Unit 10: Risk Assessment of Earthquakes
Case study Barcelona

Earthquakes

- Earthquakes are related to hazardous geological processes
- It is very difficult to predict such events
- The events can be statistically described
- Sensitive regions, zones can be identified
- Characterised by location of origin and probabilities of exceedance rates

Earthquakes

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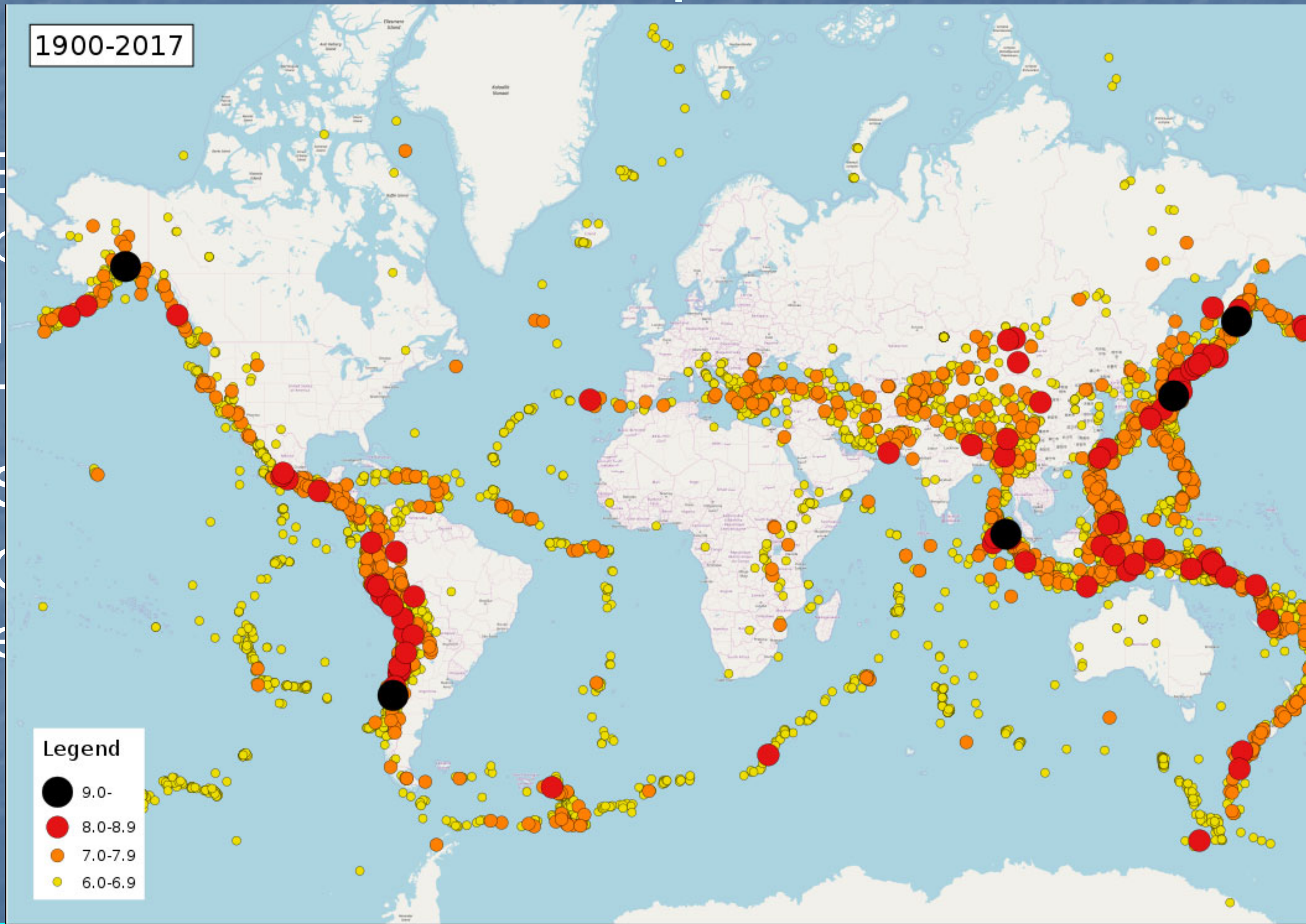

Consequences of earthquakes

Rank	Event	Date	Location	Fatalities	Magnitude	Notes
1	1556 Shaanxi earthquake	January 23, 1556	Shaanxi, China	820,000–830,000 [90]	8.0	Estimated death toll in Shaanxi, China.
2	1976 Tangshan earthquake	July 28, 1976	Hebei, China	242,769–700,000+ [91][92][93]	7.8	
3	1920 Haiyuan earthquake	December 16, 1920	Ningxia–Gansu, China	273,400[91][94]	7.8	Major fractures, landslides.
4	526 Antioch earthquake	May 21, 526	Antioch, Turkey (then Byzantine Empire)	240,000[95]	7.0 [96]	Procopius (II.14.6), sources based on John of Ephesus.
5	2004 Indian Ocean earthquake	December 26, 2004	Indian Ocean, Sumatra, Indonesia	230,210+[97]	9.1–9.3	Deaths from earthquake and resulting tsunami.
6	1138 Aleppo earthquake	October 11, 1138	Aleppo, Syria	230,000	Unknown	The figure of 230,000 dead is based on a historical conflation of this earthquake with earthquakes in November 1137 on the Jazira plain and on September 30, 1139 in the Azerbaijani city of Ganja. The first mention of a 230,000 death toll was by Ibn Taghribirdi in the fifteenth century.[98]
7	2010 Haiti earthquake	January 12, 2010	Haiti	100,000–316,000	7.0	Estimates vary from 316,000 (Haitian government) to 222,570 (UN OCHA estimate)[99] to 158,000 (*Medicine, Conflict and Survival*) to between 85,000 and 46,000 (report commissioned by USAID).[100][101]
8	1303 Hongdong earthquake	September 25, 1303	Shanxi, China	200,000 [102]	8.0	Taiyuan and Pingyang were leveled.
9	856 Damghan earthquake	December 22, 856	Damghan, Iran	200,000	7.9 M_s	
10	893 Ardabil earthquake	March 22, 893	Ardabil, Iran	150,000	Unknown	Reports probably relate to the 893 Dvin earthquake, due to misreading of the Arabic word for Dvin, 'Dabil' as 'Ardabil'.[103] This is regarded as a 'fake earthquake'.[104]

Consequences of earthquakes

Rank	Event	Location	Magnitude	Property damage
1	2011 Tōhoku earthquake and tsunami	Japan	9.1[3]	$235 billion[75][76]
2	1995 Great Hanshin earthquake	Japan	6.9	$200 billion[77]
3	2008 Sichuan earthquake	Sichuan, China	8.0	$86 billion[78]
4	1994 Northridge earthquake	Los Angeles, United States	6.7	$13–44 billion
5	1980 Irpinia earthquake	Italy	6.9[79]	$15 billion[79]
6	1976 Tangshan earthquake	Hebei, China	7.8	$10 billion[80]
7	2011 Christchurch earthquake	South Island, New Zealand	6.3[81]	$15–40 billion[82][83]
8	2004 Chūetsu earthquake	Japan	6.8	$28 billion[79][84]
9	1999 İzmit earthquake	Turkey	7.6	$20 billion[79]
10	2010 Chile earthquake	Chile	8.8[85]	$15–30 billion[85]

