

**“Verso una nuova mappa della pericolosità sismica”
Regione Emilia-Romagna, Servizio Geologico, Sismico e dei Suoli
Bologna, 5 Luglio 2013**

**Perché una nuova stima di pericolosità?
Limitazioni delle valutazioni precedenti**

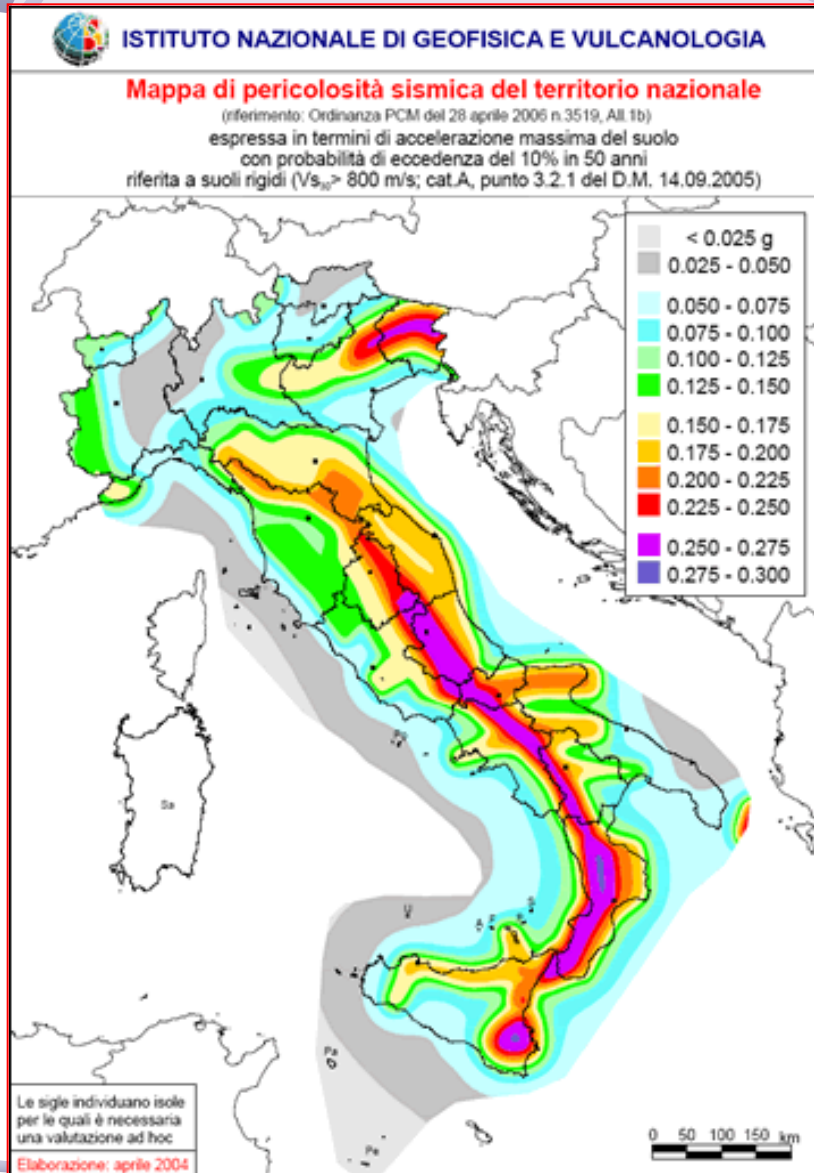
**Marcello Viti
Dipartimento di Scienze Fisiche, della
Terra e dell'Ambiente,
Università di Siena**

Probabilistic Seismic Hazard Analysis (PSHA)

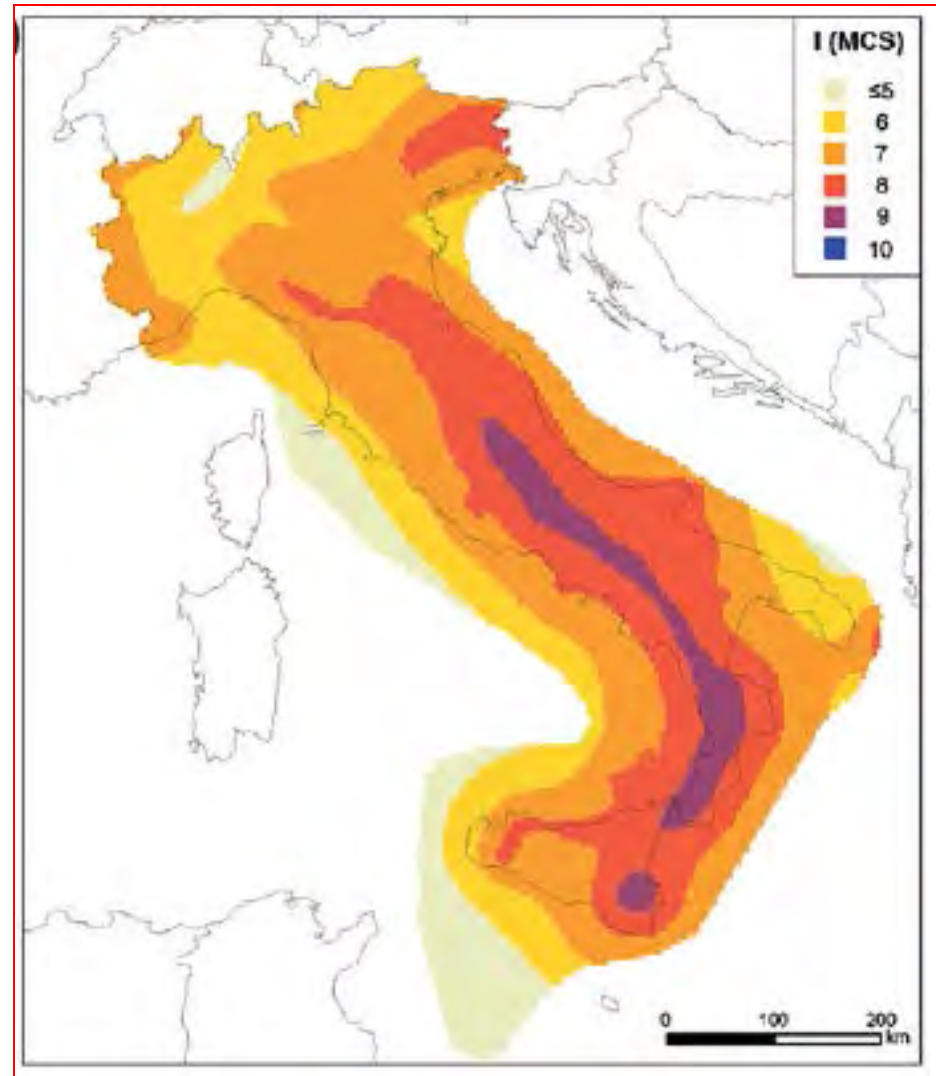
(Cornell, 1968; McGuire, 1978; Algermissen e Perkins, 1976; Frankel et alii, 2000)

- Frequenza con cui avvengono terremoti di differente magnitudo nelle varie sorgenti sismiche della regione considerata (analisi della storia sismica)**
- Propagazione degli effetti prodotti da ciascun terremoto dalla sorgente sismica al sito di interesse**
- Ampiezza massima dello scuotimento sismico (accelerazione, velocità, spostamento o intensità macrosismica) che verosimilmente interesserà in futuro il sito considerato (per es. nei prossimi 50 anni)**

Carte di pericolosità



Gruppo di Lavoro MPS (2004)



Gomez et alii (2010)

Limitazioni della procedura PSHA

E' basata sull'assunzione che l'attività sismica sia stazionaria nel tempo. Le previsioni sull'andamento temporale della pericolosità sono poco attendibili perché basate sulla stima dei tempi di ritorno dei terremoti forti, che è estremamente incerta a causa del breve intervallo di tempo coperto dai cataloghi sismici (solo alcuni secoli)

Le zone sismogenetiche vengono considerate indipendenti tra loro, in contrasto con le evidenze di interazione tra le sorgenti sismiche:

“For example, assumptions such as “independence” or “stationarity” are never actually verified in natural systems. Strictly speaking, a Poisson process (or any process) is a theoretical construct, and the transition from theory to reality must be managed at the risk of the user.” [Castanos and Lomnitz, 2000]

“In fact, Kagan et al. (2012) argue that models and hypotheses such as the “seismic cycle” (or “earthquake cycle”), “seismic gap,” and “characteristic earthquake” are not supported by the data. The reason for the failure of these models and hypotheses is probably the highly non-linear nature of earthquake occurrence, but this remains the subject of ongoing research.” [Stein et al., 2013]

“Faults usually are not isolated features but exist within a population of faults which may interact through their stress fields. This poses two serious problems for seismic hazard analysis. The most severe of such problems lies in estimating the likelihood of whether or not a future earthquake will be confined to a single fault (or fault segment) or will jump to adjacent faults and result in a larger earthquake... The second problem discussed is the hazard associated with earthquakes being triggered by earlier earthquakes on a different fault. This phenomenon produces seismic hazards distinct from that associated with ordinary aftershocks.” [Scholz e Gupta, 2000]

“A big earthquake can perturb the regional stress field and may trigger earthquakes in neighboring regions and faults... Many of the triggered earthquakes occur in years to decades after the triggering earthquake because of stress changes from post-seismic viscous relaxation and perturbations by other earthquakes.” [Lou e Liu, 2010]

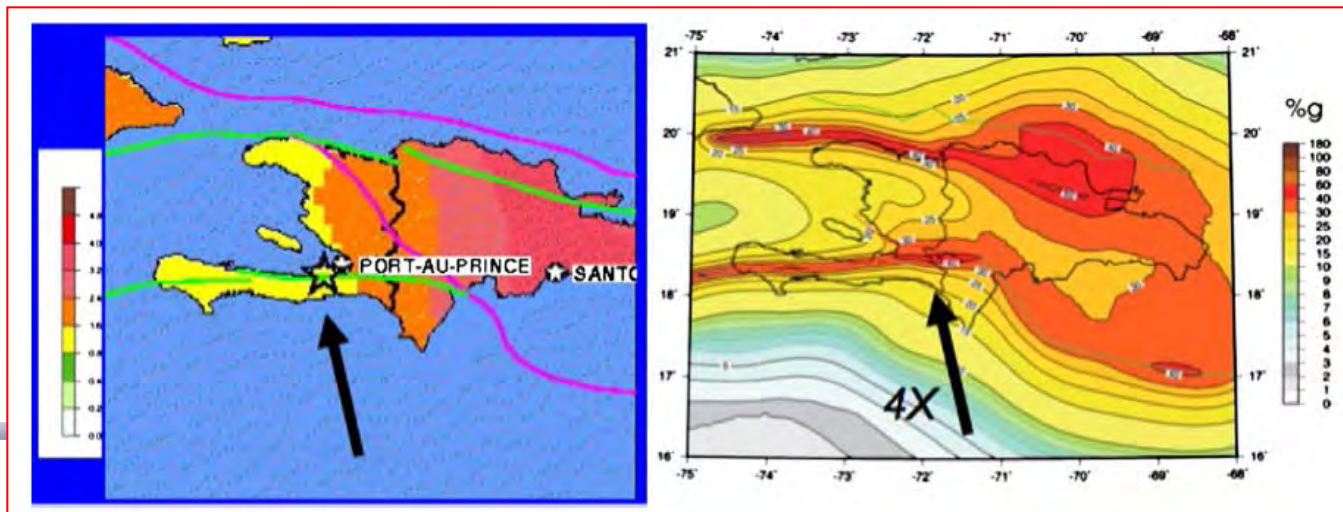
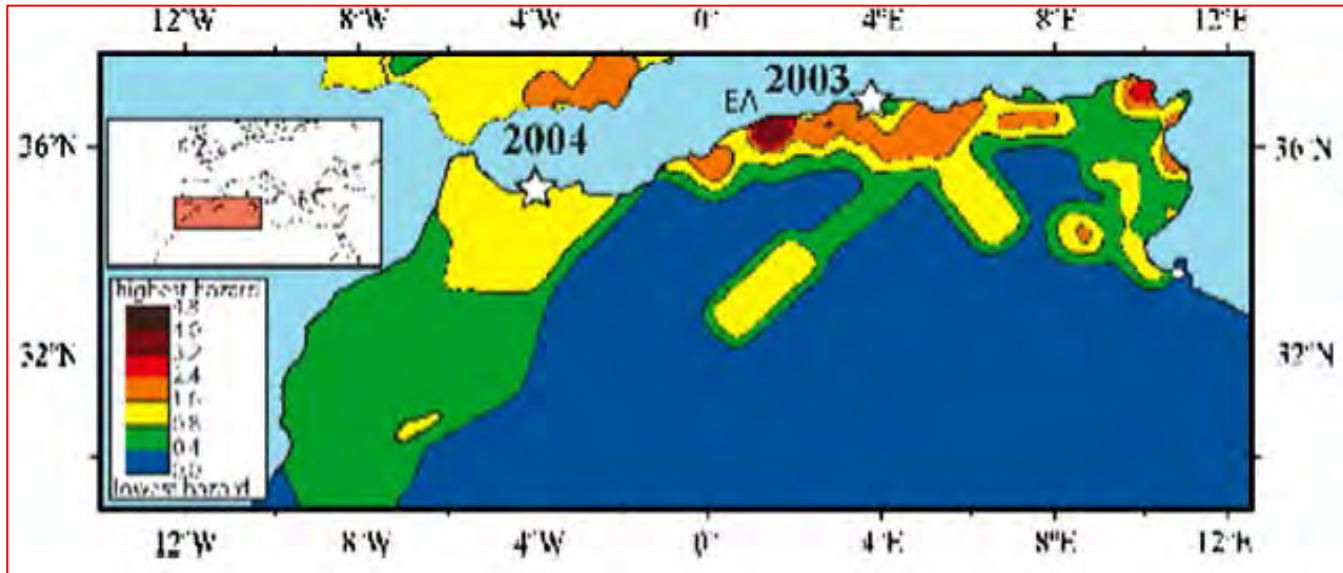
Essendo i terremoti forti eventi naturali relativamente rari, le osservazioni disponibili sullo scuotimento (registrazioni accelerometriche e simili) sono scarse. Ciò rende poco praticabile la valutazione dell'affidabilità delle previsioni proposte:

