Earthquake hazard and societal risk

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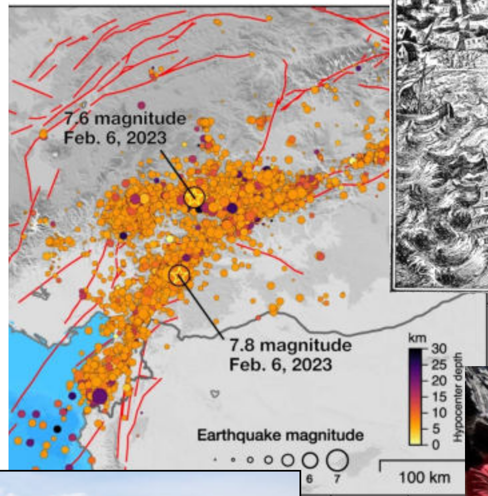
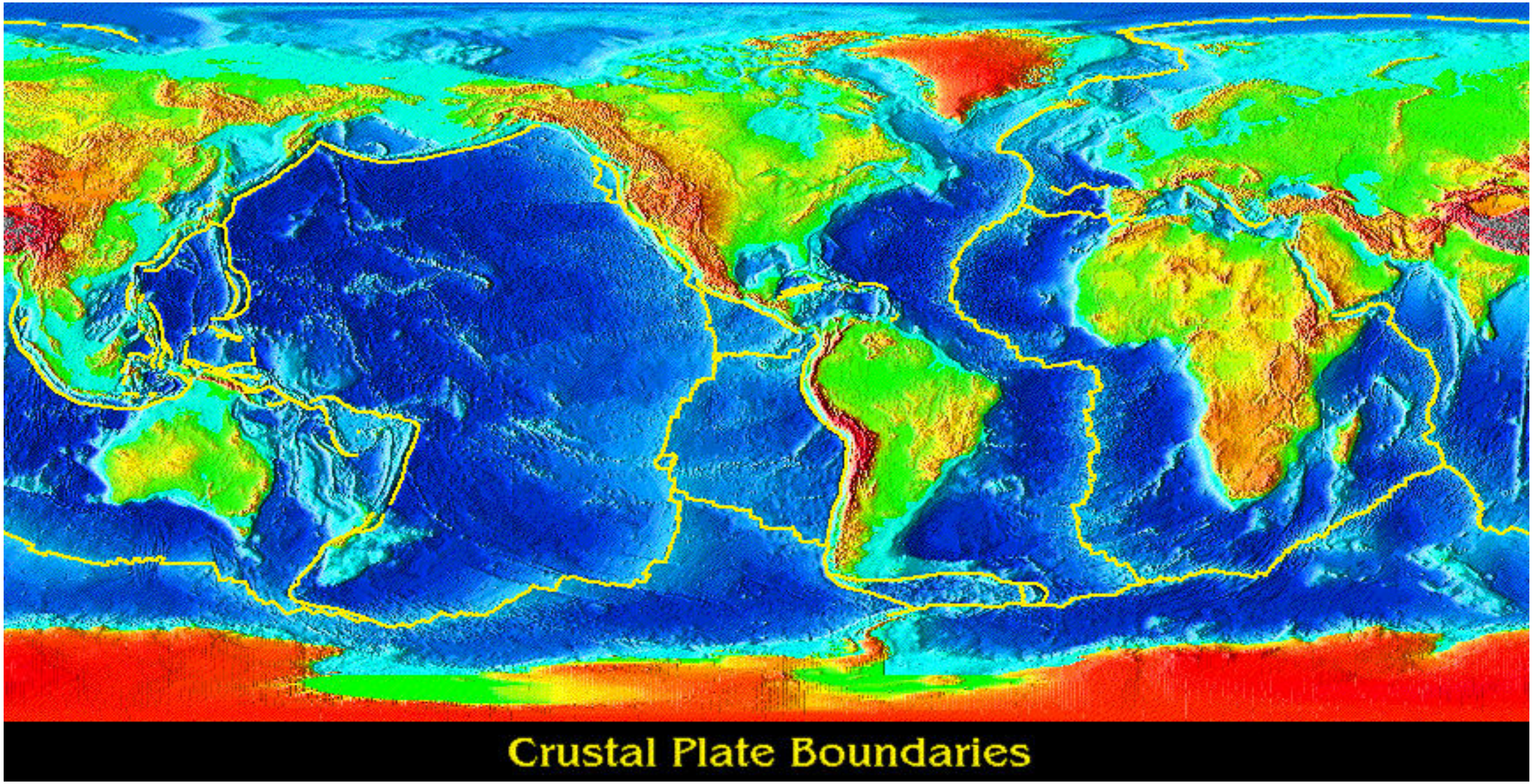


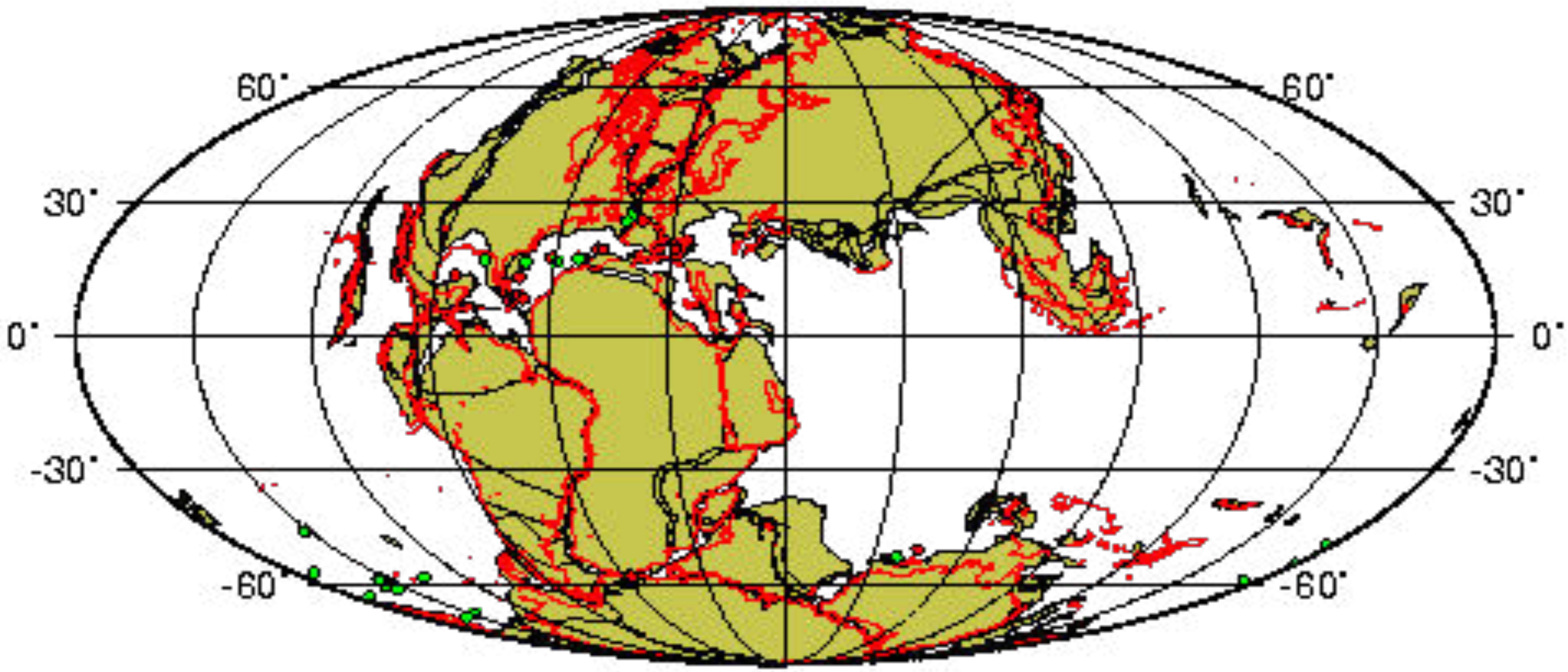
Earthquake Hazard and Societal Risk

- ✓ Definitions
- ✓ Earthquakes
- ✓ Global risk
- ✓ Urban explosion
- ✓ Lessons learned
- ✓ Hazard assessment
- ✓ Risk assessment
- ✓ What are we missing?
- ✓ Take-home message

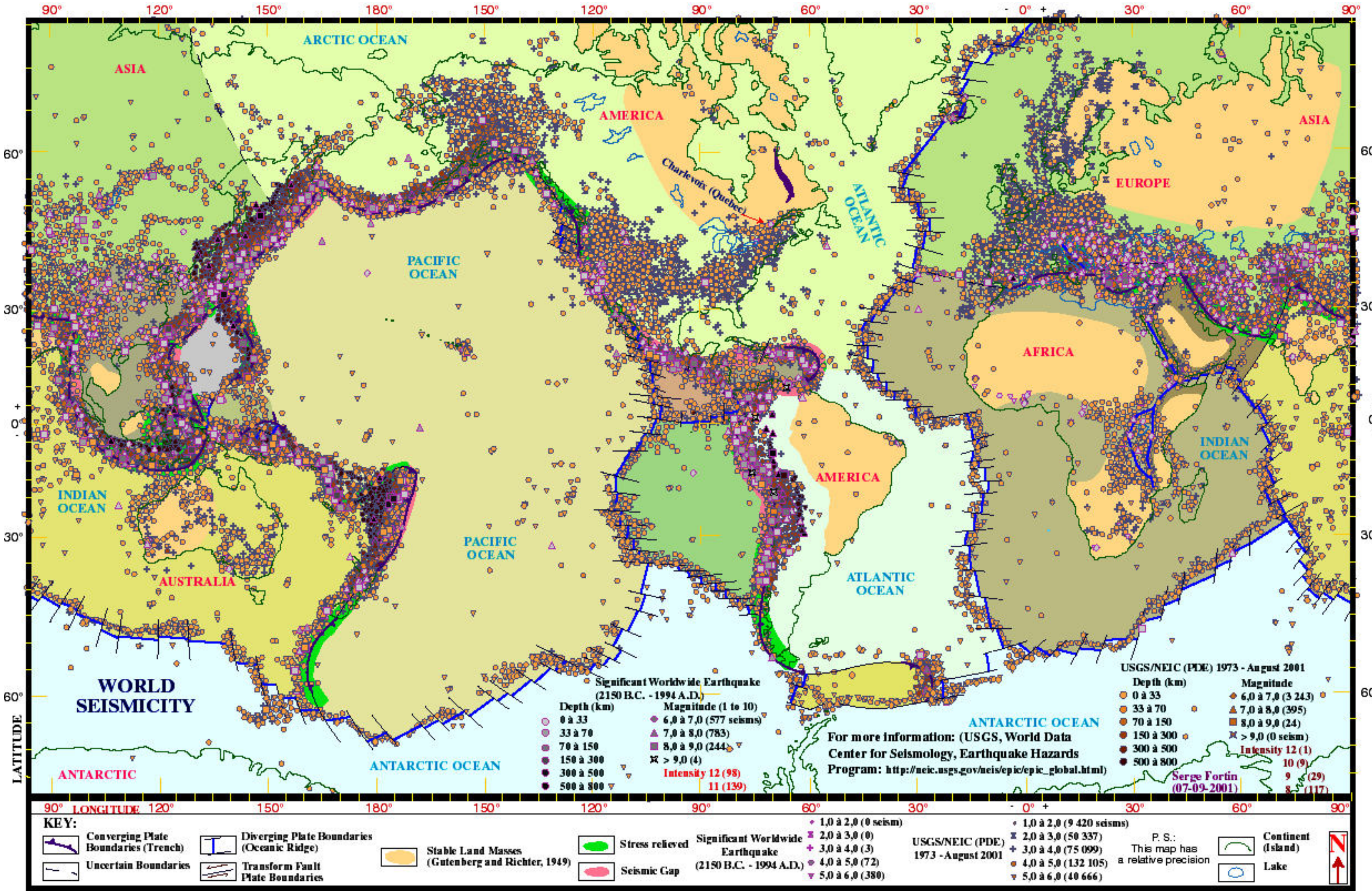
Definitions

- ✓**Earthquakes**: The natural response of the Earth crust to global strains, largely associated to plate tectonics
- ✓**Faults**: Discontinuities of the crust moving with repeated earthquakes
- ✓**Magnitude**: It measures the size of the quake in terms of ground-shaking amplitude, but also the size of the fault area and frequency content of the emitted energy
- ✓**Seismic hazard**: Probabilistic assessment of the ground-shaking expected as consequence of future earthquakes (e.g. peak ground acceleration expected to be exceeded with 10% probability in 50yr, or in the next 475 years). It is the input for the building code for design of structures agains earthquakes.
- ✓**Seismic risk**: Probabilistic assessment of the damage expected as consequence of future earthquakes, expected in terms of casualties, building damage, economic losses. It is the input for many measures of risk mitigation.


Crustal Plate Boundaries



150 My Reconstruction



Giardini, EGU GIFT, 26.4.2023

Earthquakes and religion

The Bible and all other sacred texts depict earthquakes as a powerful manifestation of God's intervention to help or punish humans

Earthquakes and religion

Greek mythology
Poseidon: God of Sea, Earth-Shaker

Roman mythology
Neptune: God of the Sea and Earthquakes

Islam
Earthquakes are sign of Allah’s anger, or punishment for some people, or signs for His creation of the world

Catholic religion
Several patron saints:
St. Alexius
St. Emidius
St. Alberto degli Abati
St. Eustachia Calafato

Earthquakes and philosophy

G.W. Leibniz (1710), in *Théodicée:* God created the best possible world, in harmony, for the good of humans, including also catastrophic events like earthquakes.

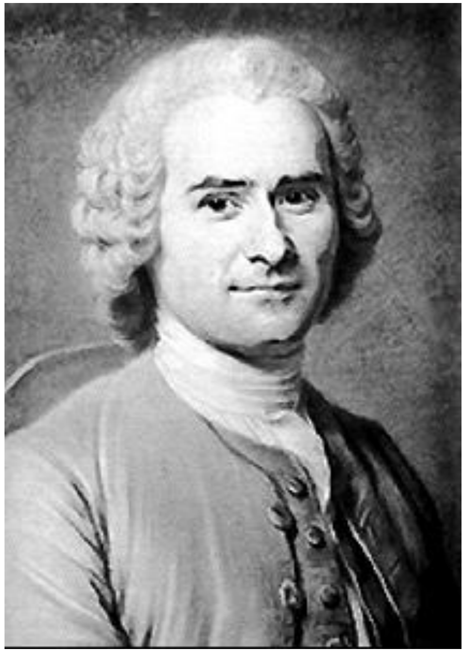
Alessander Pope (1732) wrote in *Essay on Man:* "Whatever is, is best", confirming the idea of a world in harmony and of a universal good.

→ If all is good (Pope) in the best possible world (Leibniz) nothing can be improved.