	earthquake					
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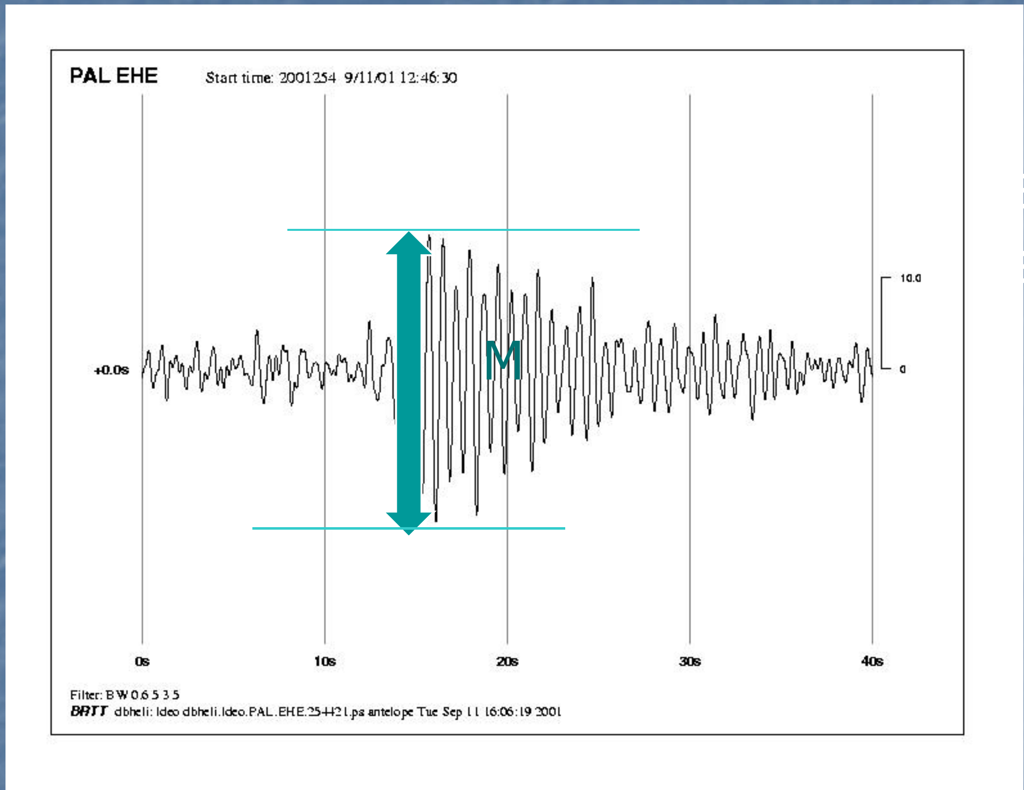
Seismic extremes

- Richter scale (logarithmic) is frequently applied to characterize earthquakes
- Magnitude: Strength of an earthquake (seismic energy) at the origin
- Intensity: characterise the intensity of an earth quake at a given surface location. It is described by the maximum amplitude of an event at the location
- Intensity depends on geologic (soil) conditions

Seismic extremes

- Richter scale is frequently applied to characterise the intensity of earth quakes. It is based on the maximum amplitude of an event

Seismic extremes



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Seismic extremes

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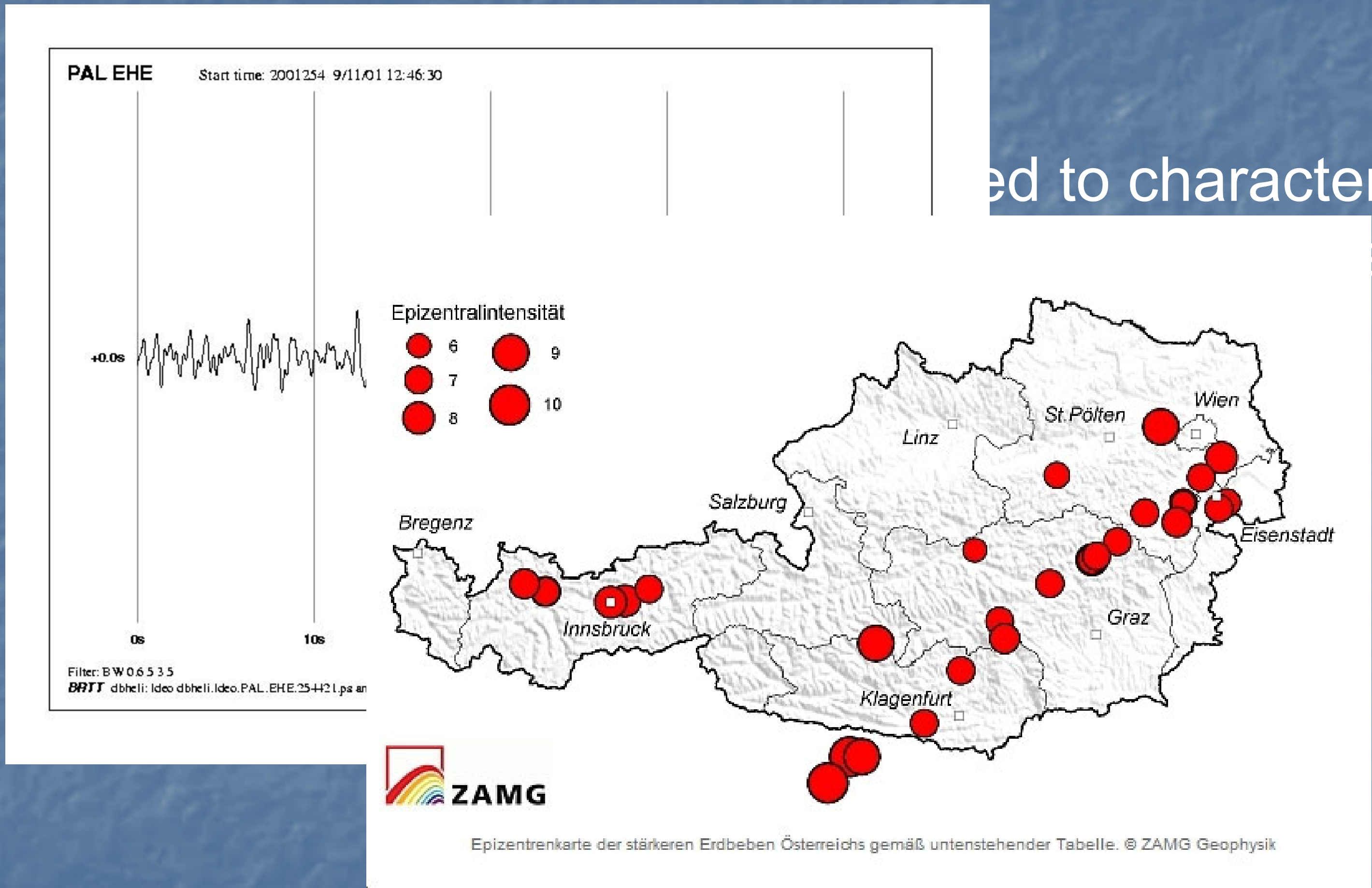
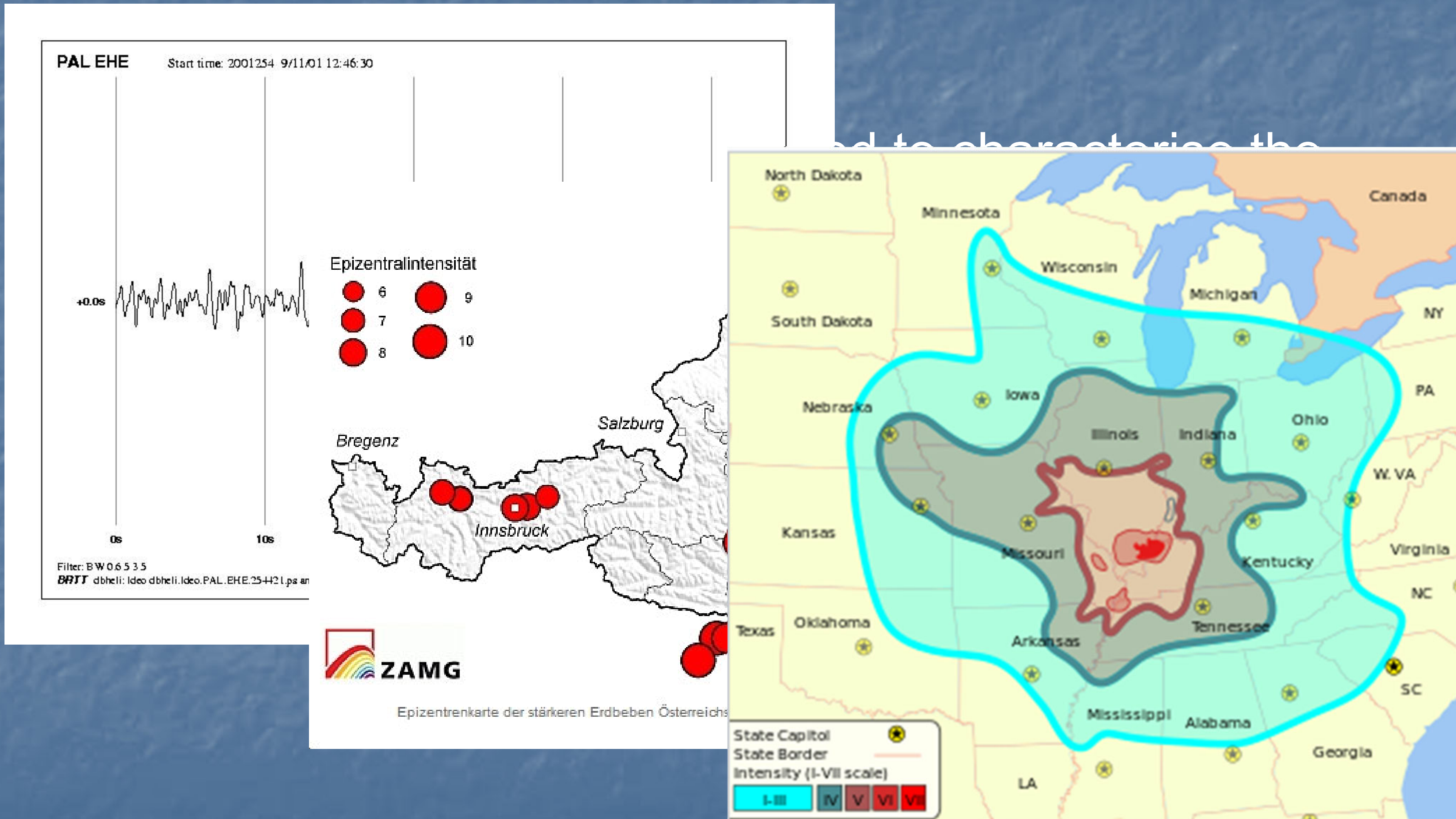