“As is well known from a statistical point of view, it is not possible to validate a probabilistic hazard estimate with data observed for a single earthquake: indeed, on one side, there is a ground-motion value expected with a certain probability of occurrence, while, on the other, there is just one observed value and we cannot know if it represents the maximum expected value, the most probable value, or something else.”

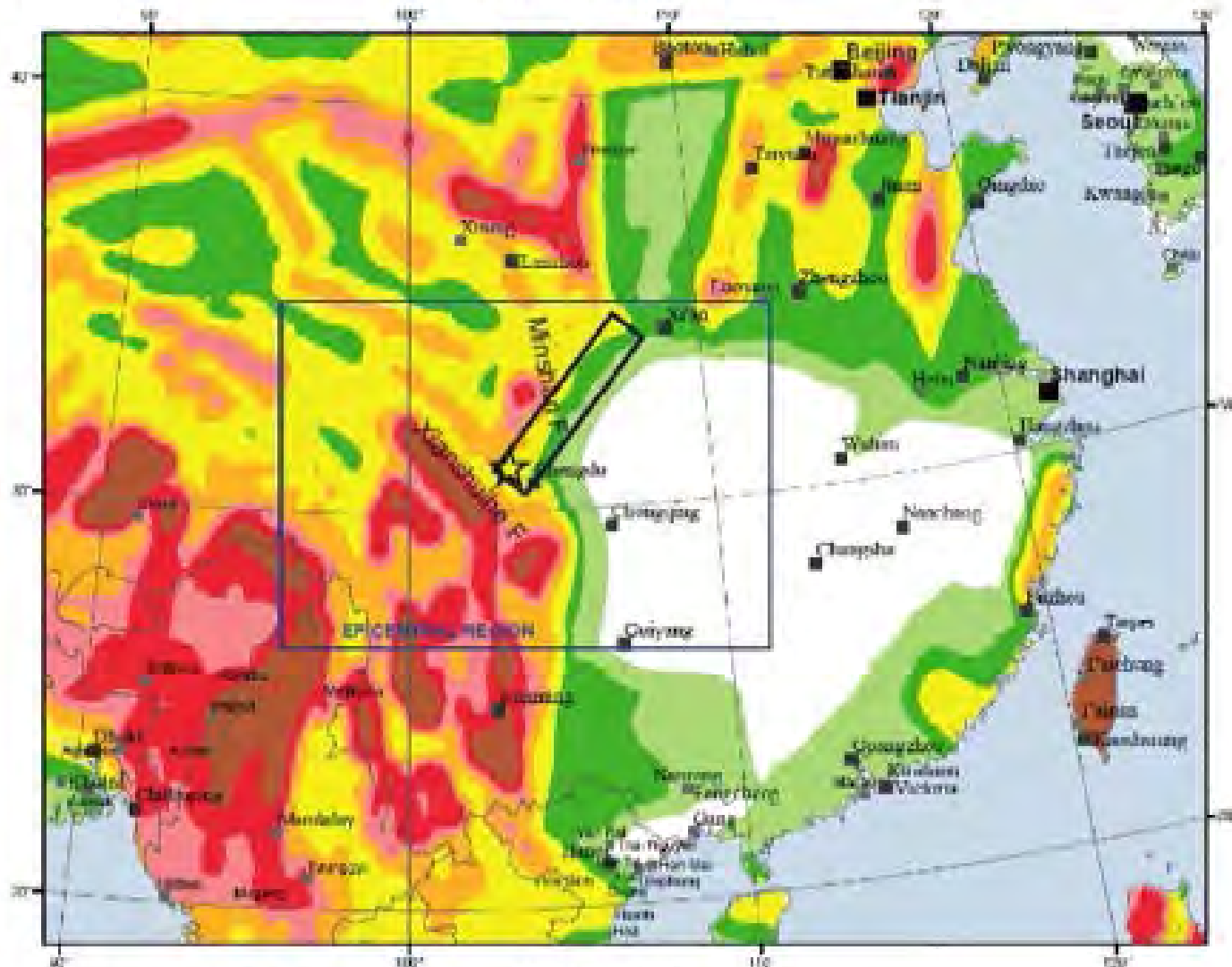
“On the contrary, a meaningful way to assess the reliability of a PSHA map, e.g., for a 475-year return period, should be to observe whether, over a period of 50 years, more than 10% of the computational sites have experienced ground motions higher than those predicted [see e.g., Albarello and D'Amico 2008]; indeed, even several consecutive 50-year periods of observations would be required to make this test robust.”
[Meletti et alii, 2012]

“It is difficult to objectively test a seismic hazard map showing ground motions with a low probability, 10% or 2%, of being exceeded over 50 years, corresponding to an annual probability of 0.0021 and 4×10^{-4} , respectively. One would need a very long record of earthquakes and ground motions in a given region to test such low probability hazard maps for that region (Beauval et al., 2008). The length of the seismicity record would have to be several times the reciprocal of the annual probability of the map (at least 10,000 years for a map with 2% probability of exceedance in 50 years).” [Frankel, 2013]

Le carte di pericolosità sismica elaborate con la PSHA hanno ripetutamente sottostimato lo scuotimento sismico nelle zone del mondo colpite di recente da forti terremoti (per es. Algeria 2003, Marocco 2004, Cina 2008, Haiti 2010, Nuova Zelanda 2010 e 2011, Giappone 2011; e.g., *Stein et alii, 2012*)



Seismic Hazard



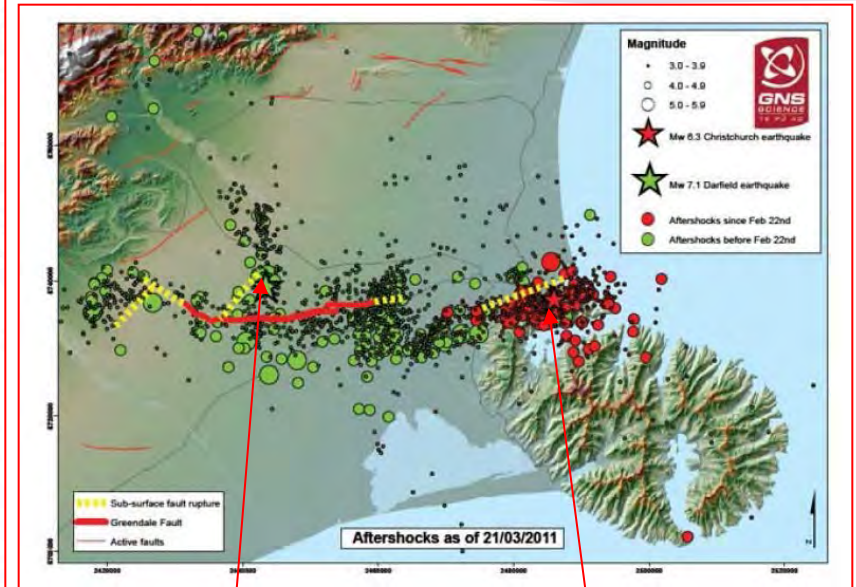
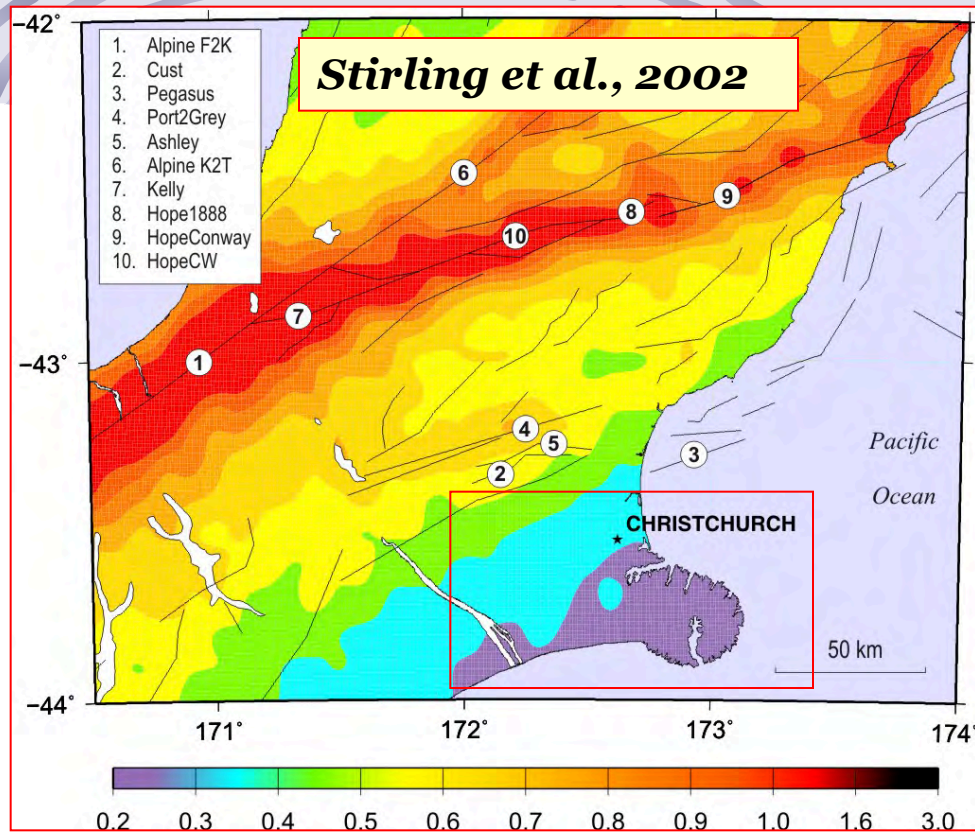
Seismic hazard is expressed as peak ground acceleration (PGA) on firm rock in m/sec^2 , reported to be exceeded in a 50-yr period with a probability of 10 percent.