Lisbon 1755

Earthquakes and philosophy

The French philosopher Voltaire in his *Poème sur le désastre de Lisbonne, ou examen de cet axiome: tout est bien* (1756) wrote “Would Pope have dared to say that whatever is, is best, if he himself had been in Lisbon?”. Voltaire was denying divine providence and optimism.



J.J. Rousseau responded that “if people insist on living in cities, and building houses six or seven stories high, they have only themselves to blame, not God”. Coping with earthquakes was not a question of God and nature, but a human problem to be solved with better theories of earthquakes and safe constructions.

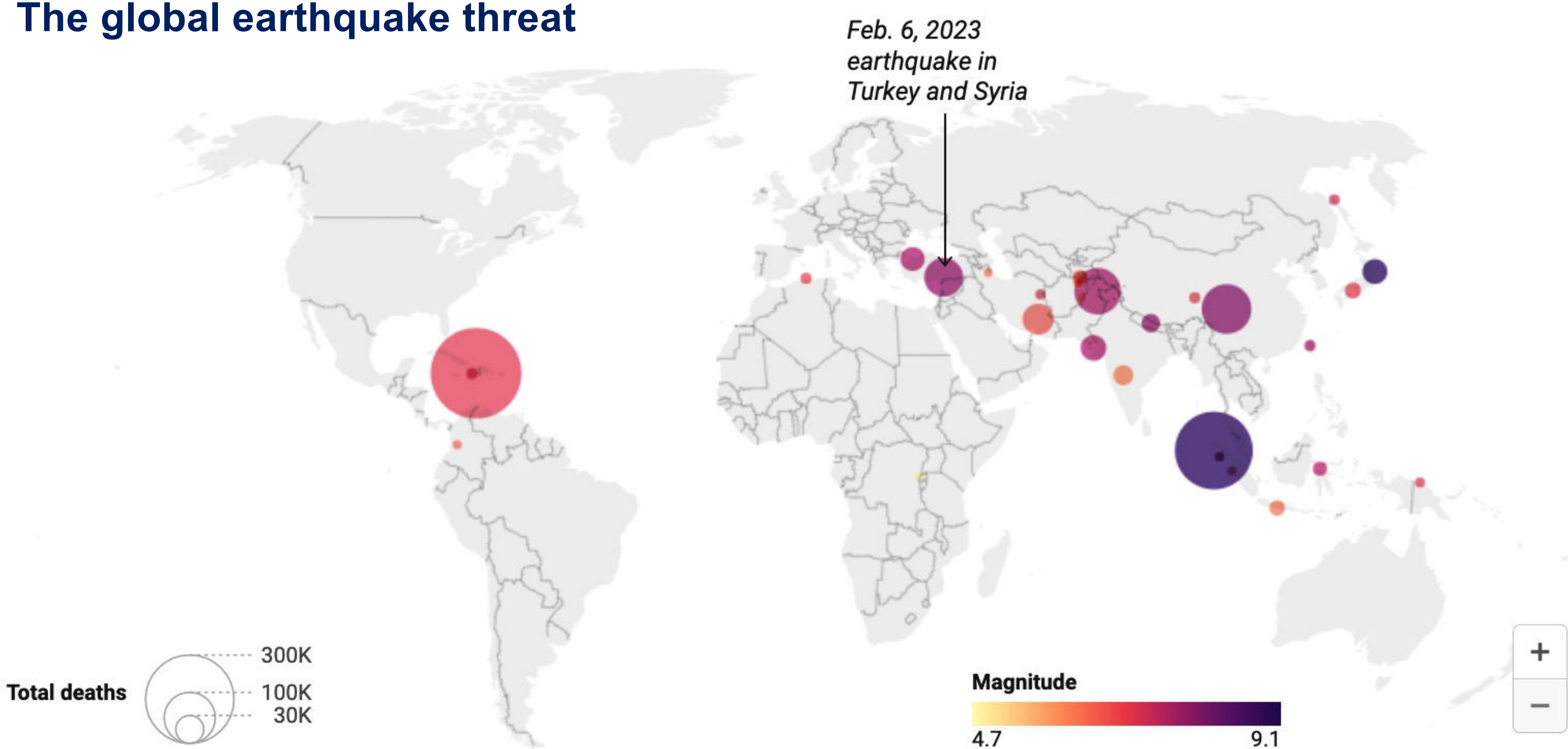
The global earthquake threat

- ✓ Among the natural hazards, earthquakes and volcanoes have the highest ratio of casualties to the affected population, averaging over 0.5% in the past 35 years.
- ✓ As the global population exposed to earthquakes continues to rapidly increase, so will also the number of casualties.

Hazard	Events	Fatalities	Affected	Damage	*R*
Earthquakes and tsunamis	865	866,882	158,794,738	737,379	0.546
Droughts	499	561,540	1,766,356,773	117,612	0.032
Floods	3,741	229,080	3,277,580,121	619,190	0.007
Extreme temperatures	461	166,921	97,822,633	54,327	0.171
Volcanoes	160	25,539	4,476,906	2,870	0.570

Disaster statistics from the OFDA/CRED International Disaster Database, UCL, Bruxelles (ESF, 2015)

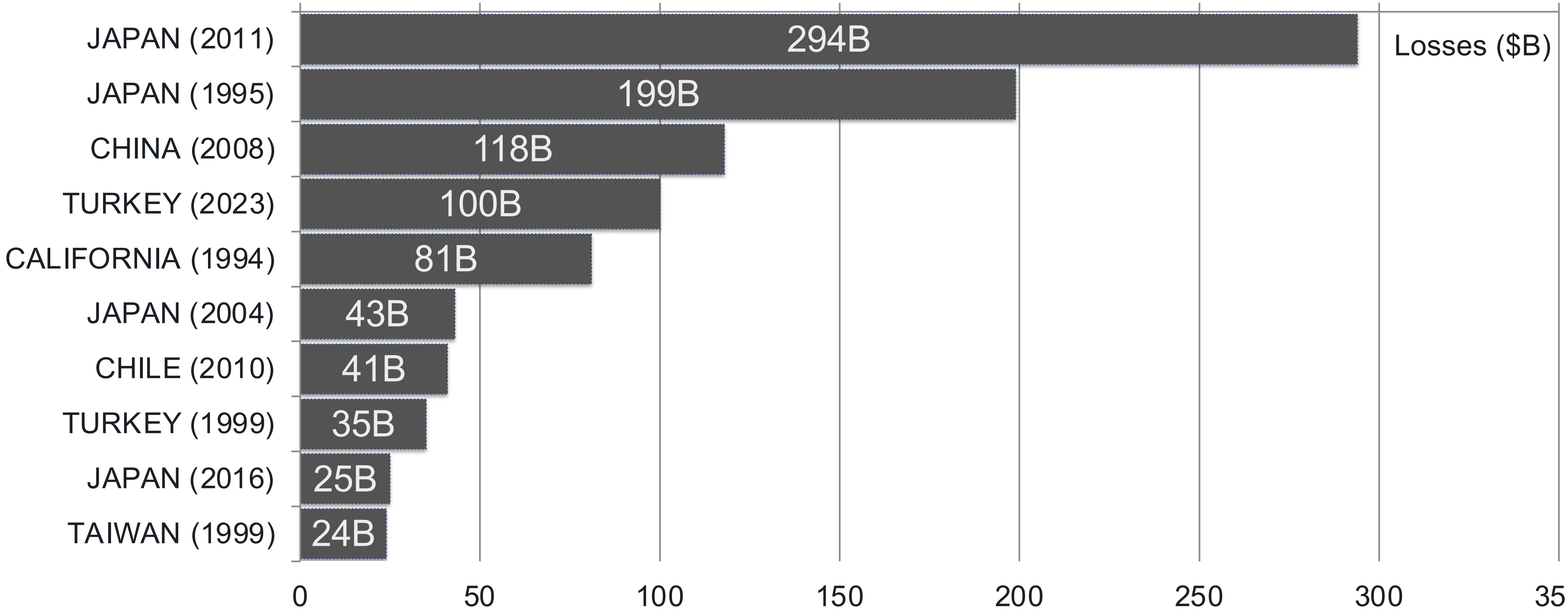
The global earthquake threat



Data was filtered for earthquakes between 1993 and 2023 with over 1,000 deaths. Total deaths measures deaths from the earthquake and those from any secondary effects of the earthquake, namely tsunamis. (Data accessed on 3/8/2023.)

Map: Benjamin Clary, APM Research Lab • Source: NOAA: National Centers for Environmental Information • Get the data • Created with Datawrapper

The global earthquake threat



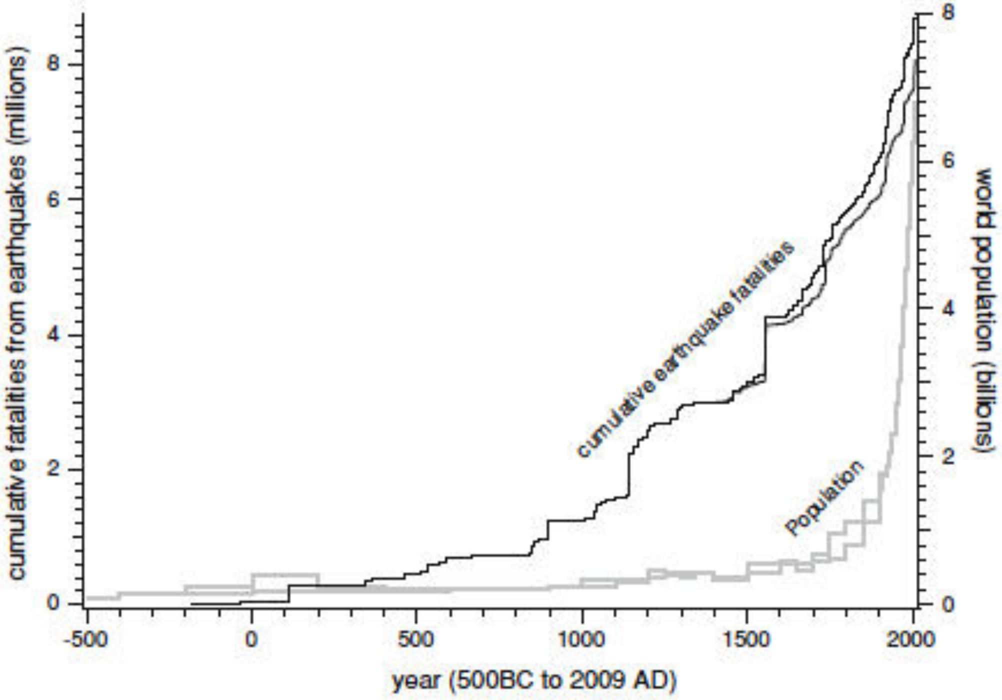
Recovery and reconstruction costs will be much larger, potentially twice as large.

(U.N. Development Programme, March 2023)

The global earthquake threat

- ✓ In the past 2000 years, global population continued to increase, and is projected to triple from 1950 to 2050.
- ✓ Economic losses, societal disruption and casualties associated to the occurrence of catastrophes are largely concentrated in urban areas. The population growth of the future will take place in megacities, making our society ever more vulnerable.
- ✓ In many countries of the world, over 50% of the population and most of the economic power is concentrated in the capital city. If the capital is hit, the country is lost.
- ✓ As result of the building vulnerability and societal resilience, extreme events may produce very different impacts on cities and society worldwide.

Global earthquake threat

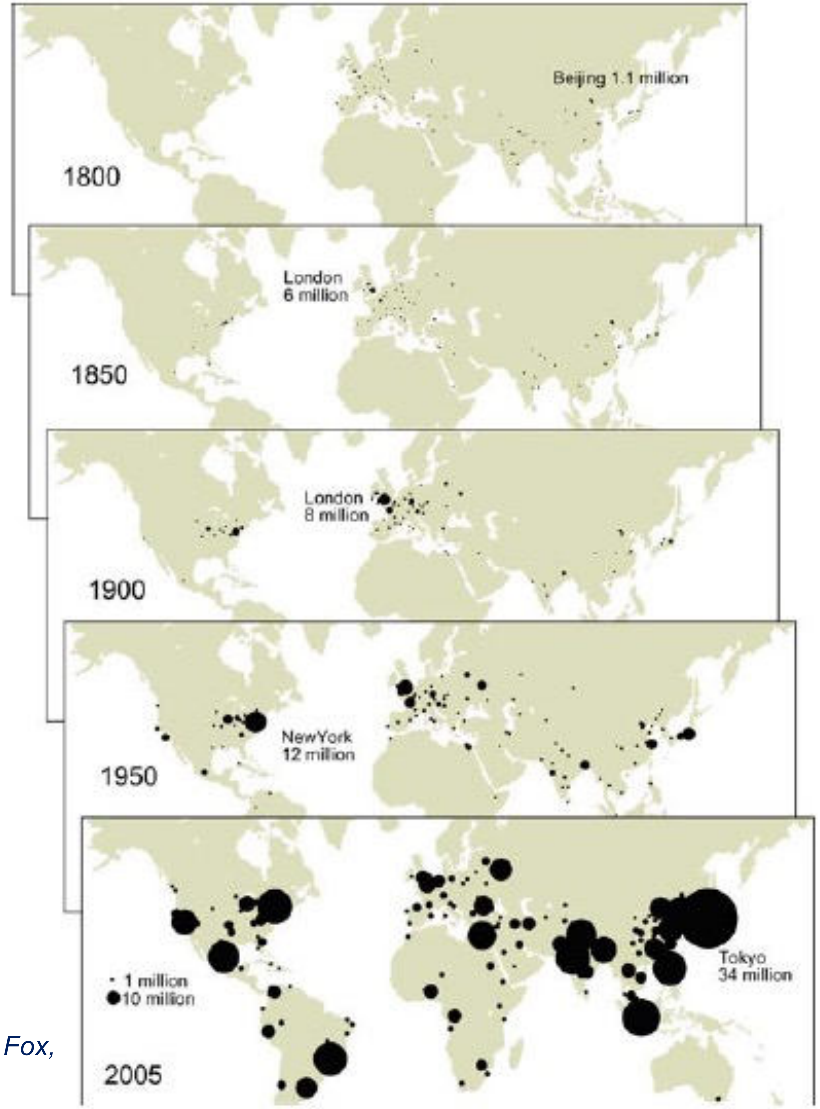


Bilham, 2009; high and low population data from McEvedy and Jones, 197, and Thomlinson, 1975; high and low casualty data from Dunbar et al, 1992 and Utsu, 2002.

- ✓ In the past 200 years population has increased by ten times, and in the past 50 years the growth has accelerated.
- ✓ The next 2 billion people will be born mostly in emerging countries and will all live in megacities.
- ✓ Urban population doubles every 15 years, whereas informal settlements double every 7 years.
- ✓ Fatalities from earthquakes also continue to increase, but not as fast as global population, owing to improved building practice.

