main issues

How to we get an early and reliable estimate of losses? ***A la GMM***
Were the observed losses expected? ***A la GMM residual distribution***
Is this event a one-off in terms of losses? ***A la LPHC definition***
What are the annual occurrence of losses? ***A la GR model - catalogue completude***

Losses database - LEQ445 from EM-DAT, CATDAT, Desinventar

Hazard module

M,lat-lon,Depth:->Epicentral intensity
Exposed area (MMI>V) from USGS Shake-Map

Exposure module - Adjustment to a reference date 2016

Social model: Exposed population at the time of the earthquake from Global Urban Settlement (European Commission 2018) + UN Country population growth

Economic model: Exposed GDP : GDP per capita at the time of the earthquake + Consumer Price Index conversion

Risk module

Average Annual Losses **AAL** - Non-stationary Poissonian process (population and economy global growth)

Global earthquakes losses

LEQ445 flat file (Dollet and Guéguen, 2022): all earthquakes at a glance

Losses

76% of M5.6-7.3

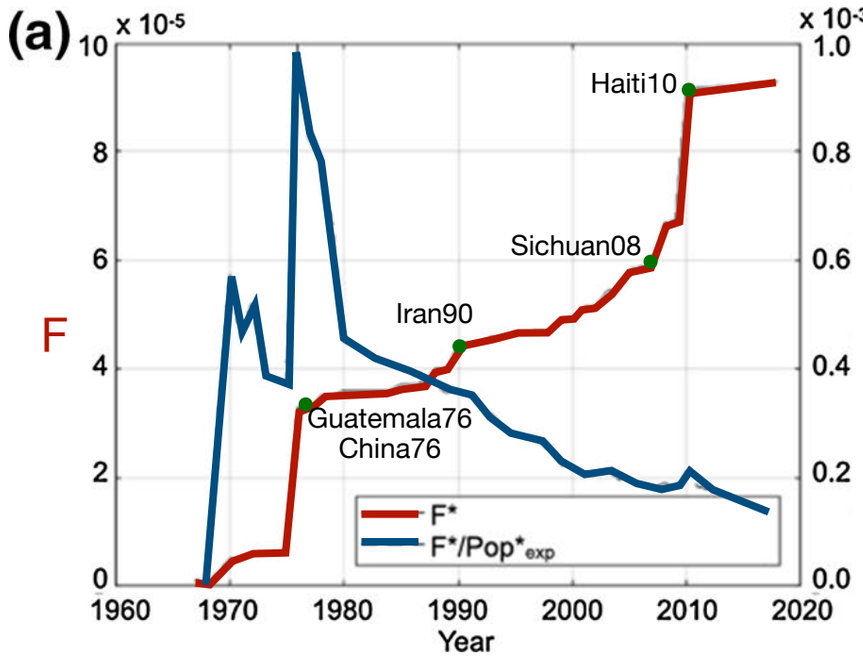
Economic: 46%

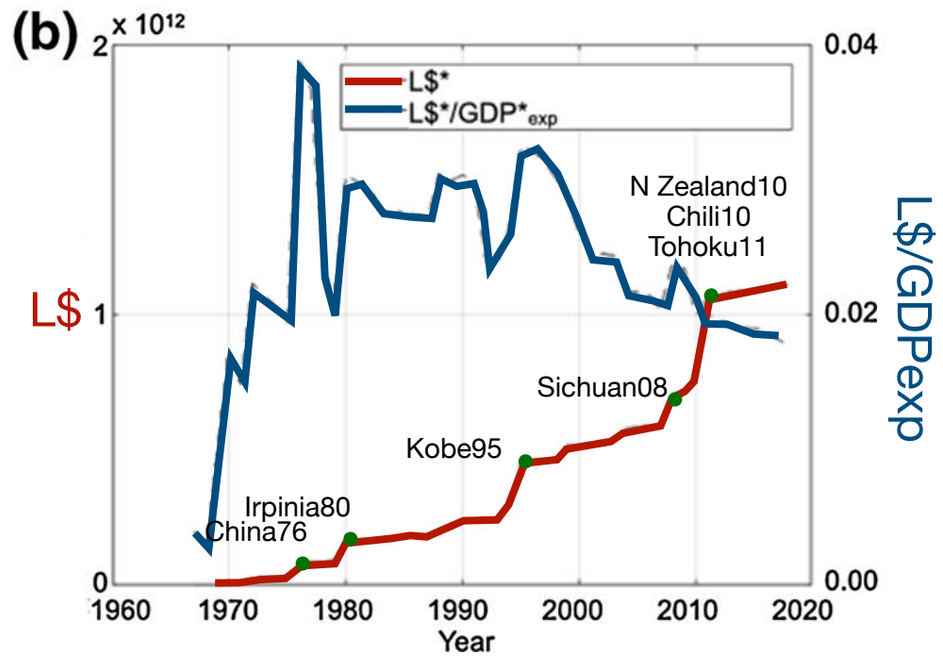
Casualties: 39%

Statistical analysis (Kurtosis, skewness)