Scale 1:15,000,000

0 200 400 600 800 1,000 Kilometers

Peak Ground Acceleration in m/sec^2





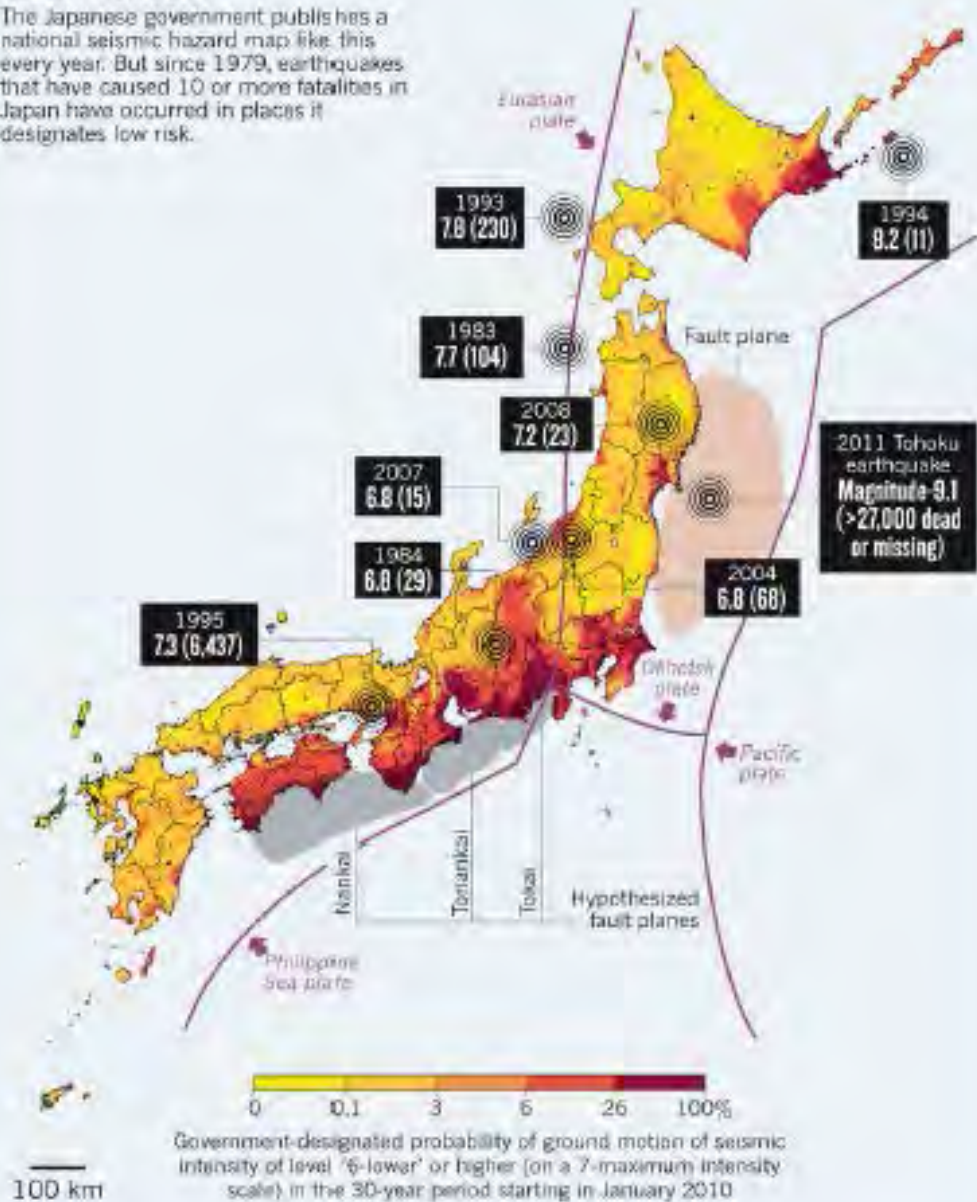
$PGA = 1.26 \text{ g}$

$PGA = 2.20 \text{ g}$

“The problem is that the extreme ground motions recorded for both the M 7.1 mainshock and M 6.3 aftershock were greater than this model predicted (even at 10,000-year return periods for the case of the M 6.3 aftershock).” [Reyners, 2011]

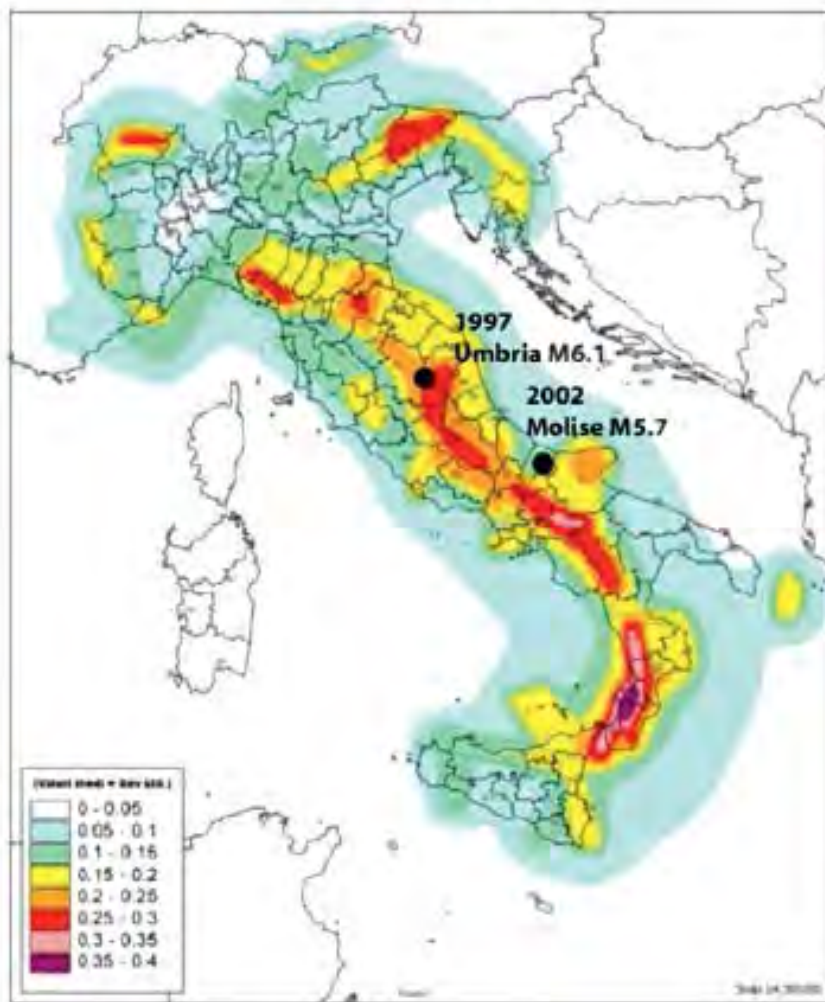
REALITY CHECK

The Japanese government publishes a national seismic hazard map like this every year. But since 1979, earthquakes that have caused 10 or more fatalities in Japan have occurred in places it designates low risk.

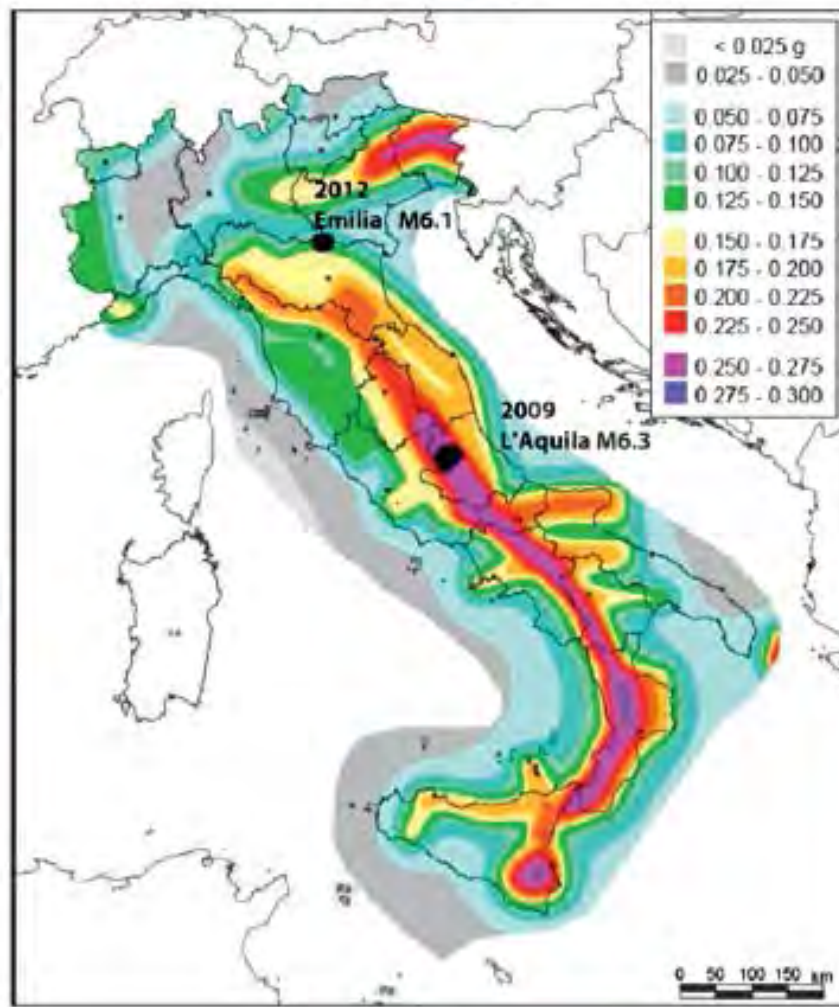


“The 1999 map (Albarello et al., 2000) was updated after the missed 2002 Molise earthquake and the 2006 map (INGV, 2006) will be updated after it missed the 2012 Emilia earthquake.” [Stein et al., 2013]