Seismic extremes



Modeling earthquake frequency

- Peak over threshold
- Considering also the clustering of earthquakes
- Spectral analysis

Modeling earthquake frequency

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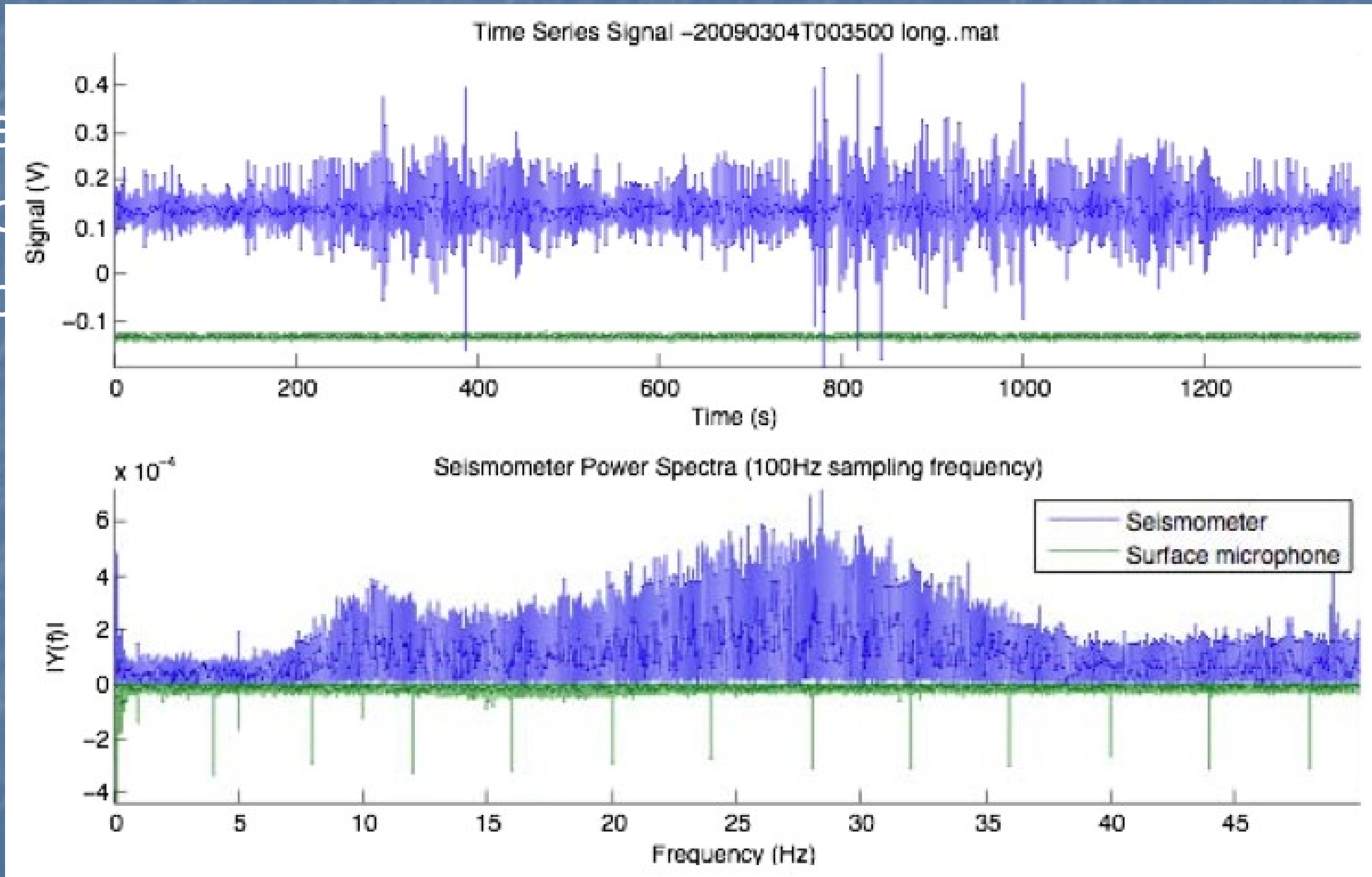


Characterisation of intensity

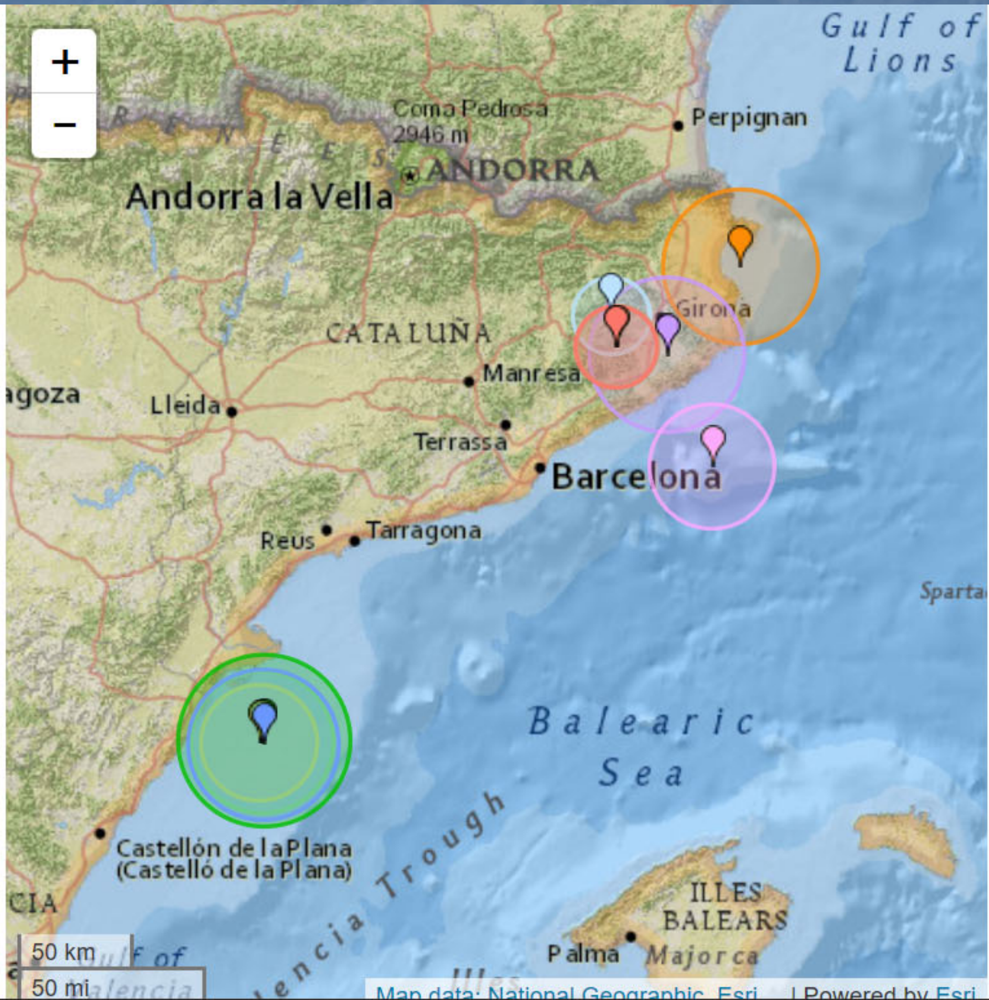
	INTENSITY	SHAKING	DESCRIPTION
	I	Not Felt	Not felt except by a very few under especially favorable conditions.
	II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
	III	Weak	Felt quite noticeable by persons indoors. Many people do not recognize it as an earthquake. Standing cars may rock slightly, vibrations are similar to a passing truck.
	IV	Light	Felt indoors by many, outdoors by few. At night, some are awakened. Dishes, windows, and doors are disturbed. Sensation like a heavy truck striking a building. Standing cars rock noticeably.
	V	Moderate	Felt by nearly everyone; many awakened. Dishes and windows are broken. Unstable objects are overturned. Pendulum clocks may stop.