Moderate earthquakes: majority of cumulative losses

Strong earthquakes: significant losses





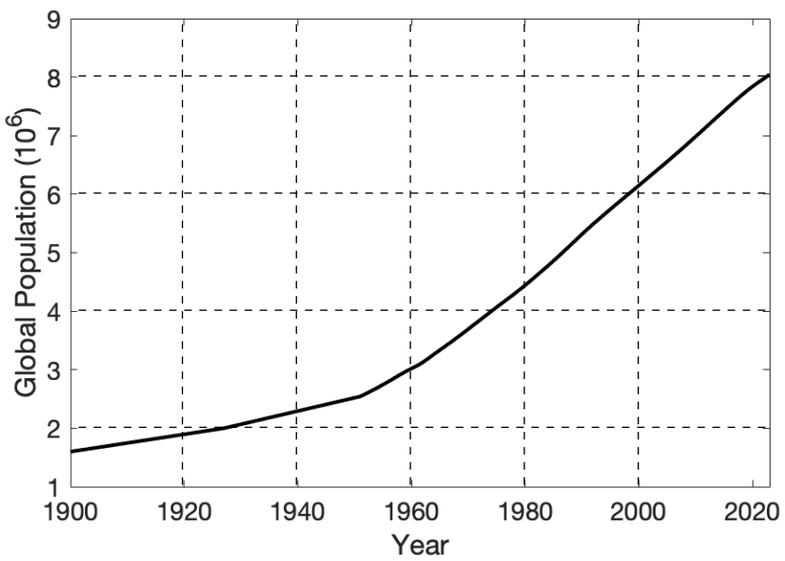
Mitigation

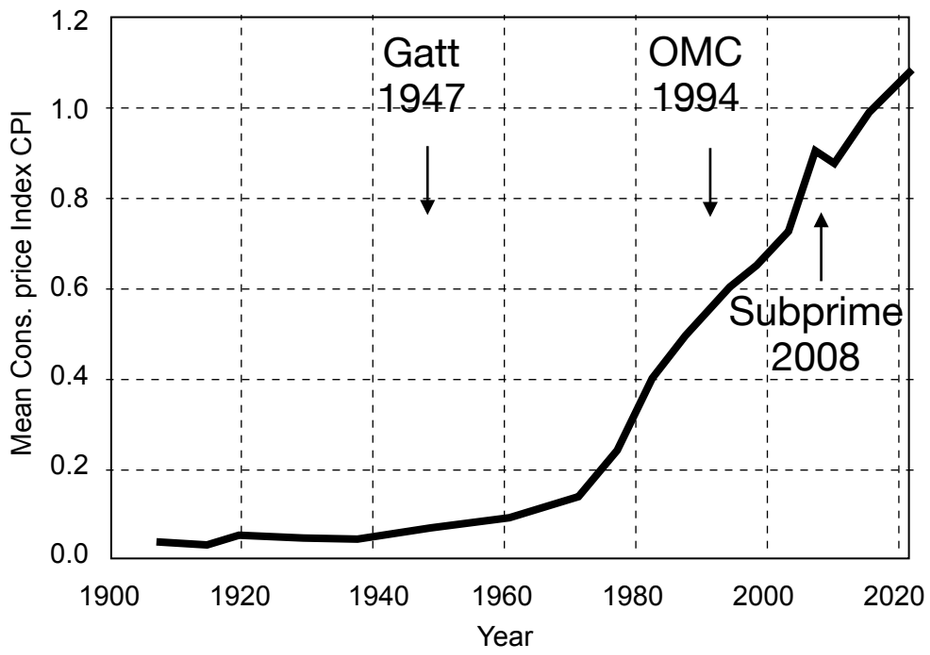
Losses increase: exposure

Losses/exposure decrease:

->Global improvement of seismic design (Gülkkan and Reitherman, 2014)

->Efficay of UN mitigation programme (Shreve and Kelman, 2014 ; Nations Unies, 2015)





