Academy

Disaster Risk Finance Academy: Affordable Disaster Risk Insurance through Public-Private Partnerships

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WORLD BANK GROUP

FROM EARTHQUAKE RISK ASSESSMENT to EARTHQUAKE INSURANCE PRICING

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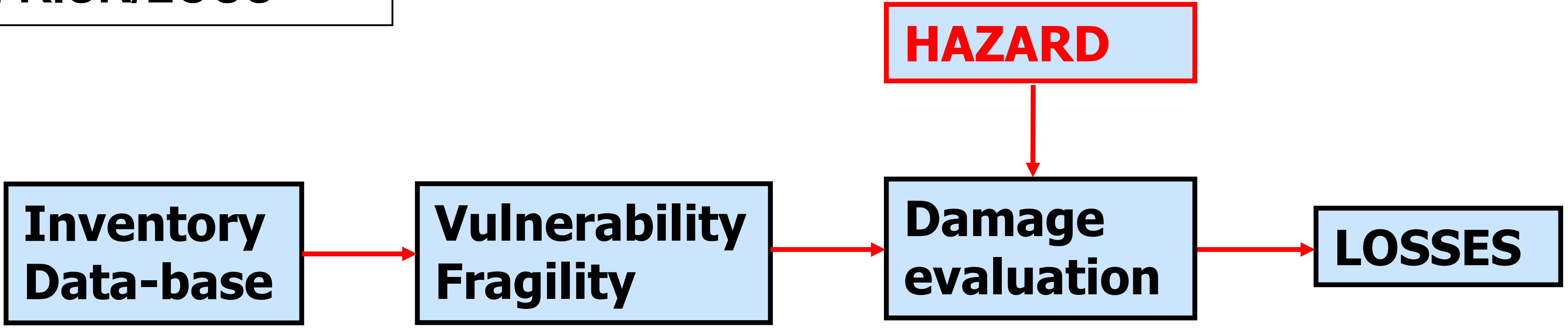
EARTHQUAKE RISK/LOSS



Sendai Framework for Disaster Risk Reduction (SFDRR; United Nations Office for Disaster Risk Reduction (UNDRR), 2015a),
Seismic risk, referring to given asset types (Exposures), is a probabilistic measure of the damage or loss expected in a given time interval, in a region of interest.
The calculation of seismic risk entails the convolution of the seismic hazard with vulnerability and exposure of the assets at risk.

- **Inventory - Assets** may be property, people, profits, or other things of value.
- **Loss** is the reduction in value of an asset due to damage.
- **Risk** is the uncertainty of loss.
- **Risk or Loss estimation** is the quantification of the earthquake loss.

HISTORY OF EARTHQUAKE RISK ASSESSMENT

- Around 1990, Commercal Cat Modelers: RMS, AIR, CoreLogic (EQCAT), AON, WillisRe
- *1994 Mw6.7 Northridge Earthquake (Estimated Losses USD 3Bn, Insured Losses USD 20Bn)*
- 1996 UN (International Decade for Naturak Disaster Reduction– IDNDR) RADIUS Project
- 1997 HAZUS-USA
- Black Box Models: *FM Global, Swiss Re, Munich Re, Oasis, Touchstone (AIR), RQE (CoreLogic), RMS-One (RMS)*
- 2000 GEM (Global Earthquake Model) Foundation(OECD & Munich-Re)
- Post 2000 - Research Projects: WB, *EU and GEM Projects (EU-SHARE, GEM- EMME and EMCA)*
- *2006 USGS PAGER Started to Report Earthquake Losses*
- 2015 Open Source - OpenQuake (GEM)
- 2018 Global Earthquake Risk (GEM)
- 2020 European Risk
- Post 2020 – Numerous Earthquake Risk and Cat Loss Models

PROBABILISTIC EARTHQUAKE RISK

Seismic Risk analysis entails a set of earthquakes, the associated consequences (e.g. damage and loss) and the probabilities of occurrence of these consequences over different time periods.
The simple direct way of making probabilistic estimates of Damage State D exceeding D=d, is to express it as a function of earthquake source, E, and site parameters, S (McGuire, 2004).

$$P(\text{damage exceeds d} \mid \text{earthquake}) = P(D>d \mid E, S)$$

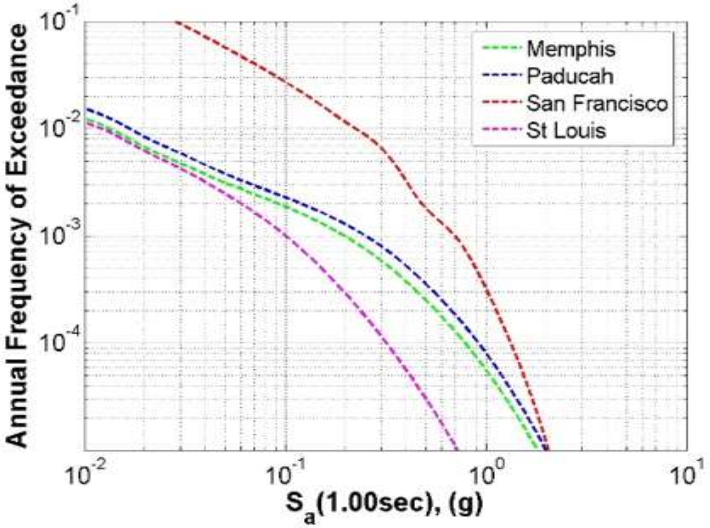
The probability of D>d is estimated as a function of a ground motion Intensity Measure (IM)

$$P(D > d) = \int P(D > d|IM) \times d\lambda\,(IM > im)$$

P(D>d | IM) represents the so called fragility function

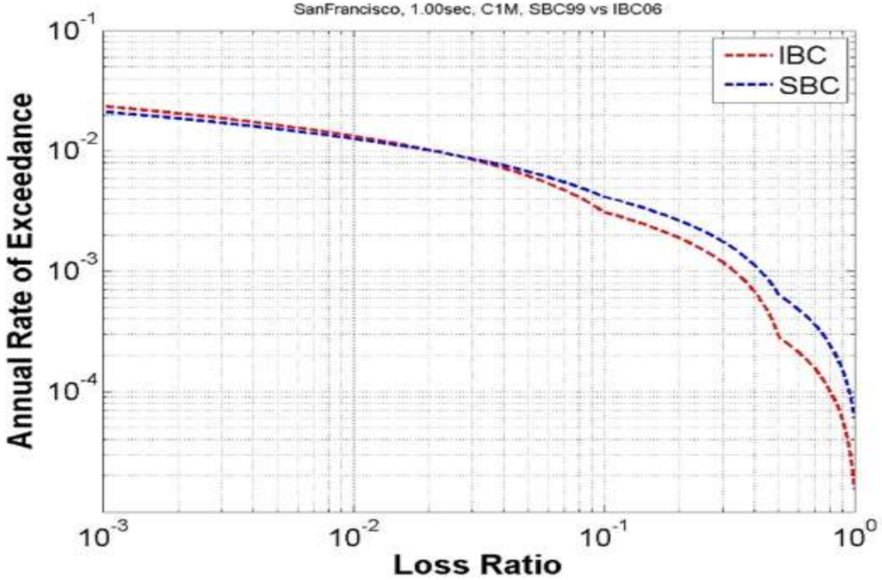
λ(IM>im) is the total frequency which IM exceeds IM and, represents the basic seismic hazard at the site.

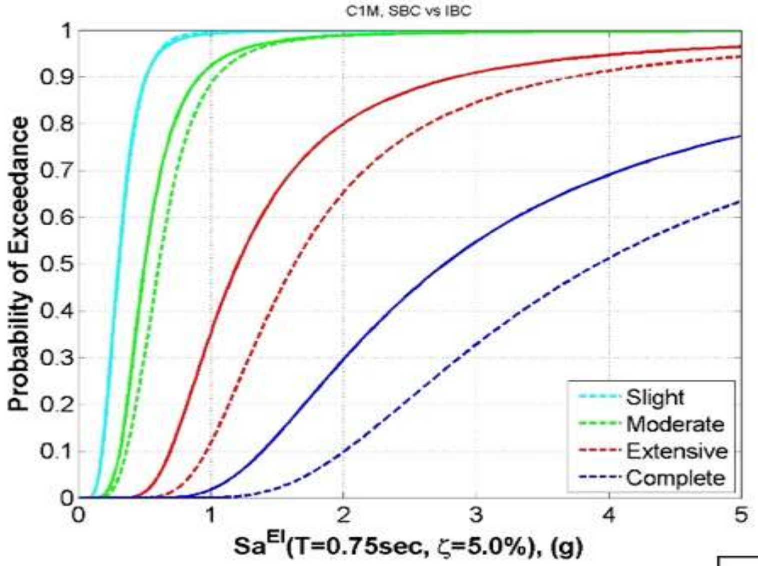
Hazard $\lambda(IM)$



Inventory

Loss/Risk $\lambda(DV)$





Fragility/Vulnerability $\lambda(DM)$

Luco and Karaca, 2006

PUBLIC DOMAIN (Non-proprietary) SOFTWARE for EARTHQUAKE RISK ASSESSMENT

- CAPRA GIS- Earthquake module, http://www.ecapra.org/software
- HAZUS-MH earthquake module, http://www.fema.gov/hazus
- OpenQuake, https://www.globalquakemodel.org/openquake/
- ELER, http://www.koeri.boun.edu.tr/Haberler/NERIES%20ELER%20V3.1_6_176.depmuh
- RiskScape-Earthquake, https://riskscape.niwa.co.nz/
- SELENA, http://www.norsar.no/seismology/engineering/SELENA-RISe/

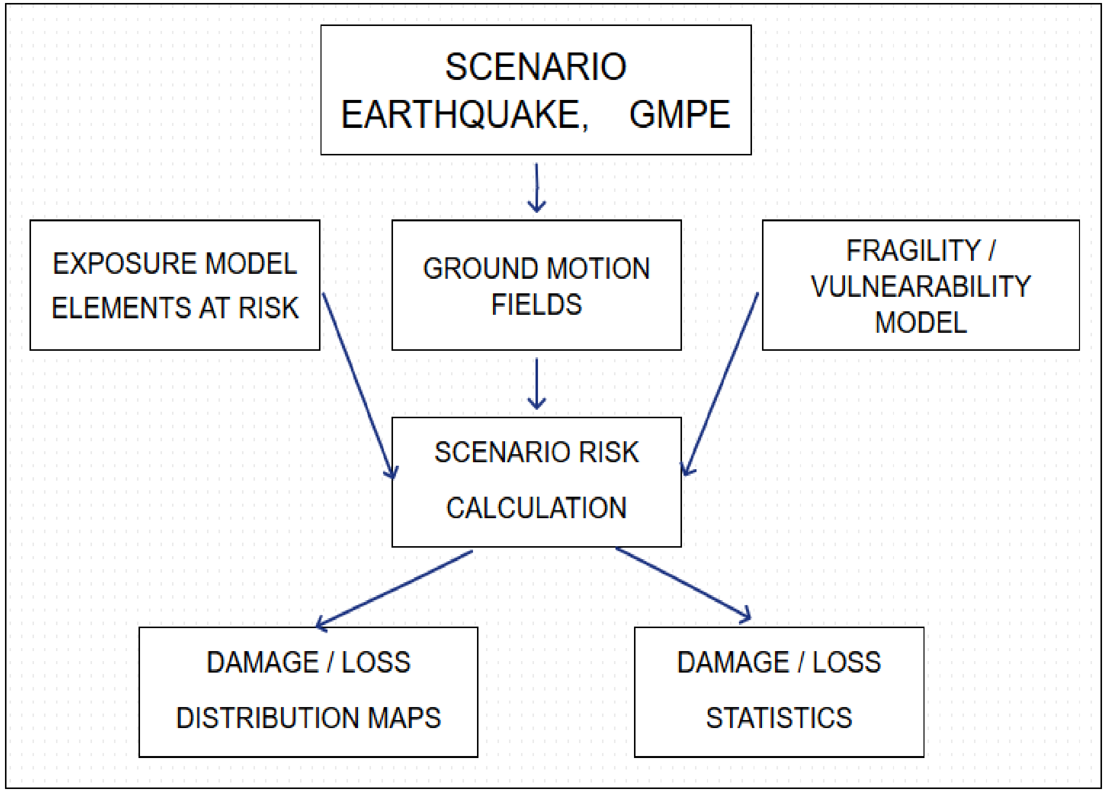
The main approaches (Pagani et al. 2014; Silva et al. 2014) for Earthquake Risk assessments are :

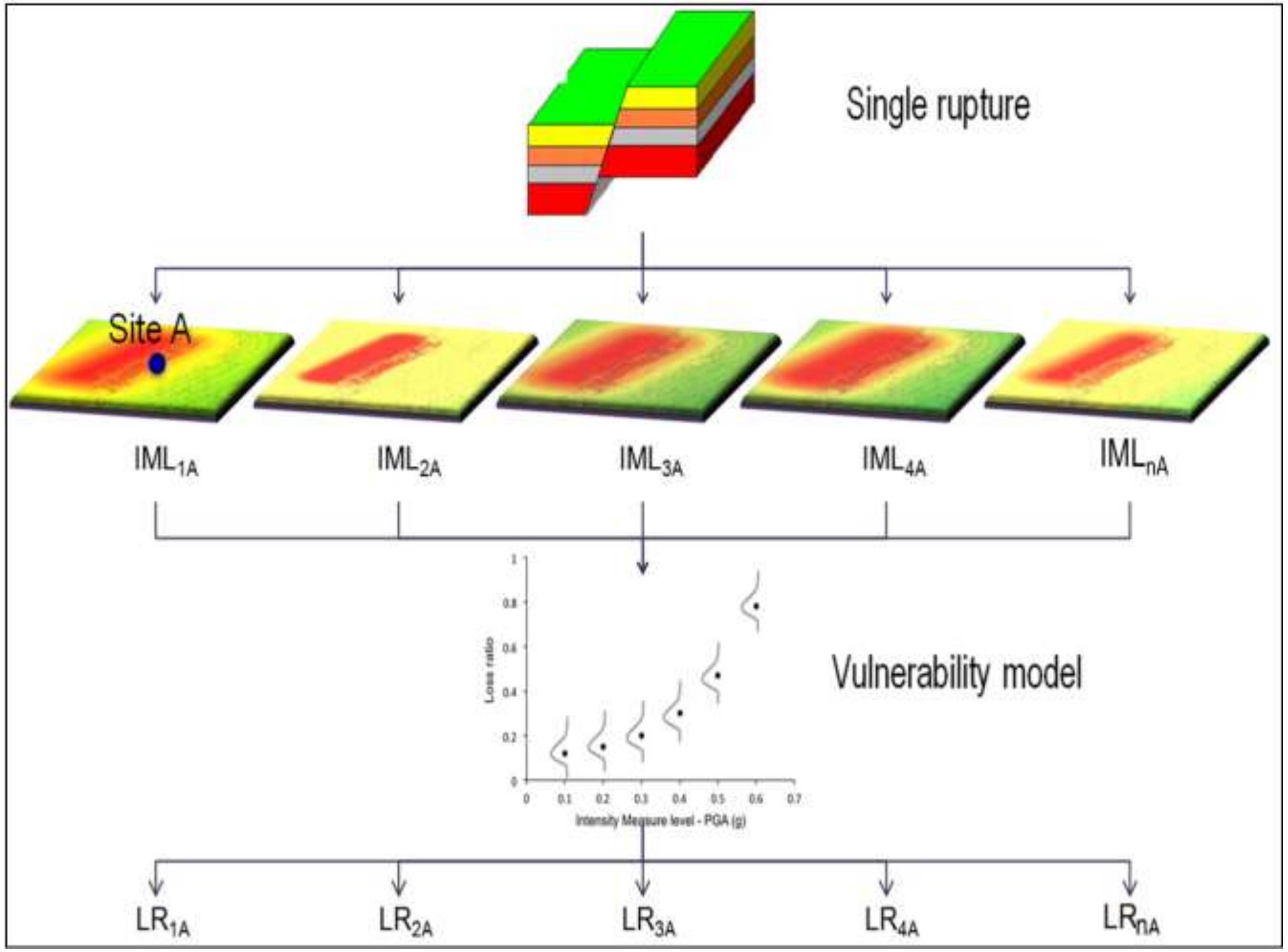
Intensity-Based: The risks/losses are estimated for a level of ground shaking intensity that occurs at a given return period (obtained as an output of a seismic hazard assessment, PSHA or DSHA).

Deterministic Event (Earthquake Scenario)- Based Risk Assessment
To estimate the distribution of risk due to a single earthquake scenario, for a spatially distributed building portfolio taking into account aleatory and epistemic ground-motion variability using Monte-Carlo simulation.

Risk Assessment Based on Probabilistic Description of the Events (Stochastic Event-Based)
In this risk assessment methodology, stochastic earthquake catalogues and associated ground motion fields are generated, and combined with the exposure and vulnerability models using Monte-Carlo simulation.