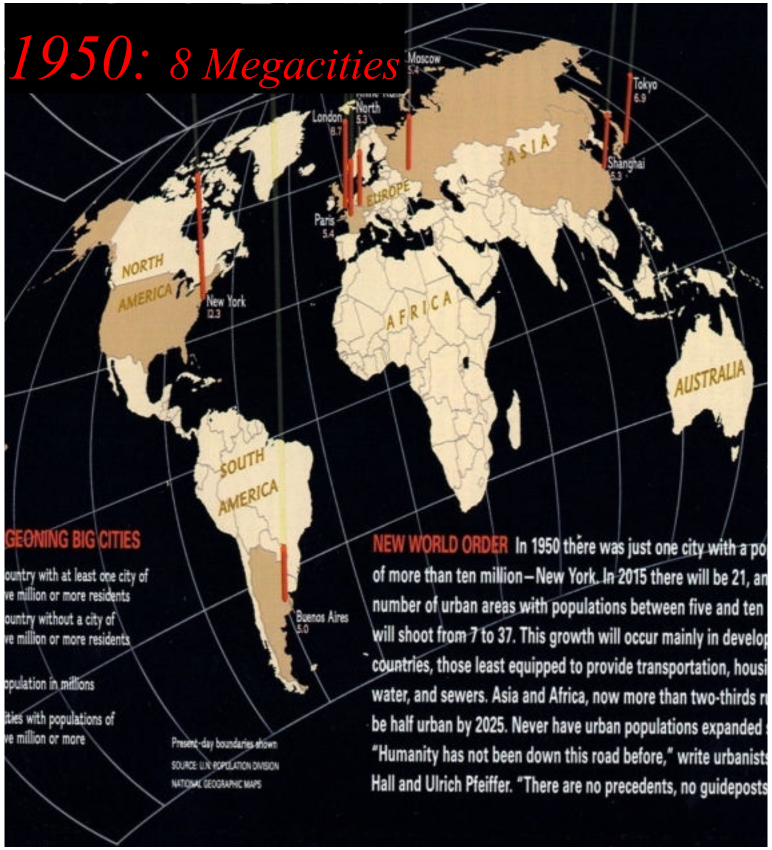
The global earthquake threat

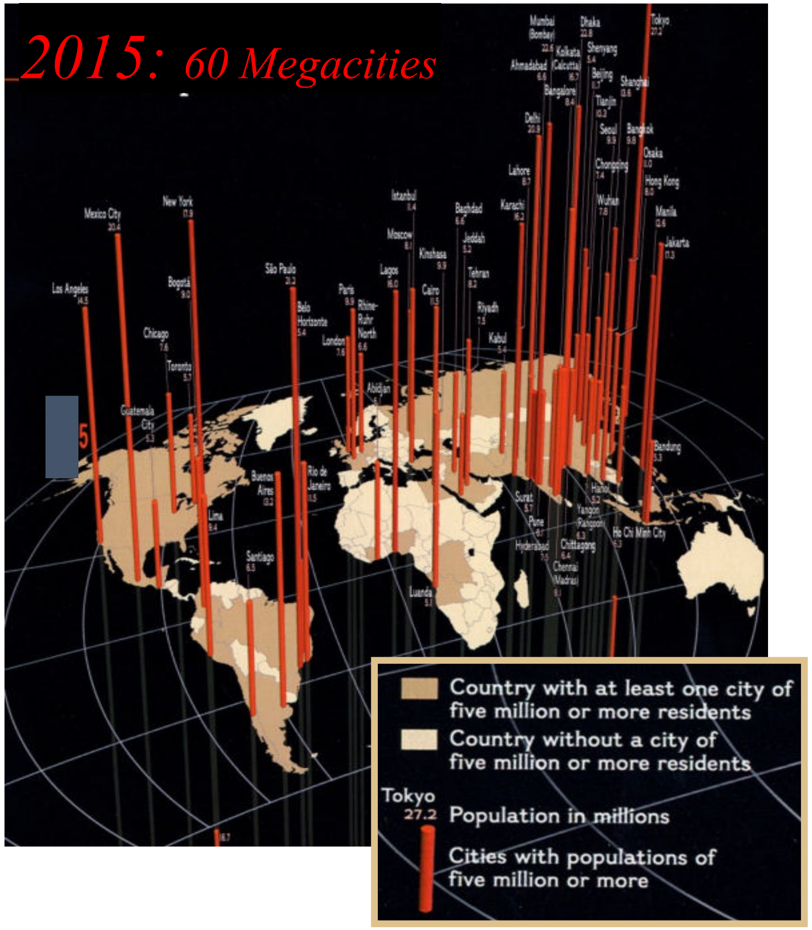
- ✓ The population of the world's largest cities, following the earlier megacity of Rome (900'000, 14 AD), remained stable and reached again 1'100'000 with Beijing in 1800.
- ✓ In developing nations, by 2020 urban population will surpass rural population, and by 2050 it will constitute over 80% of global population. In developed nations, rural population will essentially disappear by 2050.



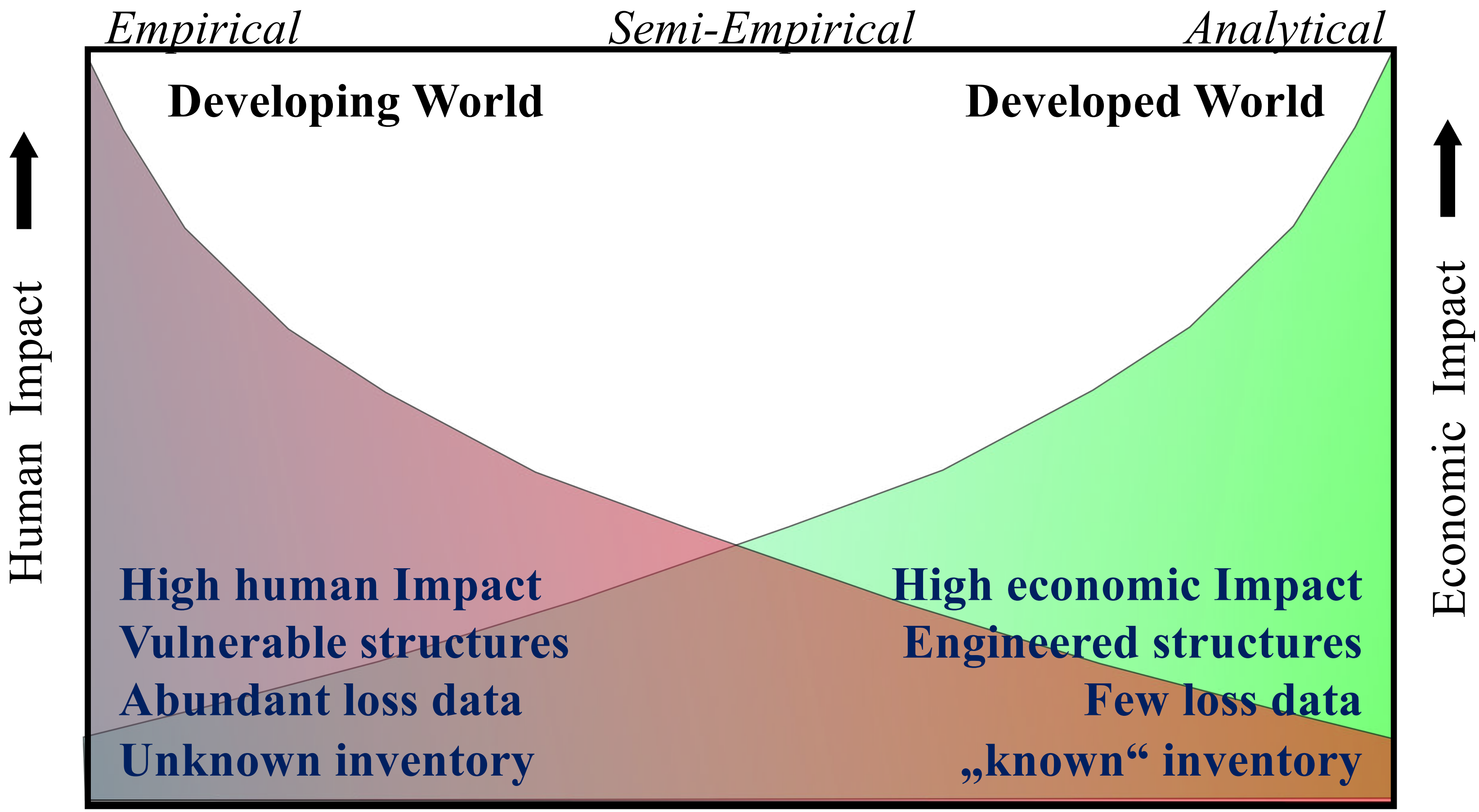
Bilham, 2009. Data from Chandler and Fox, 1974 and Chandler, 1998.

The global earthquake threat





Global earthquake threat: vulnerability

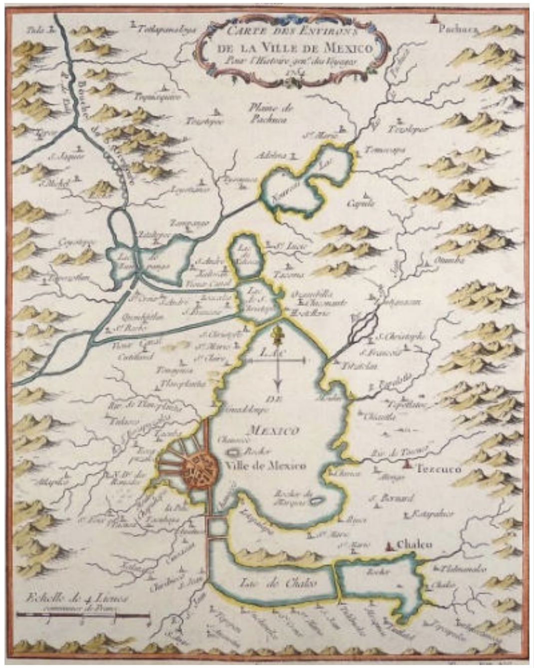


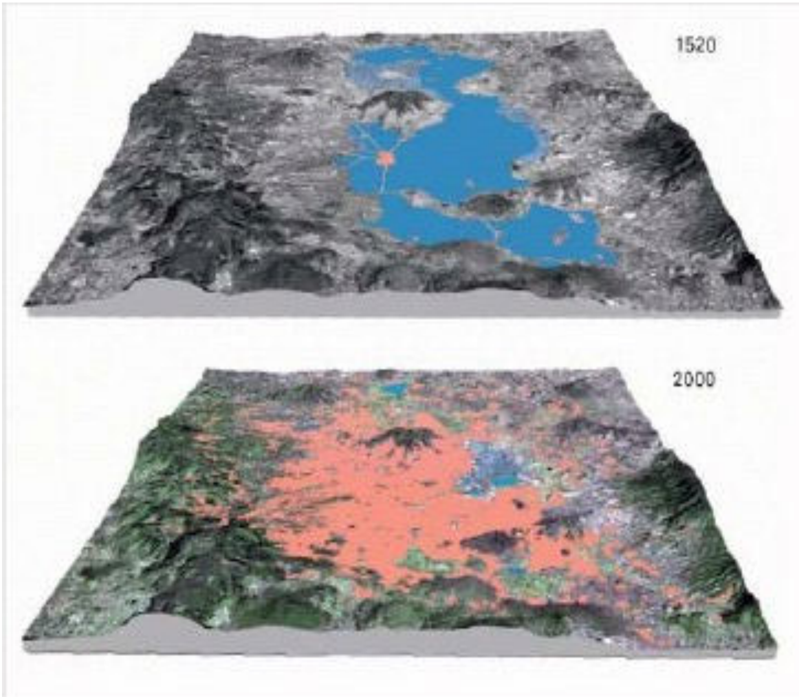
Wald, 2007

Lessons learned: 1985, M8.1 Michoacan

- ✓ Mexico City grew from a small city in 1500 to 25 million inhabitants today
- ✓ Built on the former lake bed, which amplified seismic waves up to a factor 100, with catastrophic consequences

→ The distant quake (d=300km) resulted in 30’000 victims





Lessons learned: 2011, M9 Tohoku

✓ Unexpected high magnitude, unexpected extreme slip on the fault, unexpected size of tsunami, unexpected cascade failure of critical infrastructures, unexpected failure of tsunami protection

→ Even in a well prepared society, mitigation can be insufficient and consequences catastrophic

Lessons learned: 2008, M8.3 Sichuan, China

- ✓ Event larger than expected, on a known fault
- ✓ Almost total loss in few cities located close to the fault, but overall negligible GDP loss
- ✓ ~80'000 casualties, 1% of the affected population

→ New cities in rapidly developing countries can be at risk, if they are not well built

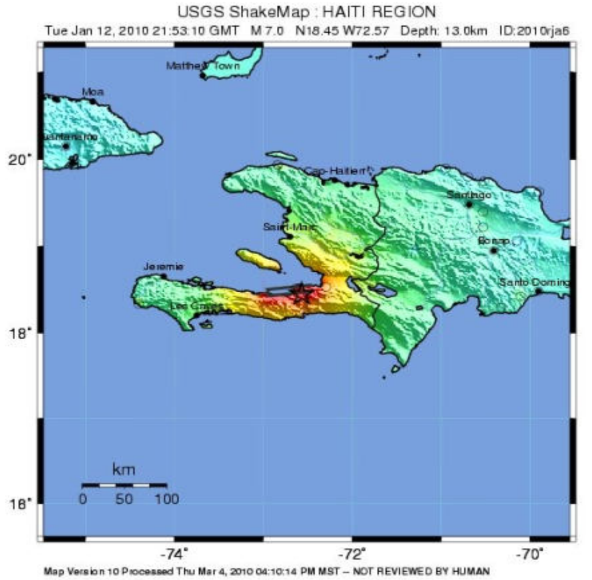





Lessons learned: 2009, M7 Haiti

- ✓ Devastation in the capital Port-au-Prince, societal collapse
- ✓ ~250'000 casualties, 10% of the affected population
- ✓ Total GDP loss

→ In less developed countries, earthquakes are still catastrophic !