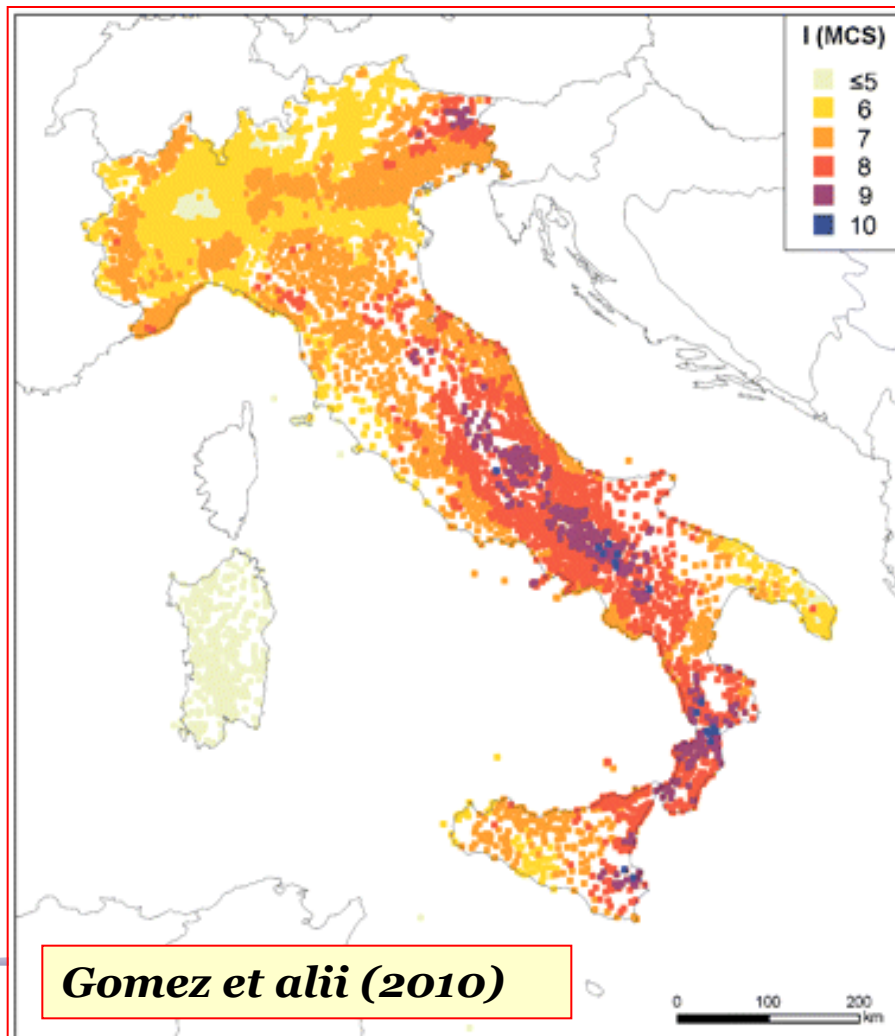
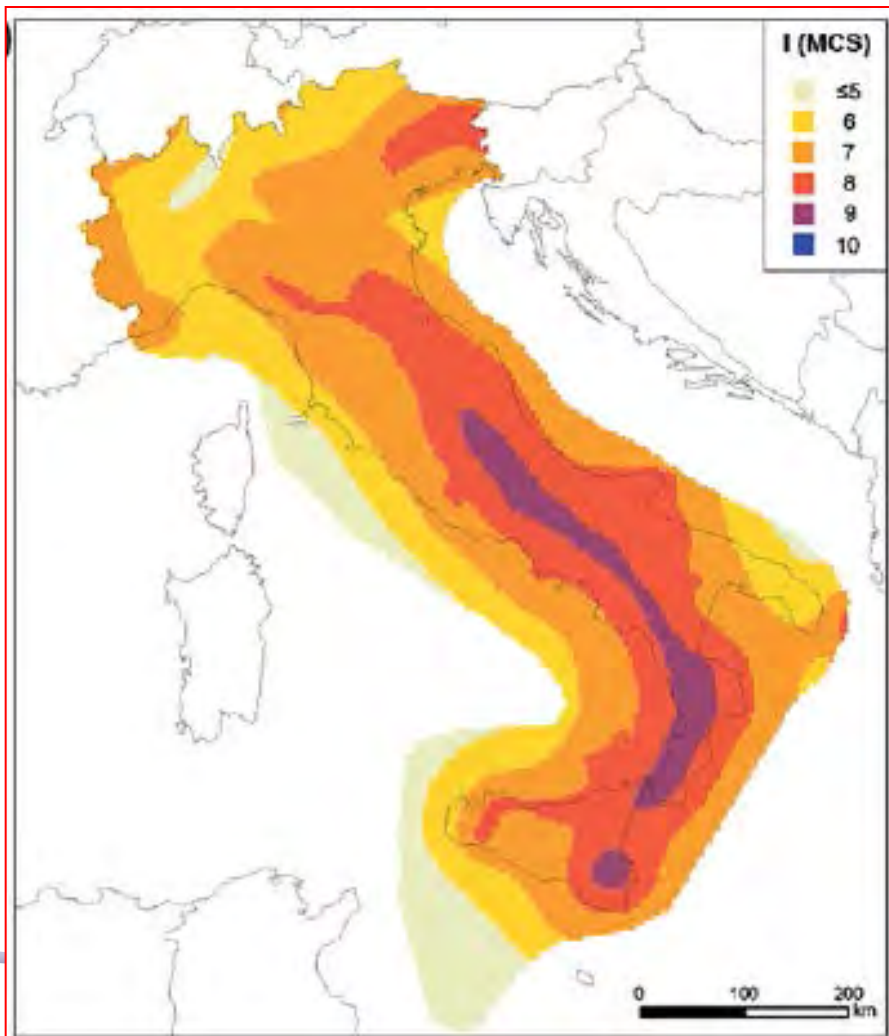
1999 Map



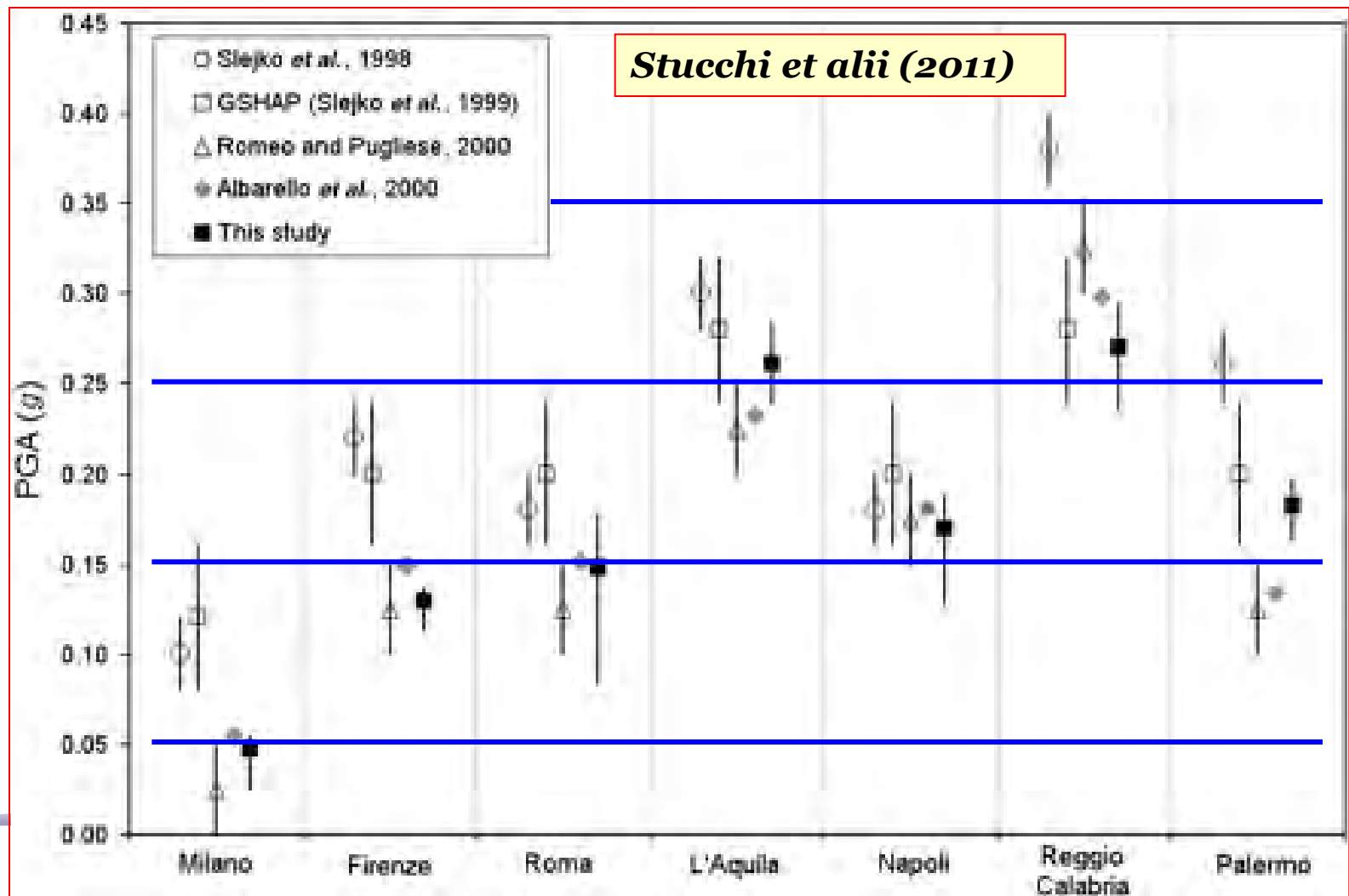
2006 Map



La procedura PSHA è stata messa a punto per zone, come gli Stati Uniti, dove i dati disponibili sono prevalentemente di tipo strumentale. Per l'Italia, invece, oltre il 70% degli eventi sismici maggiori è descritto da informazioni macrosismiche. Ciò impone di trasformare i dati disponibili (intensità MCS) in termini di parametri di sorgente (magnitudo)



La procedura richiede la definizione di molti parametri (per es. i tassi annuali di sismicità e le curve di attenuazione) e la valutazione delle rispettive incertezze. L'assegnazione dei parametri dipende dalle scelte più o meno personali degli autori (per. es. l'uso degli “alberi logici”), le quali possono condurre a risultati finali significativamente diversi



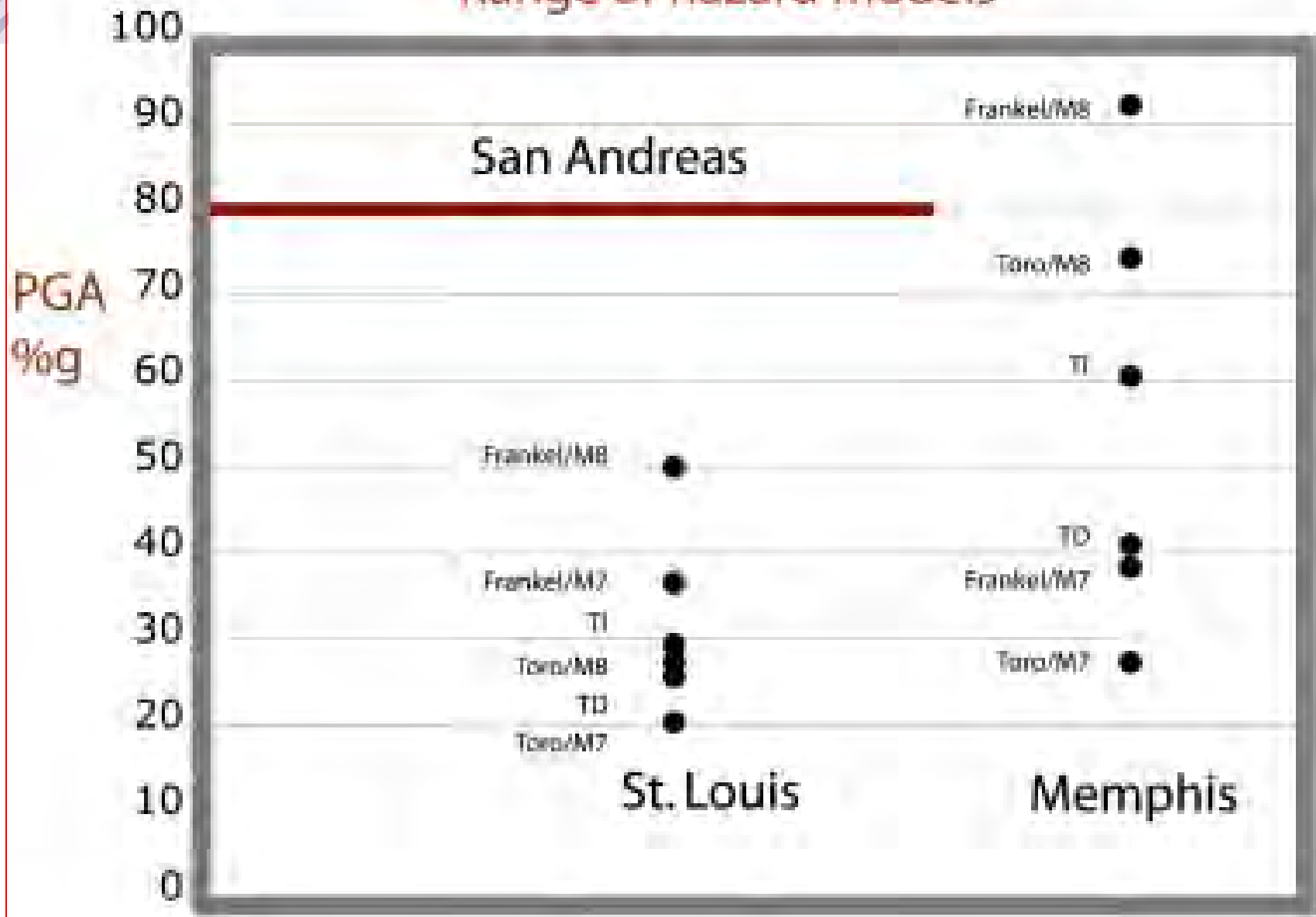
1

2

3

4

Range of hazard models



Stein et alii (2012)

La procedura fornisce l'accelerazione orizzontale massima per il caso del sito su roccia rigida ($V_s \geq 800 \text{ ms}^{-1}$). Restano da valutare gli eventuali effetti di sito (amplificazioni dello scuotimento causati da particolari situazioni stratigrafiche e topografiche)