DETERMINISTIC EVENT-BASED EARTHQUAKE RISK ASSESSMENT

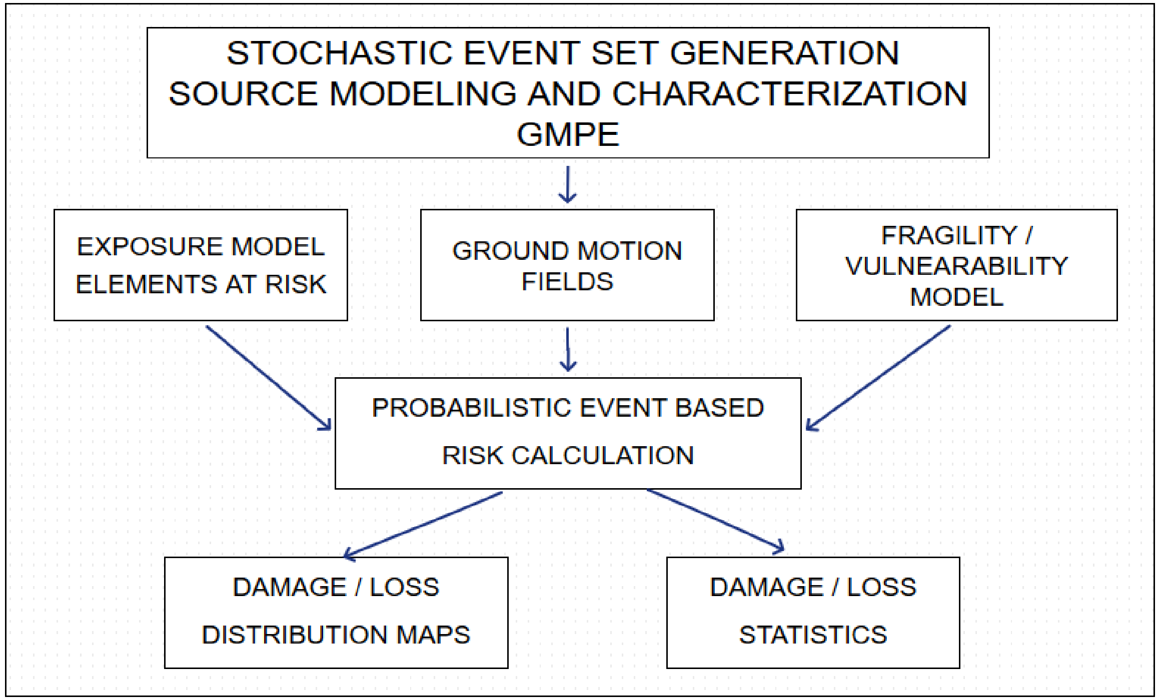




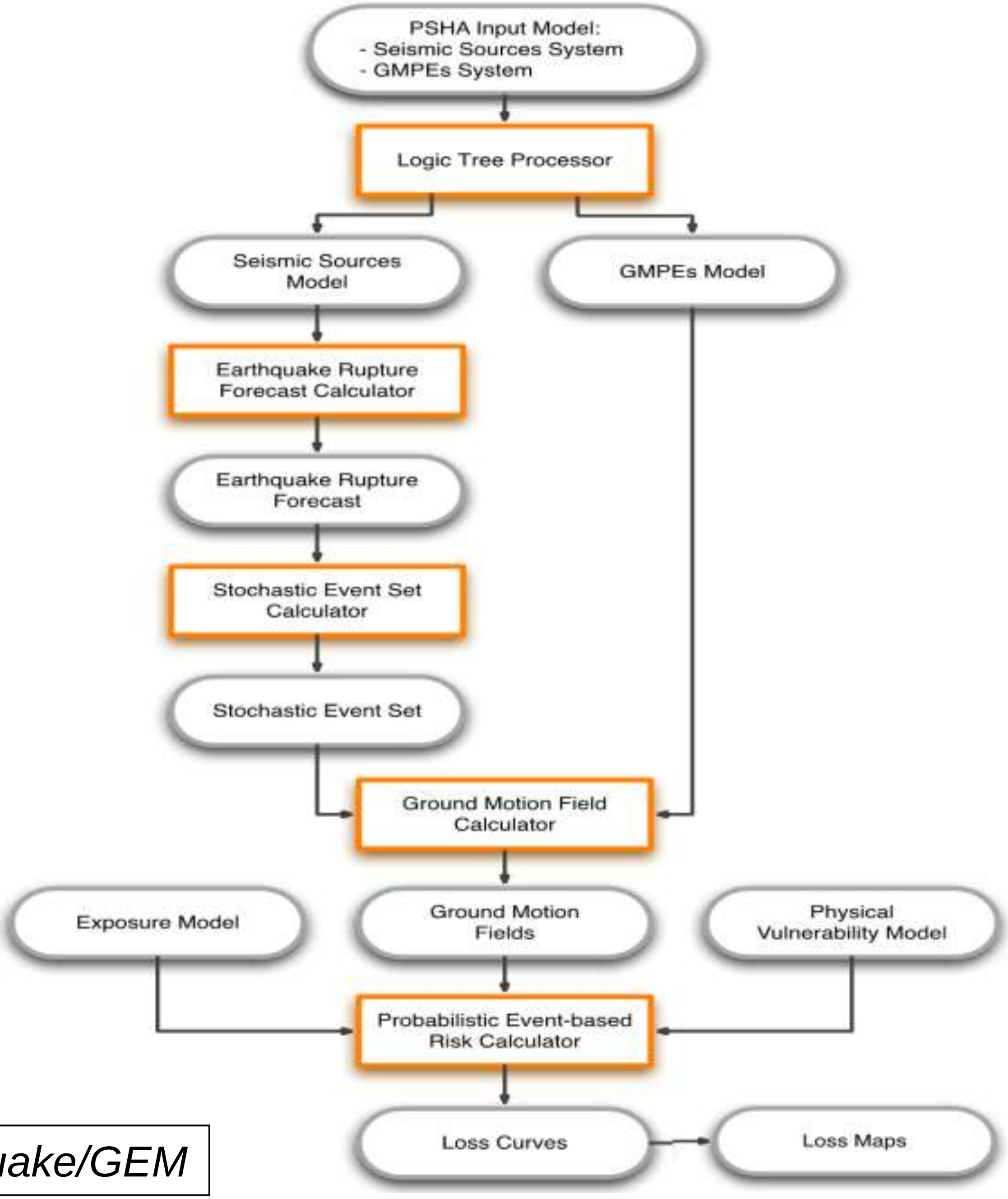
This calculation is used to estimate the distribution of damage due to a single scenario earthquake (a finite rupture definition). A set of ground-motion fields is computed, by repeating the same rupture, and sampling the inter- and intra-variability from the GMPE each time, many ground motion fields can be computed to account for the aleatory variability in the ground motion. Damage/Loss distribution is calculated for each asset using the fragility/vulnerability models.

Open Quake/GEM

STOCHASTIC EVENT-BASED PROBABILISTIC EARTHQUAKE RISK ASSESSMENT



- Stochastic event sets (also known as a synthetic catalog, representative of the seismicity of the region over the specified time period) and the associated ground motion fields are used to compute loss exceedance curves for each asset contained in an exposure model.
- For each ground-motion field, the intensity measure level at a given site is combined with a vulnerability function, from which a loss ratio is randomly sampled for each asset.
- The main results of this calculator are loss exceedance curves for each asset and risk/loss maps for the region



Open Quake/GEM

KEY INGREDIENTS OF EARTHQUAKE RISK

Exposure Model

Exposure model defines assets and their properties. An asset may a collection of structures at a particular geographic location that share similar characteristics.

Site Conditions Model

Local soil conditions need to be taken into consideration in risk calculations (generally) through the use of Vs30, Z1.0 and Z2.5 values in the ground motion prediction equations (GMPEs)

Ground Motion Fields

Ground motion IM estimates is obtained at each site in consideration of Ground Motion Model (GMPE), Site Conditions, Inter-event and Intra-event Variabilities/

Fragility Models

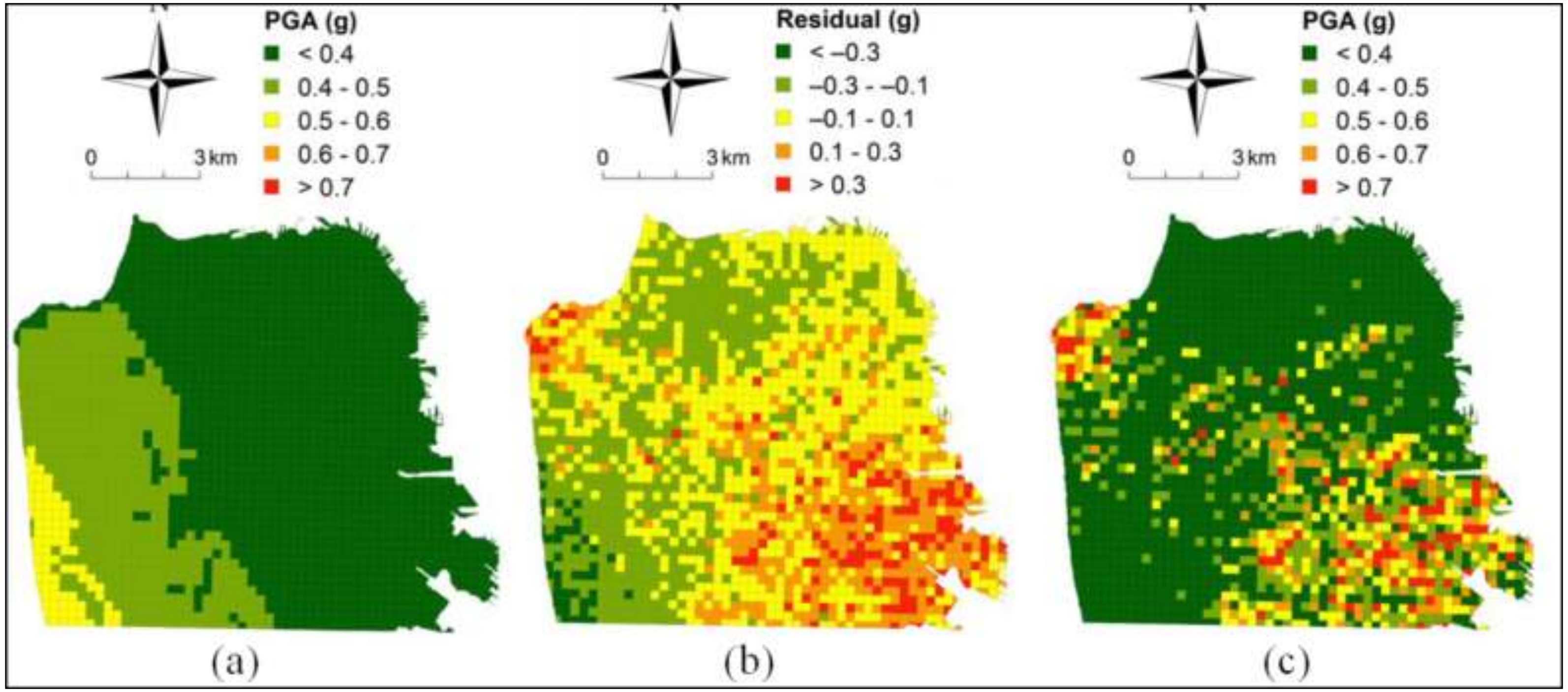
A fragility relationship for a building describes the probability of exceeding a set damage states conditional on a set of ground shaking intensity levels, for each building class.

Consequence Models

A consequence model defines a set of consequence or “damage-to-loss” functions, describing the distribution of the loss ratio conditional on a set of discrete damage states, for each building class.

Vulnerability Models

A vulnerability relationship prescribes the distribution of loss ratio conditional on the level of ground shaking, for each building class. Uncertainty in the vulnerability relationship needs to be considered.



GROUND MOTION FIELDS- SPATIAL CORRELATION

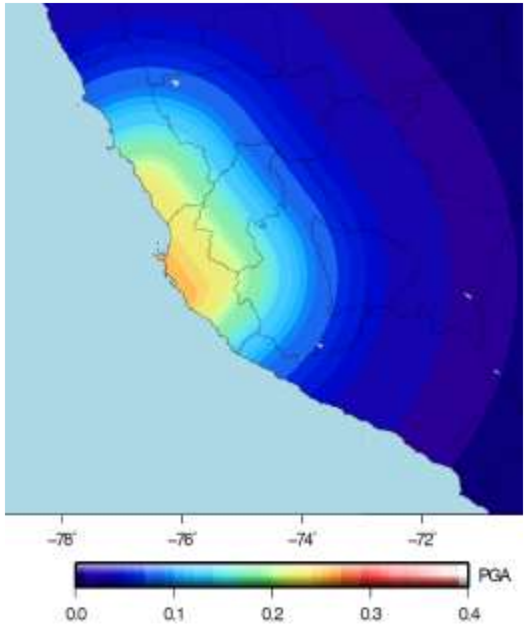
PGA in the San Francisco area using Boore and Atkinson (2008) GMPE for an Mw 7.9 earthquake on North San Andreas Fault

(a) Median PGA values

(b) One realization of the inter-event and intra-event residuals and

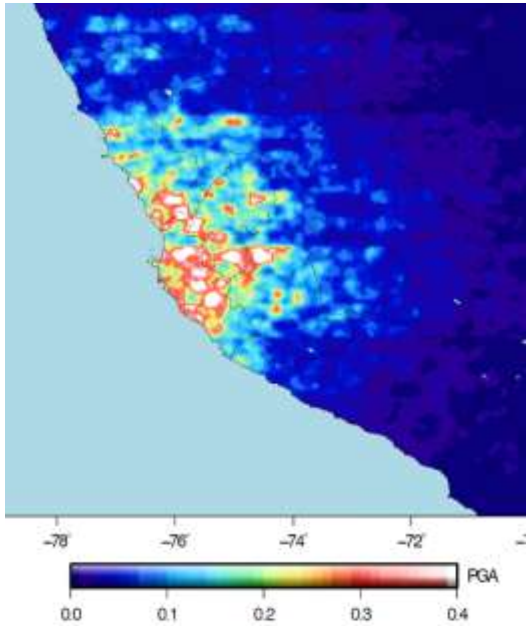
(c) One realization of PGA after implementing the between-event and within-event residuals to the median values.

(Wu and Baker, 2014)

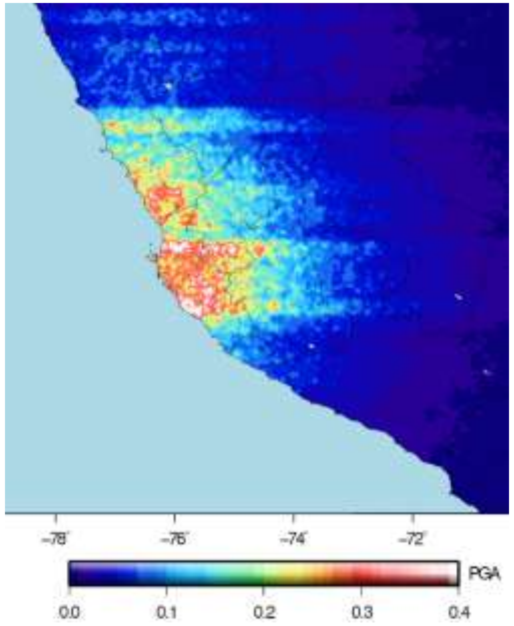


Simulated Median Ground Motion Field with Full Spatial Correlation

(Silva et al.,2014)



One Realization of Spatially Correlated Ground Motion Distribution Simulation



One Realization of Uncorrelated Ground Motion Distribution Simulation

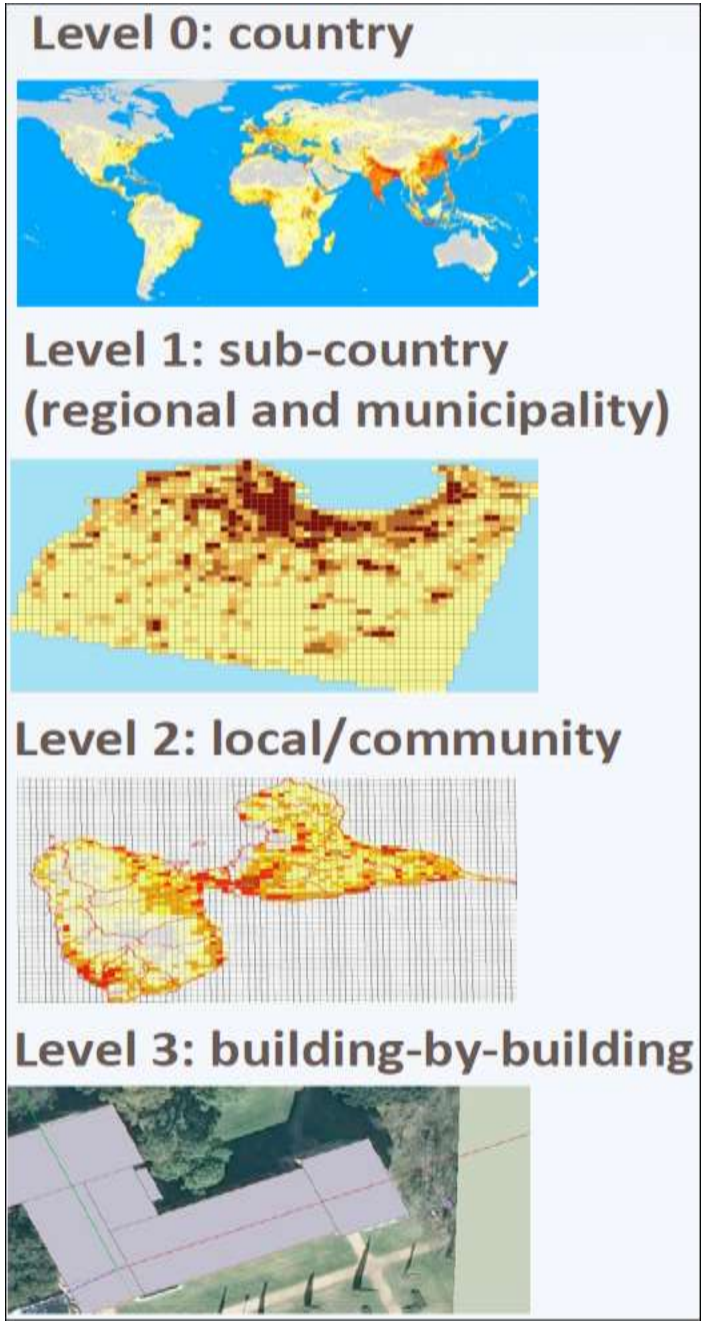
EXPOSURE (ELEMENTS – PORTFOLIO EXPOSED TO HAZARD)

Assets Exposed to Hazard are represented by the Exposure Model, which contains the information regarding the assets (such as building inventories and population) within the area of interest.