Characterisation of intensity

	VI	Strong	Felt by all; many frightened. Some heavy furniture moved. A few instances of fallen plaster. Damage is slight.
	VII	Very Strong	Negligible damage to buildings of good design/construction. Slight to moderate damage in well-built/ordinary construction. Considerable damage in poorly built/designed structures. Some chimneys broken.
	VIII	Severe	Slight damage to specially designed structures. Considerable damage to ordinary construction, including partial collapse. Damage is great in poorly built structures. Fall of chimneys, columns, monuments, and walls. Heavy furniture overturned.
	IX	Violent	Considerable damage to specially designed structures; well-designed frame structures are thrown out of plumb. Damage is great in substantial buildings, with partial collapse. Buildings shifted off foundations.
	X+	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures with foundations are destroyed. Rails are bent.

Earthquakes in Barcelona

Sites of source (origin)



3 years ago 4.1 magnitude, 7 km depth
l'Escala, Catalonia, Spain

5 years ago 3.7 magnitude, 6 km depth
Vinaròs, Valencia, Spain

5 years ago 4.0 magnitude, 0 km depth
Vinaròs, Valencia, Spain

5 years ago 4.3 magnitude, 0 km depth
Vinaròs, Valencia, Spain

5 years ago 4.1 magnitude, 0 km depth
Vinaròs, Valencia, Spain

8 years ago 4.1 magnitude, 0 km depth
Llagostera, Catalonia, Spain

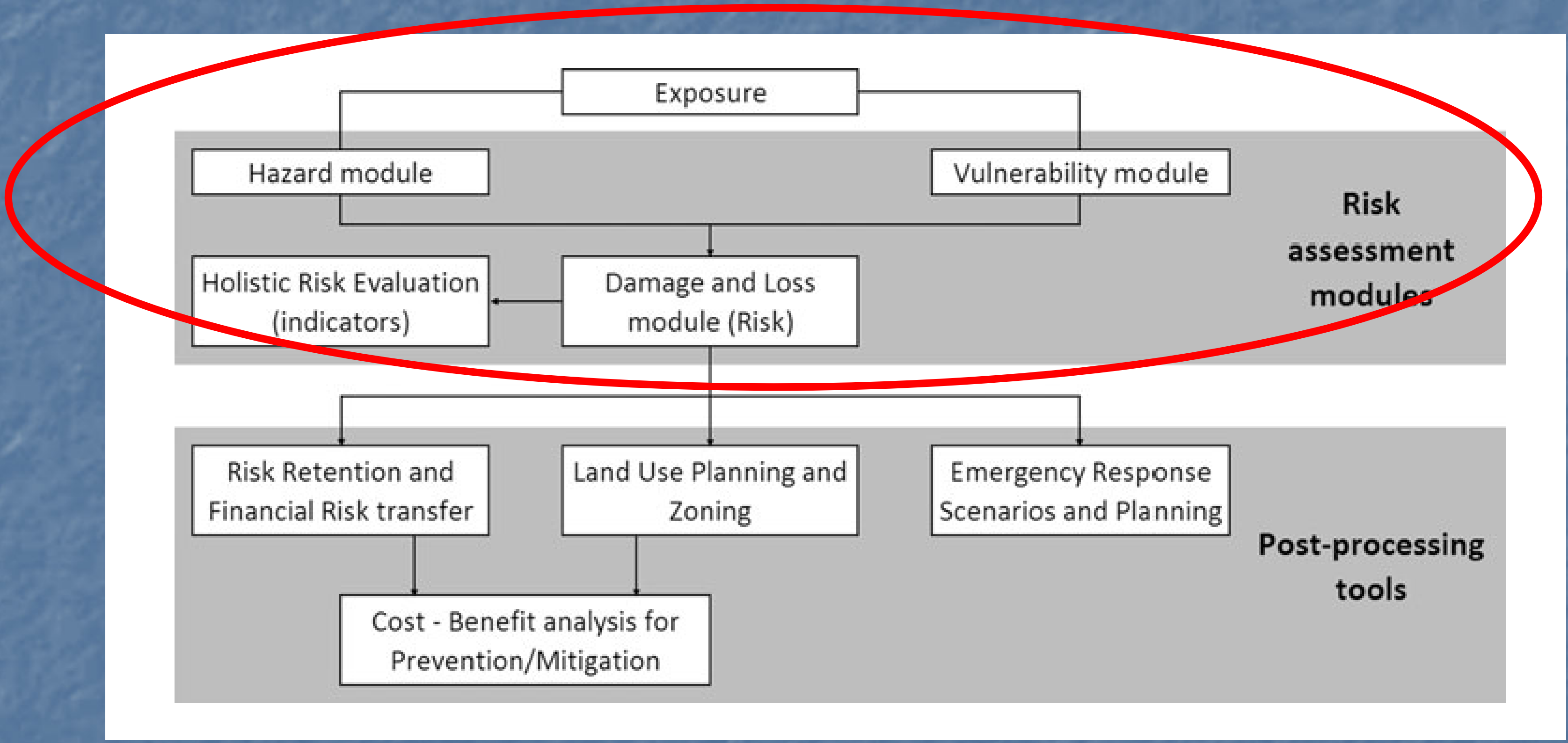
11 years ago 3.8 magnitude, 7 km depth
Tossa de Mar, Catalonia, Spain

11 years ago 2.6 magnitude, 5 km depth
Susqueda, Catalonia, Spain

11 years ago 2.8 magnitude, 0 km depth
Santa Coloma de Farners, Catalonia, Spain

11 years ago 2.7 magnitude, 7 km depth
Santa Coloma de Farners, Catalonia, Spain

General approach



Methodology

- Seismis zones are identified
- For each zone statistical analysis is applied to estimate the magnitude, intensity and frequency of exceedances
- To estimate the exposure, distance (and attenuation) from the endangered area have to be identified
- Intensities