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
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

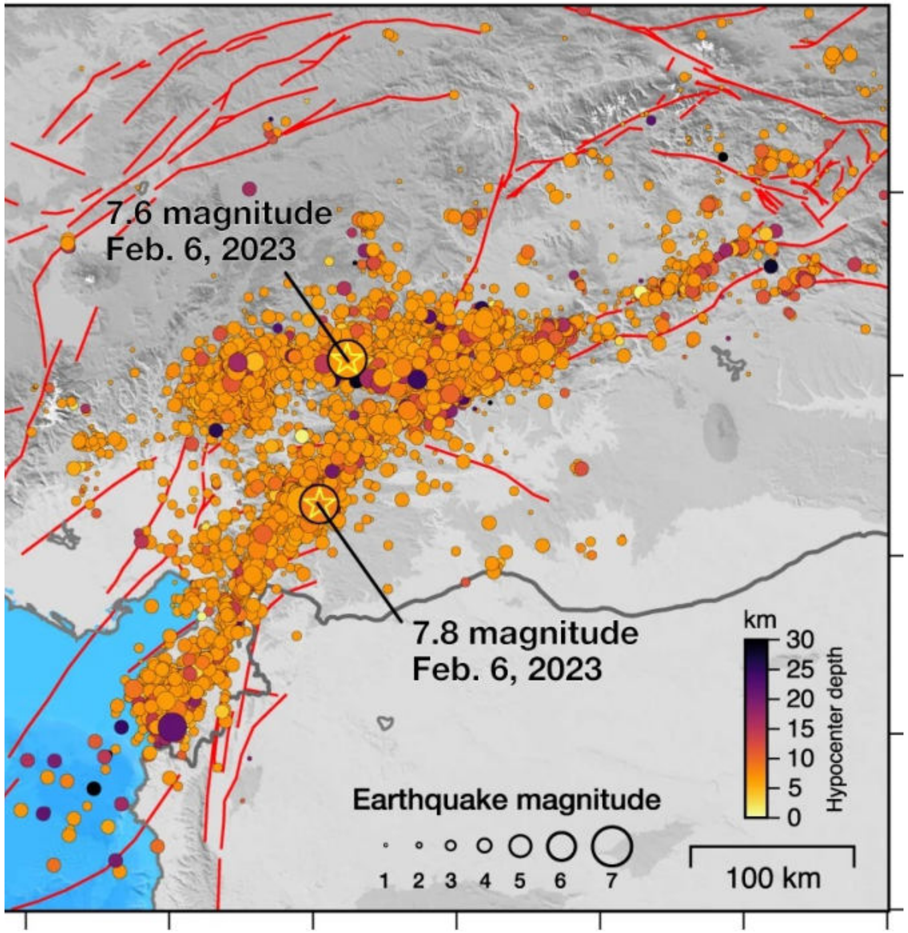
Lessons learned: 1999, M7.6 Izmit, Turkey

- ✓ Expected event on a known fault system
- ✓ ~25'000 casualties, 1% of population affected
- ✓ Negligible GDP loss
- → Good building code helps

Lessons learned: 2023, M7.8 Turkey-Syria

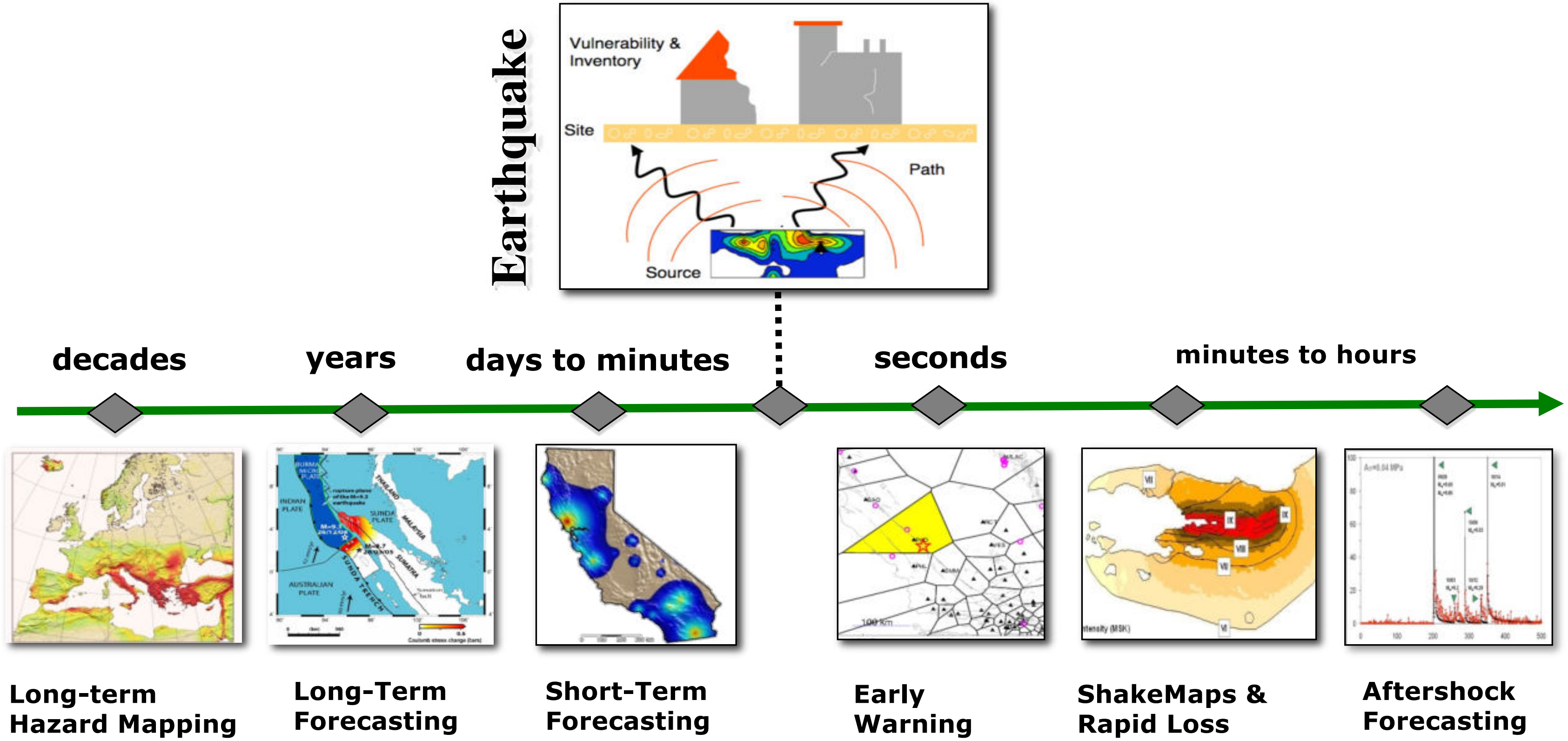
- ✓ Expected event on a known fault system
- ✓ ~60'000 casualties, 0.5% of population affected
- ✓ Significant GDP loss

→ Good building code helps, but still a long way !

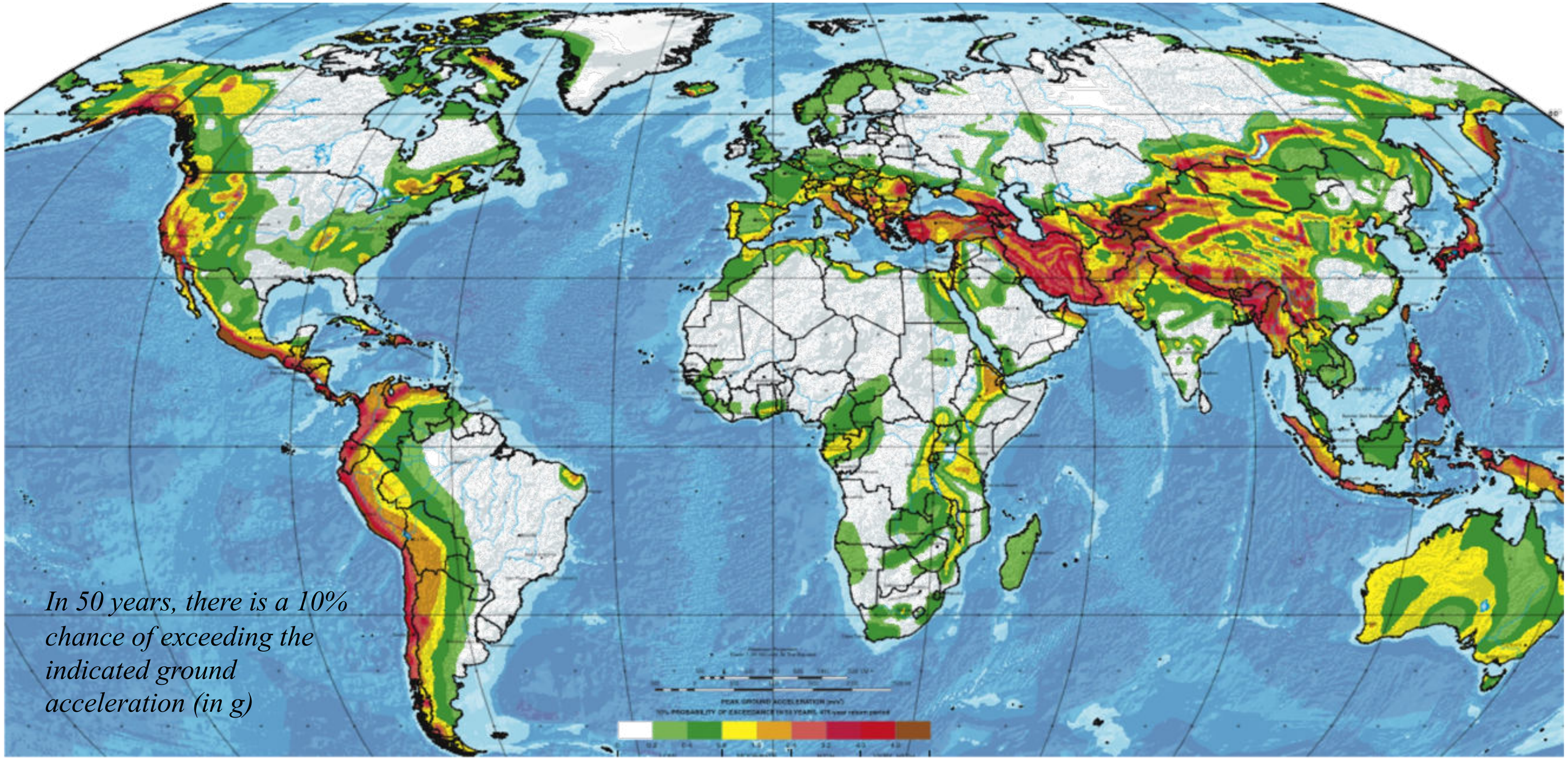


Measures of seismic hazard

Different hazard measures are computed for the long term and short term probability of shaking, and in the aftermath of the earthquake, serving different mitigation purposes