Building inventories are is linked to the fragility/vulnerability models and are determined based on specific classification systems (taxonomies) that define the building categories by various combinations of use, time of construction, construction material, lateral force-resisting system, height, applicable building code, and quality.

Publicly available data, at country and regional spatial scale, includes:

- UN-Housing database,
- UN-HABITAT, UN Statistical Database on Global Housing,
- Population and Housing Censuses of individual Countries,
- World Housing Encyclopaedia (WHE)
- Global Exposure Database for the Global Earthquake Model (GEM)
- USGS - PAGER
- LandScan
- Global Rural-Urban Mapping Project (GRUMP)
- Gridded Population of the World (GPW)



BUILDING TYPOLOGY/ TAXONOMY

General Attributes Used For Building Fragility Relationships

Material
- Steel
  - Structural
  - Light Metal
- Concrete
  - Cast-in-place
  - Pre-cast
  - Mixed
- Masonry
  - Un-reinforced
  - Reinforced
  - Adobe
- Wood
  - Light wood
  - Heavy timber
  - Masonry Veneer

System
- MRF
  - Distributed
  - Perimeter
- Braced
  - Concentric
  - Eccentric
  - X-shaped
  - Diagonal
- Shear Wall
  - w/ frame
  - w/o frame
- Tilt-Up
- Bearing wall
- Mobile
  - Tied-down
  - Not tied-down
- Special Building
  - Base Isolators
  - Special connections

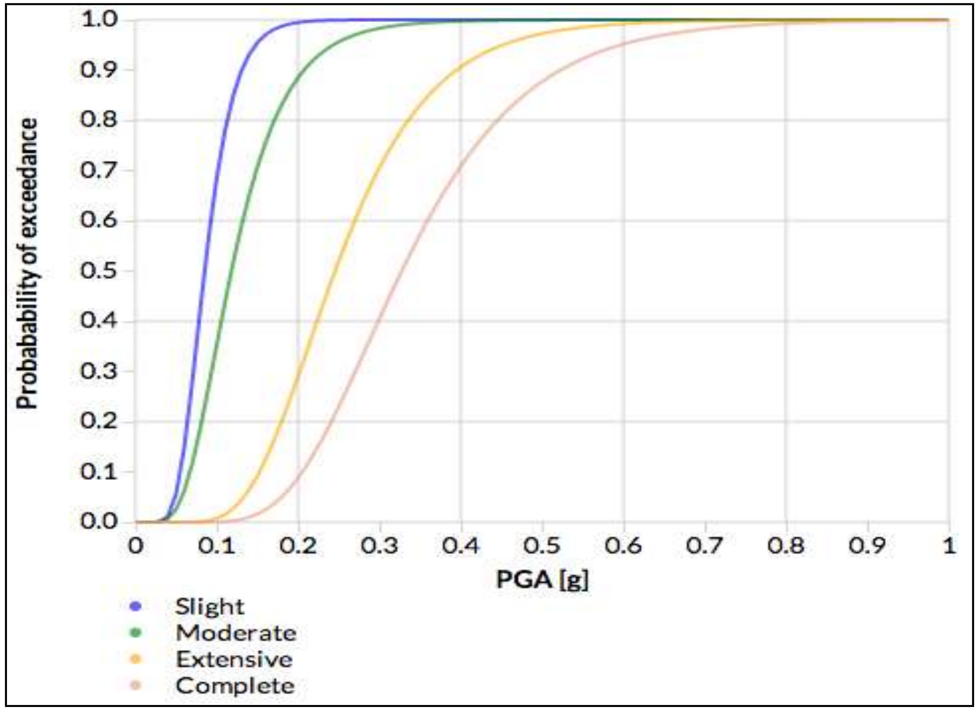
Number of Stories
- Low Rise (1 - 3)
- Mid Rise (4-7)
- High Rise (8-19)
- Tall (>20)

Year Built
- Pre-Code
- Post- i^{th} Code

For an extensive list of attributes associated With GEM Building Taxonomy: (https://github.com/gem/gem_taxonomy)

FRAGILITY, DAMAGE-TO-LOSS (CONSEQUENCE) and VULNERABILITY FUNCTIONS

P(DS>=ds | PGA=a) Fragility



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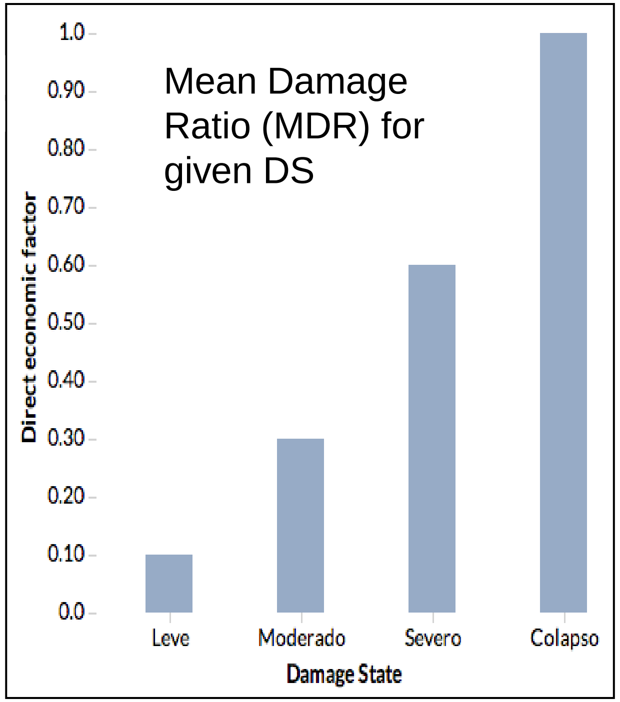
Damage-to-loss



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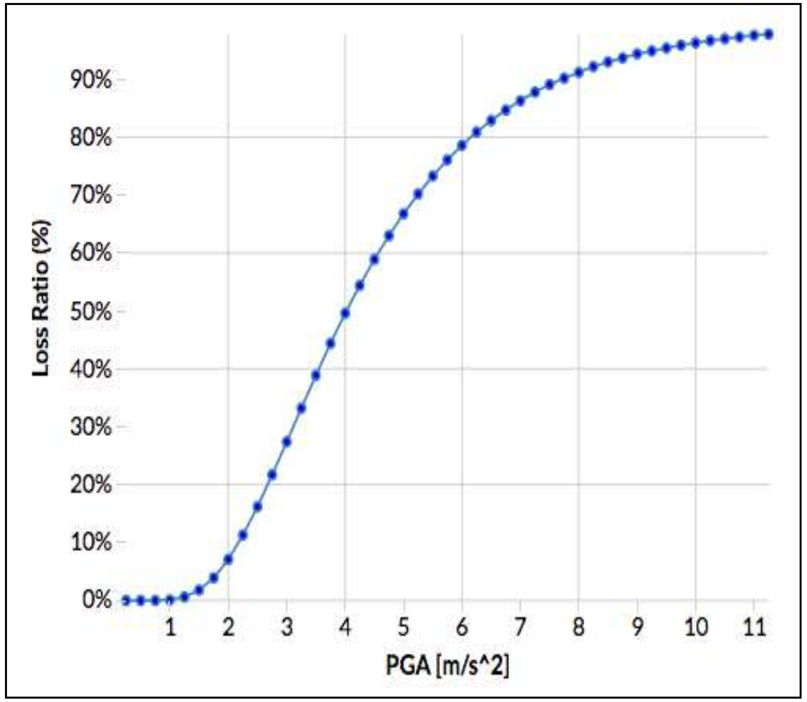
Vulnerability P(MDR>=mdr | PGA=a)



(Estrada et al., 2014)

Damage Grade	BU-KOERI (2003)	HAZUS (1999)	Bramerini et al. (1995)	ATC 13 (1987)	Tyagunov et al. (2006)
D1	0.05	0.02	0.01	0.05	0.05
D2	0.2	0.1	0.1	0.2	0.1
D3	0.5	0.5	0.35	0.55	0.4
D4	0.8	1	0.75	0.9	0.8
D5	1	1	1	1	1

Losses due to damaged buildings are usually expressed in terms of Mean Damage Ratio (MDR) or Loss Ratio defined as the cost of repairing the structure divided by replacement cost.

For European fragility and vulnerability functions for all of the building classes
https://gitlab.seismo.ethz.ch/efehr/esrm20/
http://vulncurves.eu-risk.eucentre.it/

EARTHQUAKE RISK METRICS

Types of Losses Modelled

• Direct (Physical damage to buildings and contents, Casualties)

• Indirect (Loss of use, Business Interruption)

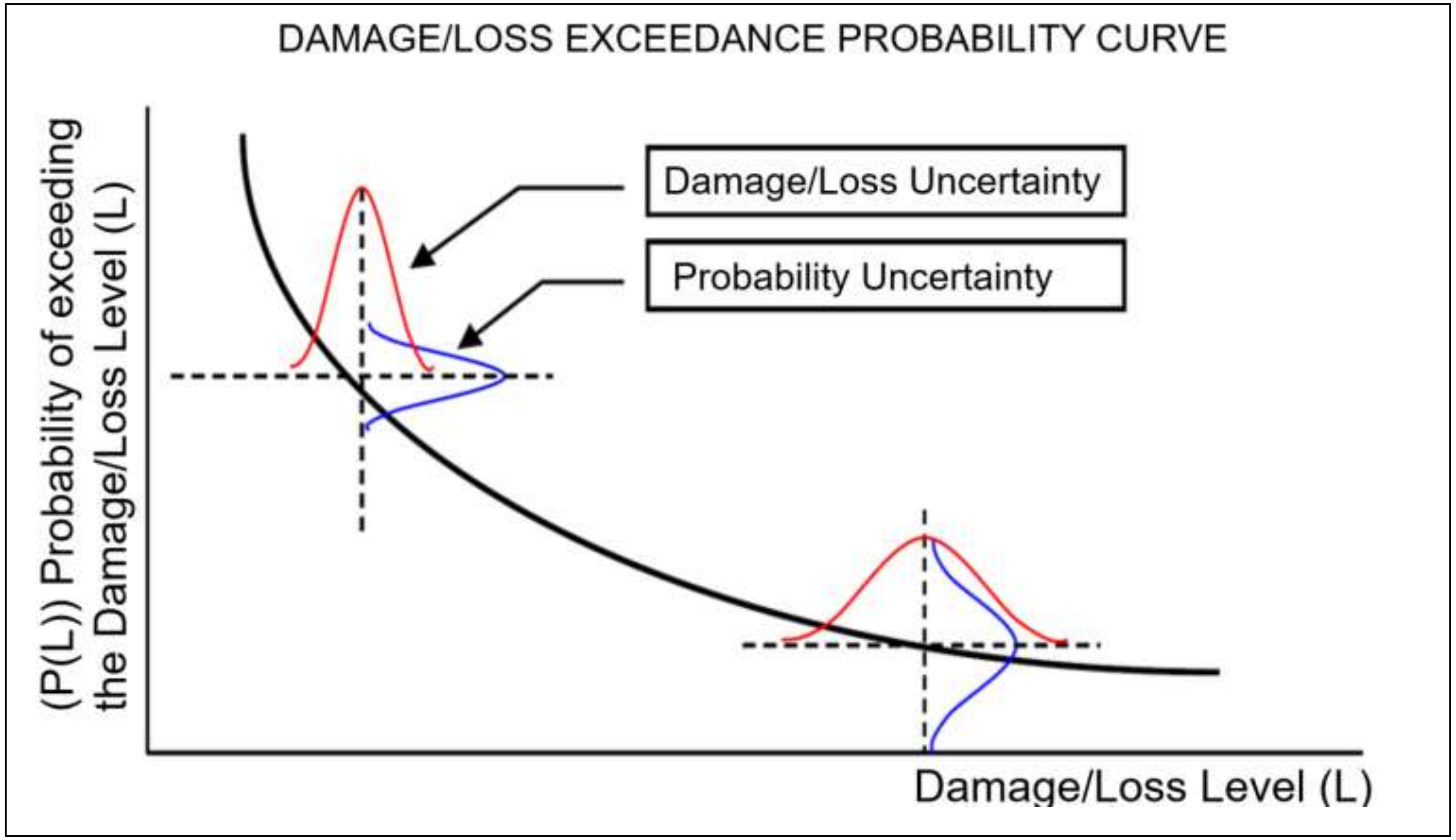
Primary Metrics

• Exceedance Probability (EP)

• Average Annual Loss (AAL)

• Average Annual Loss Ratio (AALR)

• Probable Maximum Loss (PML)



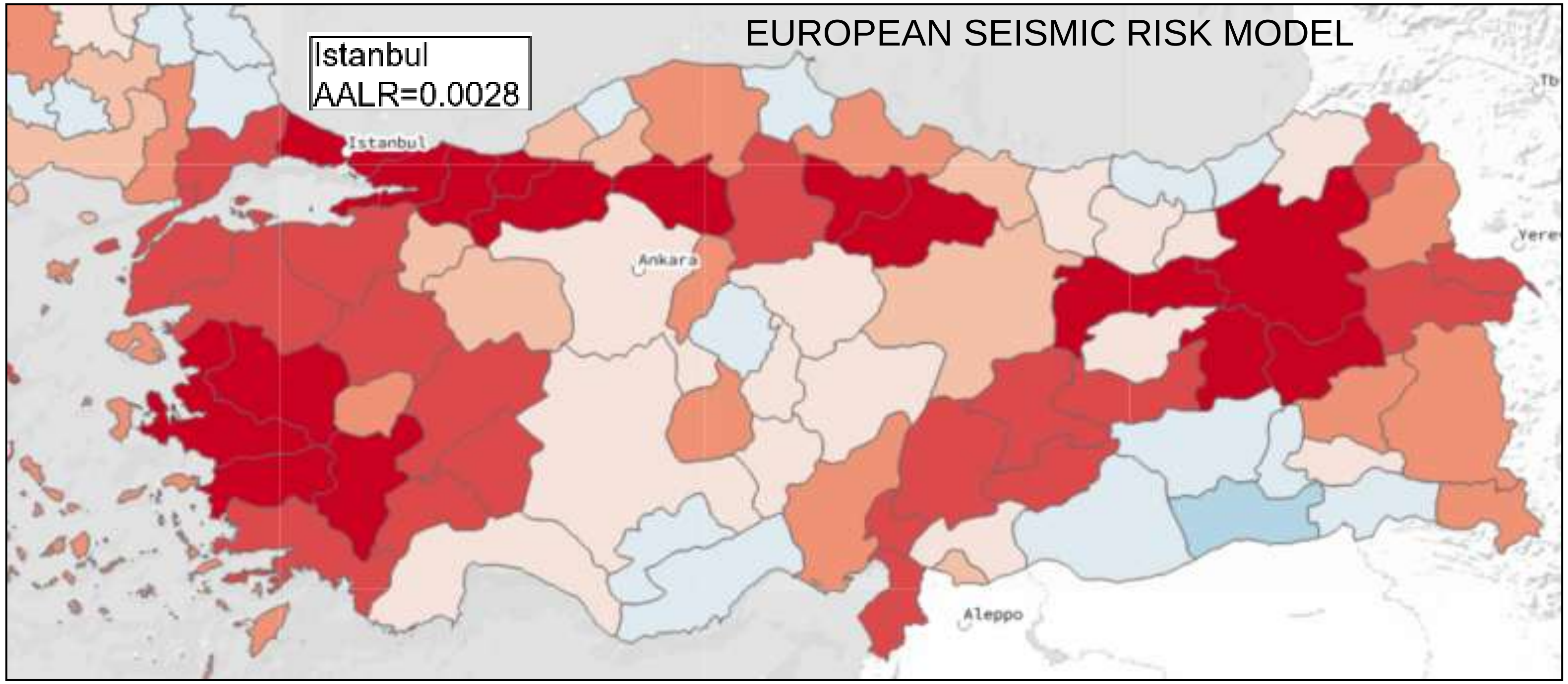
EP Curve (Exceedance Probability) is a cumulative distribution, that provides the annual probability that any given level of loss is likely to be equaled or exceeded.