Model

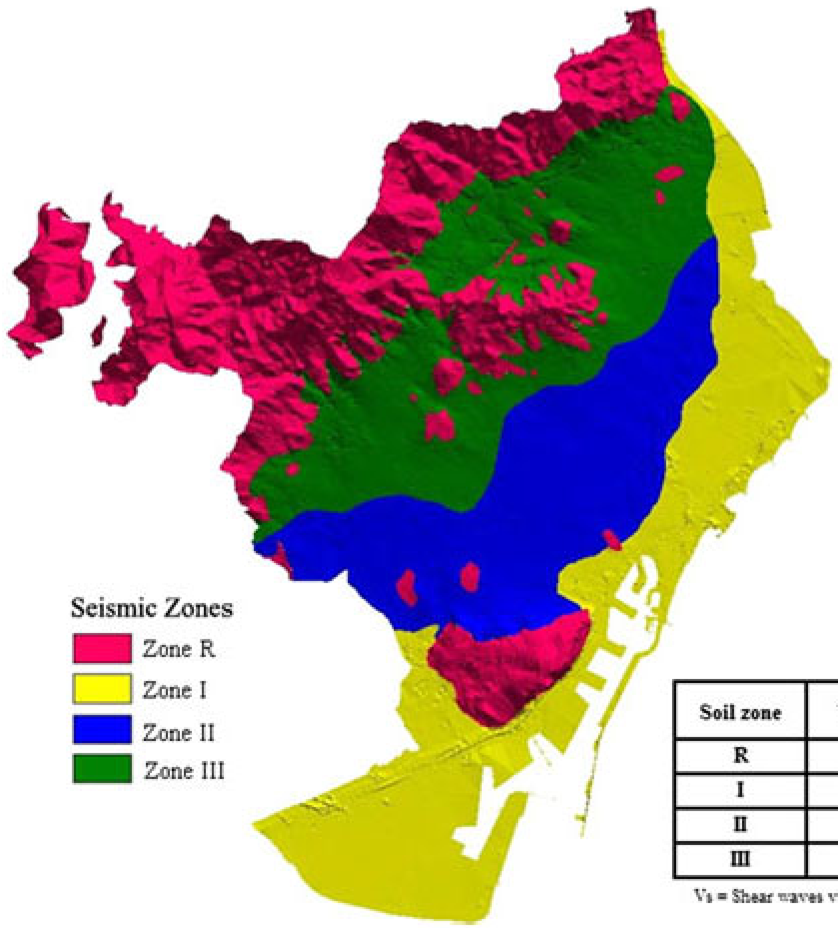
- Event has magnitude M (at the source) following a log NV
- Intensity A at distance R_0
- a is a certain intensity
- Φ is standard NV with median MED $(A|M,R_0)$ and $\sigma_{\ln a}$ is the standard deviation of the logarithm of a

$$Pr(A > a|M, R_0) = \Phi\left(\frac{1}{\sigma_{\ln a}} \ln \frac{\mathrm{MED}(A|M, R_0)}{a}\right)$$

Application

- City of Barcelona (Marulanda, M.C. et al. (2013) Nat. Hazards

- City of Barcelo
  Hazards



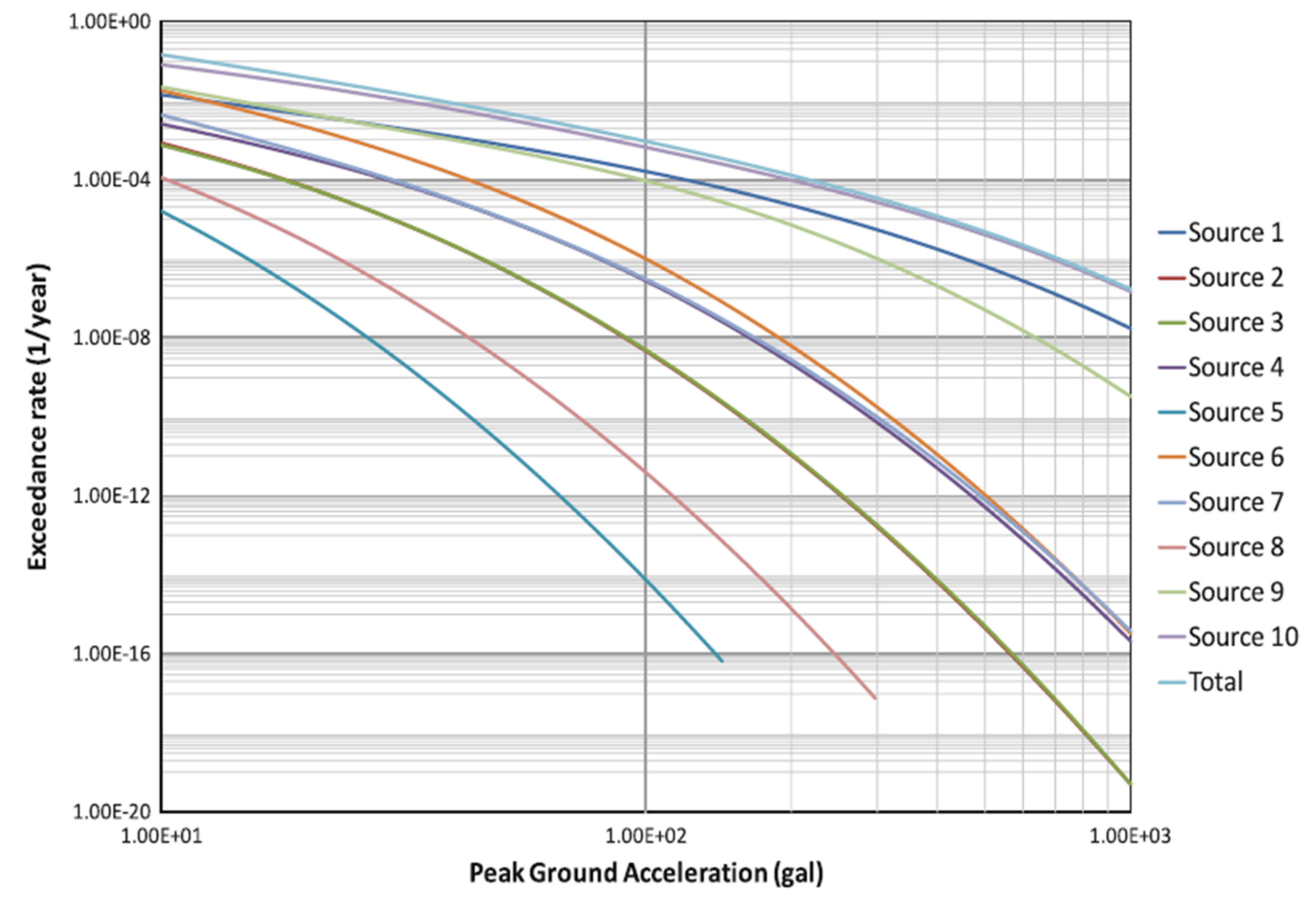
Soil zone	Vs(m/s)	Eurocode subsoil class
R	225	C
I	384	B
II	405	B
III	800	A

Vs = Shear waves velocity

Seismic zonation of Barcelona based on local effects (Cid et al. 2001)

Hazard probability distribution

for a given geological formation (bedrock site)



Exposure characterisation

- The exposure is mainly related to the infrastructure components or to the exposed population that can be affected by a particular event.
- Number of objects
- Classification of objects
- Damage potential of objects
- Establishing a loss function (relating intensity with consequences)
- Identification of # of humans exposed to an event

Impact estimation

- Regional classification
- Object identification
- Object classification
- Economic value of individual classes