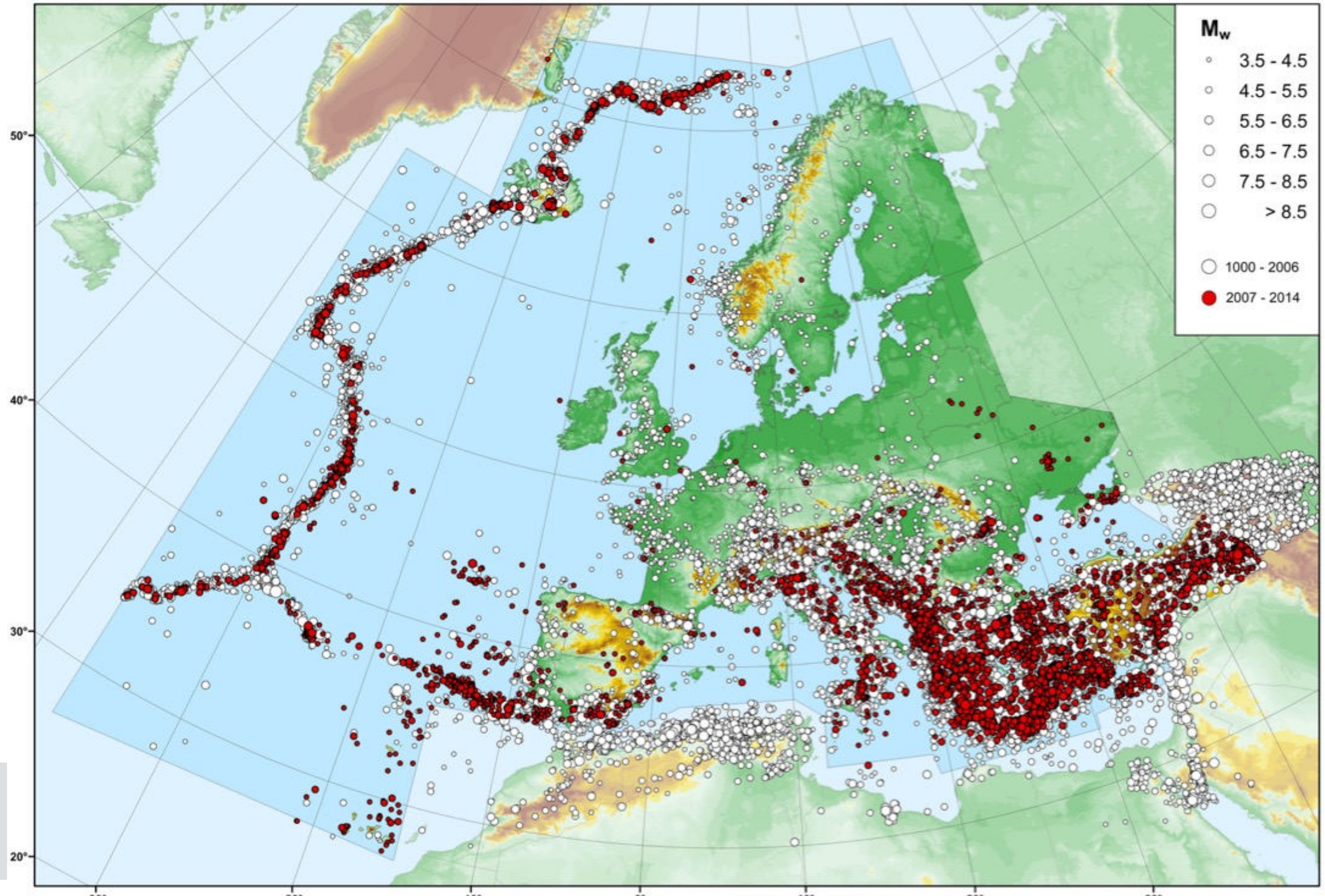


GLOBAL SEISMIC HAZARD



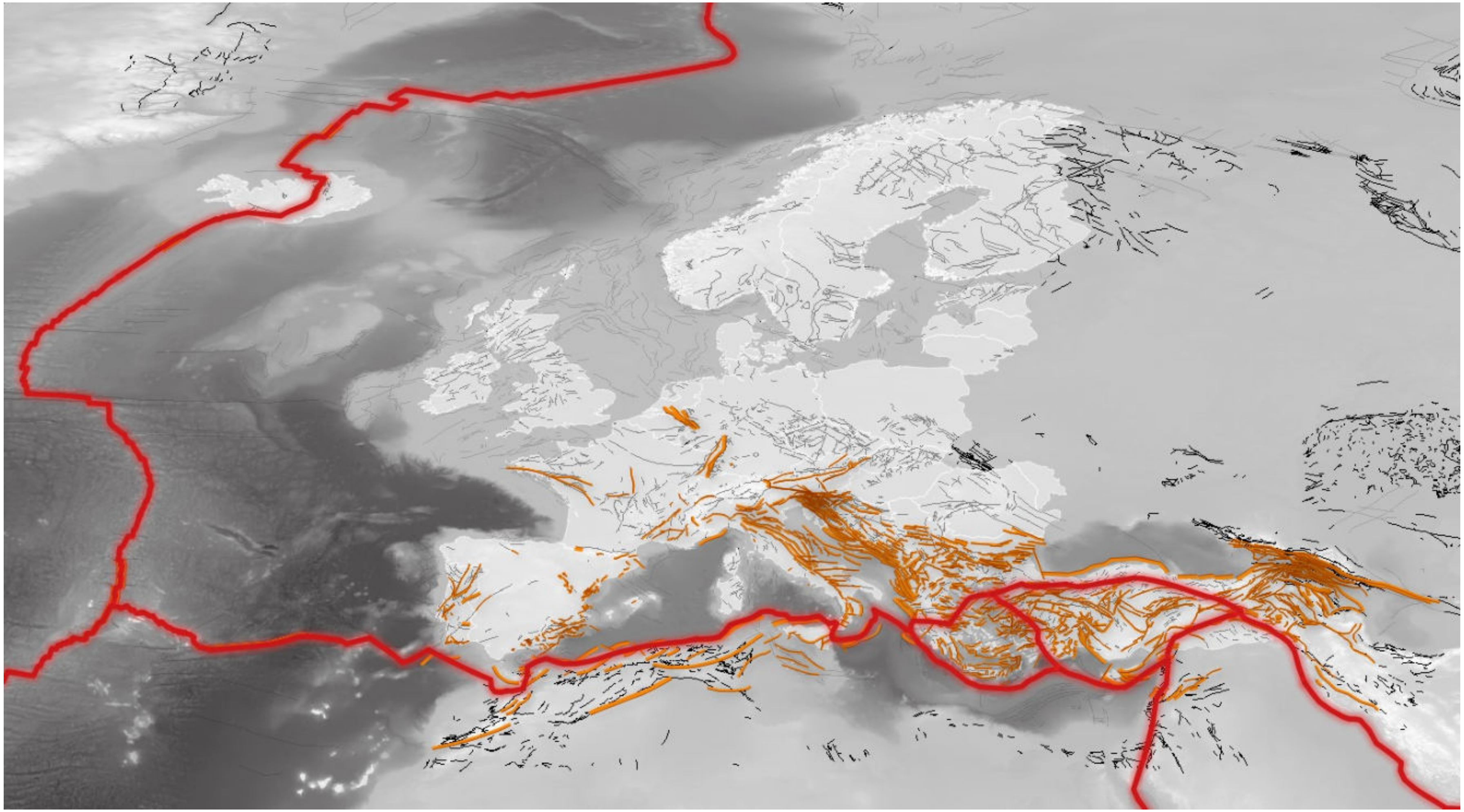
GSHAP, 2000

ESHM20: Unified Earthquake Catalogue



www.efehr.org

ESHM20: Active Faults



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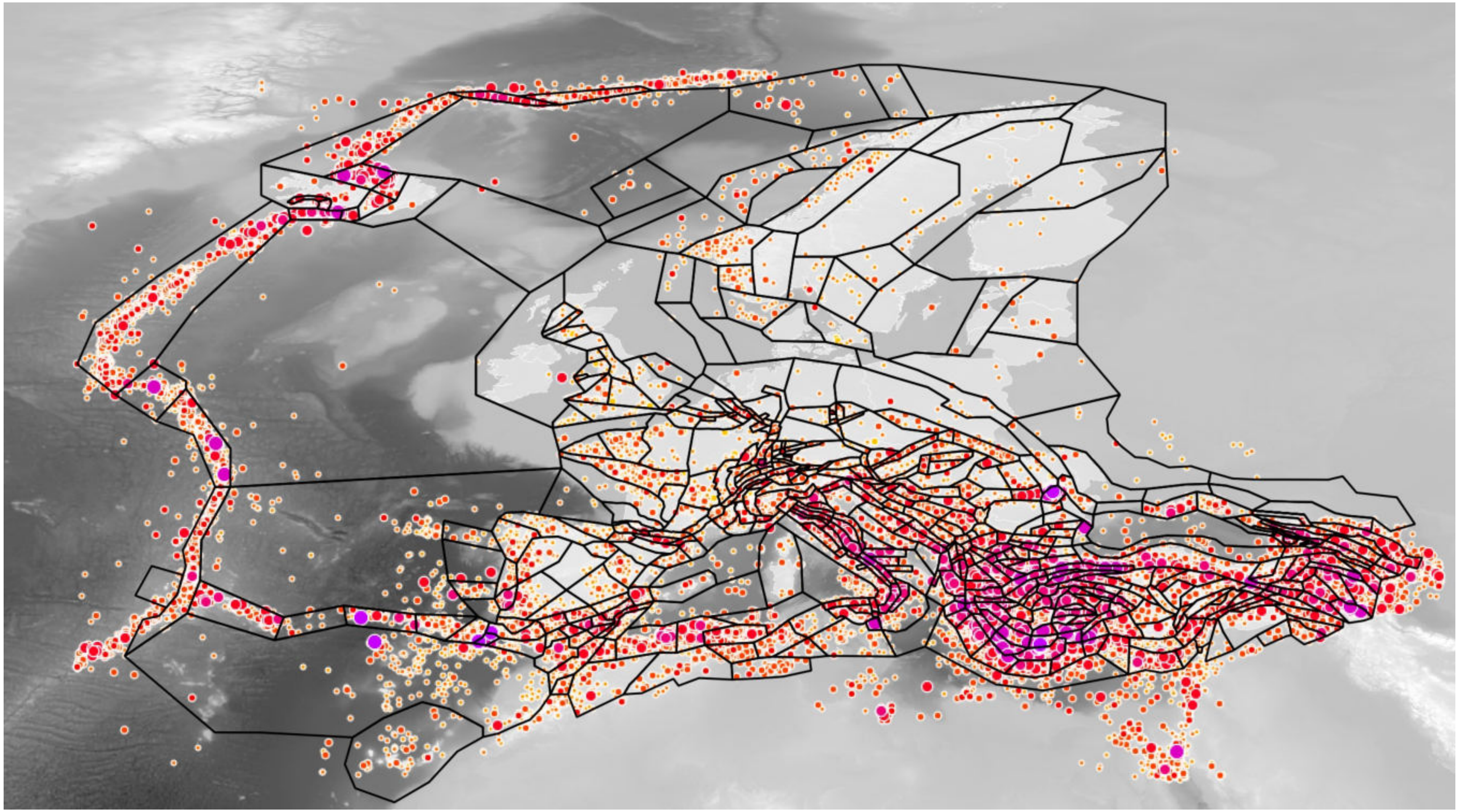
ESHM20: Seismogenic sources



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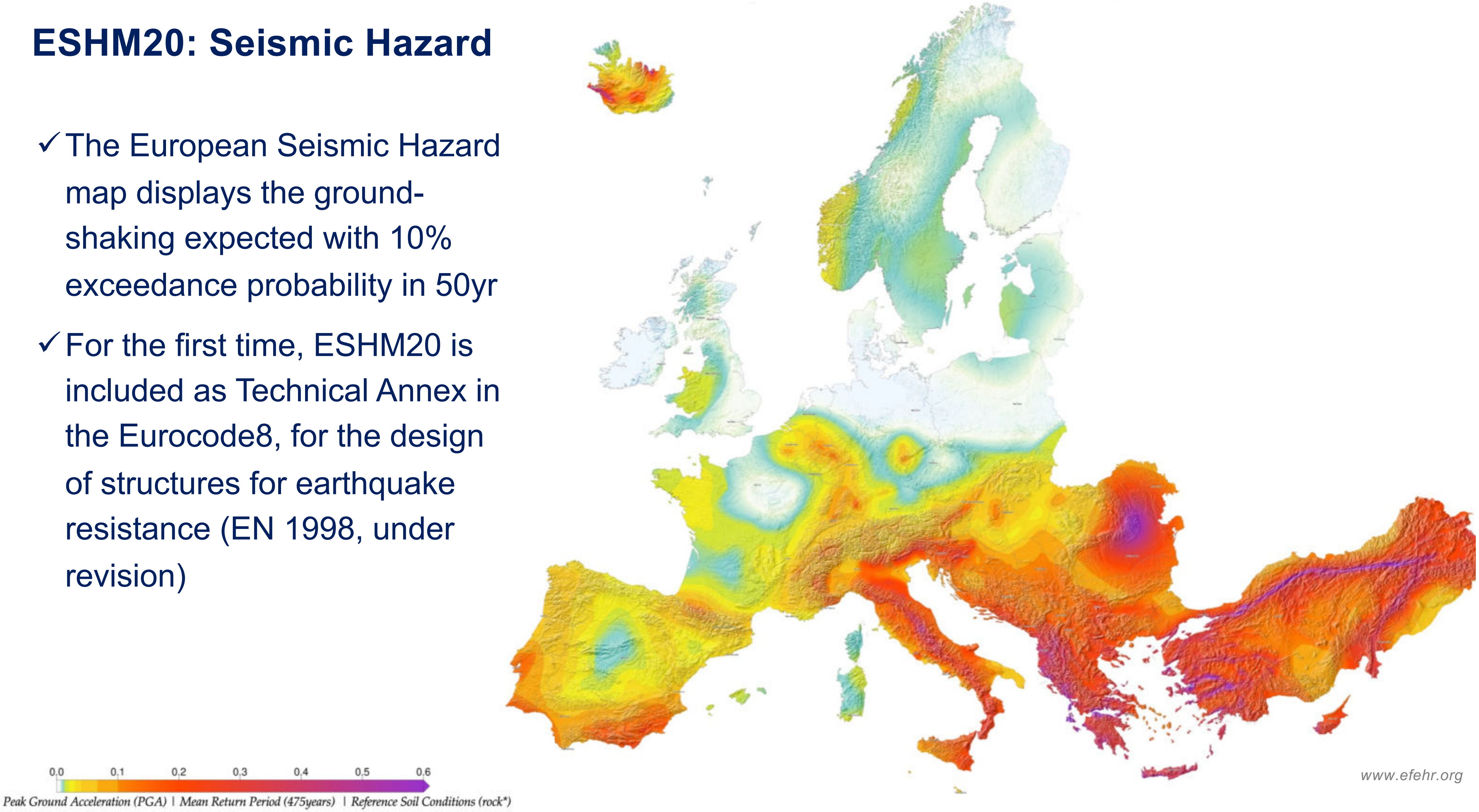
ESHM20: Seismic Hazard

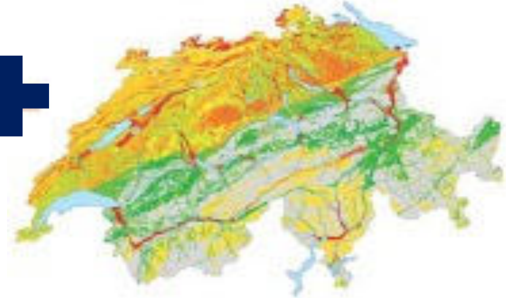
- ✓ The European Seismic Hazard map displays the ground-shaking expected with 10% exceedance probability in 50yr
- ✓ For the first time, ESHM20 is included as Technical Annex in the Eurocode8, for the design of structures for earthquake resistance (EN 1998, under revision)



From hazard to risk

Seismic hazard

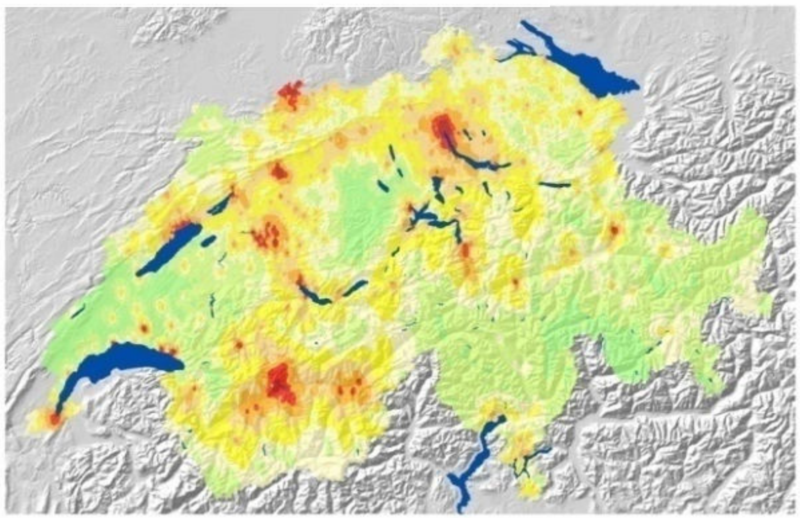
Local effects



Exposed value

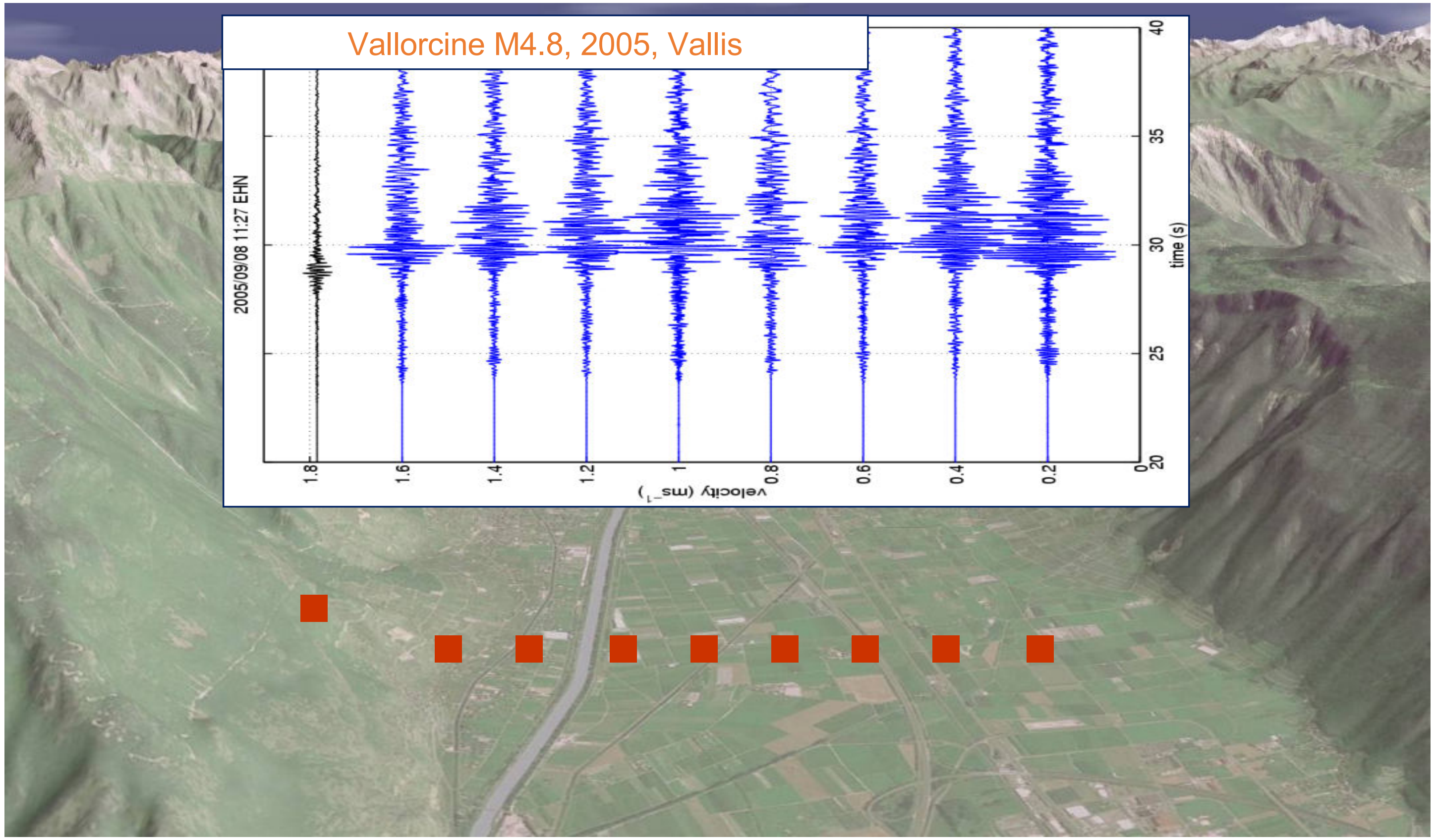
Vulnerability

Seismic risk



Risk concentrates
in urban areas !