Average Annual Loss (AAL) is the mean value of a EP distribution (the expected loss per year, averaged over many years, or pure/technical premium)

Average Annual Loss Ratio (AELR) is calculated as the ratio of AAL to the total building replacement value.

The Probable Maximum Loss (PML) represents the worst-case scenario for an insurer. The adjective "probable" is often not well defined.

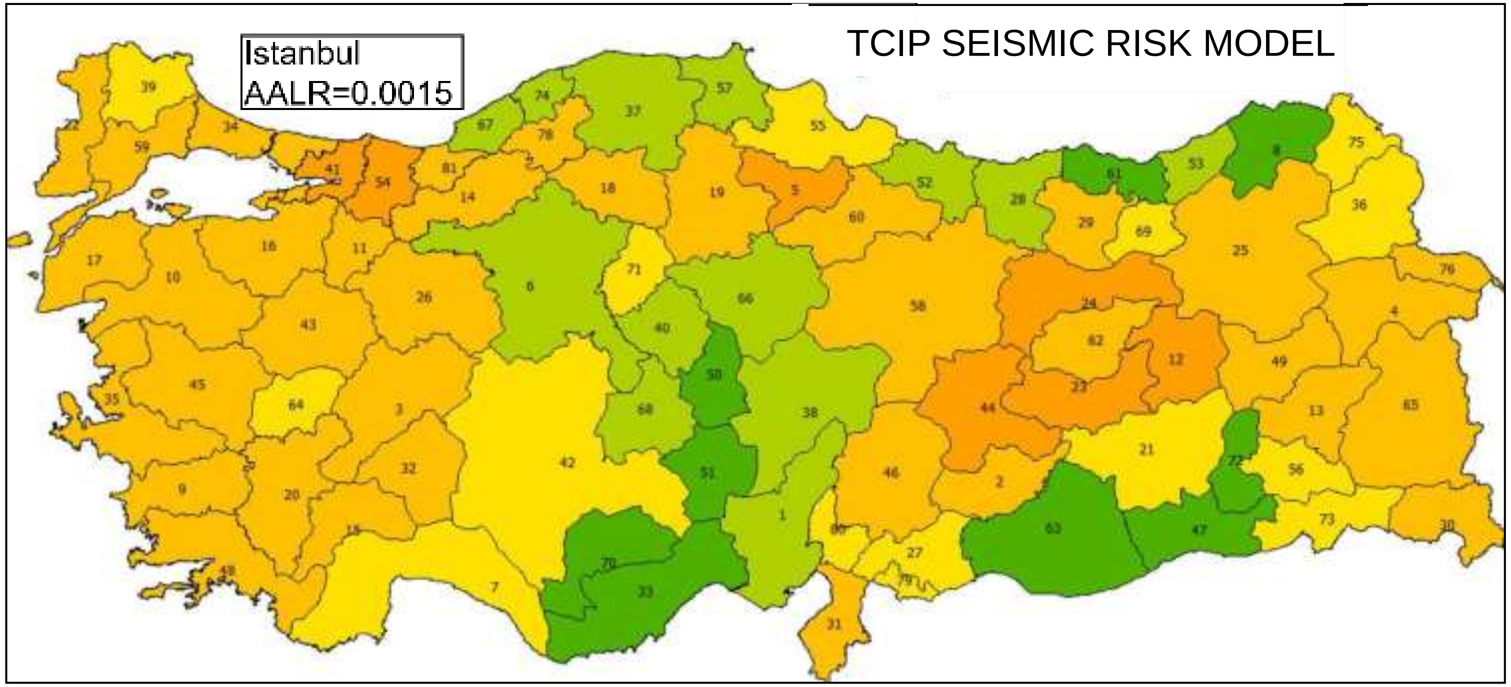
AVERAGE ANNUAL ECONOMIC LOSS RATIO (AALR)



AALR (Per mille)

- 0.039 - 0.068
- 0.068 - 0.210
- 0.210 - 0.415
- 0.415 - 0.618
- 0.618 - 0.886
- 0.886 - 1.575
- 1.575 - 4.638

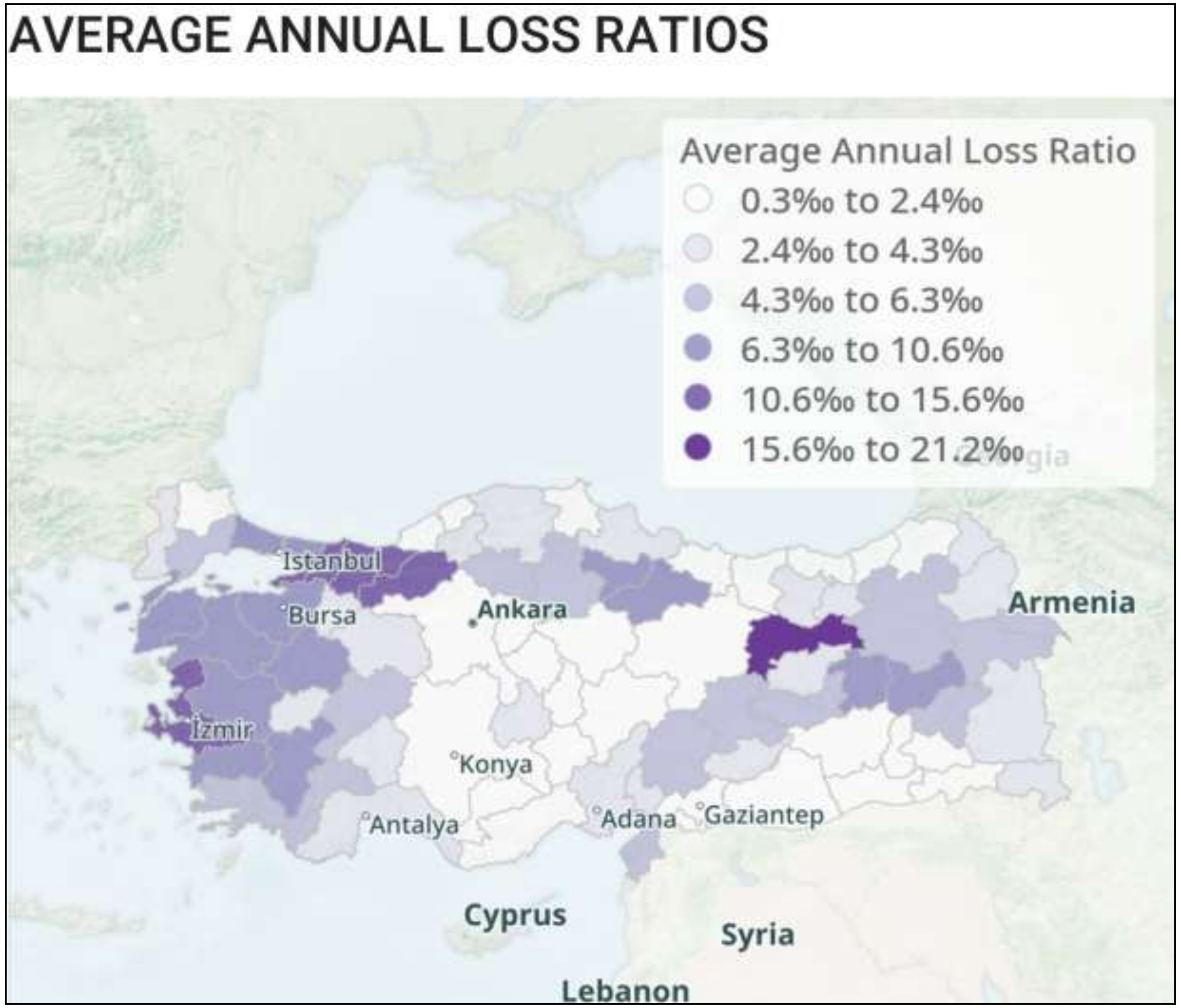
For residential, commercial and industrial building stock, considering structural and non-structural components and contents

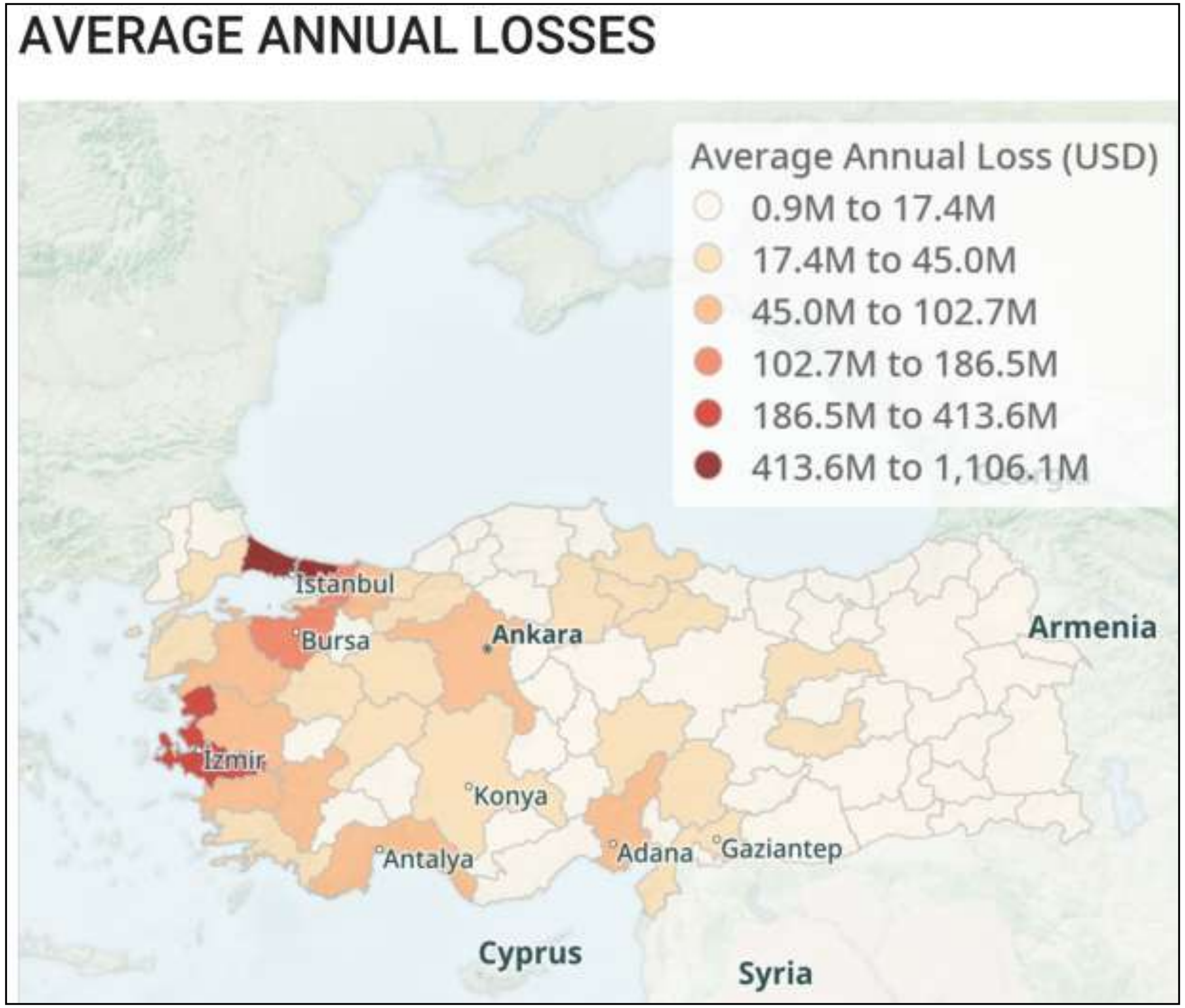


Province Based (AS50FS50)
AAL(%)

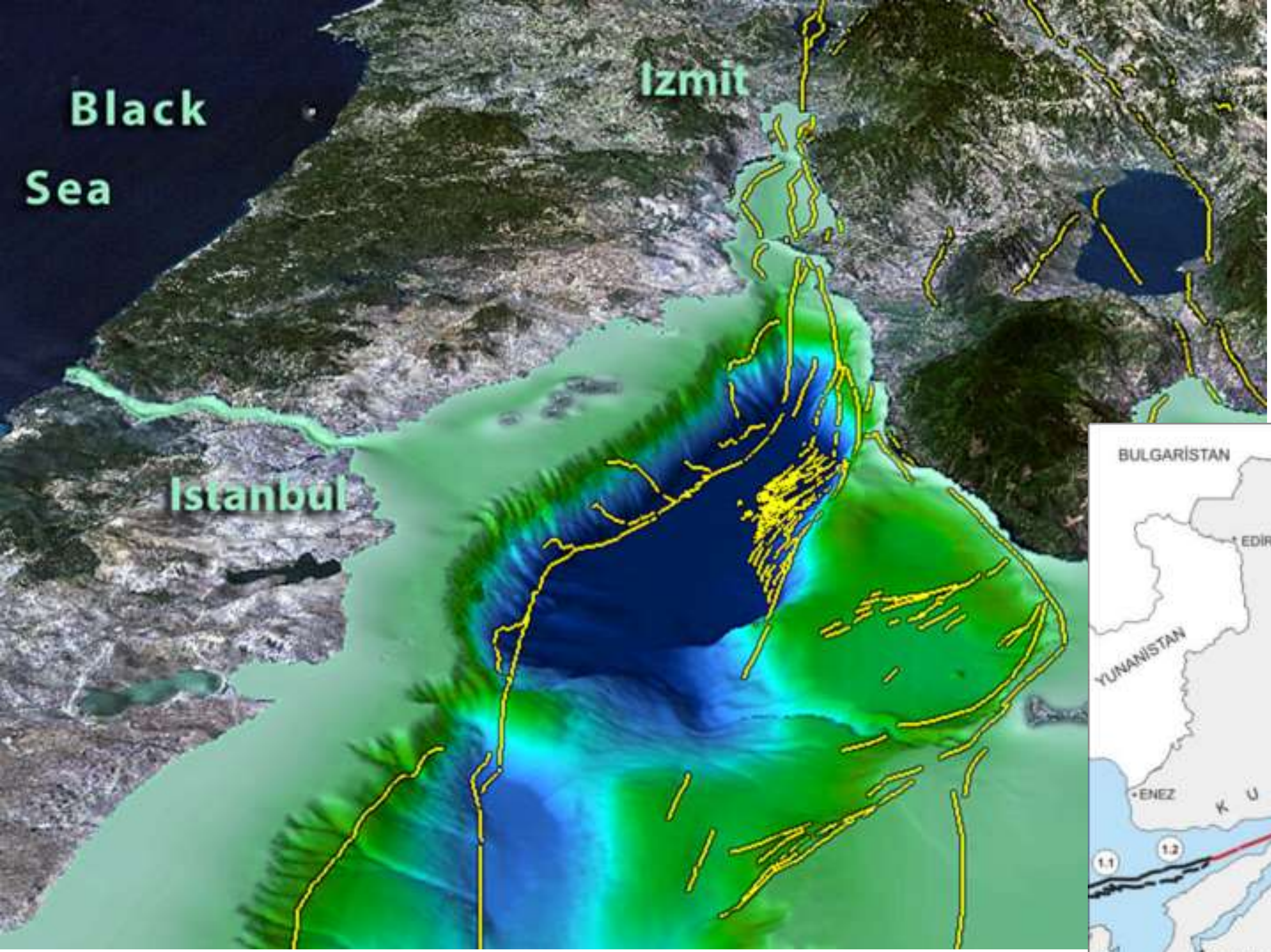
- 0.5 to 0.62
- 0.4 to 0.5
- 0.3 to 0.4
- 0.2 to 0.3
- 0.1 to 0.2
- 0.075 to 0.1
- 0.05 to 0.075
- 0.025 to 0.05
- 0 to 0.025