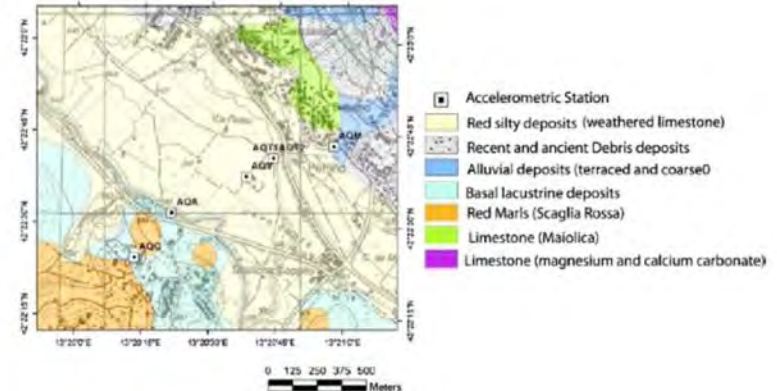
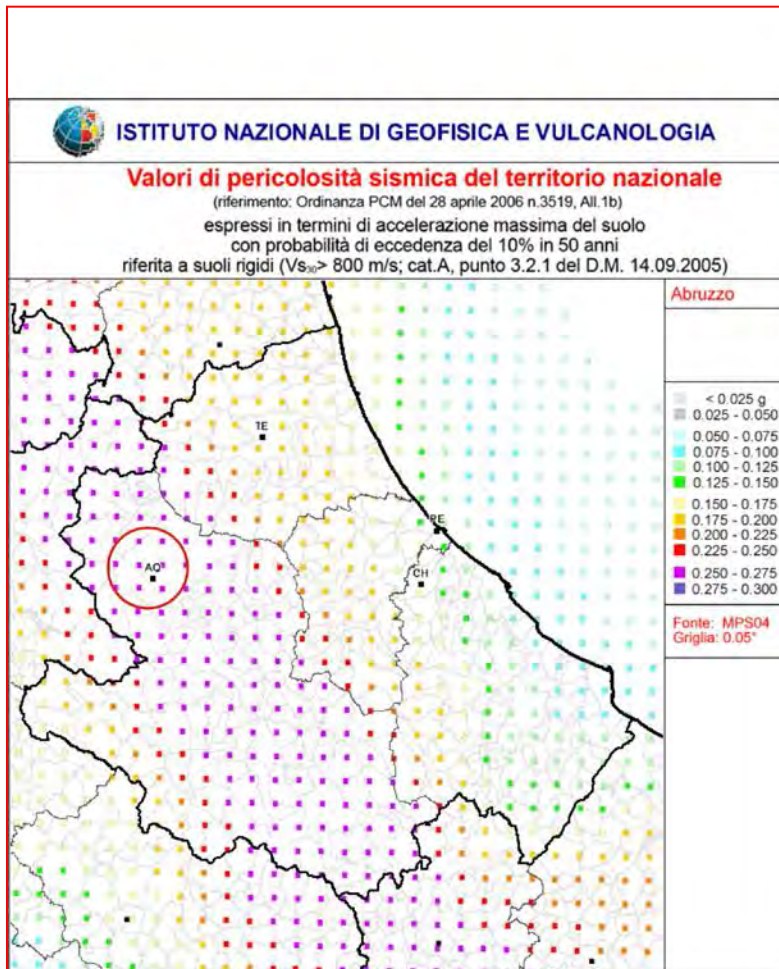
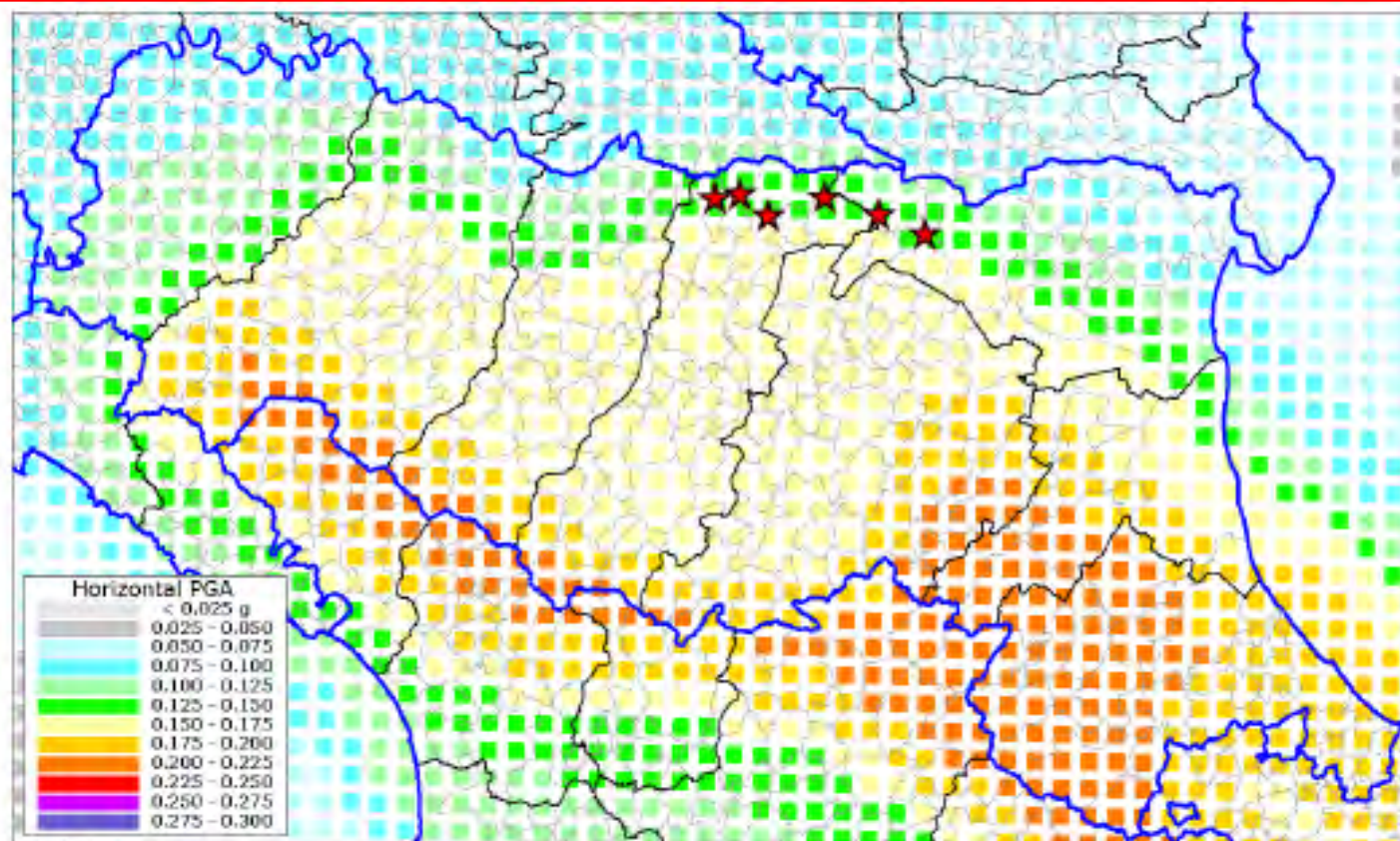


Table 1. Partial RAN-released list identifying the closest stations that recorded $>0.1 \text{ g}$ on hanging wall and footwall of the fault, and station AQU (INGV broad band station that also co-houses an accelerometer; compiled from several Italian sources including: <http://itaca.mi.ingv.it/itacaNet/>, EC8 site classification from GEER 2009, also in Appendix A).

Stations with PGA $>0.1 \text{ g}$ on hanging wall of the fault								
Station Name/Record Name/Lat & Long.	Station code	R_{JB} distance (Km)	Epic. distance (Km)	EC8 site class	PGA (cm/s ²)	PGV (cm/s)	Arias Intensity (cm/s)	Housner Intensity (cm)
V. Aterno Moro/ [42.379N, 13.349E]	AQM	0	5.2	A	1000 (saturated)	42.18	435.4	90.1
V. Aterno—Centro Valle/GX066 [42.377N, 13.344E]	AQV	0	4.9	B	646.1	42.83	285.7	94.5
V. Aterno—Colle Grilli/FA030 [42.373N, 13.337E]	AQG	0	4.4	A	506.9	35.54	137.0	92.2
V. Aterno—fiume Aterno/CU104 [42.376N, 13.339E]	AQA	0	4.6	B	435.6	32.03	175.0	86.1
L'Aquila parcheggio/AM043 [42.345N, 13.401E]	AQK	0	5.6	B	347.2	36.21	128.9	68.1
L'Aquila Castello (INGV) [42.354N, 13.402E]	AQU	0	5.8	B	309.5	35.00	71.0	78.0
Stations with PGA $>0.1 \text{ g}$ on foot wall of the fault								
Gran Sasso/EP021 [42.421N, 13.519E]	GSA	0	14.1	A	149.1	9.84	44.0	17.8

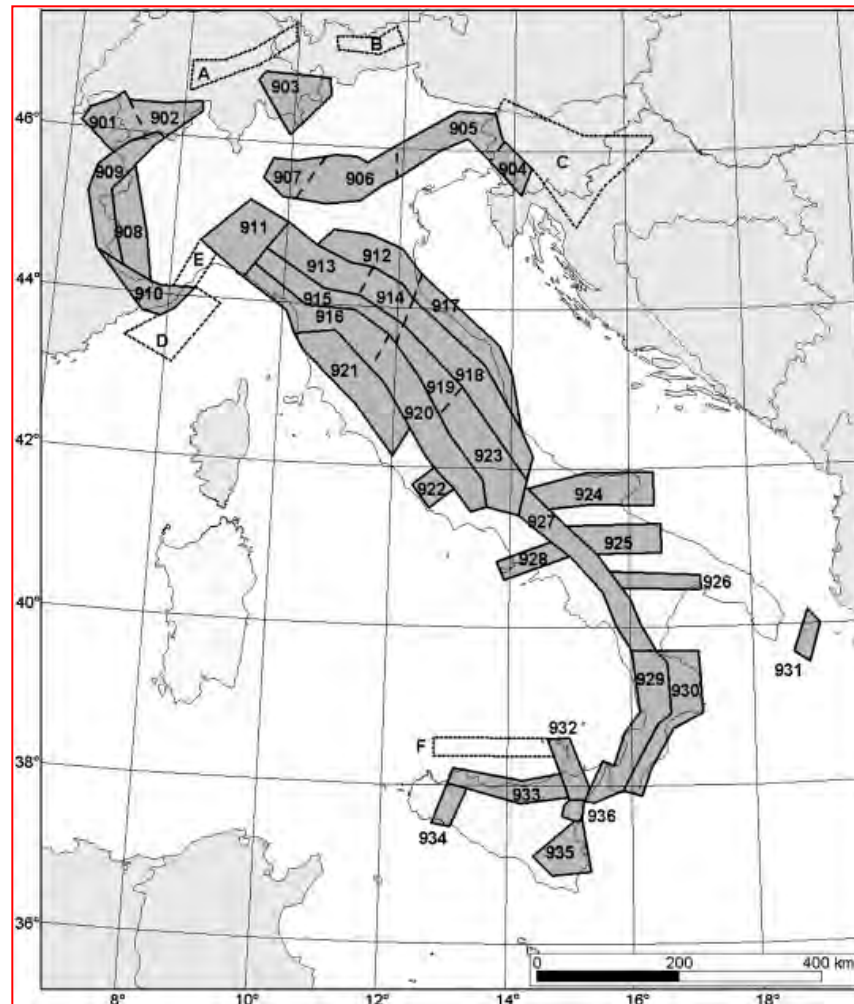


Sigla	Nome stazione	Comune	PGA _{max} (PGA/g)	Evento (M _L)	D
CAS0	Castelmassa	Castelmassa (RG)	130.000 (0.133)	29/5/2012 07.00.03 (5.8)	26.3
CRP	Carpi	Carpi	140.000 (0.143)	29/5/2012 10.55.57 (5.3)	16.0
FIN0	Finale Emilia	Finale Emilia	122.322 (0.125)	23/5/2012 21.41.18 (4.3)	5.1
MOG0	Moglia	Moglia (MN)	240.000 (0.245)	29/5/2012 07.00.03 (5.8)	16.4
			216.634 (0.221)	29/5/2012 10.55.57 (5.3)	9.0
MRN	Mirandola	Mirandola	303.300 (0.309)	20/5/2012 02.03.52 (5.9)	13.2
			205.155 (0.209)	20/5/2012 03.02.50 (4.9)	3.3
			900.000 (0.917)	29/5/2012 07.00.03 (5.8)	3.6
			155.342 (0.158)	29/5/2012 08.27.23 (4.7)	4.4
			197.267 (0.201)	29/5/2012 10.55.57 (5.3)	4.4
			250.960 (0.256)	29/5/2012 11.00.25 (5.2)	9.1
NVL	Novellara	Novellara	134.292 (0.137)	29/5/2012 10.55.57 (5.3)	22.4