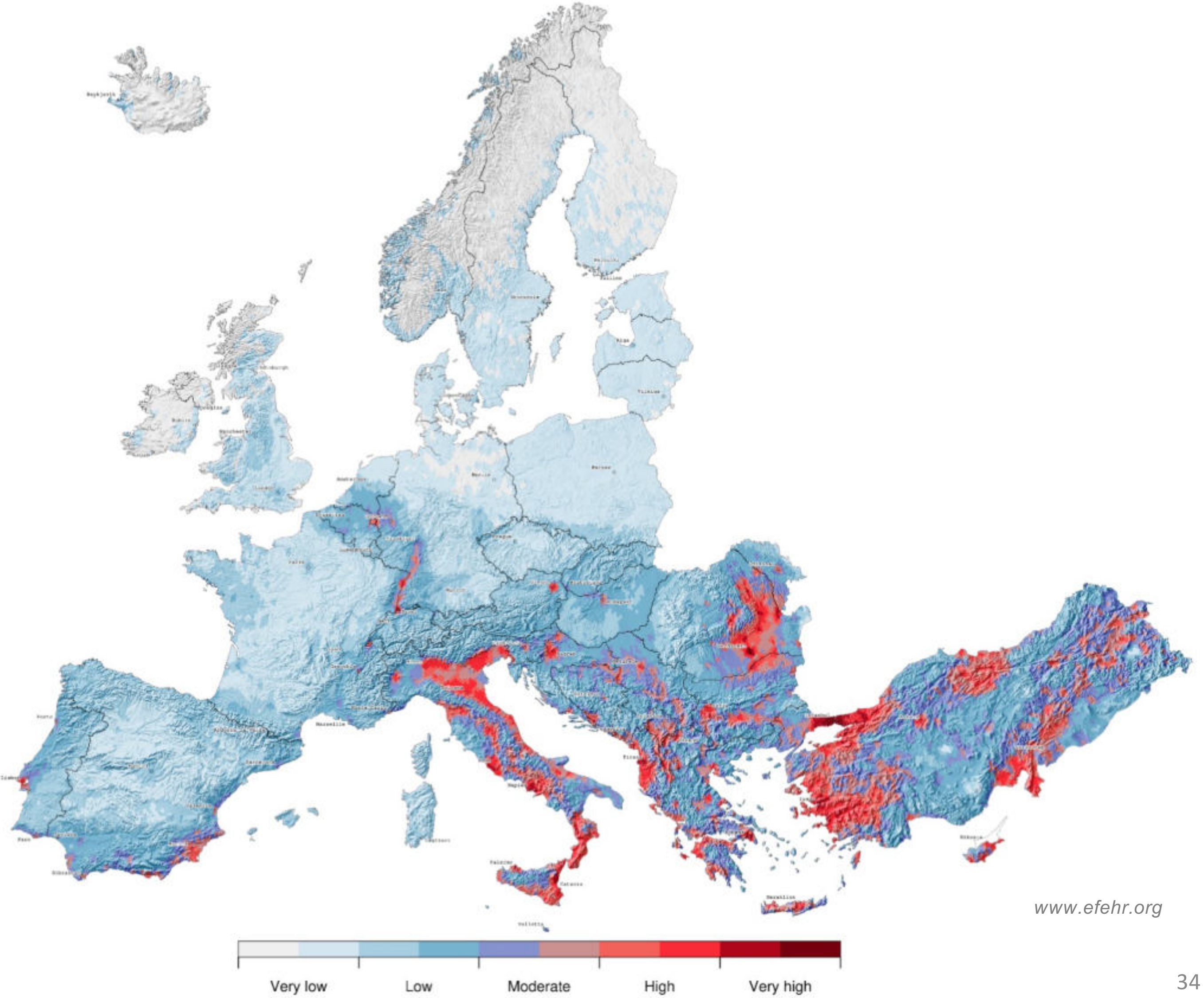
Site amplification in sedimentary valleys



Alpine valley, excavated by glaciers and filled by thick layers of fluvial sediment, trap seismic waves and produce important amplifications of the waves, which may become ten times higher and ten times longer than waves on hard rock.

ESHM20: seismic risk

Probabilistic assessment of the damage expected as consequence of future earthquakes, expressed in terms of casualties, building damage and economic losses.



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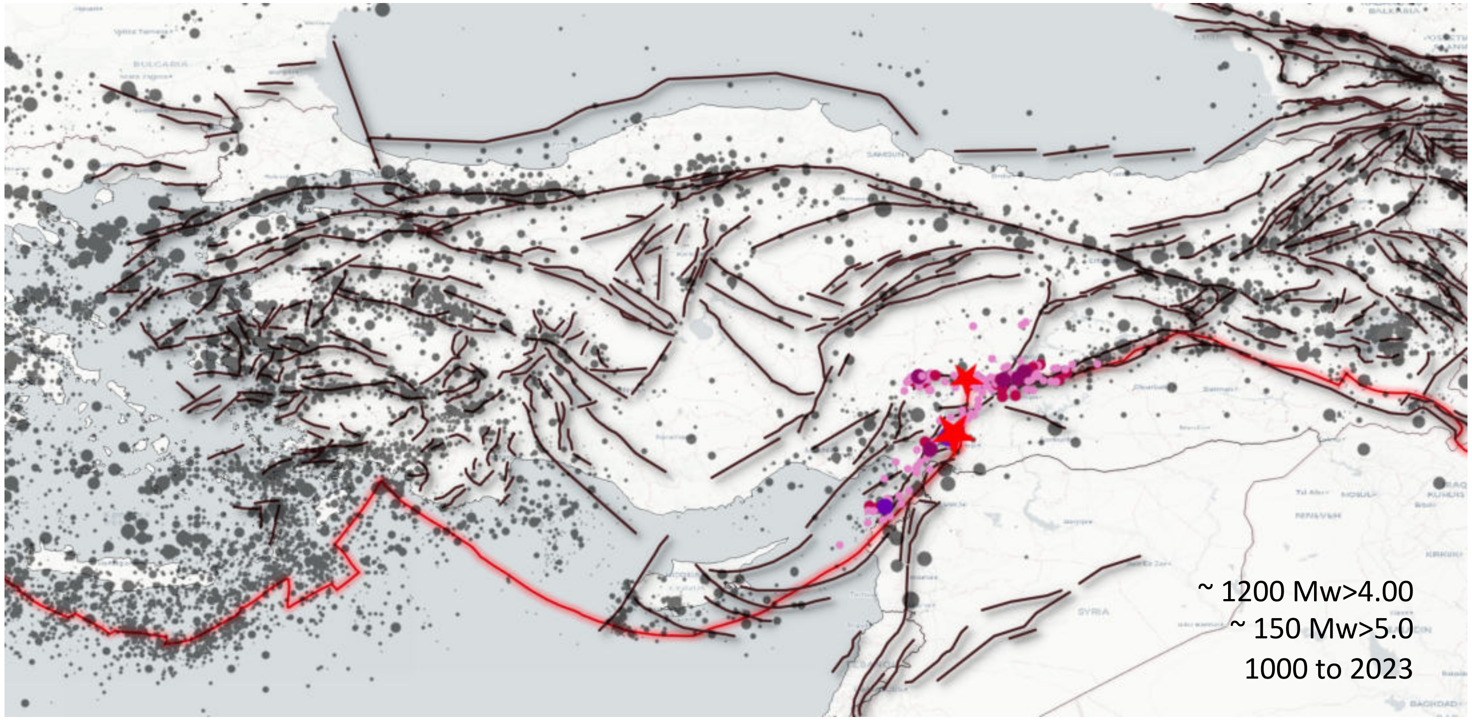
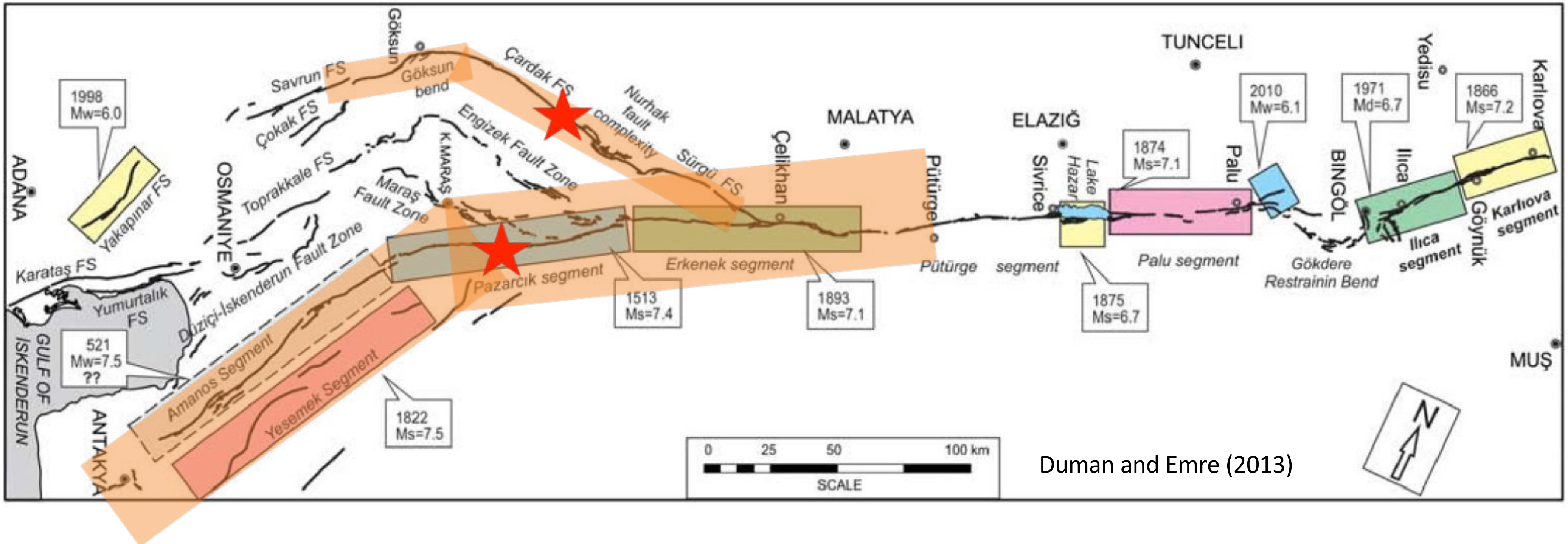
Location and size of next events

We have a very detailed knowledge of the tectonics, fault systems, seismic history and seismic potential of the Turkey region, we have excellent monitoring networks, we know where large events can occur, but …



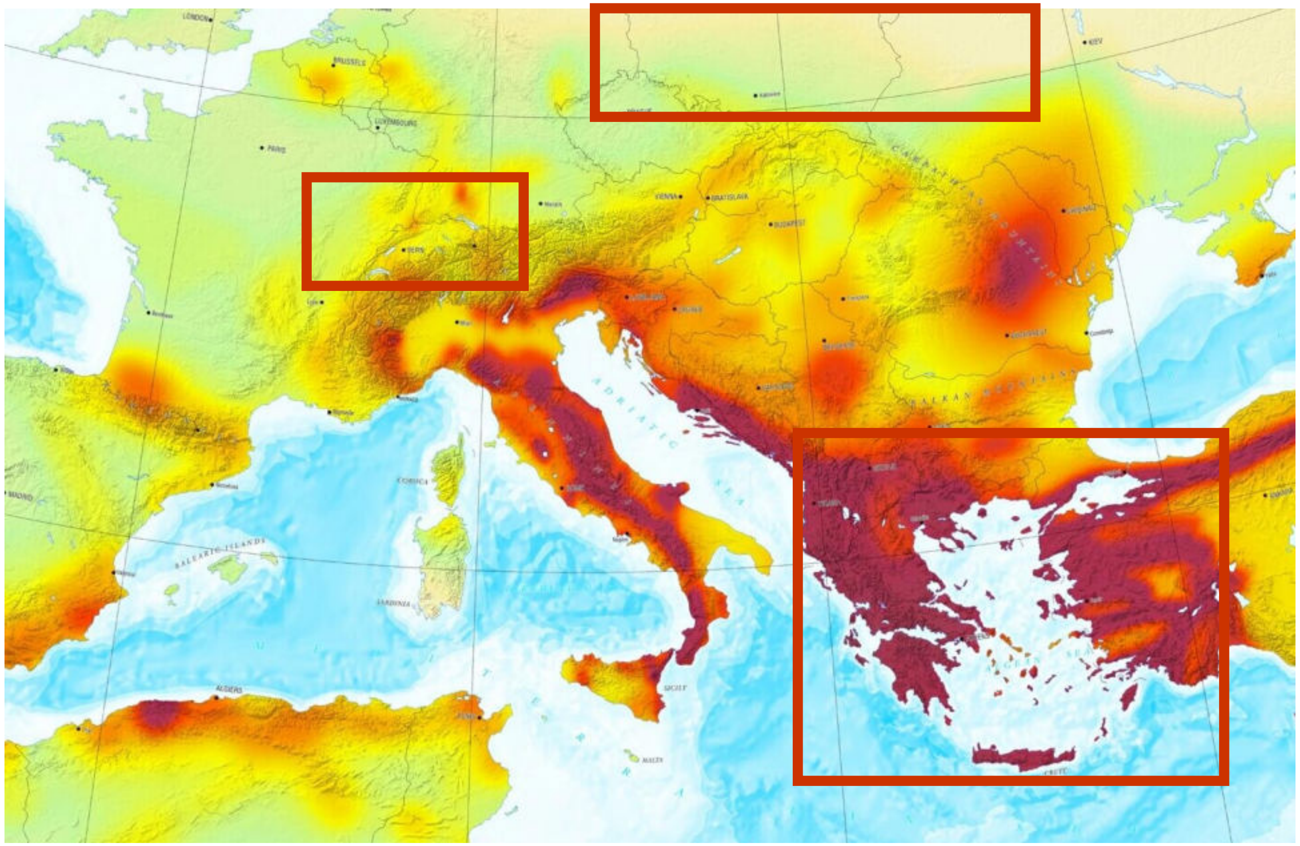
Location and size of next events

… we could not anticipate that the 2023 Turkey-Syria event was occurring, how large it would be, that a second large fault would be triggered the next day. Today the whole fault system to the South and to the NorthEast is stressed, but we are not able to anticipate where it will break next.