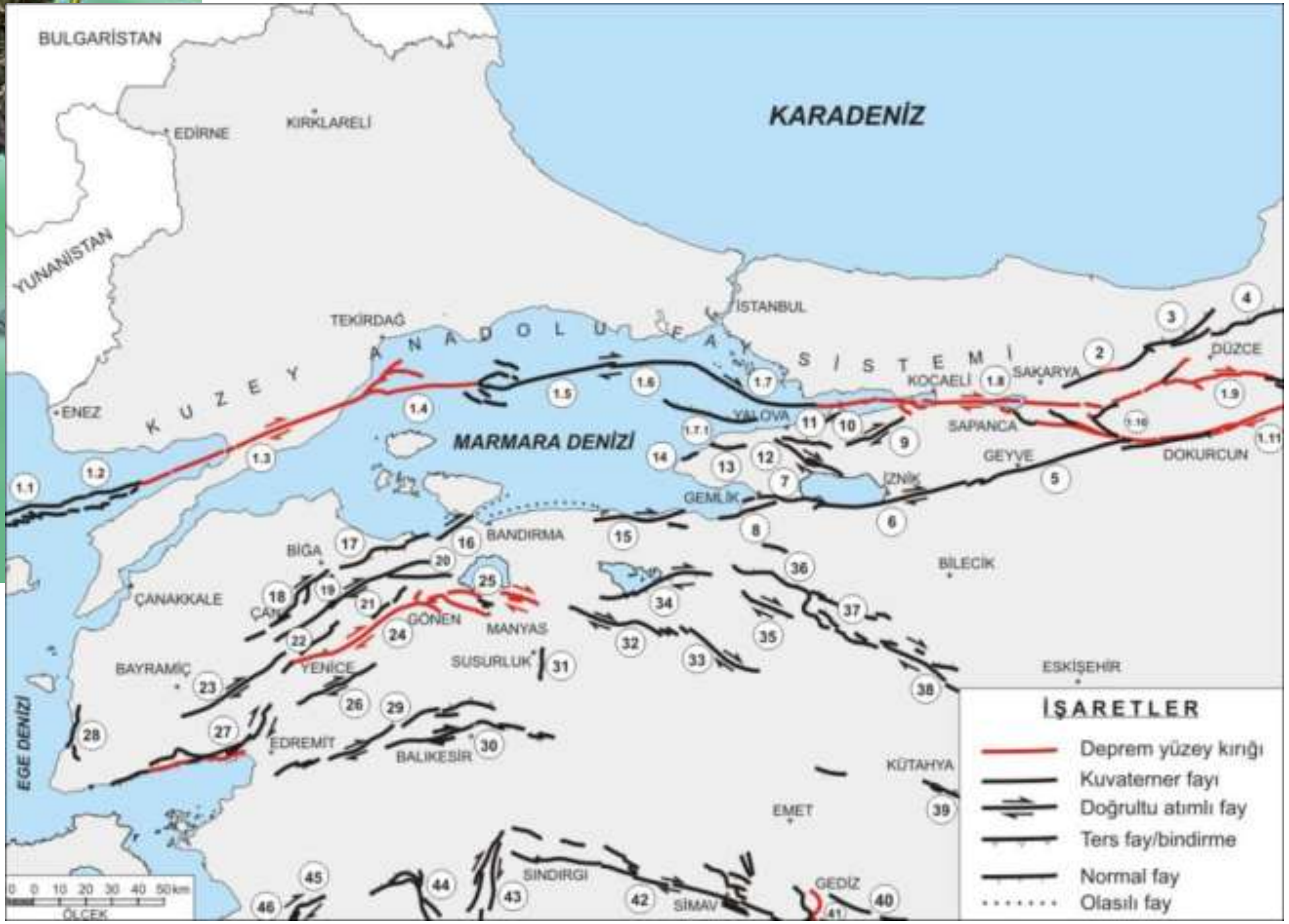
For residential, commercial and industrial building stock only https://github.com/gem/risk-profiles/tree/master/Europe/Turkey





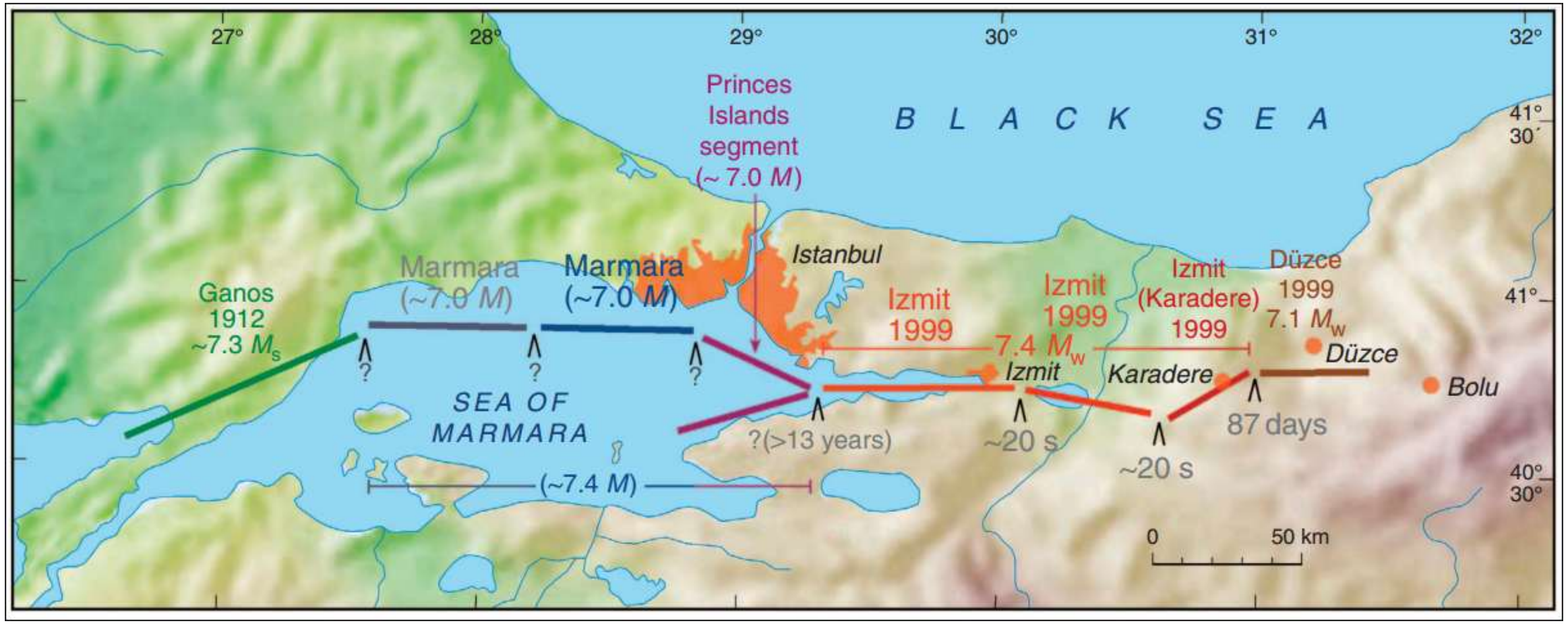
İSTANBUL EARTHQUAKE RISK ASSESSMENT





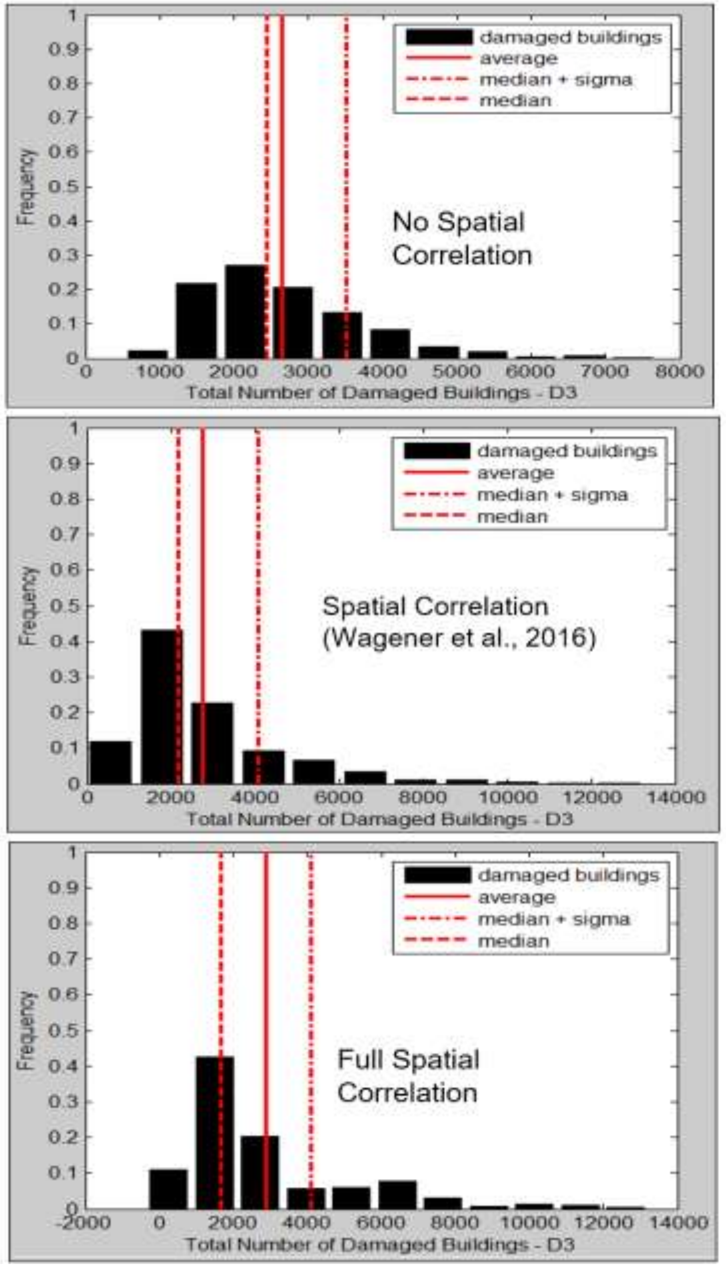
DETERMINISTIC EVENT BASED EARTHQUAKE RISK/LOSS ASSESSMENT IN ISTANBUL

The Princess Islands Segment of the Main Marmara Fault has been identified as the “most imminent danger” to Istanbul. This fault segment was considered with a regional GMPM and a local spatial correlation model to compute 1000 simulations of earthquake ground motion distribution.
Intensity-based fragility/vulnerability relationships are considered.
During the generation of each ground motion field, the spatial correlation of the intra-event residuals were considered according to a regional (Wagener et al, 2016) and California (Goda et al, 2008) correlation model.
Loss ratios for each building type were multiplied by the associated economic value, leading to a distribution of possible losses. The losses across the region can be aggregated per each ground motion field, to obtain an aggregated mean and standard deviation

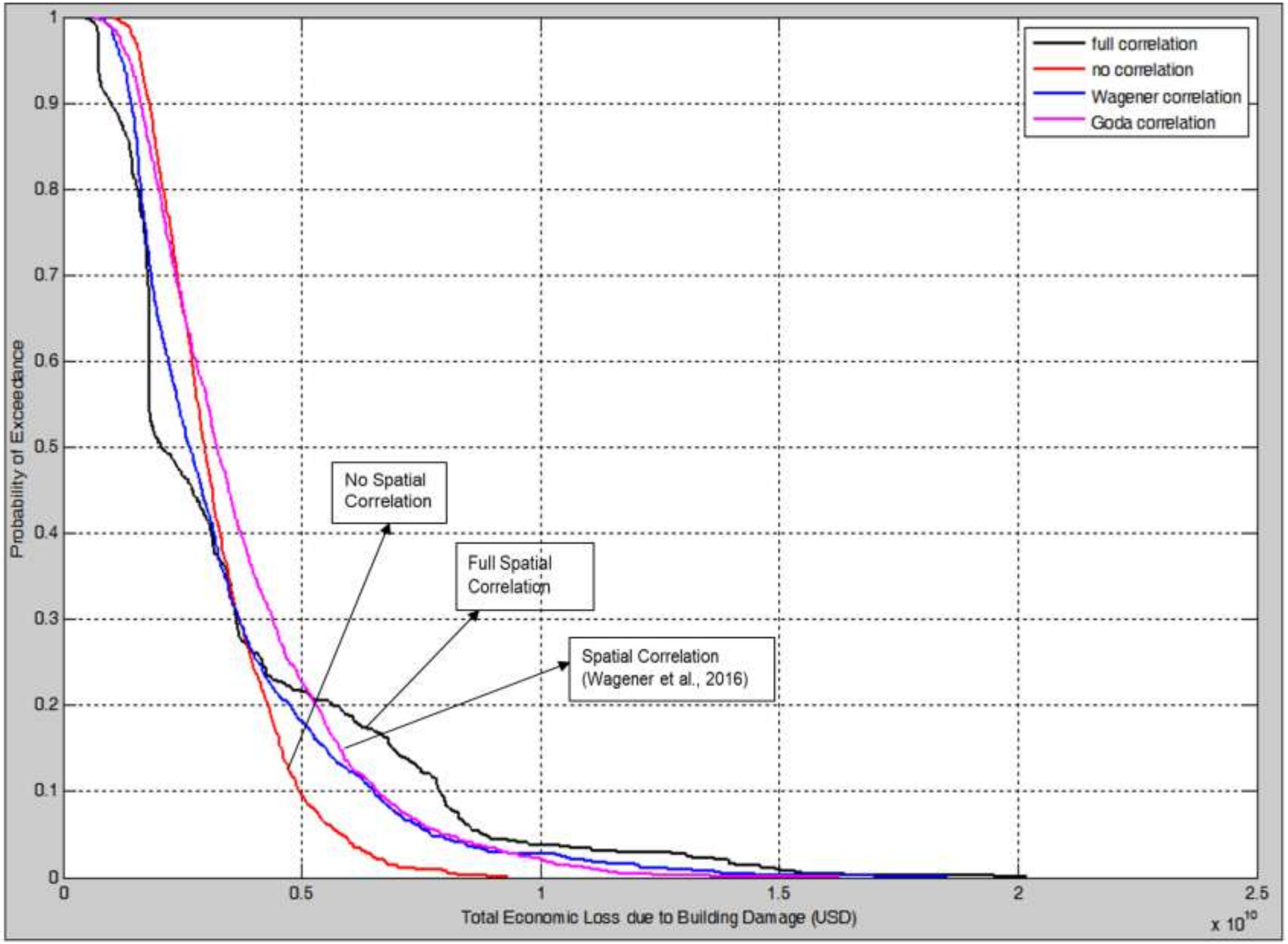


Seismic source: Prince’s Islands segment
Recurrence Model: Fully characteristic
Magnitude: M_w7.3
Slip Rate: 20 mm/yr
Dip: 90° Rake: 0°
Type: Strike-Slip
GMPE: Kale et al. 2015
Number of simulations: 1000
Spatial correlation model:
Wagener et al. (2016),
Goda and Hong (2008)