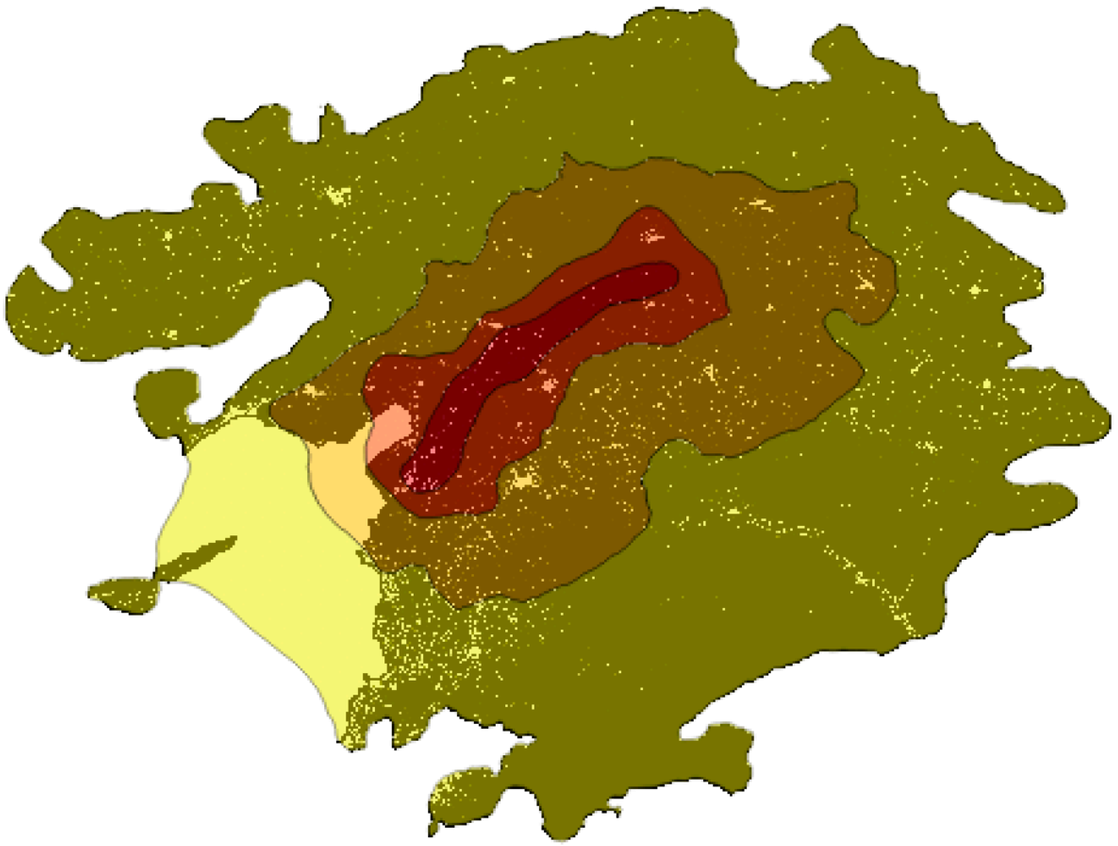
1999 versus 2023 Turkish earthquake losses

2023

USGS - Macroseismic Intensity: VIII-IX
Global Human Settlement - European Commission

Exposed population 2023: 48,806,841 (56% of the total Turkish population)
GDP per capita: 9,660 $ (2022)

Losses 2023 $US: **+34bn$**
Fatalities: **59,259** (Turkey+Syria)

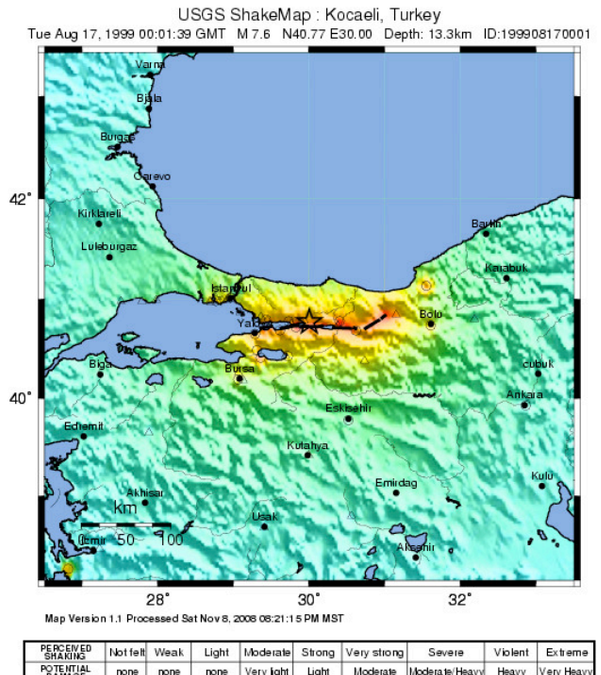


1999-Izmit earthquake

Macroseismic Intensity: IX

Exposed population 1999: 21,654,157

Losses 2016: **26bn$** (CPI conversion)
Fatalities: **17,242**



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

Turkish earthquakes (non exhaus.)