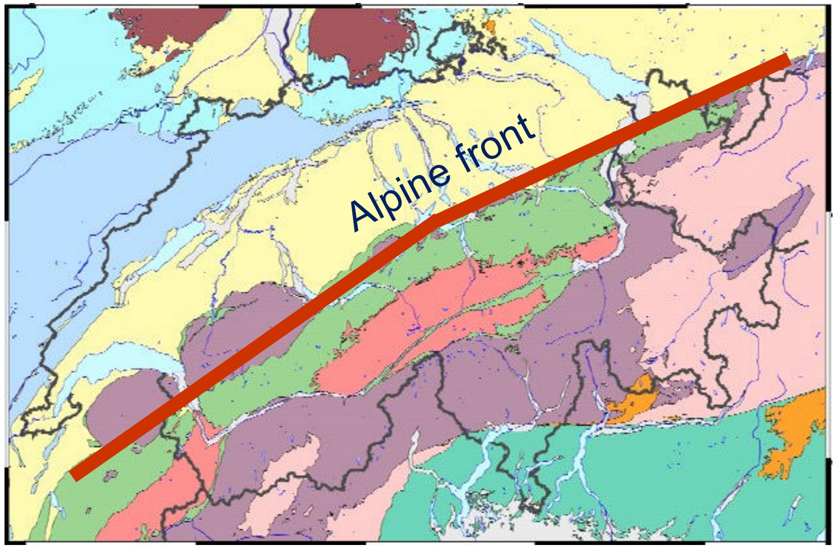


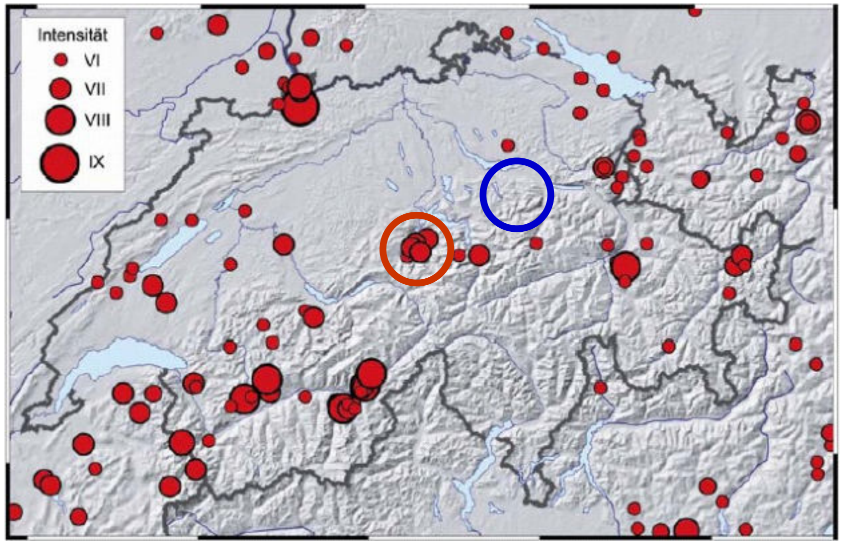
Red - Green - Yellow

We are more confident in red zones (where a 500yr period covers msot of the expected shaking and in green zones (where strong shaking is very rare). We have more difficulties with yellow zones, where strong shaking is expected beyond the hazard period.

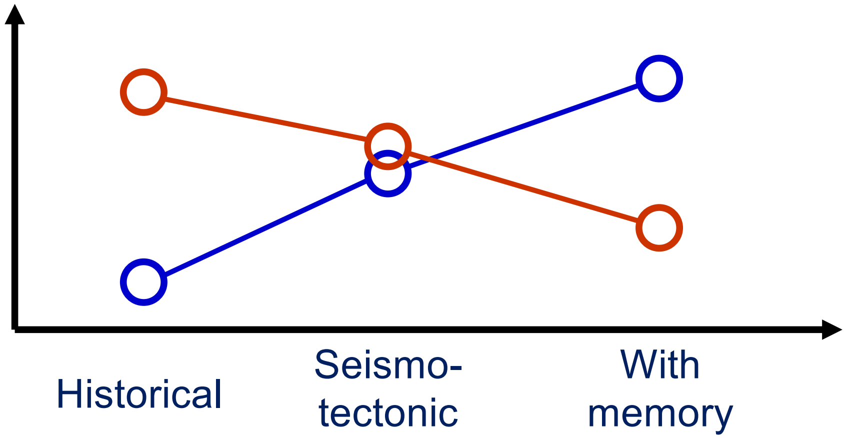


Location and size of next events



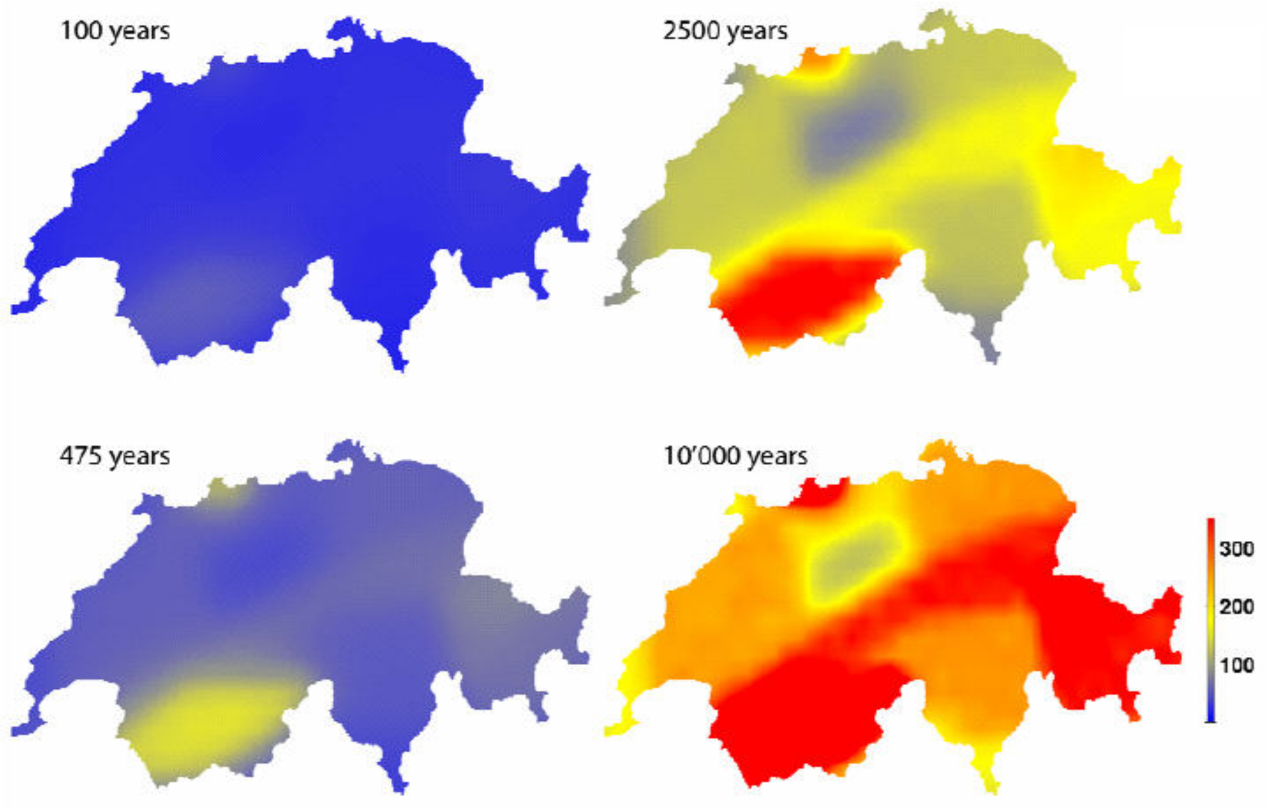


Three principal approaches to estimate seismic hazard, taking into account history and seismo-tectonics.



What level of hazard should we use?

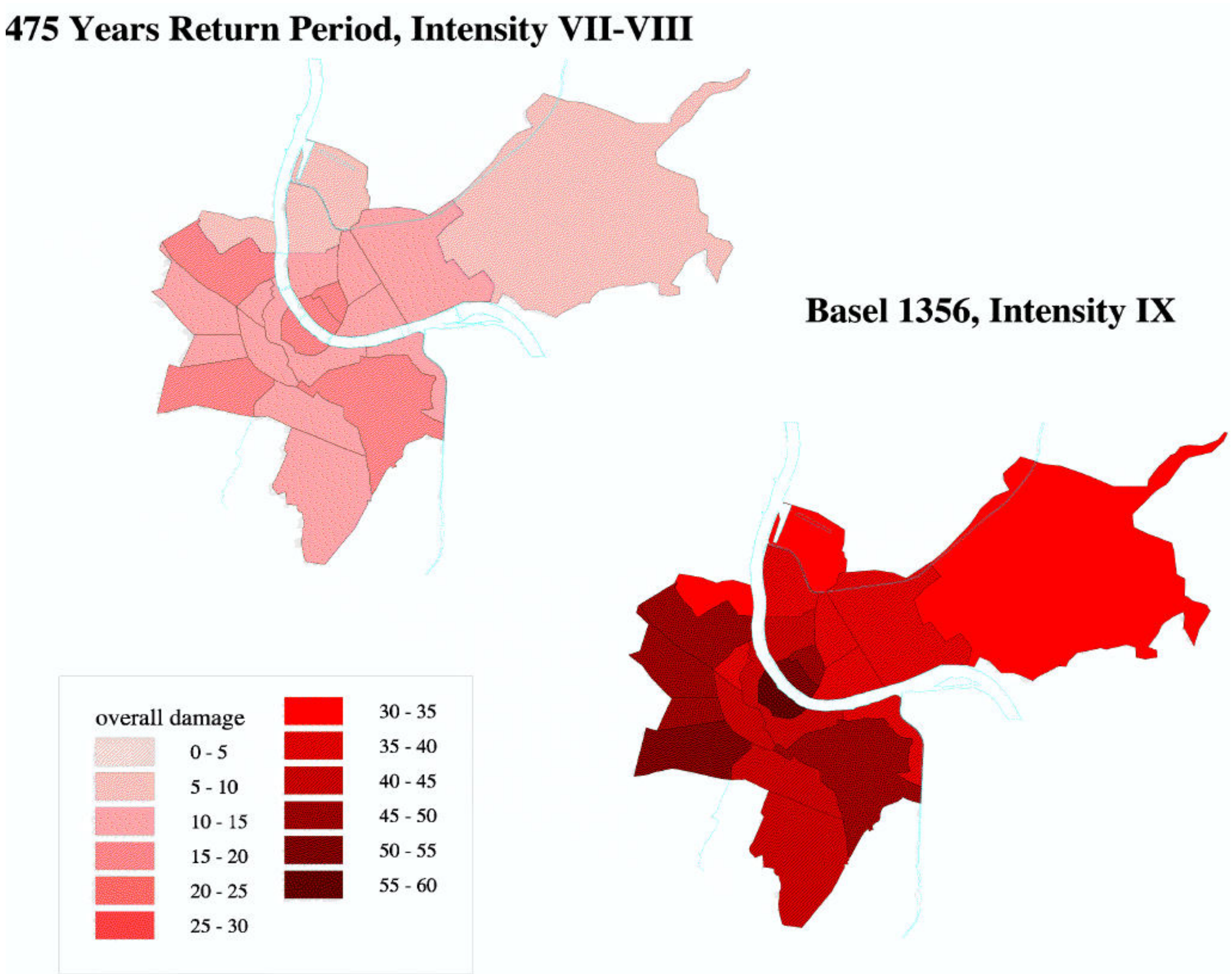
In areas of low-intermediate hazard, large shaking is expected only rarely and not everywhere. Expected shaking increases with return time and reaches the same levels as in active areas, but for small exceedance probabilities.



Seismic hazard of Switzerland. 5% damped horizontal acceleration response spectrum, 5Hz

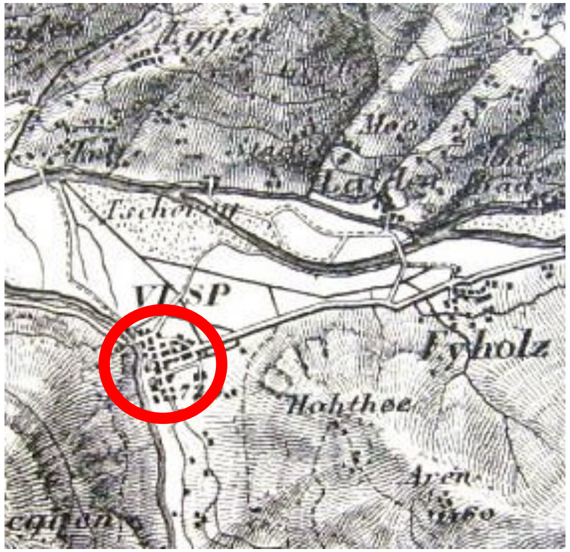
What risk should we cover?

In areas of low-intermediate hazard, the level of protection is lower than the shaking expected for the repetition of rare historical earthquakes (for example, the 1356 Basel earthquake).