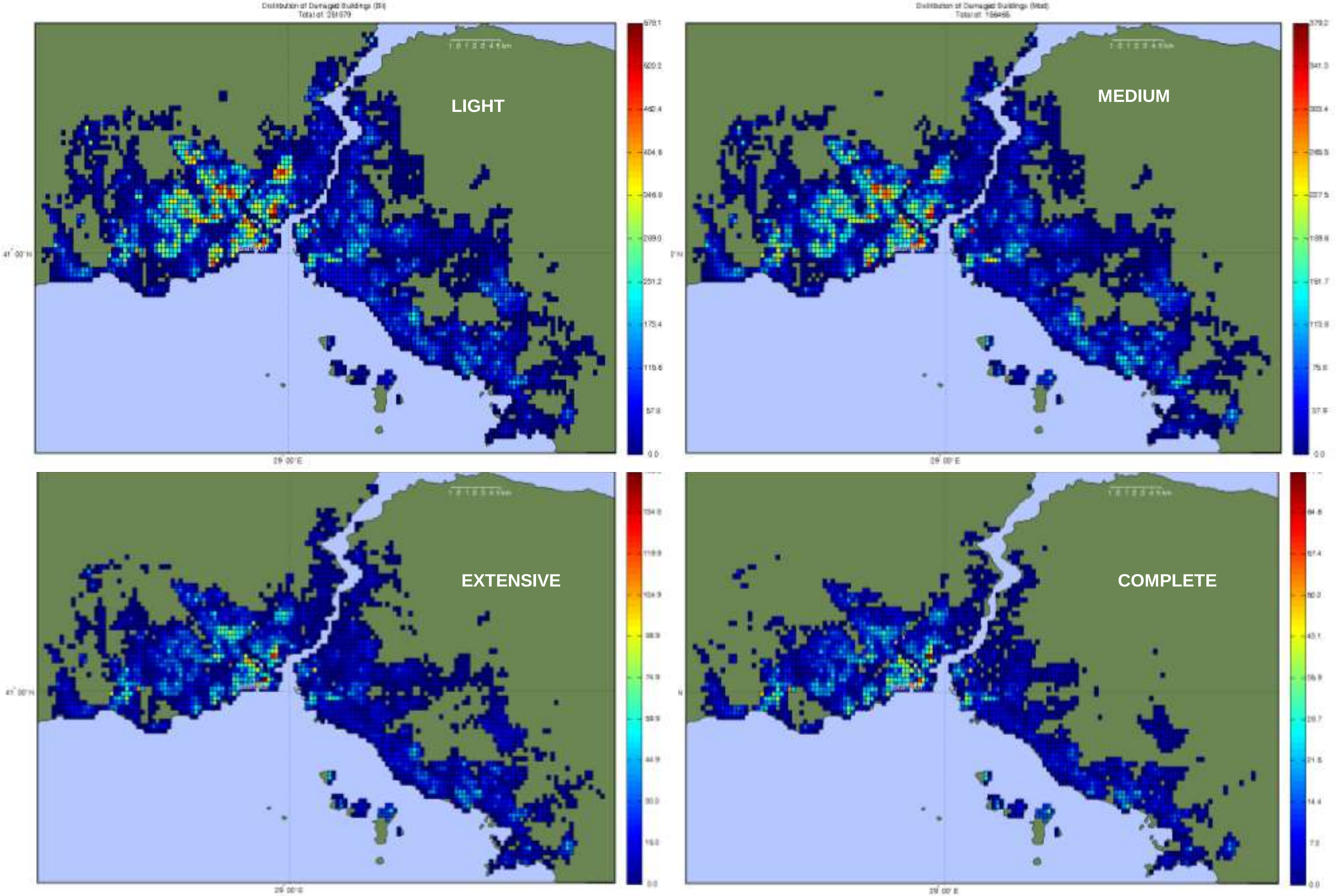
Number of Damaged Buildings at Damage Level D3 (Heavy Damage), 1000 Simulations

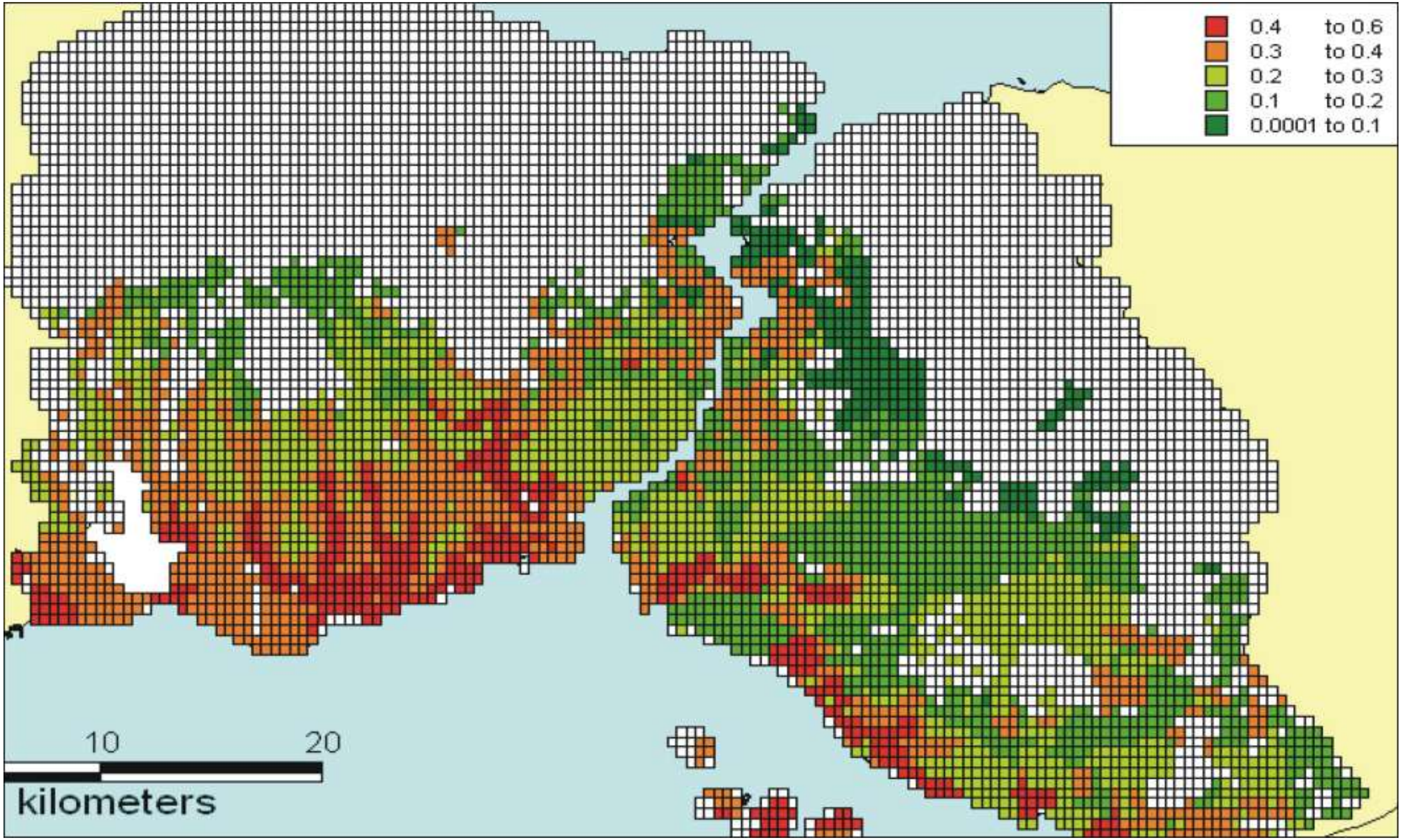


Exceedance Probability (EP) Curve

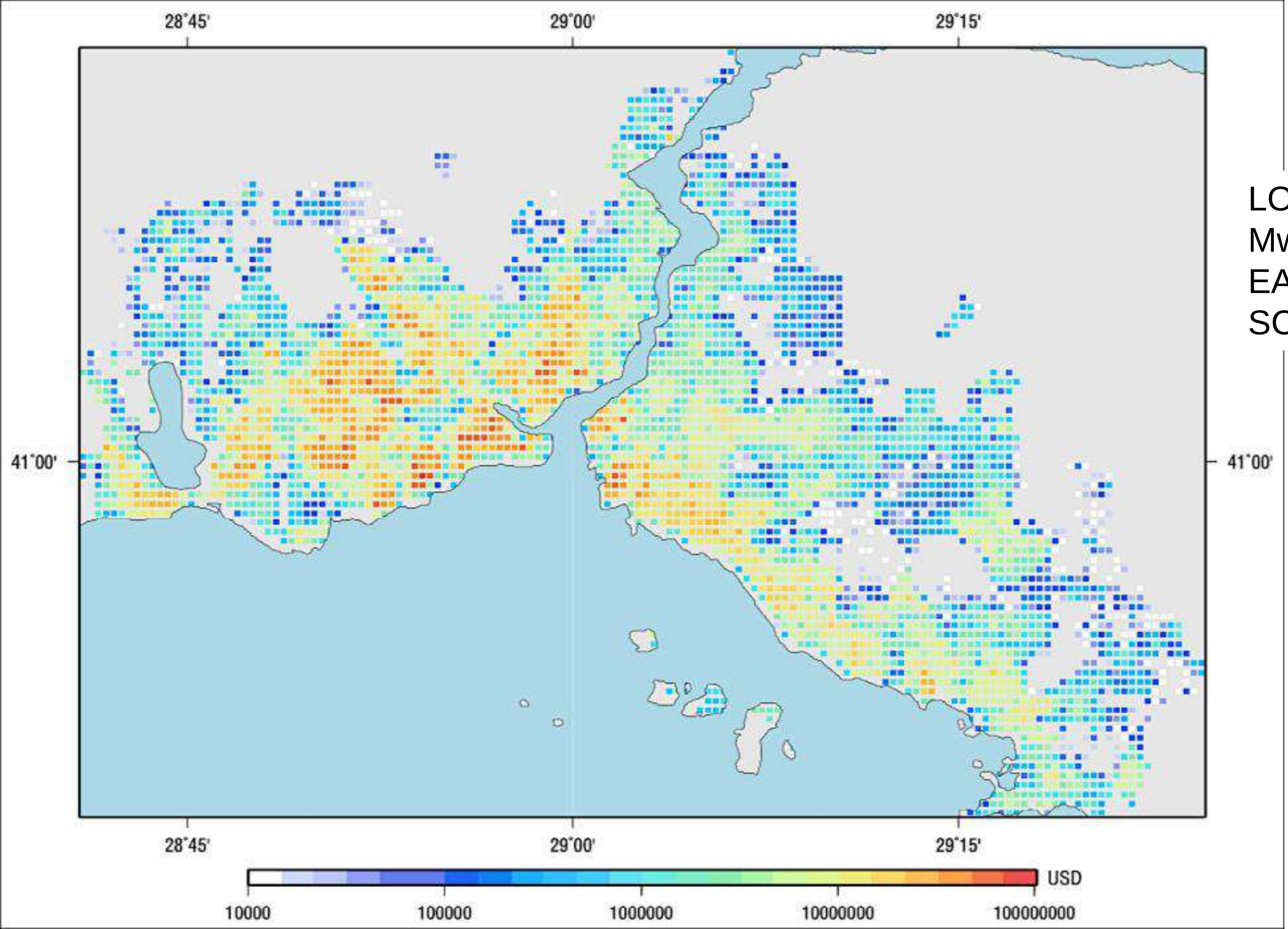


BUILDING DAMAGE ESTIMATION (Median), M7.5 Scenario Earthquake



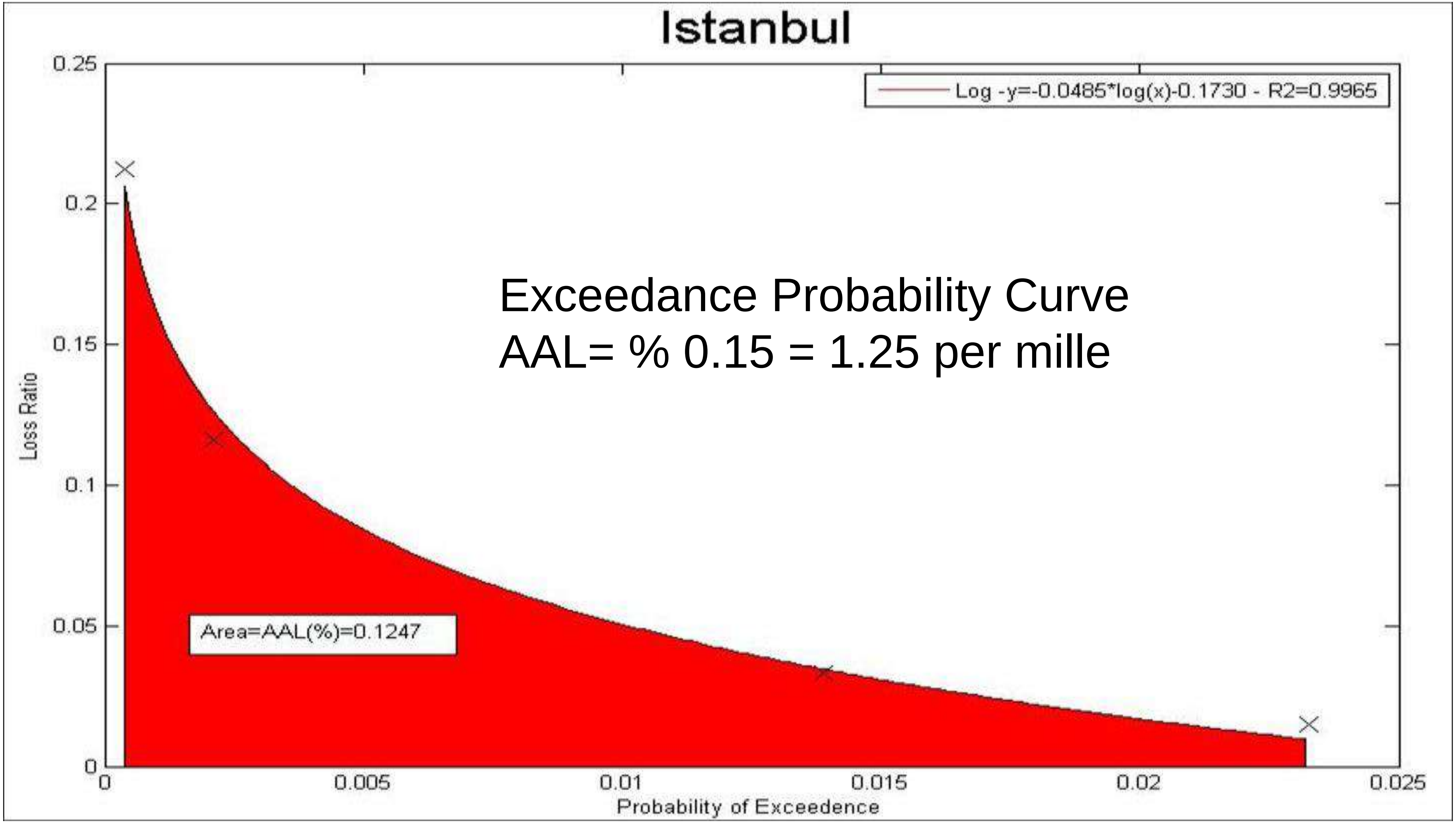


Cell-based distribution of median loss ratios in Istanbul using spectral displacement based and intensity based vulnerabilities for the Mw 7.5 scenario earthquake.



LOSS MAP FOR AN Mw7.5 EARTHQUAKE SCENARIO

Silva et al 2014



Exceedance Probability Curve
AAL= % 0.15 = 1.25 per mille

Loss Ratio

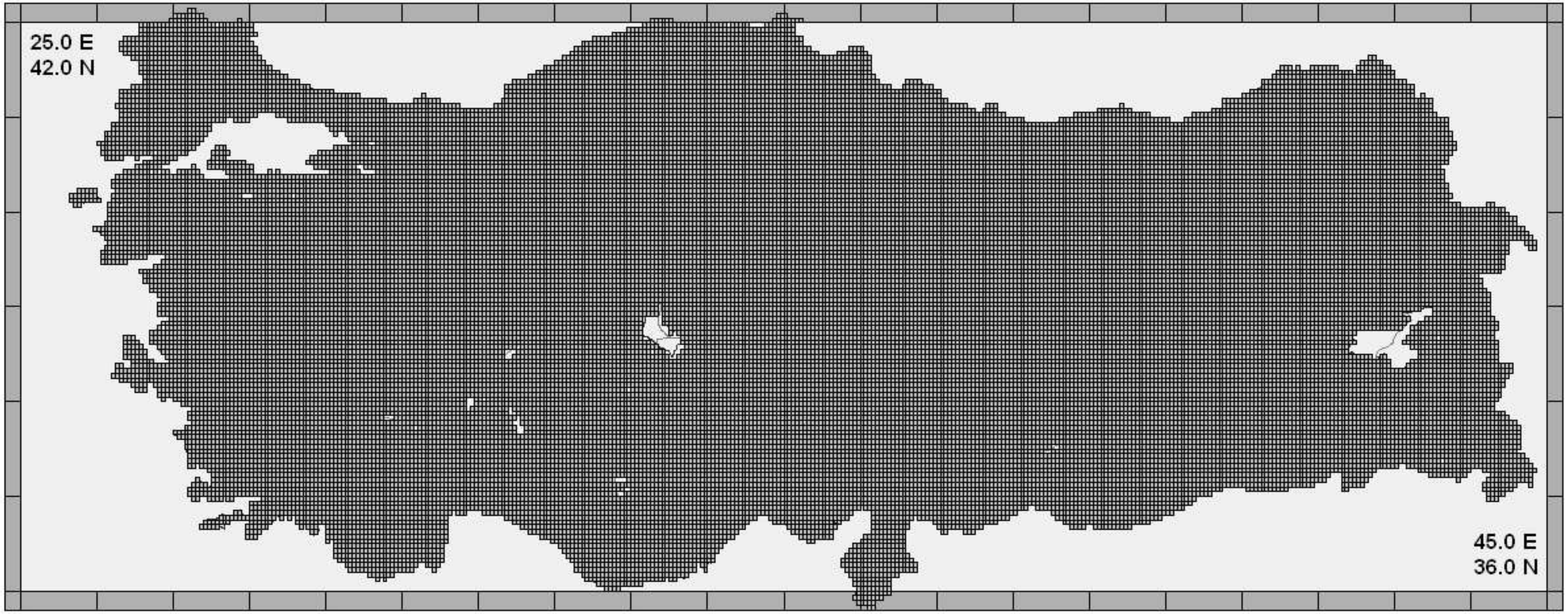
Probability of Exceedance

EARTHQUAKE LOSS ASSESSMENT FOR TURKEY

	Building typology
	Unreinforced Masonry
M1	Rubble stone
M2	Adobe (earth bricks)
M3	Simple stone
M4	Massive stone
M5	U Masonry (old bricks)
M6	U Masonry - r.c. floors
	Reinforced /confined masonry
M7	Reinforced /confined masonry
	Reinforced Concrete
RC1	Concrete Moment Frame
RC2	Concrete Shear Walls
RC3	Dual System
S	**Steel Typologies**
W	**Timber Typologies**