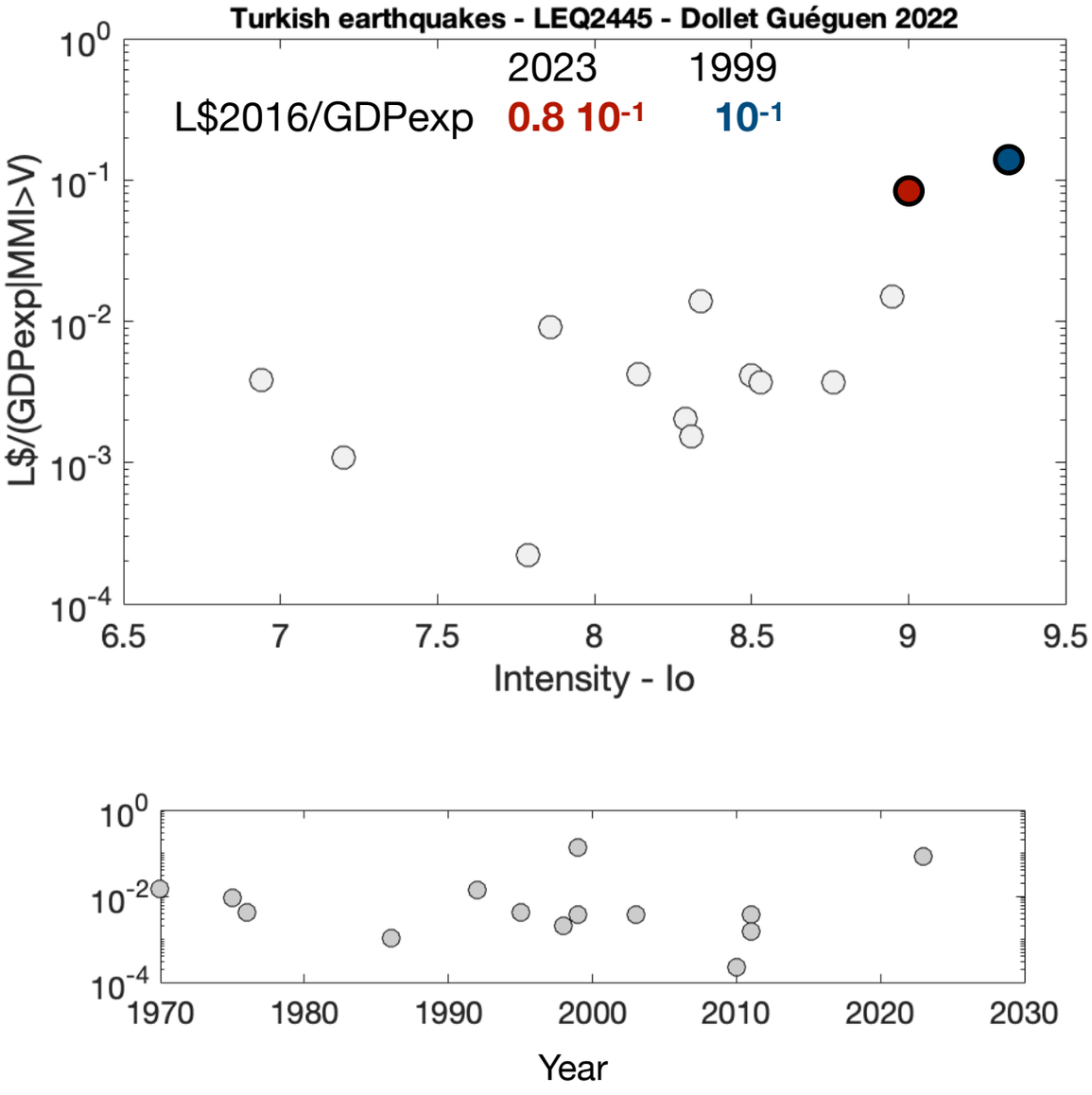
LEQ445 flat file (Dollet and Guéguen, 2022)