Impact estimation

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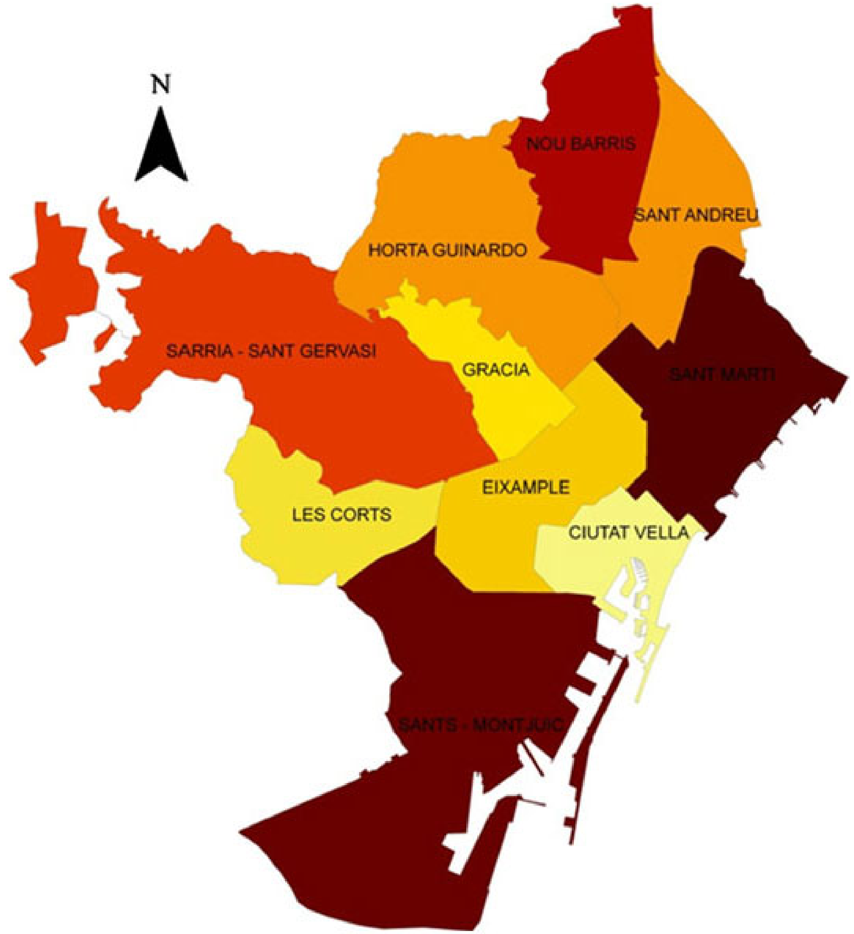
f individual classes



Territorial subdivision of Barcelona

Impact estimation

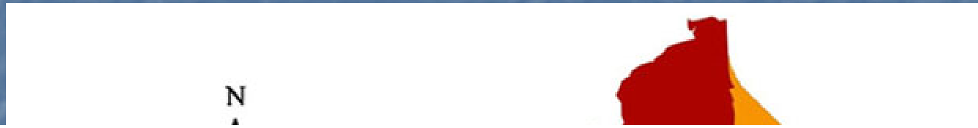


Table 1.Each structural type is subdivided into 3 classes according to the height of the building:

- *Low-rise buildings, L*: 1–2 floors for masonry and wood structures; 1–3 floors for reinforced concrete and steel buildings.
- Medium-rise buildings, *M*: 3–5 floors for masonry and wood structures; 4–7 floors for reinforced concrete and steel buildings.
- High-rise buildings, *H*: 6 or more floors for masonry and wood structures; 8 or more floors for reinforced concrete and steel buildings.

Territorial subdivision of Barcelona

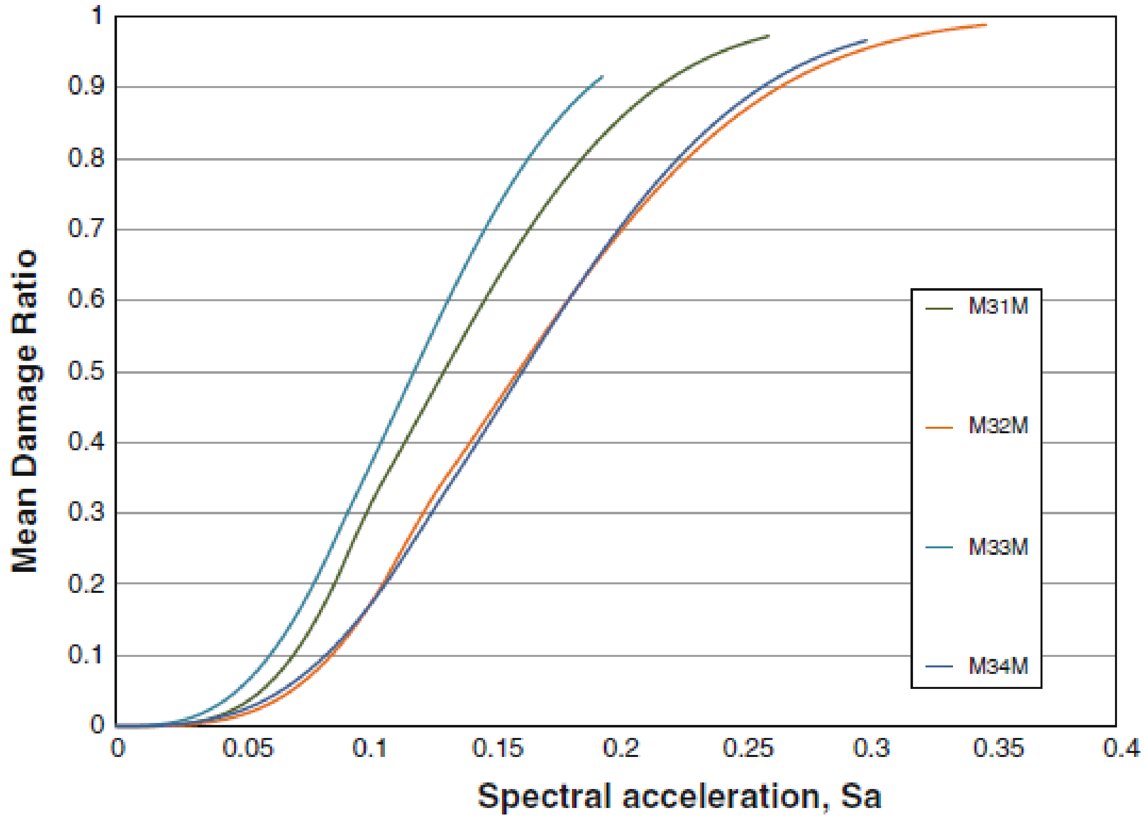
Impact estimation

Table 1 Building classes matrix for Barcelona (ICC/CIMNE 2004)

Unreinforced masonry	M3.1	Unreinforced masonry bearing walls with wooden slabs
	M3.2	Unreinforced masonry bearing walls with masonry vaults
	M3.3	Unreinforced masonry bearing walls with composite steel and masonry slabs
	M3.4	Reinforced concrete slabs
Reinforced concrete	RC1	Concrete frames with unreinforced masonry infill walls with irregularly frames (i.e., irregular structural system, irregular infill, soft/weak storey)
Steel moment frames	S1	A frame of steel columns and beams
Steel braced frames	S2	Vertical components of the lateral-force-resisting system are braced frames rather than moment frames
Steel frames with unreinforced masonry infill walls	S3	The infill walls usually are offset from the exterior frame members, wrap around them, and present a smooth masonry exterior with no indication of the frame
Steel and RC composite systems	S5	Moment resisting frame of composite steel and concrete columns and beams. Usually, the structure is concealed on the outside by exterior non-structural walls
Wood structures	W	Repetitive framing by wood rafters or joists on wood stud walls. Loads are light and spans are small

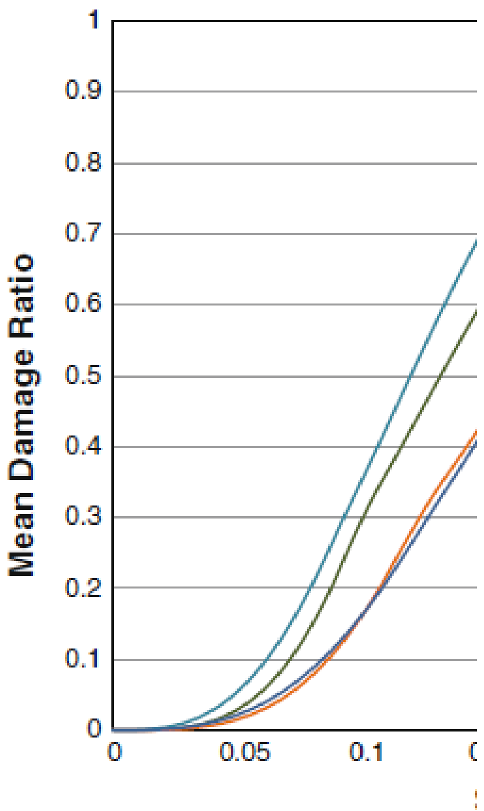
Territorial subdivision of Barcelona

Damage function (Potential)