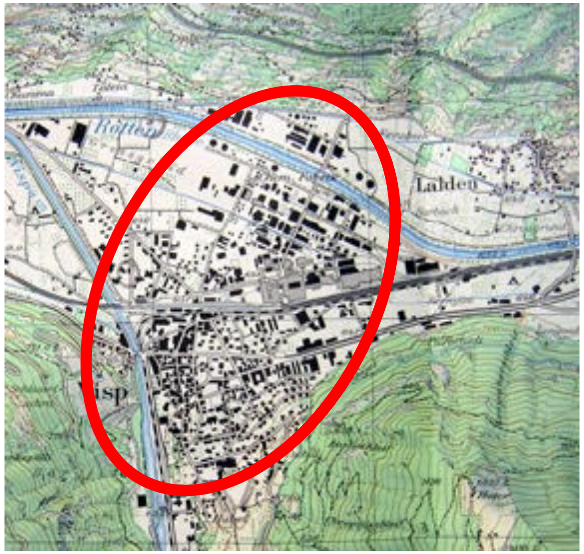
Short memory

- ✓ In 1850 Visp was a small village built on the side of the Rhone valley floor, to avoid floods.
- ✓ The 1855 earthquake provoked severe damage in the whole area; widespread liquefaction was observed in the sediments north of Visp, and further urbanization on the valley bottom was forbidden in the building zoning.
- ✓ Since then, the Rhone has been regulated twice and the flooding risk has sharply diminished; as consequence, Visp expanded and occupied the whole valley floor.



1850

1940

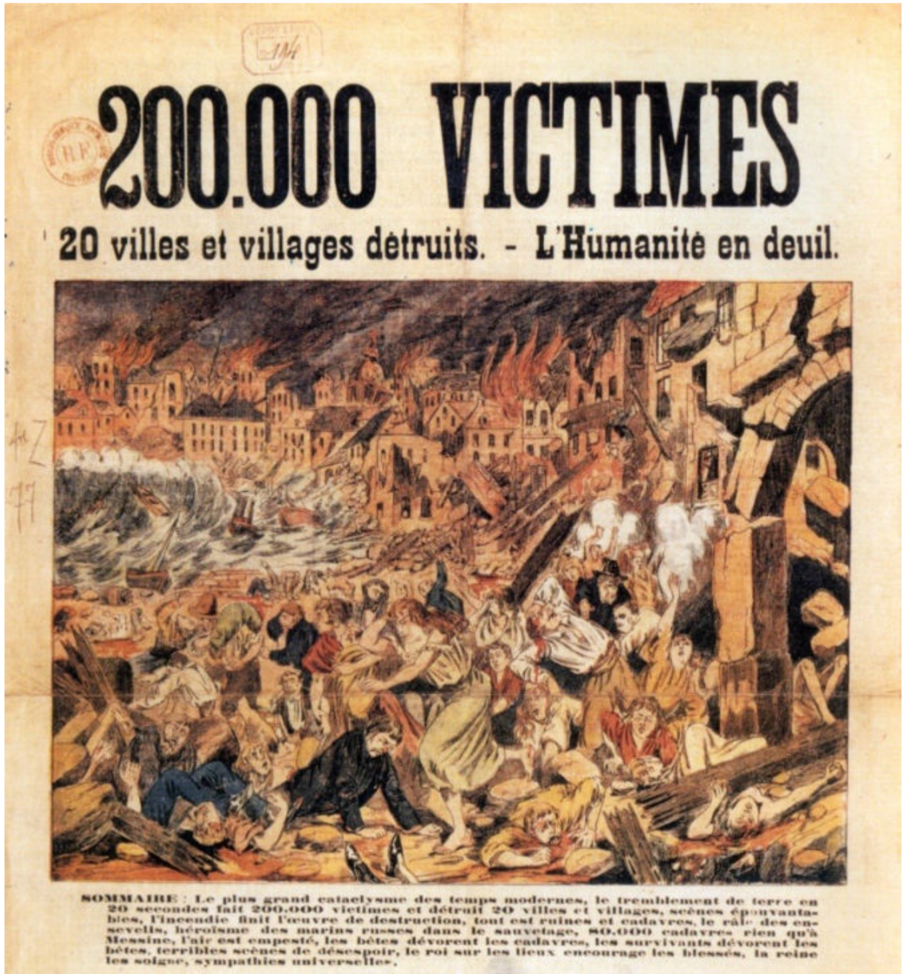


1980

Messina 1783

- ✓ The earthquake was the last of a long sequence of M6.5-7 evevnts in Calabria.
- ✓ 60% of population died due to the narrow alleys of the medioeveal city, which left no escape.
- ✓ The city was redesigned with larger roads and a wide sea-front boulevard, as refuge in case of earthquake.

Messina 1908



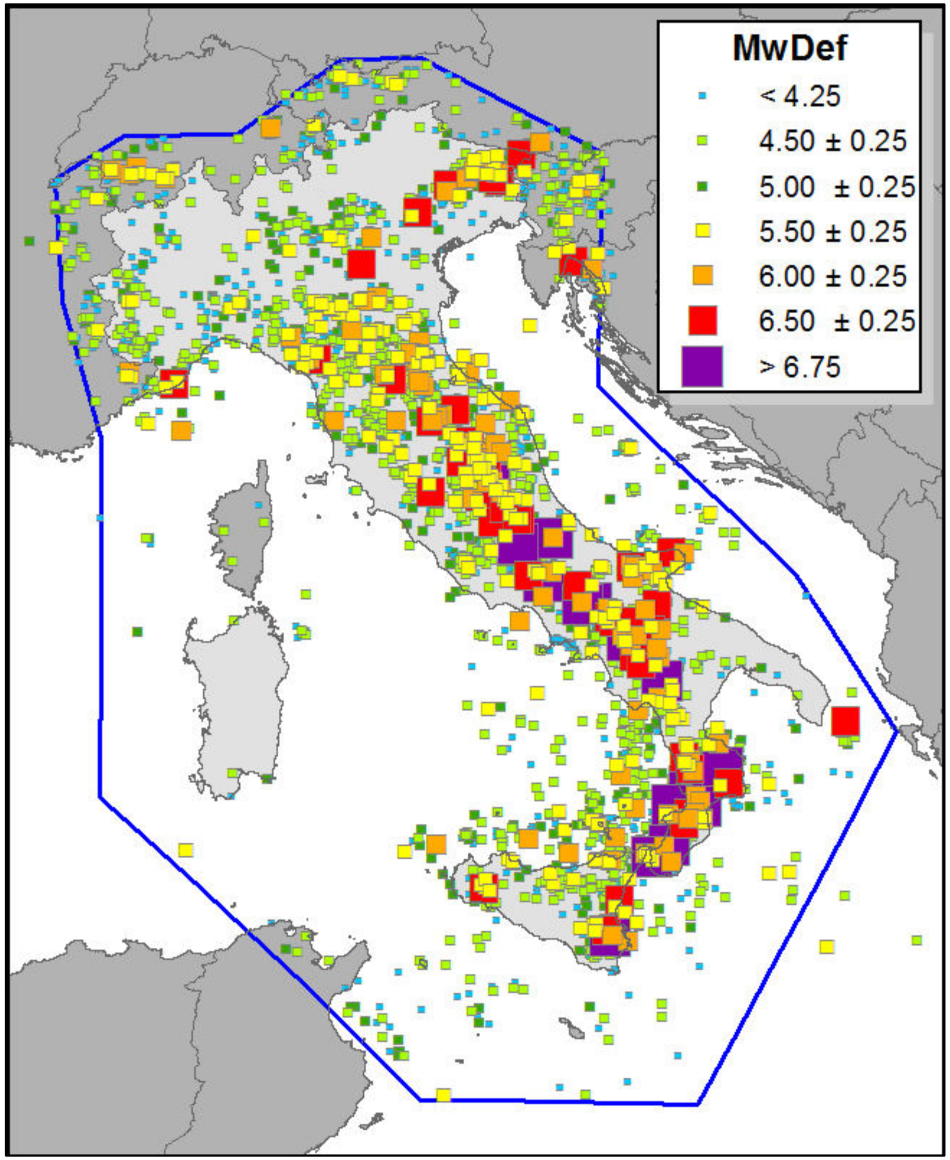
1908: the earthquake took place on the main graben fault of the Messina Straits. People found refuge on the sea-front and massive tsunami waves washed away over 60‘000 people, with total casualties of over 80‘000.

1911: the government implemented the Borzí plan to rebuild Messina according to the best seismic criteria.

1943: Messina was bombed to rubble by the US allies in WW-II, and was reconstructed after the war

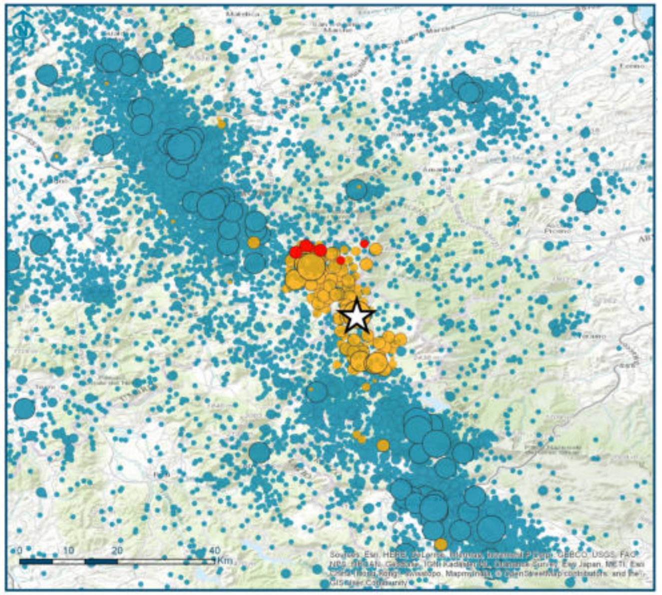
Messina today: a disaster waiting to happen

Are we prepared?



Umbria-Abruzzo-Marche 2016-2017

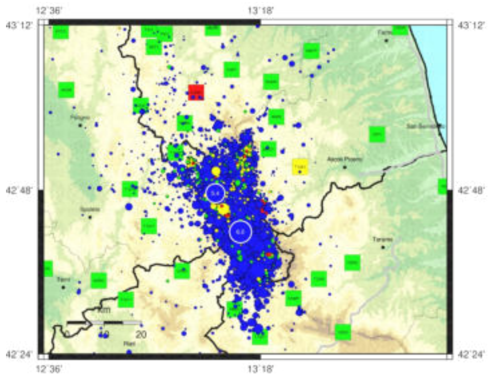
- ✓ Well known seismic history and tectonics
- ✓ The sequence hit a gap area in the Central Apennines between areas already hit by damaging quakes in the past 30 years
- ✓ The region had already implemented mitigation measures, but the damage in Amatrice and other villages was total loss



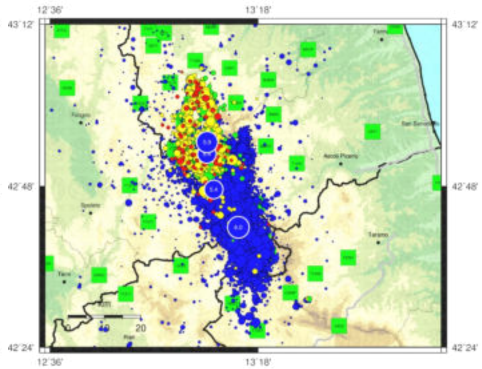
Umbria-Abruzzo-Marche 2016-2017

- ✓ The sequence lasted 8 months, breaking several faults
- ✓ This is a common pattern in the seismic history of the Central Apennines, but we miss the ability of forecasting duration and complexity of the sequence
- ✓ The October 30, M6.5 event did not produce any fatality, as the whole area had been evacuated
- ✓ 100’000 buildings lost

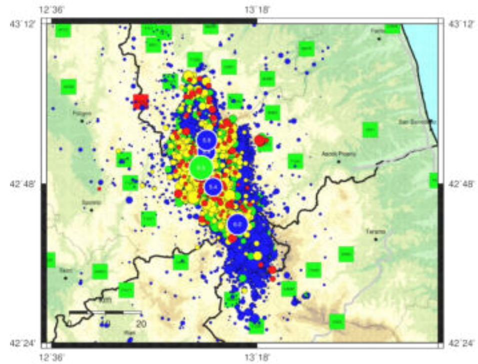
17.10.2016



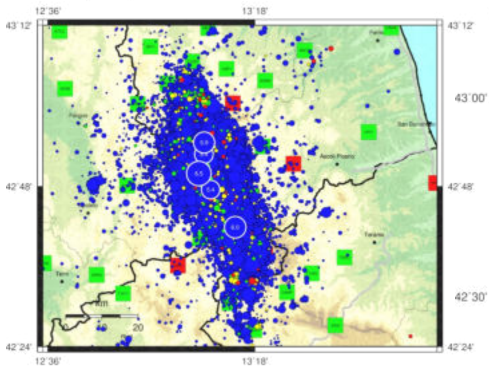
29.10.2016



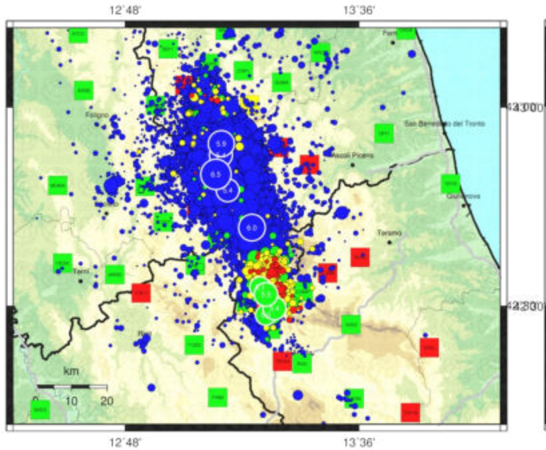
1.11.2016



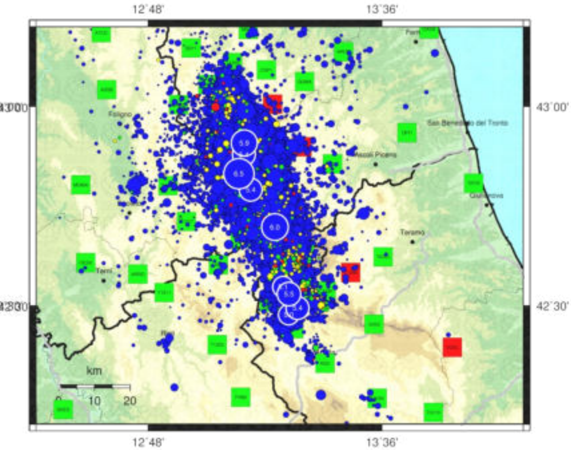
16.1.2017



20.1.2017



2.2.2017



Messages to take home

- We learn from past disasters and today we are much better at mitigating the catastrophic consequences of natural events. However, all elements of risk (hazard, exposure, vulnerability) are increasing and we are increasingly vulnerable to larger events.

- Zero-risk is not possible and should not be a target; all our mitigation strategies have limits and we cannot protect against all possible events. We need to define the risk levels acceptable for our society, communicate them clearly and work to protect them.

- A good assessment of hazard and risk is the first step for a sound policy of risk mitigation: we need to know how much risk we are protecting and how much risk we are taking. Catastrophes should not come as surprise.

- We need to focus on all three phases of the risk cycle: preparation, intervention and recovery. Preparation needs decades: we can't wait for an event to start preparing for the next.

- We are improving, there is hope !

Haiti, 2009