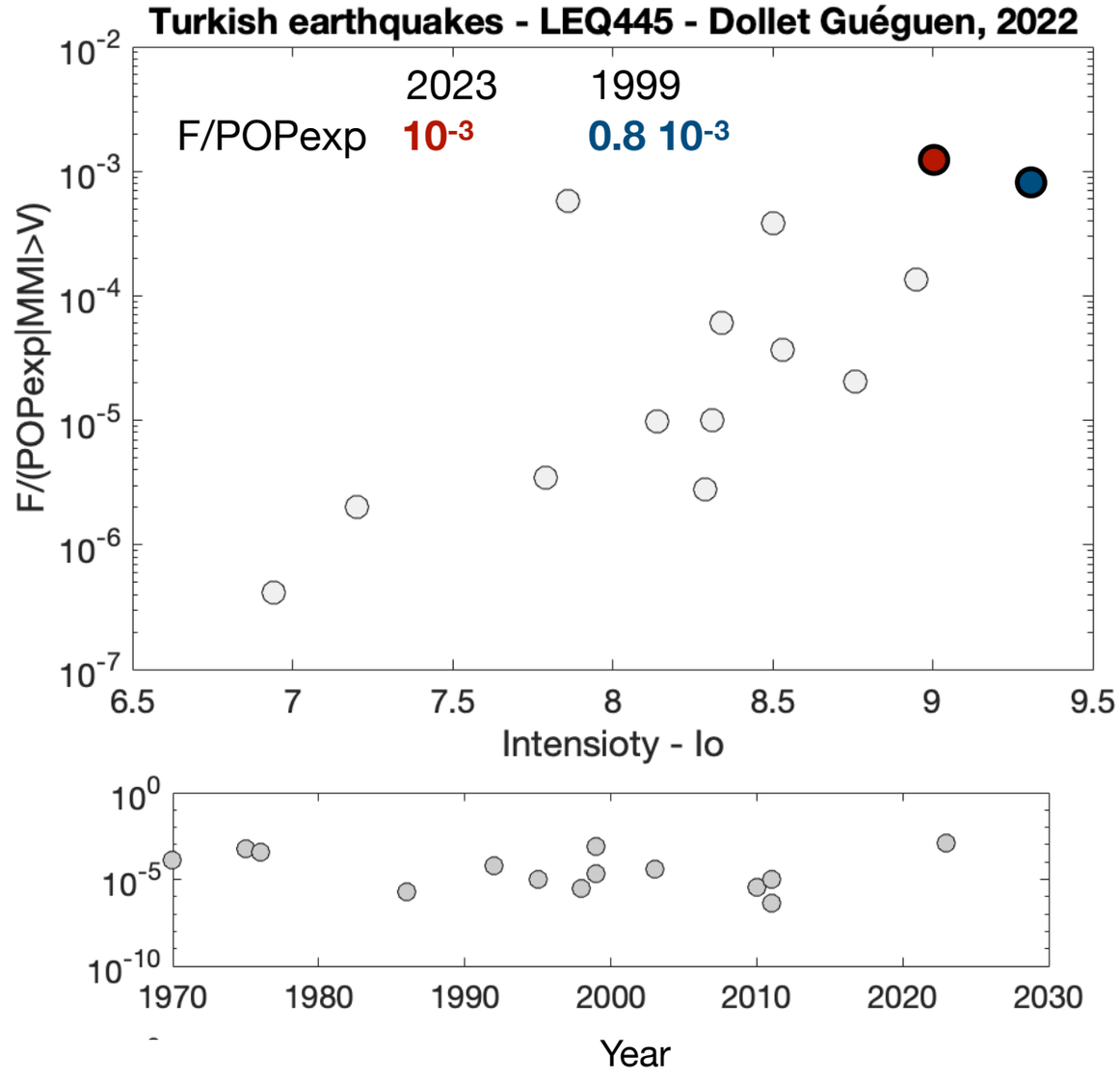
Date	Mw	Io	$L (2016) 10^6 $US	GDPc $US	GDPexp|MMI>VI 10^6 $US	POPexp|MMI>VI 10^6	F
1970	7.4	IX	574	4 787	38 555	8	1 086
1975	6.6	VII-VIII	206	5 633	22 923	4	2 367
1976	7.0	VIII-IX	281	6 081	67 606	11	4 227
1986	6.0	VII	45	6 731	42 138	6	13
1992	6.6	VIII	1 166	7 861	84 748	11	653
1995	6.4	VIII	334	8 295	80 208	10	94
1998	6.2	VIII	985	9 349	481 098	51	145
1999	**7.6**	**IX**	**25 669**	**8 893**	**192 577**	**22**	**17 242**
1999	7.1	VIII-IX	1 313	8 893	357 399	40	816
2003	6.3	VIII-IX	168	9 448	45 809	5	179
2010	6.1	VII-VIII	35	12 102	156 659	13	45
2011	5.8	VI-VII	287	13 249	75 262	7	2
2011	7.2	VIII	1 235	13 249	808 452	61	614
2023	**7.8**	**VIII-IX**	**34 000**	**9 660**	**471 488**	**49**	**59 259**
		Total	**66 298**				**86 741**
		2023 contrib.	**51 %**				**68 %**

Source: 09/2023

Turkish earthquakes (non exhaus.)

LEQ445 flat file (Dollet and Guéguen, 2022)