L'attività sismica è considerata uniforme all'interno di ogni zona sismogenetica. La scelta della geometria delle zone influenza significativamente i risultati dell'elaborazione

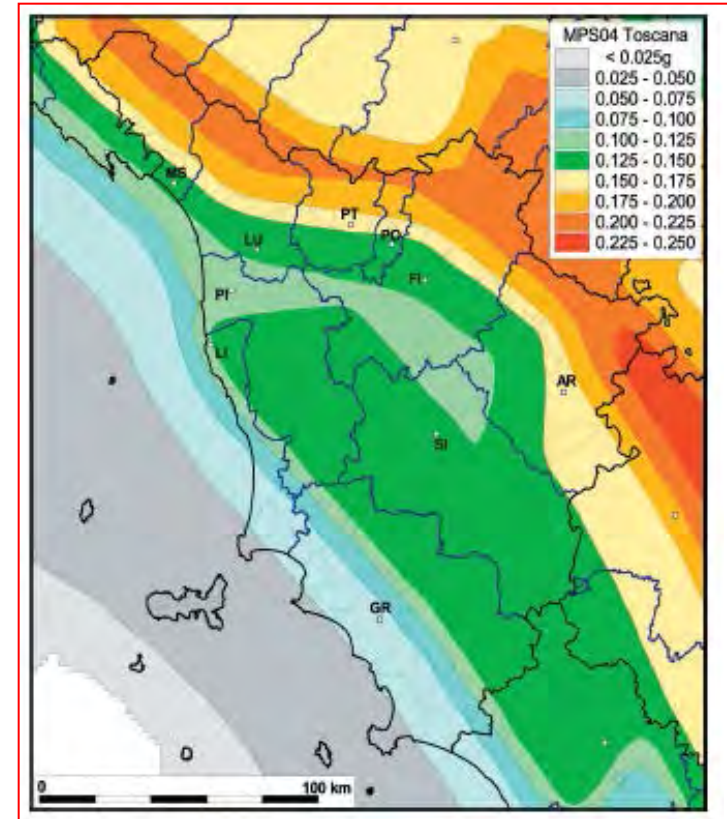
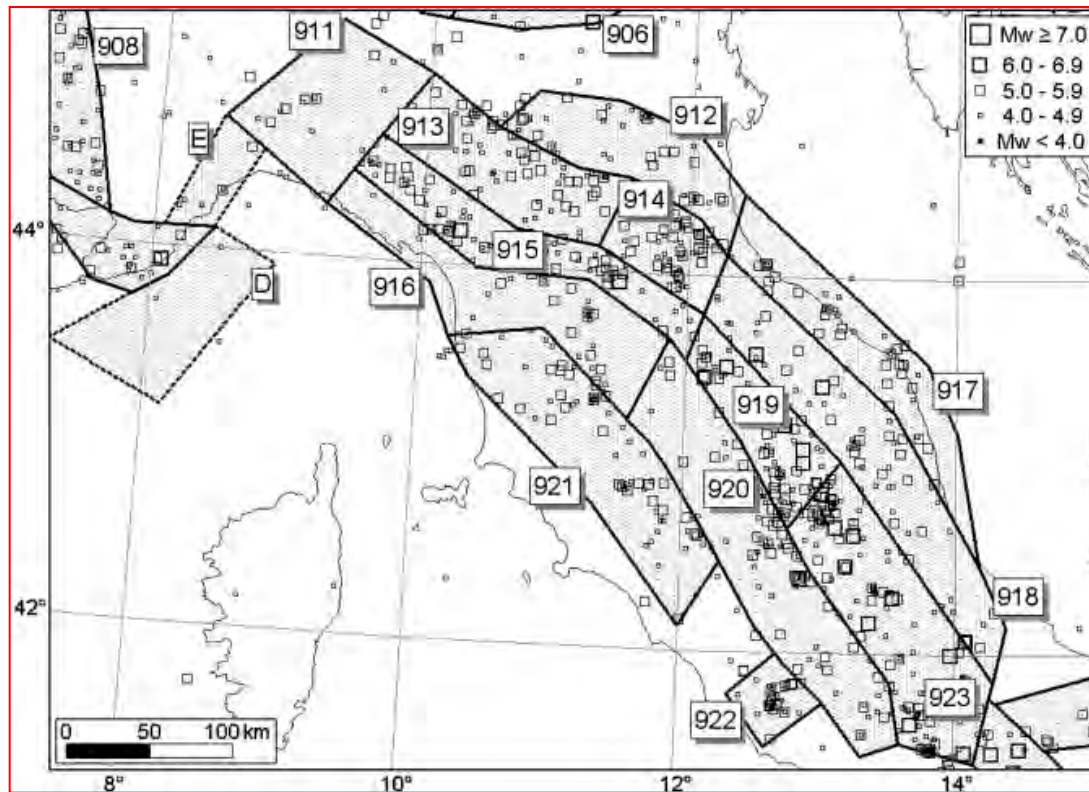


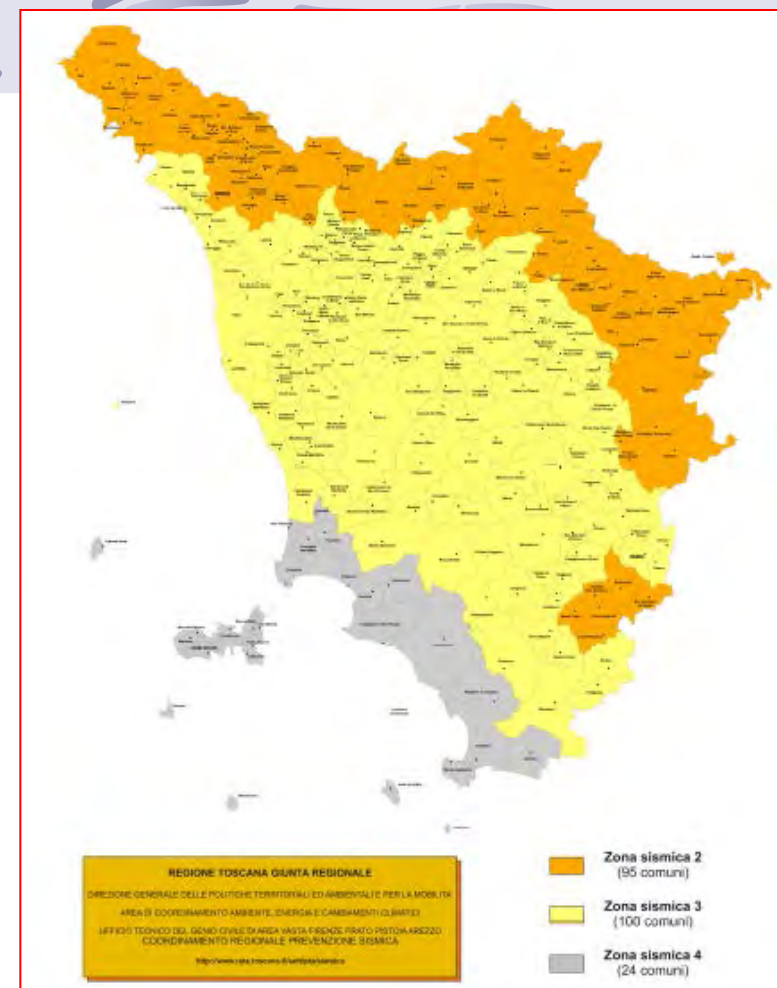
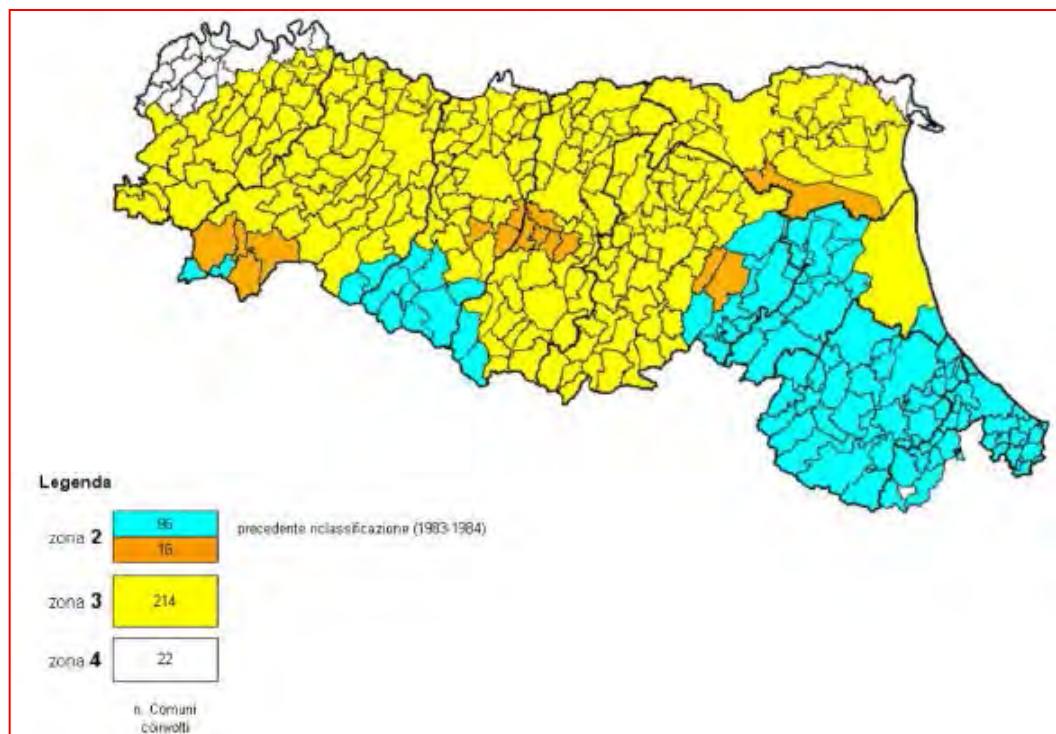
ZS4 (Meletti et alii, 2000)