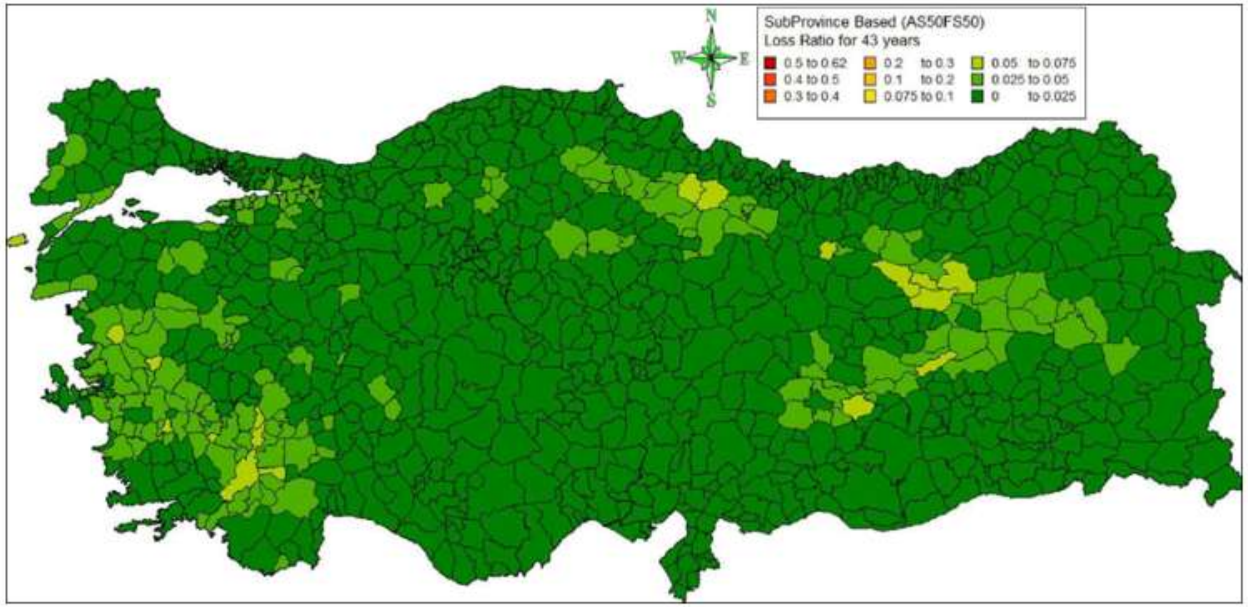
BUILDING TAXONOMY AND NATIONAL SCALE BUILDING INVENTORY

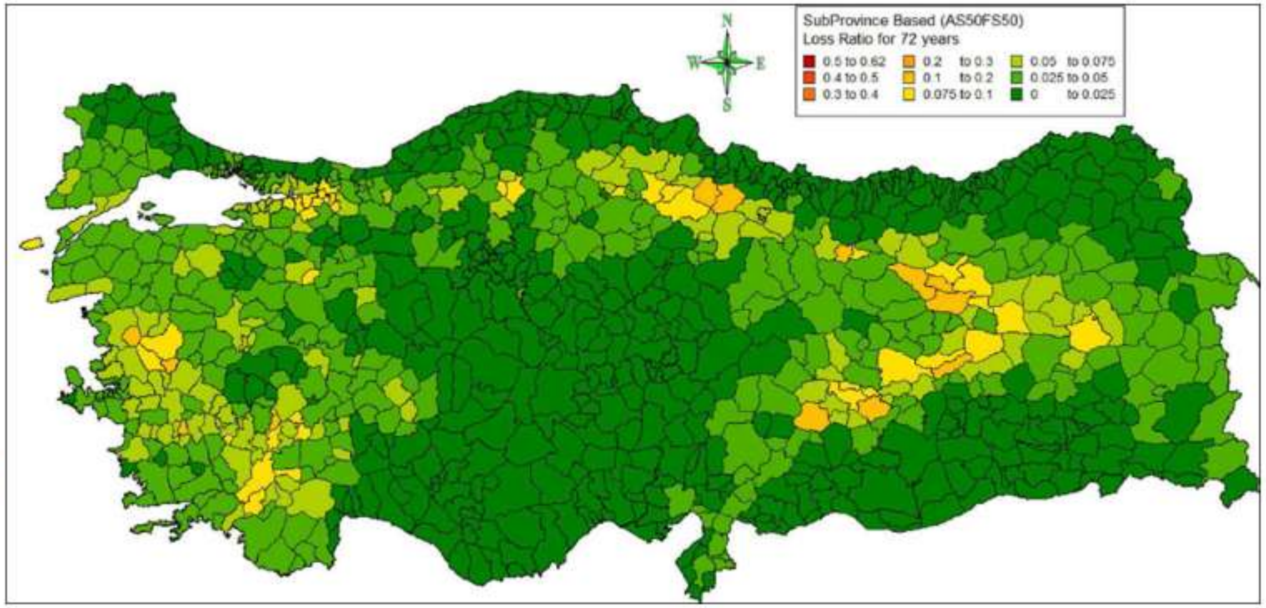
Construction Type		Number of Stories		Construction Date	
RC1-Moderate	3,837,576	Low Rise	6,647,014	Pre-1979	3,167,482
M5	2,977,263	Mid Rise	763,143	Post -1979	4,345,890
M2	472,562	High Rise	103,223	-	
M1	225,976	-		-	
TOTAL	7,513,377		7,513,380	-	7,513,371

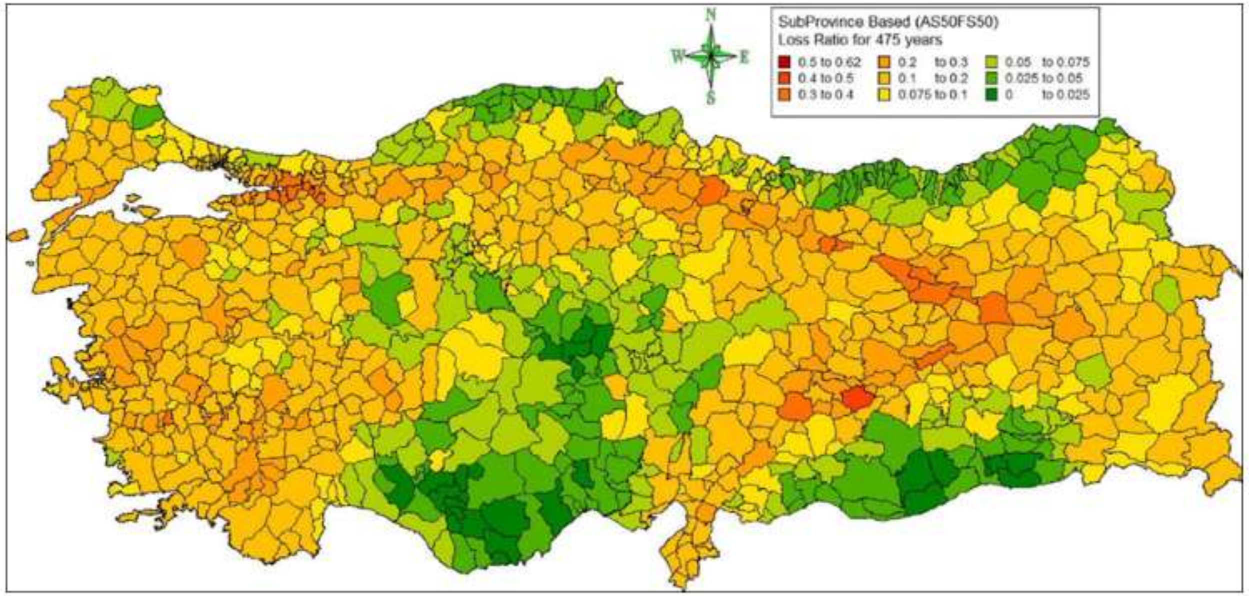


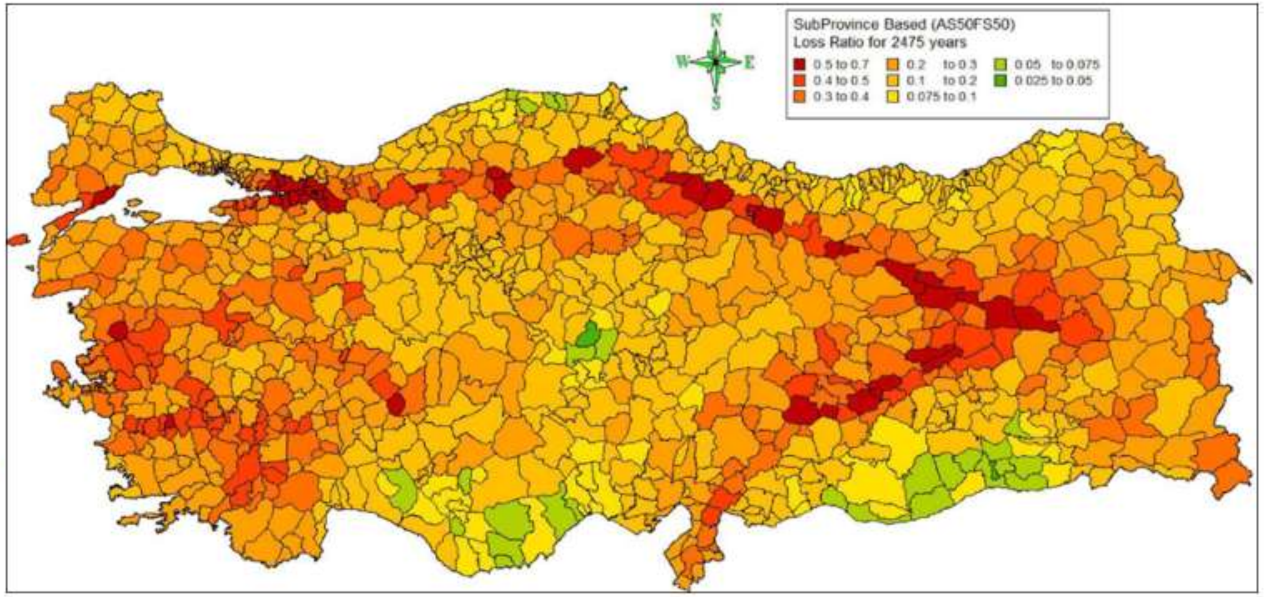
Grid size of 0.005° x 0.005° (400m x 600m) cells

DISTRICT BASED LOSS RATIOS FOR 43, 72, 475 and 2475 YEAR RETURN PERIOD

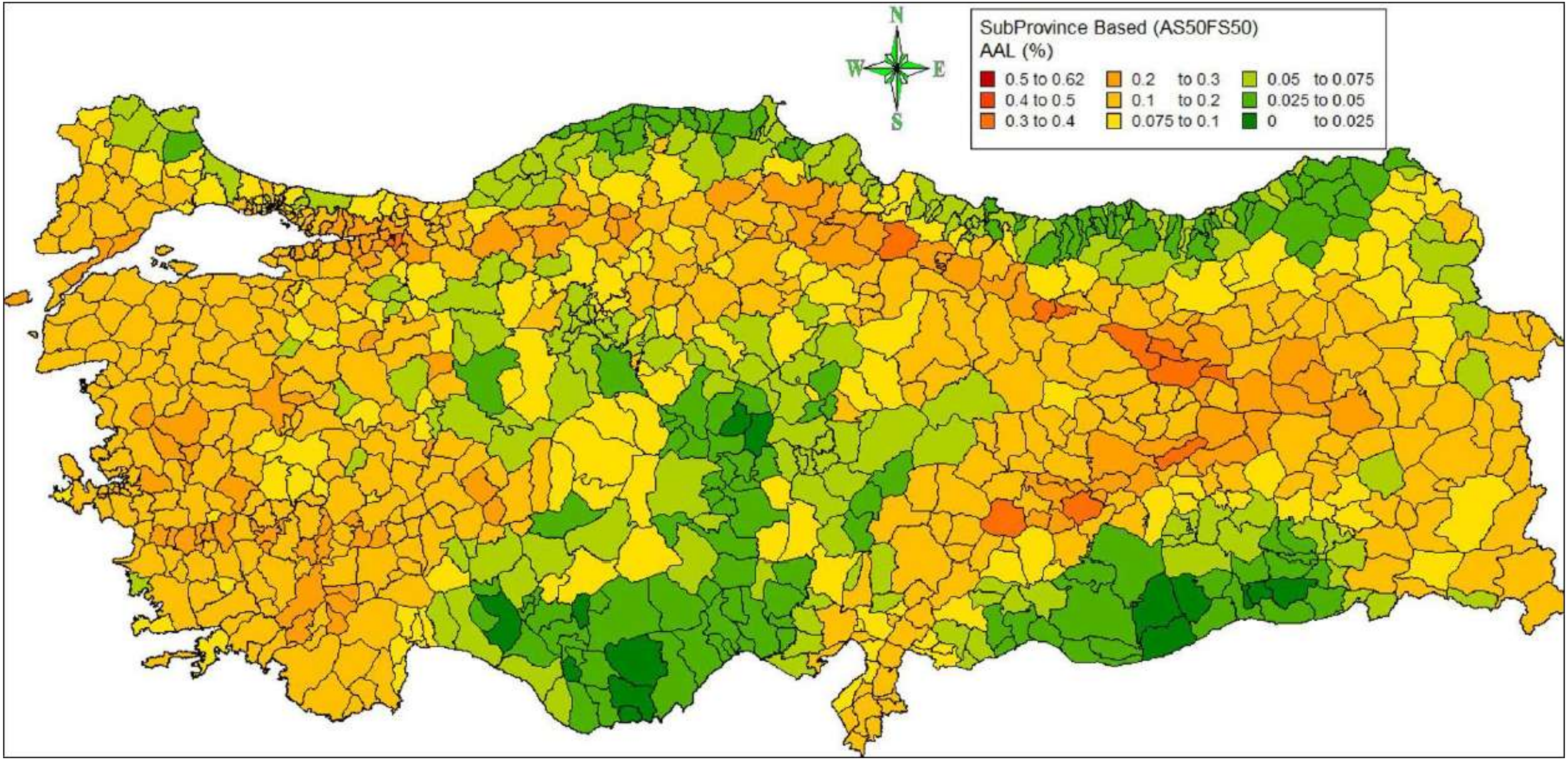








DISTRICT BASED AVERAGE ANNUAL LOSS RATIO (AALR) For TURKEY



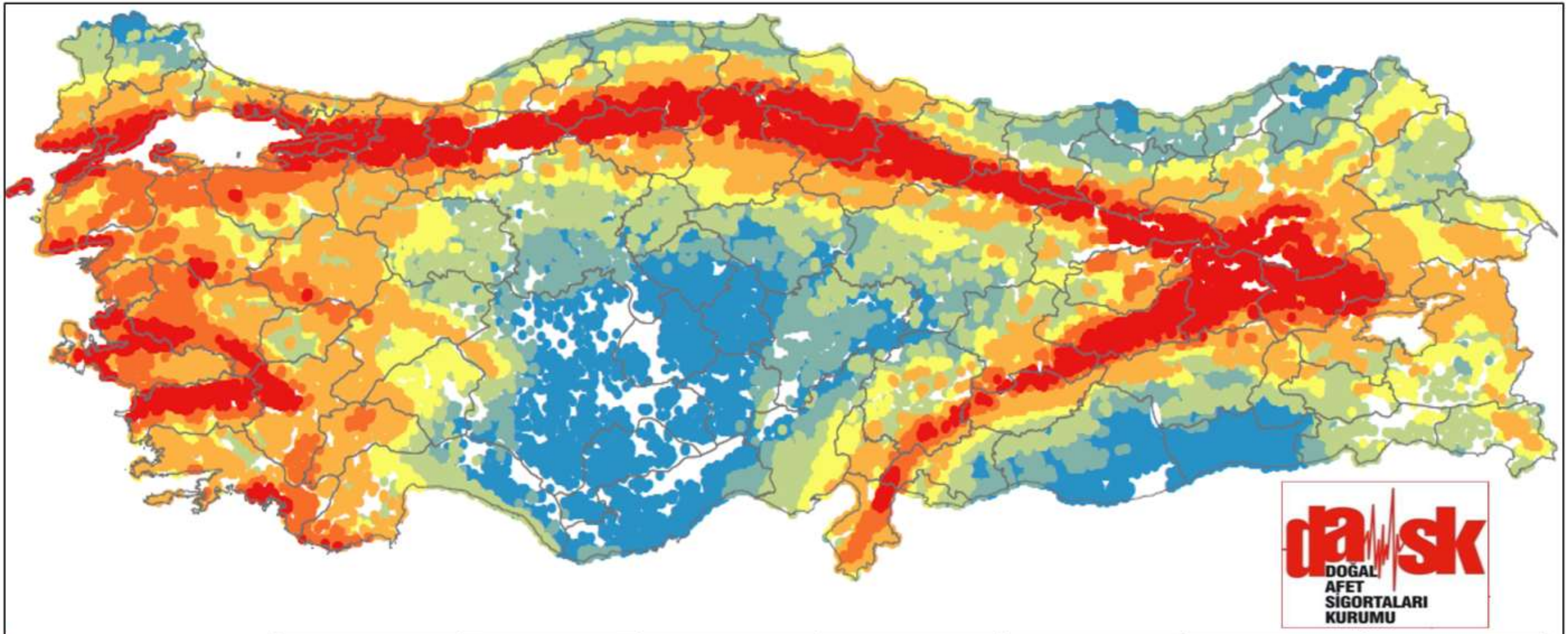
Sub-province based average annualized loss ratio (AALR) distribution