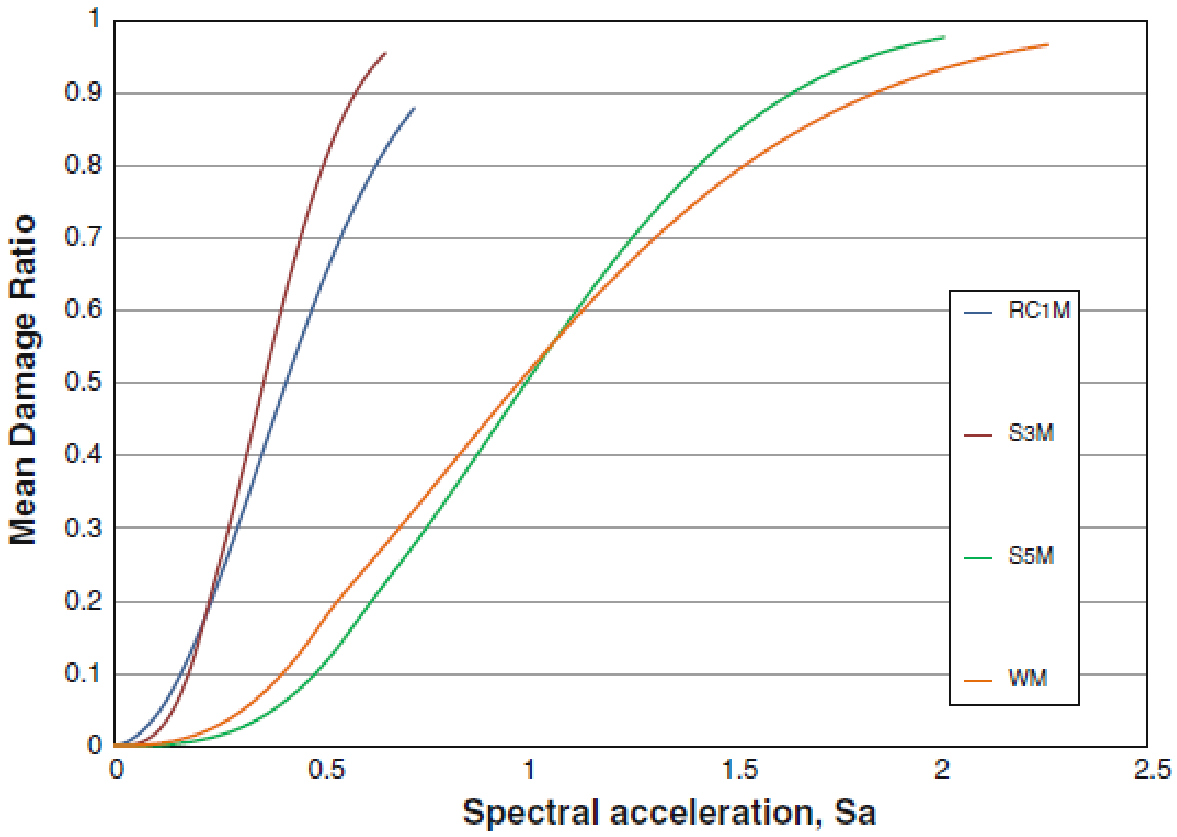


Vulnerability functions for unreinforced masonry buildings

Damage function (Potential)



Vulnerability functions for unreinforce



Vulnerability functions for reinforce concrete, steel and wood buildings

Economic assessment

Physical exposure		
Exposed value	€ × 10^6	31,522.80
AAL	€ × 10^6	72.14
	‰	2.29 ‰

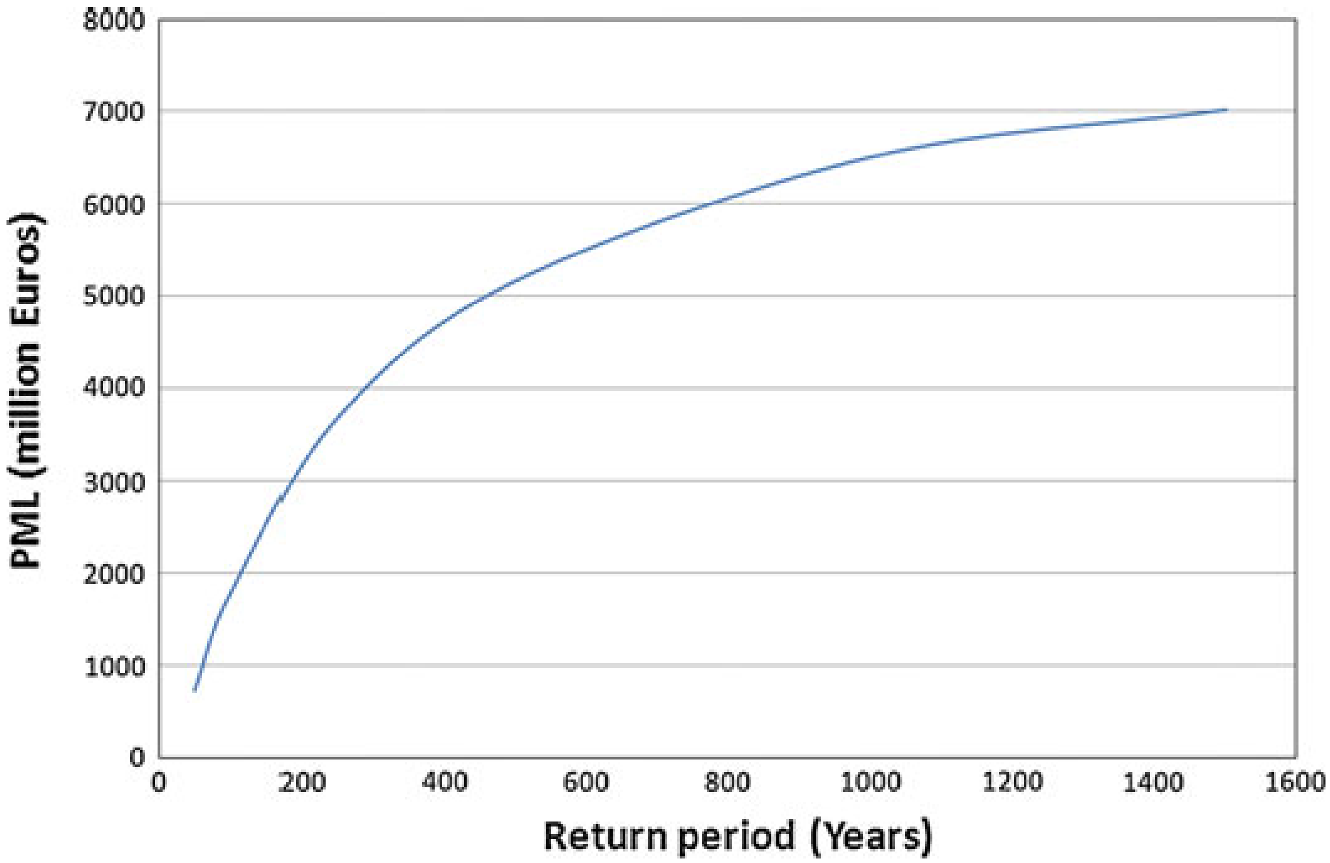
PML		
Return period (years)	Loss	
	€ × 10^6	%
50	729.35	2.31
100	1,770.16	5.62
250	3,699.35	11.74
500	5,172.26	16.41
1000	6,510.67	20.65
1500	7,021.14	22.27