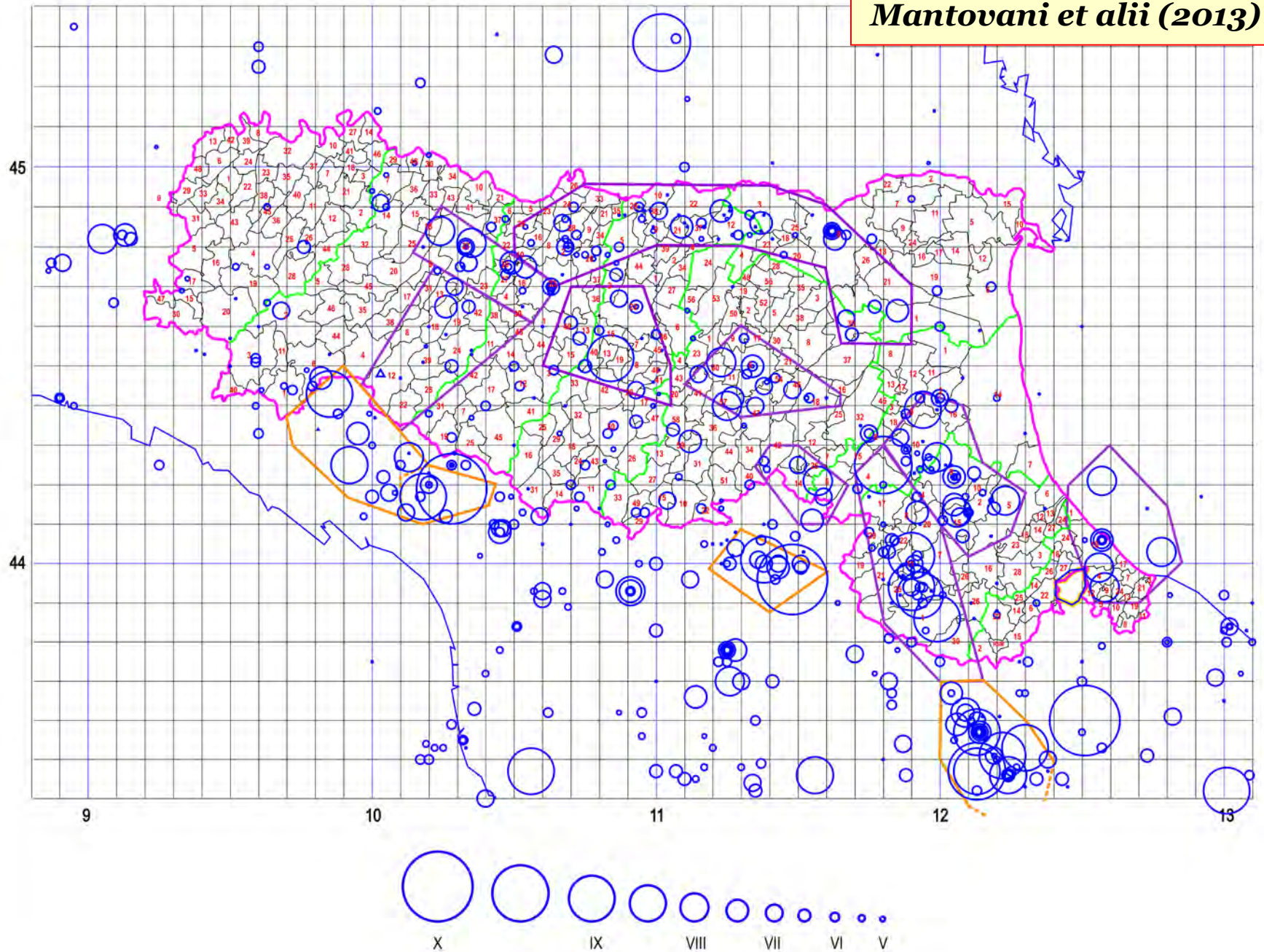
ZS9 (Meletti et alii, 2008)

La zonazione ZS9 suddivide l'Appennino settentrionale in pochi, vasti settori, molto allungati in senso NO-SE. Essi sono poco rappresentativi della reale distribuzione spaziale delle strutture sismogenetiche e della sismicità storica

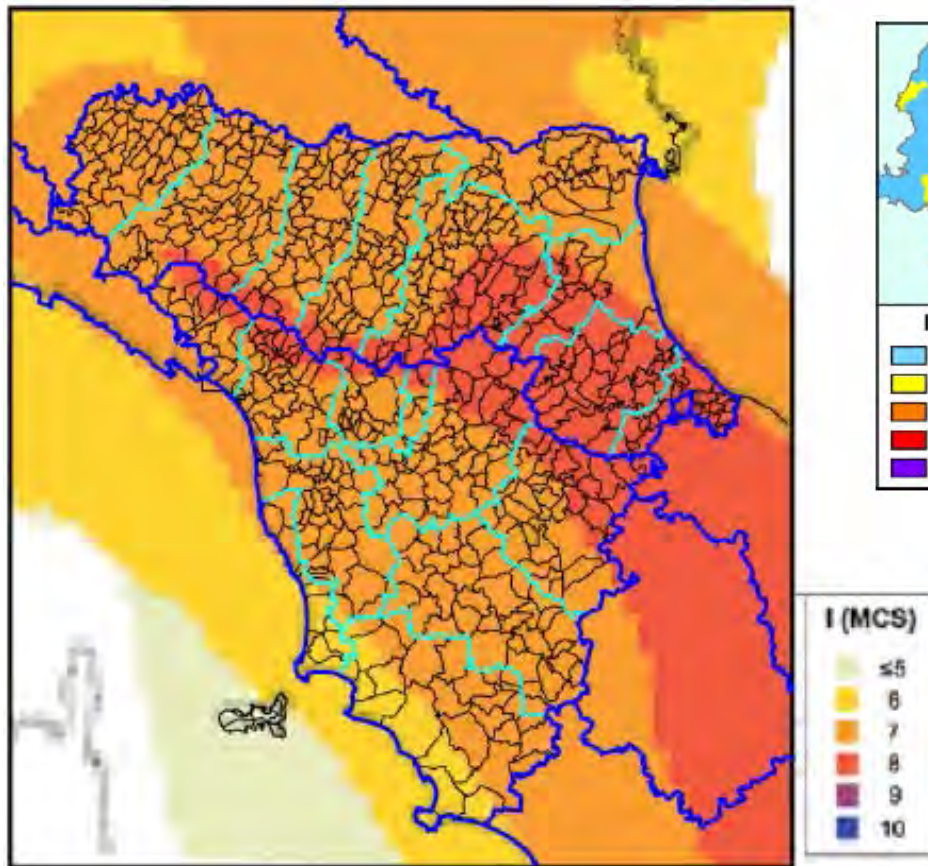




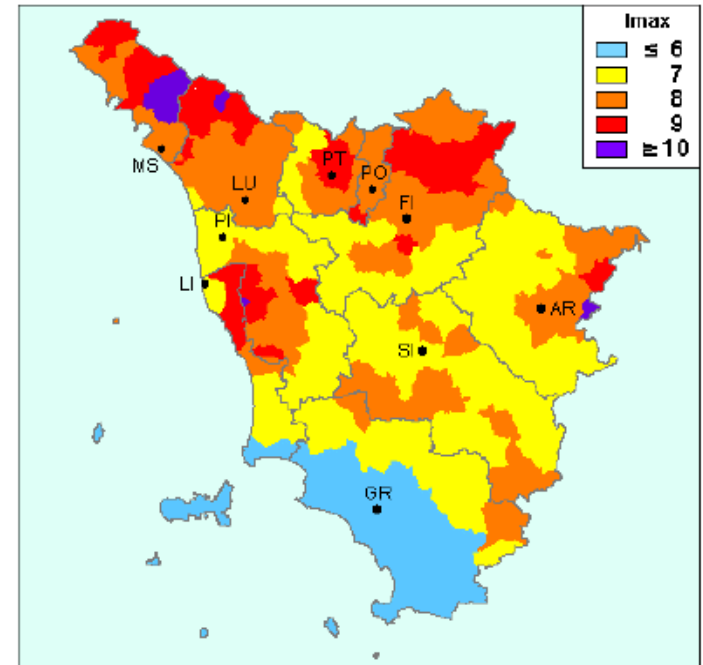
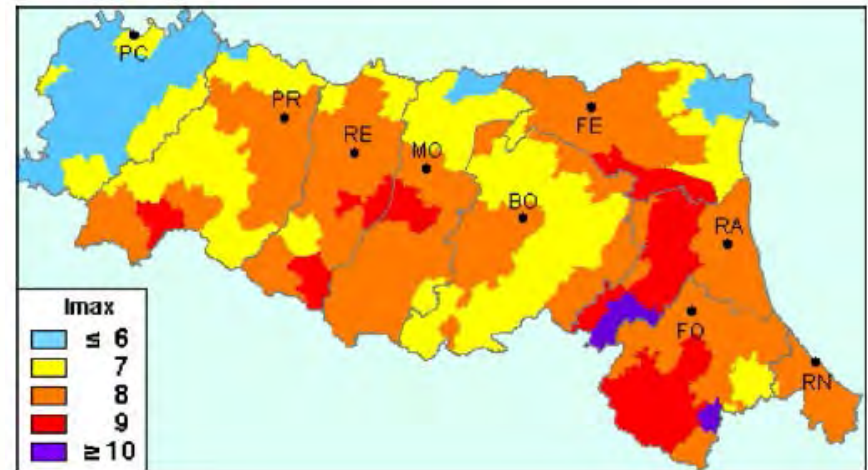
Classi 1, 2, 3 e 4 (ed eventuali sottoclassi), basate sulla carta della PGA per la probabilità di superamento del 10% in 50 anni



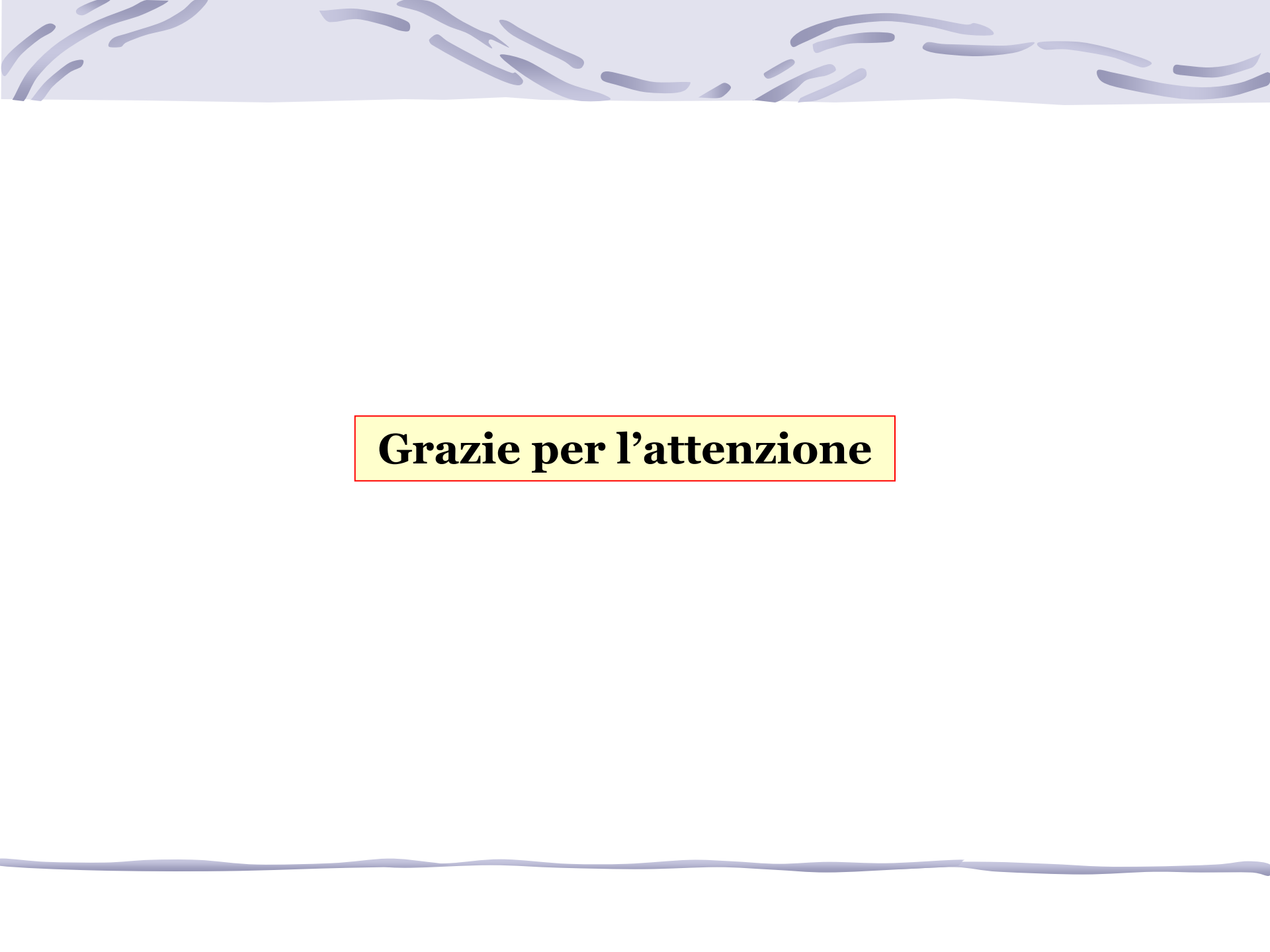
Stima dell'intensità massima attesa



da Gomez et alii (2010)



Molin et alii (1996)



Grazie per l'attenzione

1) Zonazione sismogenetica

2) Parametrizzazione della sismicità nelle zone sismogenetiche

- Classi di magnitudo**
- Intervalli di completezza dei cataloghi sismici**
- Magnitudo massima attesa**
- Tasso di sismicità annuale**