Earthquake-resistant design failure: 1999, 2003, 2011, 2023

Turkish earthquakes

Pattern of the seismic damage at urban scales: the Turkish paradox

2020

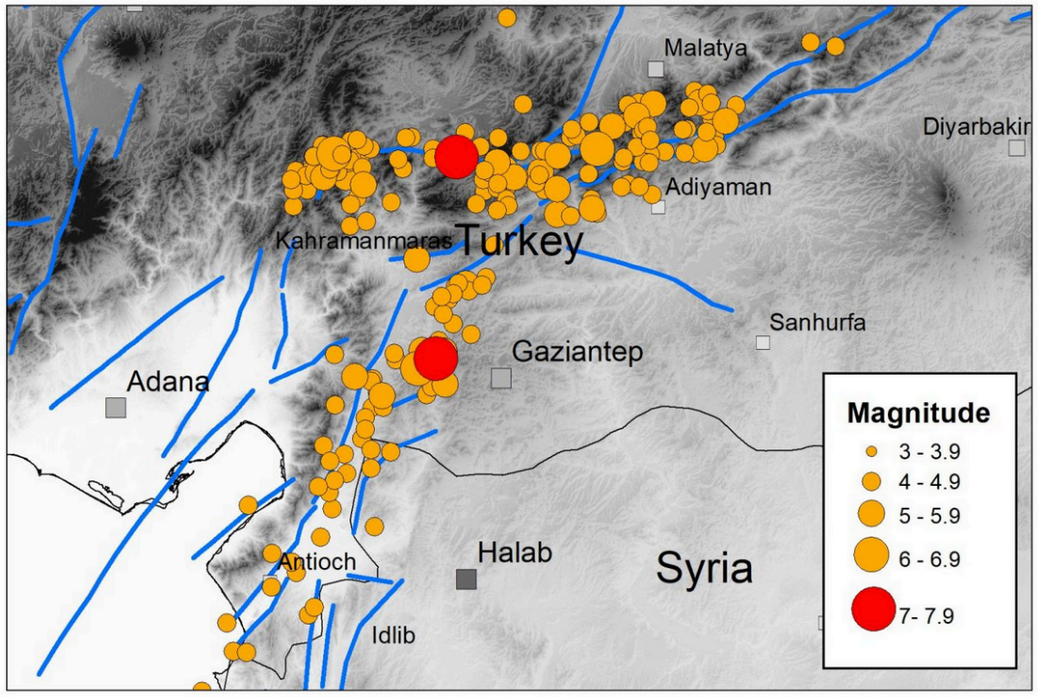
1999

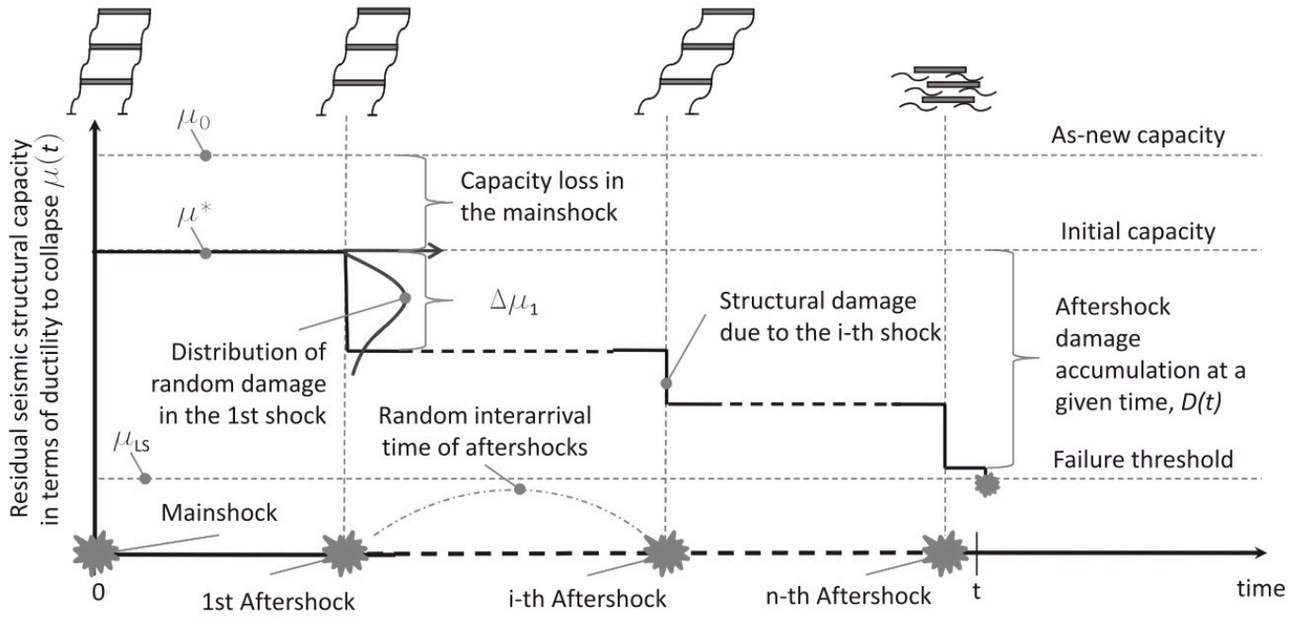
2023

2023

Full earthquake sequences

mainshock-aftershock sequence



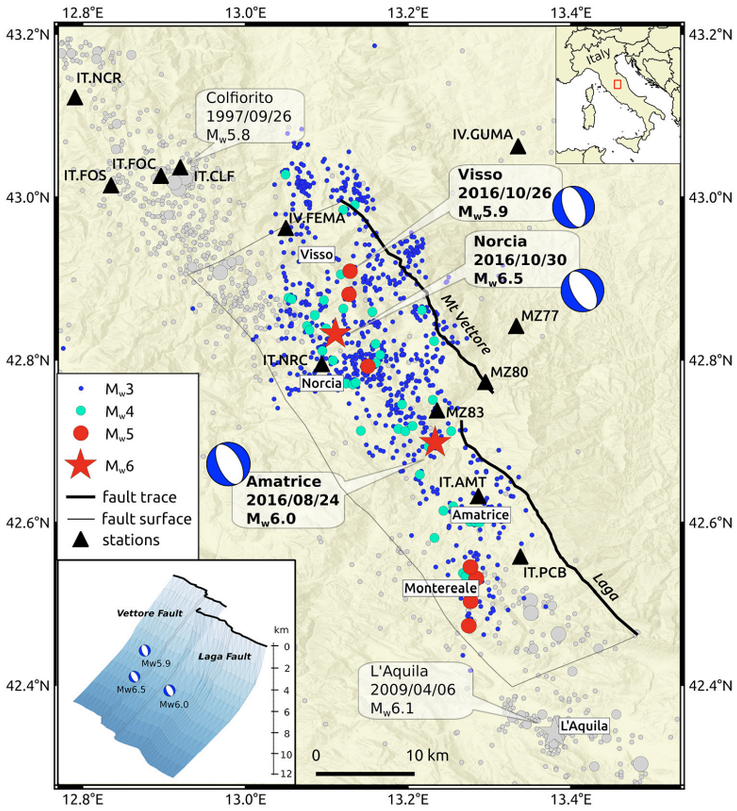


Cousin et al., 2012 - Five times more losses due to aftershocks Christchurch earthquake

Shokrabadi and Burton, 2019 - The aftershock-induced losses during the same period (Los Angeles) were estimated at approximately 30% of the losses due to the mainshock.