AAL = annual expected loss

PML= probable maximum loss

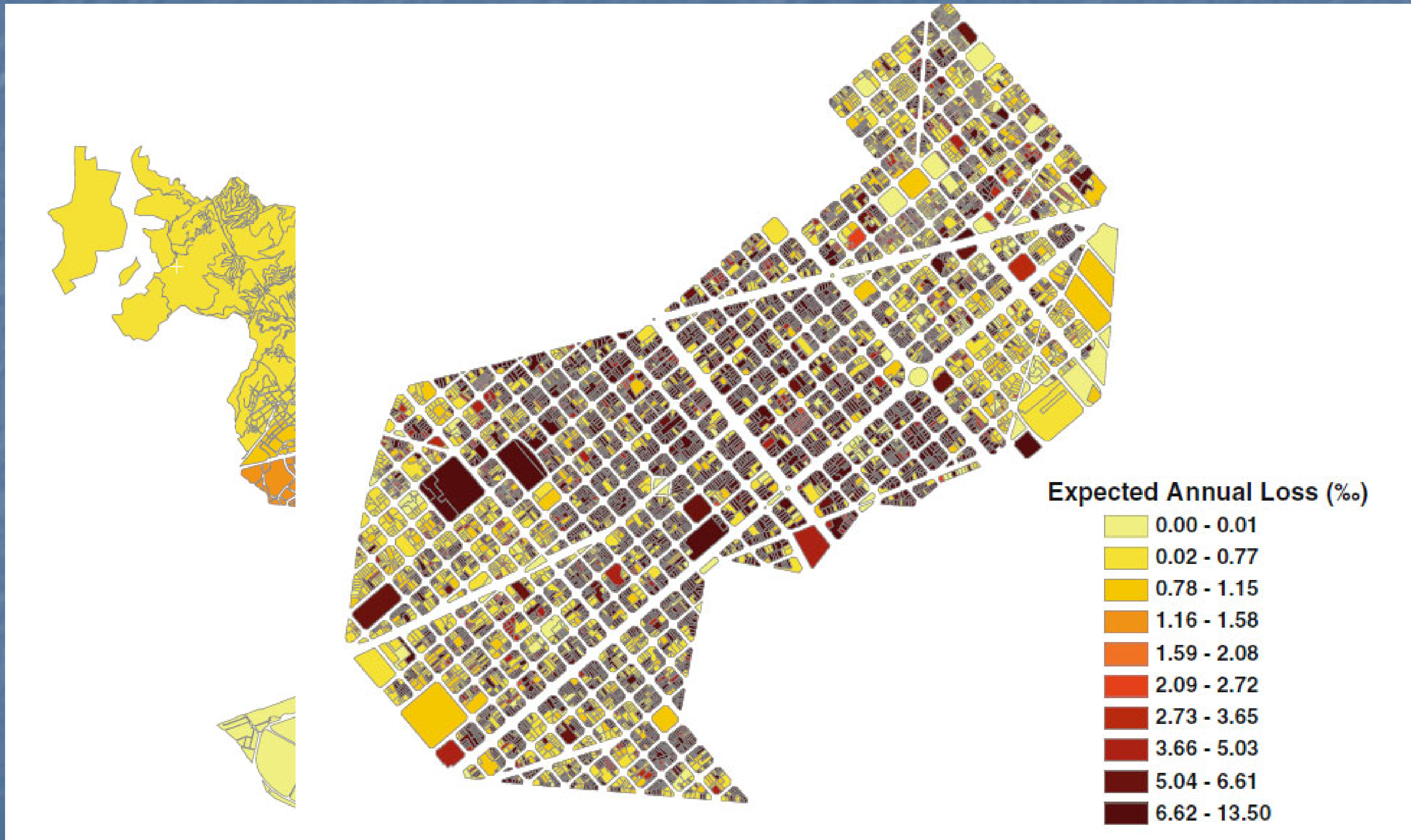
Economic assessment

Physical exposure
Exposed value
AAL
PML
Return period (years)
50
100
250
500
1000
1500



PML curve for the total portfolio of buildings of Barcelona

Spatial distribution of expected losses



Risk for humans

Dead people		
Exposed value	Inhabitants	1,639,880.00
AAL	Inhabitants	28.27
	‰	0.017 ‰

PML		
Return period (years)	Loss	
	Inhabitants	%
50	101.41	0.01
100	654.30	0.04
250	2,069.97	0.13
500	3,380.29	0.21
1000	4,898.39	0.30
1500	5,799.44	0.35

Risk for humans

Dead people	
Exposed value	Inhat
AAL	Inhat
	‰
PML	
Return period (years)	
50	
100	
250	
500	
1000	
1500	

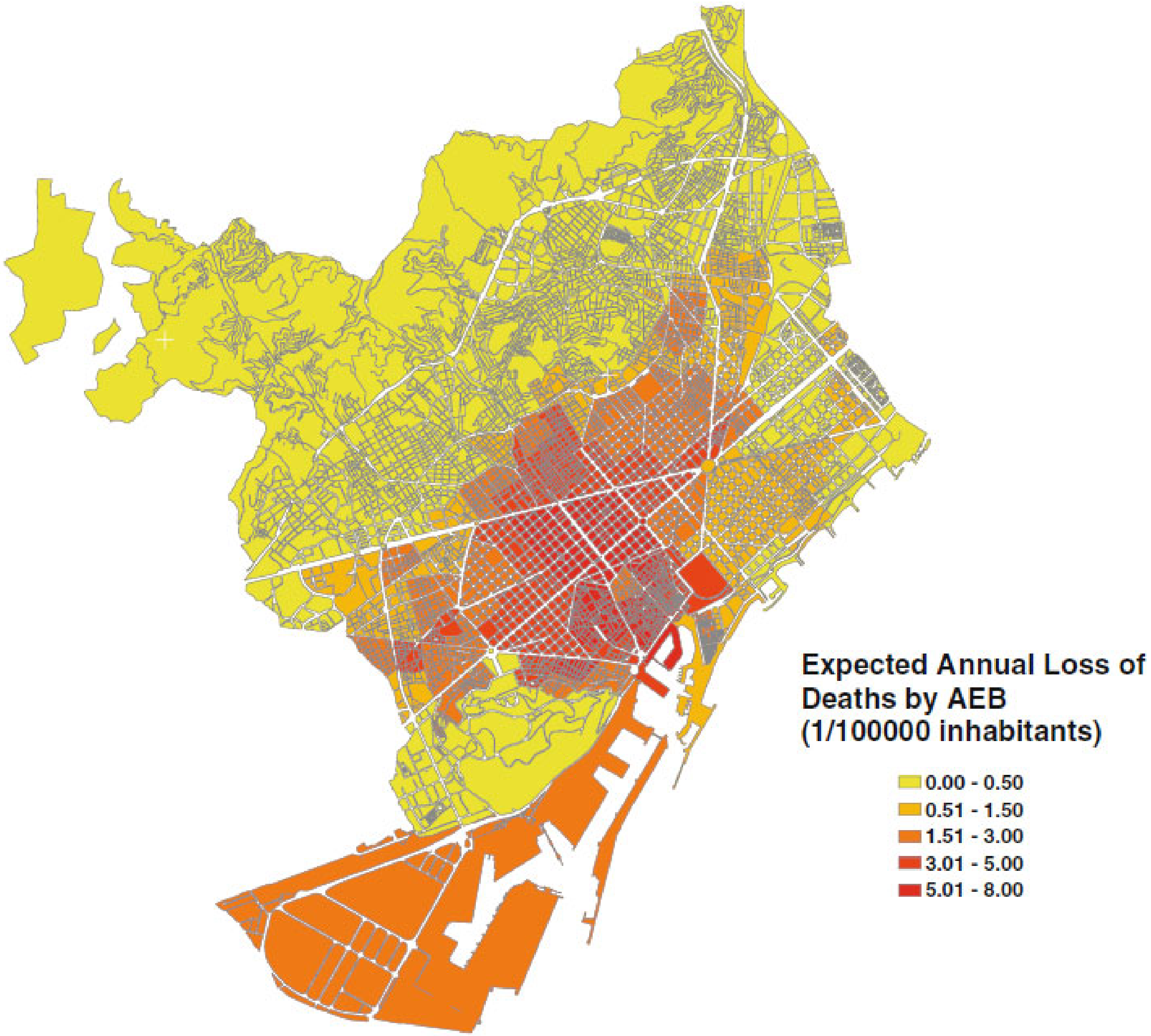


Fig. 11 Expected annual loss of deaths by AEB in Barcelona, Spain

Summary

- The probability of intensity of the hazardous event has been described by a Log NV
- An attenuation model has been used to link origin of the hazard with the impact area
- Impact area has been divided into subunits
- Objects in subunits have been identified
- Objects in subunits have been classified
- Value of objects has been estimated
- Risk has been estimated
- # of fatalities has been estimated