(Varies between 0.0002-0.0040. For Istanbul: 0.0013)

Average Annual Loss (Pure Premium) Rates for Different Reinforced Concrete Building Types

Structure Type	Number of Floors	Construction Year	Premium Rates (‰)				
			Group 1	Group 2	Group 3	Group 4	Group 5
Reinforced Concrete	1–3 Floors	Pre-1975	2.37	1.22	0.80	0.46	0.17
		1976–1999	1.68	0.93	0.63	0.38	0.14
		Post-2000	1.56	0.90	0.61	0.37	0.14
	4–7 Floors	Pre-1975	3.14	1.72	1.14	0.67	0.25
		1976–1999	1.61	0.90	0.62	0.37	0.14
		Post-2000	1.58	0.90	0.61	0.37	0.14
	8–19 Floors	Pre-1975	3.61	1.79	1.12	0.62	0.21
		1976–1999	2.02	1.06	0.70	0.40	0.14
		Post-2000	2.07	1.09	0.71	0.40	0.14

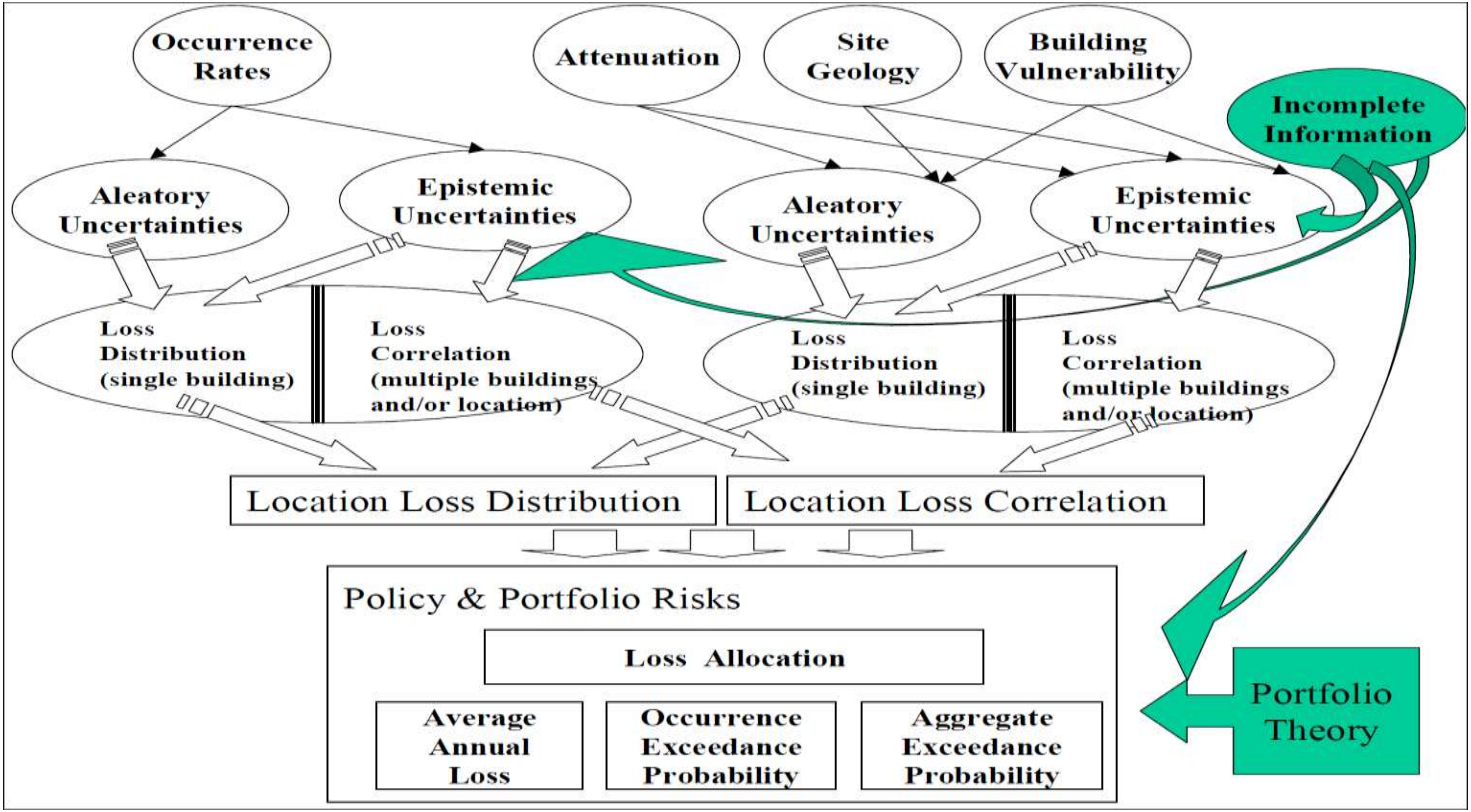
TCIP PREMIUM TARIFF, 2025



	1. Group	2. Group	3. Group	4. Group	5. Group	6. Group	7. Group
Reinforced Concrete	2.56 ‰	2.28 ‰	1.94 ‰	1.82 ‰	1.36 ‰	0.97 ‰	0.66 ‰
Masonry	4.51 ‰	3.86 ‰	3.39 ‰	3.17 ‰	2.54 ‰	1.69 ‰	0.99 ‰

EFFECT OF UNCERTAINTIES ON LOSS ESTIMATION *(Wong et al, 2000)*

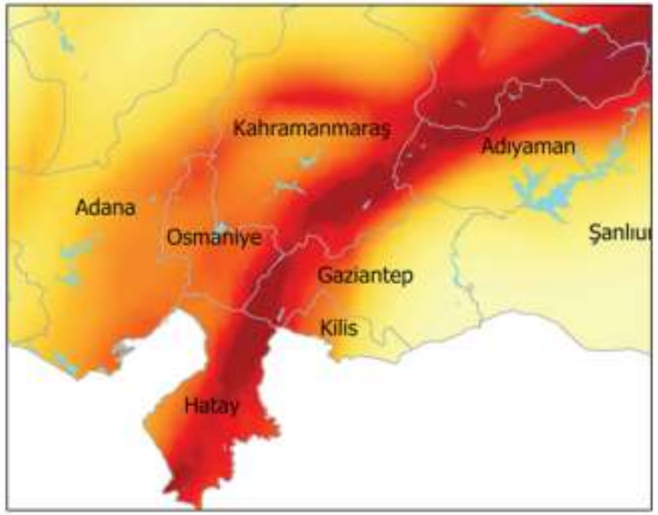
These uncertainties can be aleatory or epistemic. Alleatoric uncertainty deals with sources of inherent variability that cannot be reduced. The epistemic uncertainties can be reduced with additional data or knowledge



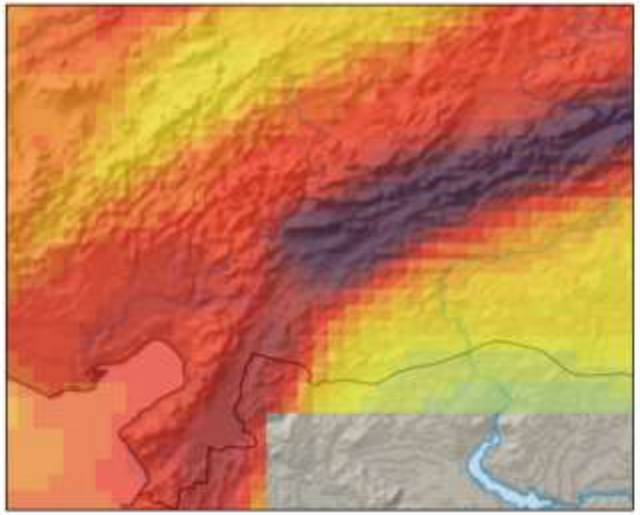
COMPARISON of PSHA-PGA RESULTS with 2023 KAHRAMANMARAŞ EARTHQUAKE SEQUENCE RESULTS

PGA (cm/s2; MAXIMUM)
(HORIZONTAL COMPONENTS)

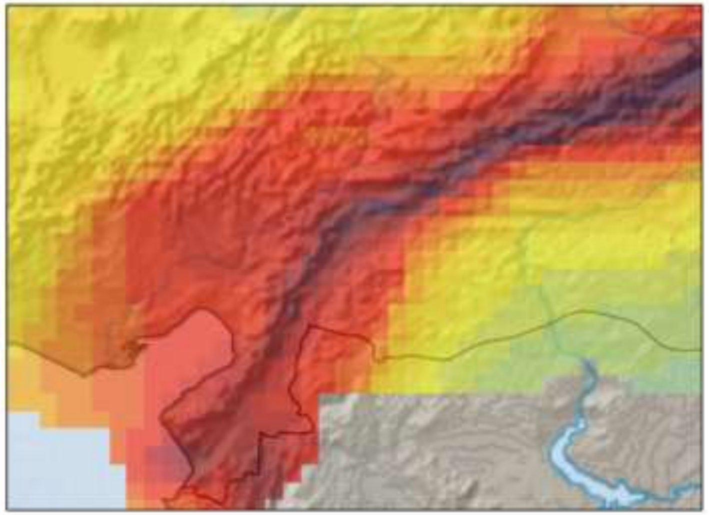
- 0.0 to 0.10
- 0.1 to 100
- 100 to 200
- 200 to 400
- 400 to 500
- 500 to 800
- 800 to 1000
- 1000 to 1200
- 1200 to 1409



Turkish Code (2018) Based Seismic Hazard Model



European Seismic Hazard Model 2013 (ESHM13)



European Seismic hazard Model 2020 (ESHM20)

- 0.15 < accl. [g] < 0.175
- 0.2 < accl. [g] < 0.225
- 0.25 < accl. [g] < 0.275
- 0.3 < accl. [g] < 0.325
- 0.35 < accl. [g] < 0.375
- 0.4 < accl. [g] < 0.425
- 0.45 < accl. [g] < 0.475
- accl. [g] > 0.5

In these PSHA assessments the 475-year PGA levels in the vicinity of the northern section of the East Anatolian Fault (EAF) are about 0.5g and in the Hatay Province 0.3g to 0.4g levels. The PSHA-based 2475-year PGA levels reach 0.7g-0.8g in the northern section of the EAF and about 0.5g to 0.6g levels in the Hatay Province.

The observed PGA levels in the 2023 Kahramanmaraş Earthquake Sequence in the northern section of the EAF are similar to PSHA-based 2475-year PGA levels. However, in the Hatay Province, the observed PGA levels exceed the PSHA-based 2475-year PGA levels by about 50%.

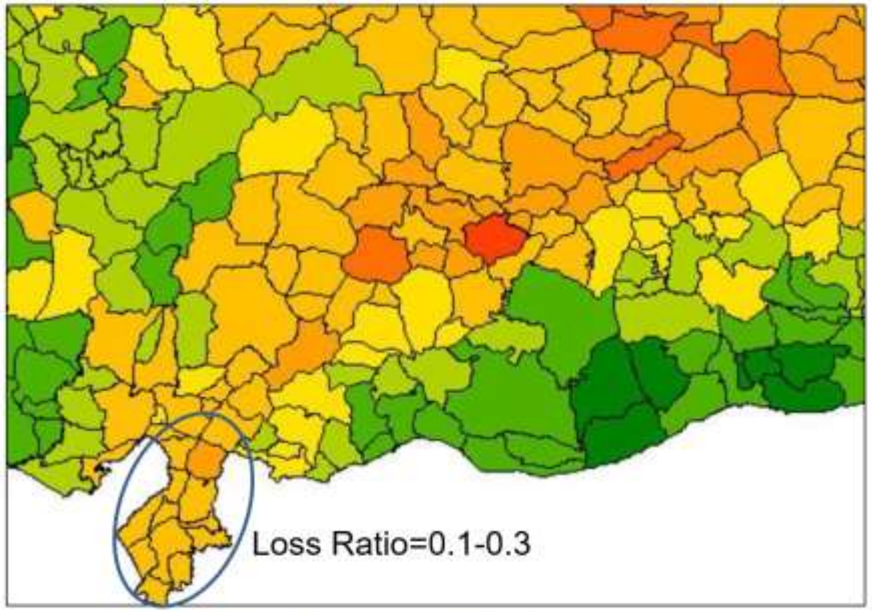
EARTHQUAKE DAMAGES in 2023
Mw 7.8 Kahramanmaraş Earthquake

87% of Buildings with Major Damage-to-Collapse were Located in Adıyaman (11%), Kahramanmaraş (20%), Malatya (14%) and Hatay (42%)

For Antakya-Hatay

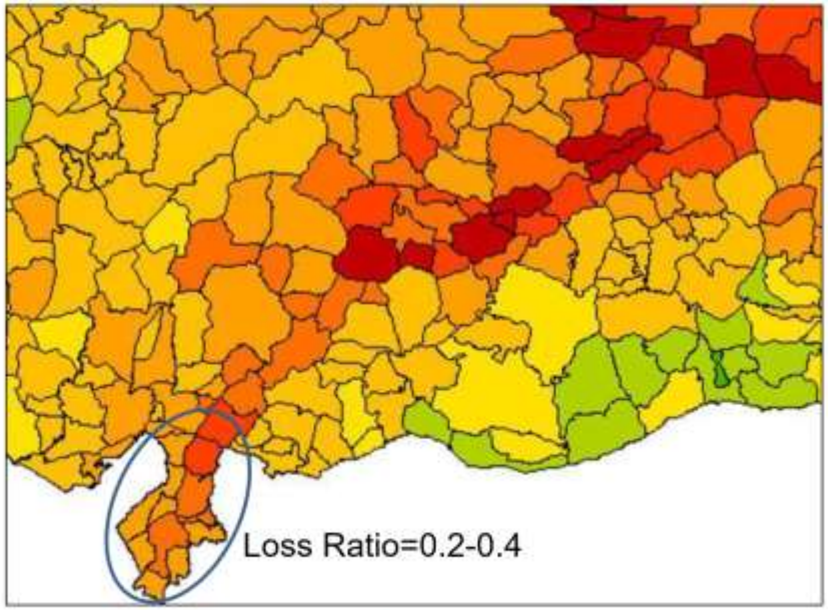
% No Damage	% Minor Damage	%Medium Damage	% Major to Collapse	Loss Ratio
%15	%38	%5	%42	%60

CITY	# Damaged Buildings
Adıyaman	59,000
Kahramanmaraş	115,000
Malatya	77,000
Hatay	172,000
Other Cities	357,000
Total	780,000



SubProvince Based (AS50FS50)
Loss Ratio for 475 years

0.5 to 0.62
0.4 to 0.5
0.3 to 0.4
0.2 to 0.3
0.1 to 0.2
0.075 to 0.1
0.05 to 0.075
0.025 to 0.05
0 to 0.025



SubProvince Based (AS50FS50)
Loss Ratio for 2475 years

0.5 to 0.7
0.4 to 0.5
0.3 to 0.4
0.2 to 0.3
0.1 to 0.2
0.075 to 0.1
0.05 to 0.075
0.025 to 0.05

Turkish Catastrophe Insurance Pool (TCIP) Risk-Based Insurance Pricing (2017)

The post-earthquake observes damages indicate Loss Ratios that varies betwen 0.3-0.5 in the ellipse bordered region

THANK YOU