In Turkey's insurance contracts, the earthquake event definition is usually governed by a 72 hours clause. However, separating losses from different events ideally requires visits from loss adjusters between occurrences. In practice, this is rarely possible within a few days or even weeks. This situation introduces uncertainty in determining the actual event loss.

Central Italy Time-dependent PSHA



Hazard module

Hazard	
▪ Source characterisation: area source model ▪ Local site effects: Vs30 map ▪ Ground motion prediction equation	
TI-model	**TD-model**
▪ Synthetic catalog: event generation using Poisson model	▪ Synthetic catalog: event generation using ETAS model

Exposure module

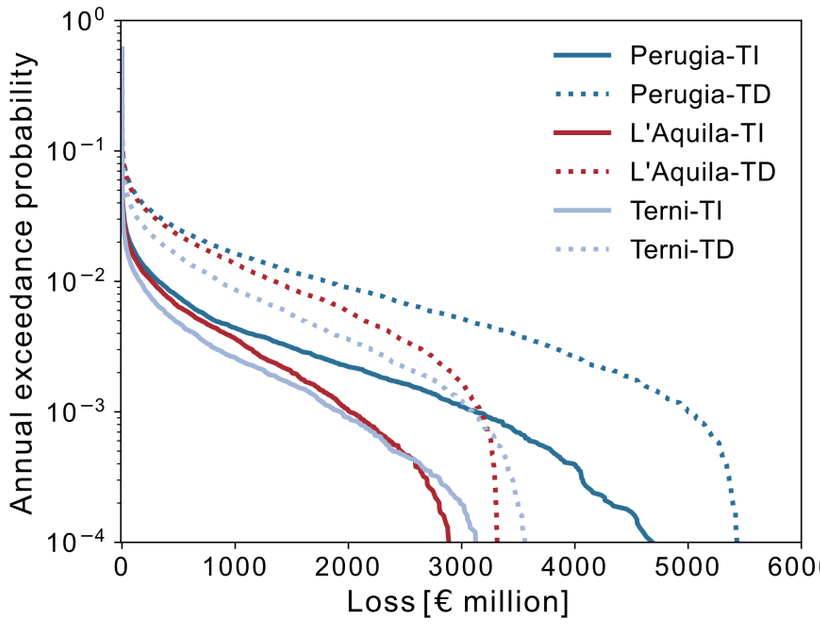
Exposure	Vulnerability	
Asset attribute information: 1. Location 2. Material type 3. No. of storeys 4. No. of dwellings 5. Floor area 6. Replacement Cost + Weighted grid using GHSL built-up area map **100m x 100m Gridded exposure database**	▪ Consequence function	
	TI-model	**TD-model**
	▪ Standard fragility function ▪ Loss estimation: Monte Carlo simulation	▪ Damage-dependent fragility function ▪ Loss estimation: Markov Chain Monte Carlo simulation

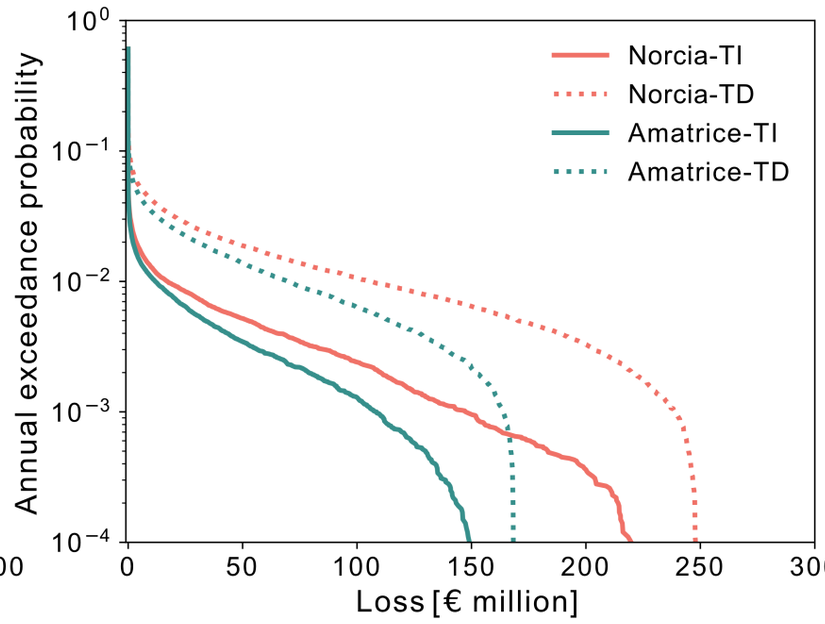
Risk module

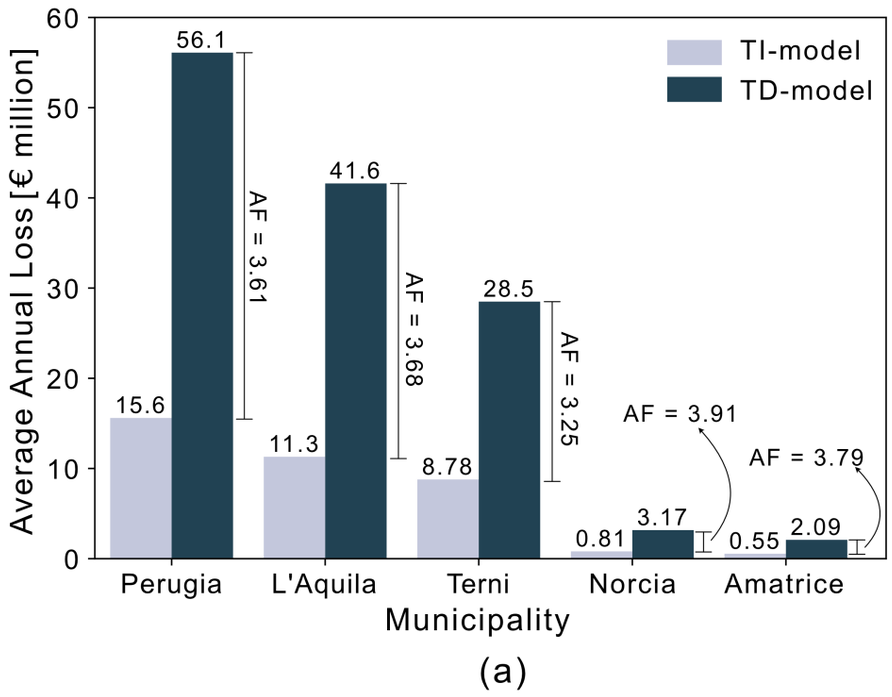
Financial	
▪ Interest rate model: Cox-Ingersoll-Ross ▪ Payoff function: zero-coupon	
Aggregare loss model (TI-model)	**Aggregare loss model (TD-model)**
▪ Catastrophe event process: λ calibrated using homogenous Poisson process ▪ Catastrophe severity process: cumulative distribution function for time-independent loss assessment (Monte Carlo)	▪ Catastrophe event process: λ calibrated using ETAS model ▪ Catastrophe severity process: cumulative distribution function for time-dependent loss assessment (Markov Chain Monte Carlo)

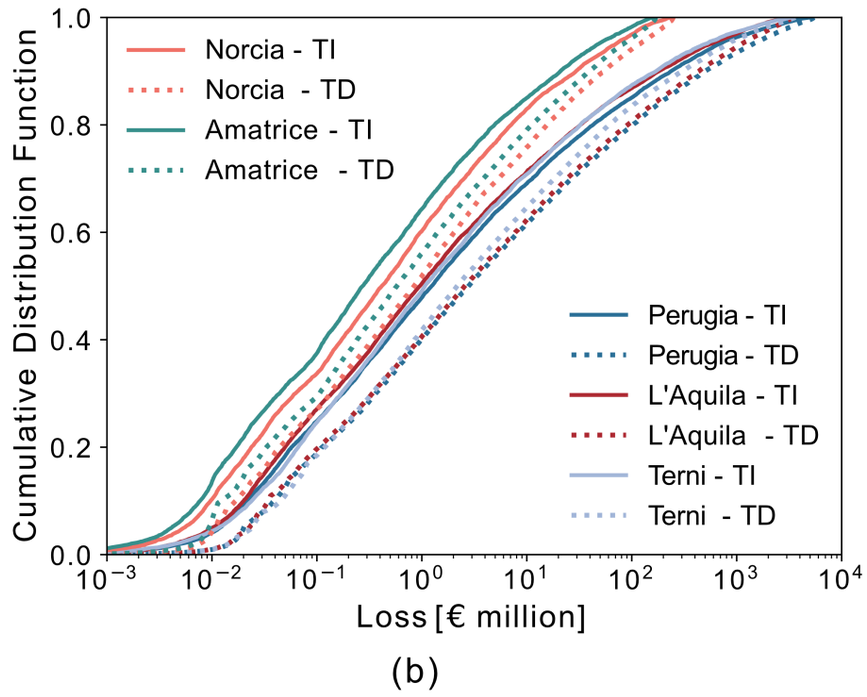
Central Italy Time-dependent PSHA

Risk module









Mistry, Hernandez, Guéguen, et al. 2024 - Risk Analysis

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Take-away messages

- Moderate-size earthquakes contribute to about 40% of the total losses
- A huge benefit (1/3) of seismic loss reduction policy: a decrease of the losses (economic and social) to exposure model ratio
- Central Italy: Aftershocks sequence contributes to about 2/3 of the total AAL

Outlooks

- Testing ESRM20 model in France: exposure model
- Improvement of the damage/loss models: between-event, within-event, host-to-target…
- 2023 Turkish aftershocks sequence: ETAS for a finit-fault

Merci de votre attention