3) Distribuzione di probabilità (processo di Poisson)

4) Attenuazione dello scuotimento sismico con la distanza

5) Stima del moto del terreno al sito

- SeisRisk III (*Bender e Perkins, 1987* e successive modifiche)**

(Gruppo di Lavoro MPS, 2004; Stucchi et alii, 2011)

PGA ai nodi di un reticolo di riferimento



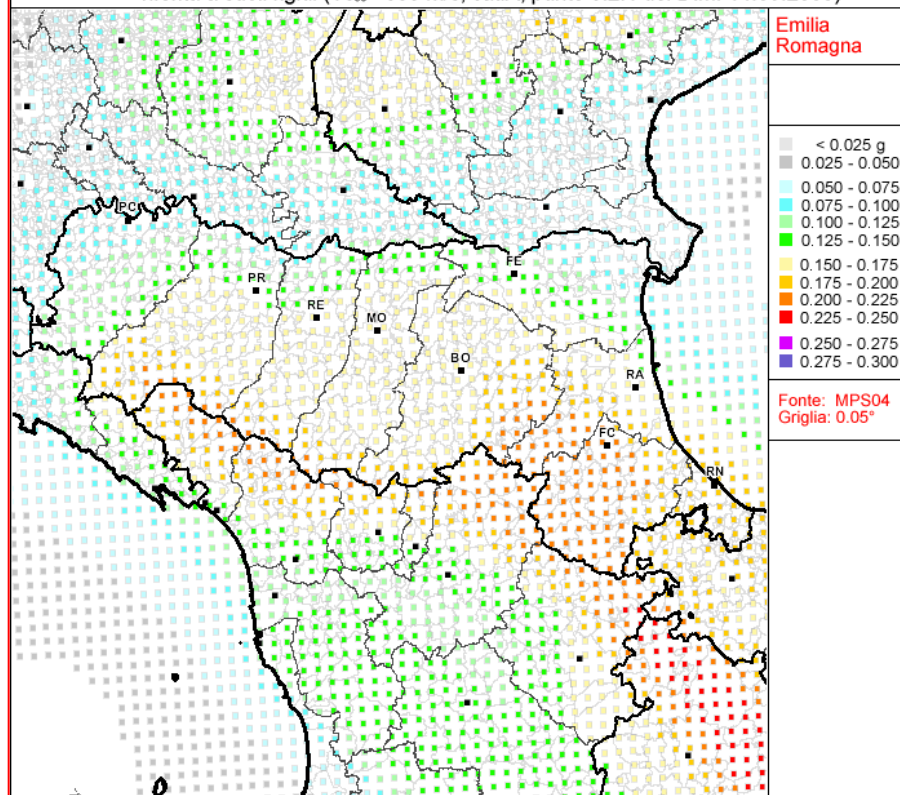
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Valori di pericolosità sismica del territorio nazionale

(riferimento: Ordinanza PCM del 28 aprile 2006 n.3519, All. 1b)

espressi in termini di accelerazione massima del suolo
con probabilità di eccedenza del 10% in 50 anni

riferita a suoli rigidi ($V_{s30} > 800$ m/s; cat.A, punto 3.2.1 del D.M. 14.09.2005)



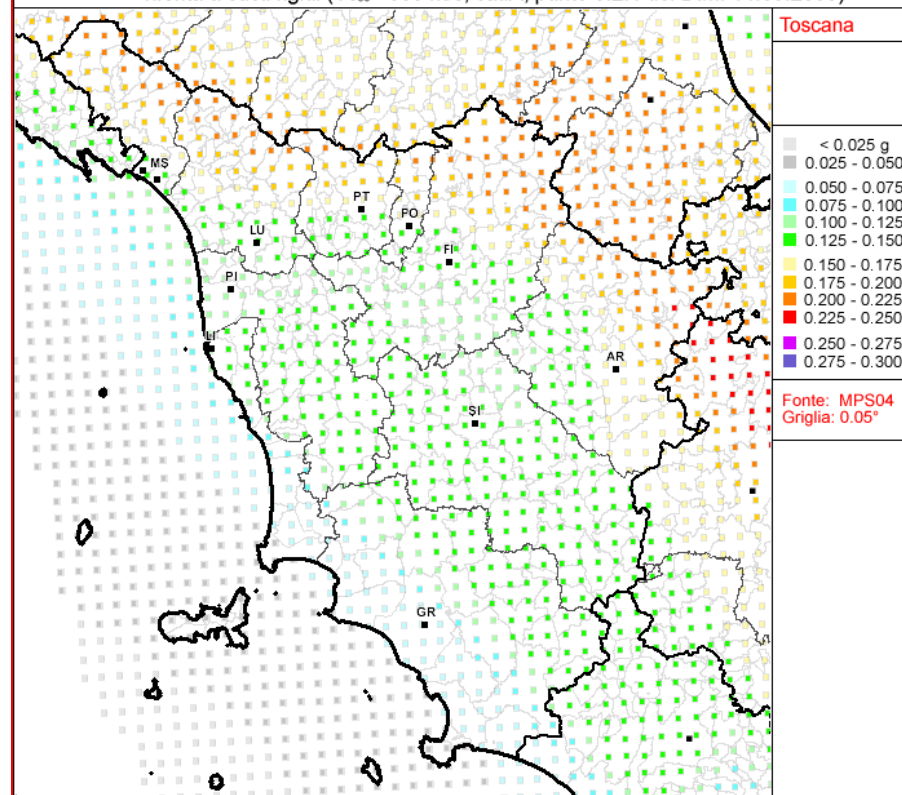
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

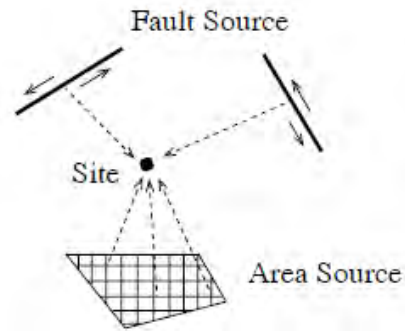
Valori di pericolosità sismica del territorio nazionale

(riferimento: Ordinanza PCM del 28 aprile 2006 n.3519, All. 1b)

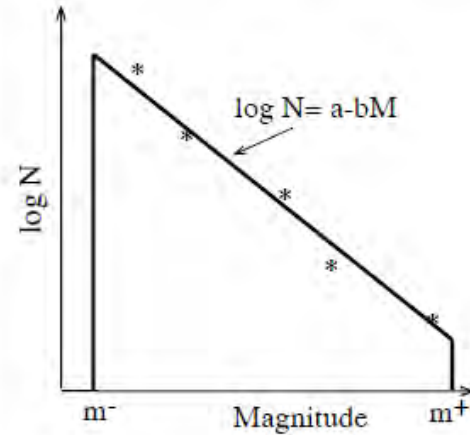
espressi in termini di accelerazione massima del suolo
con probabilità di eccedenza del 10% in 50 anni

riferita a suoli rigidi ($V_{s30} > 800$ m/s; cat.A, punto 3.2.1 del D.M. 14.09.2005)

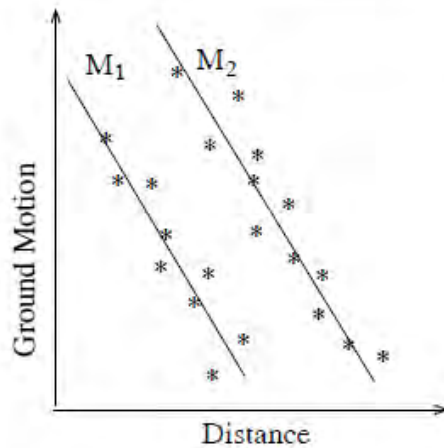




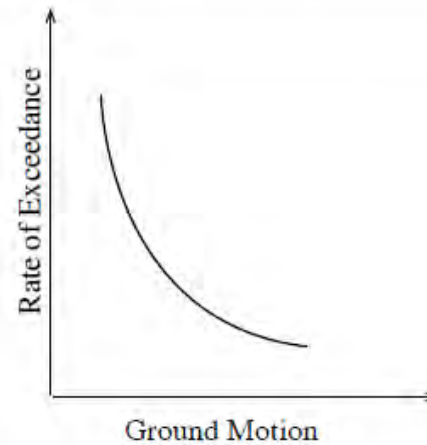
Delineation of Potential Sources



Magnitude Recurrence Relationship



Ground Motion Estimation

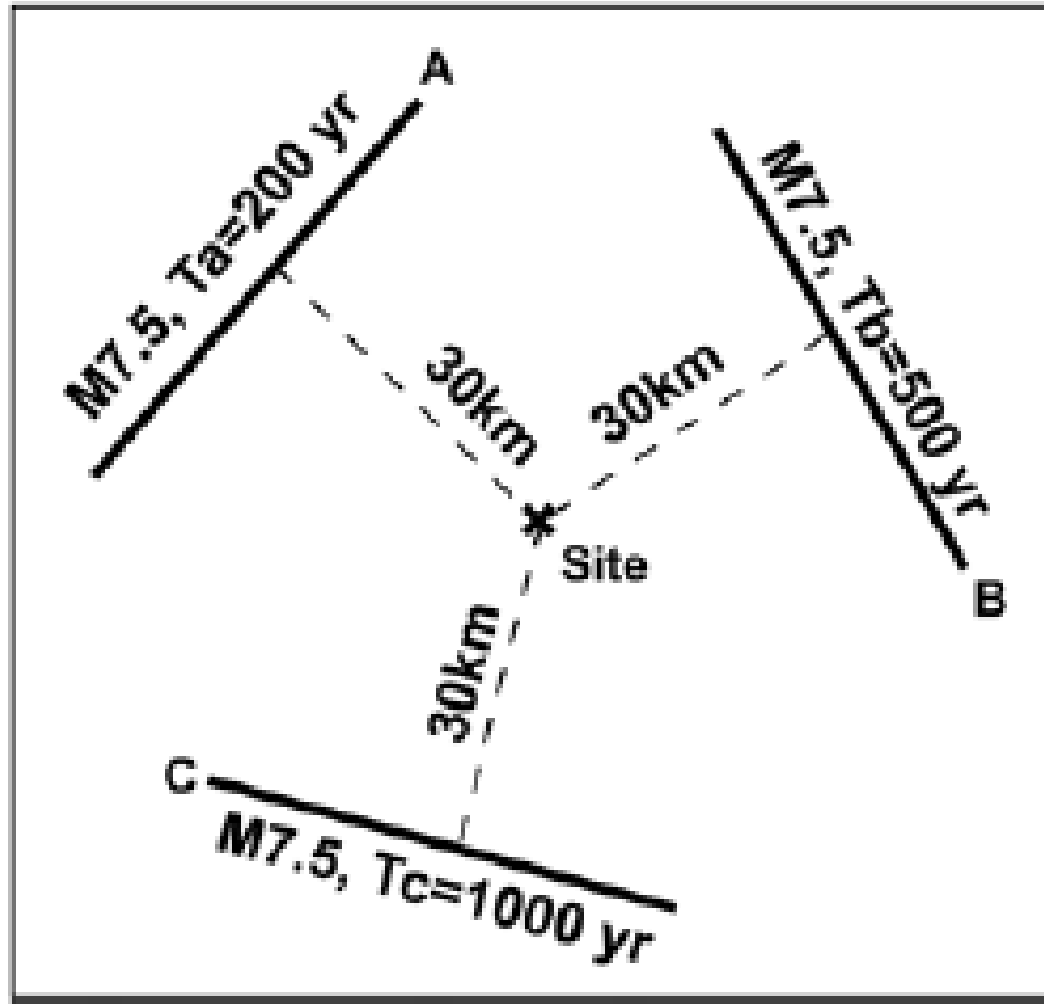


Rate of Exceedance of Ground Motion

Reiter (1990)

Stima del moto del terreno al sito

calcolo del contributo di tutti i possibili “scenari sismici” delle varie sorgenti del modello (SeisRisk III di *Bender e Perkins, 1987* e successive modifiche)



Wang et alii (2003)

Parametrizzazione della sismicità nelle zone sismogenetiche (Gruppo di Lavoro MPS, 2004)

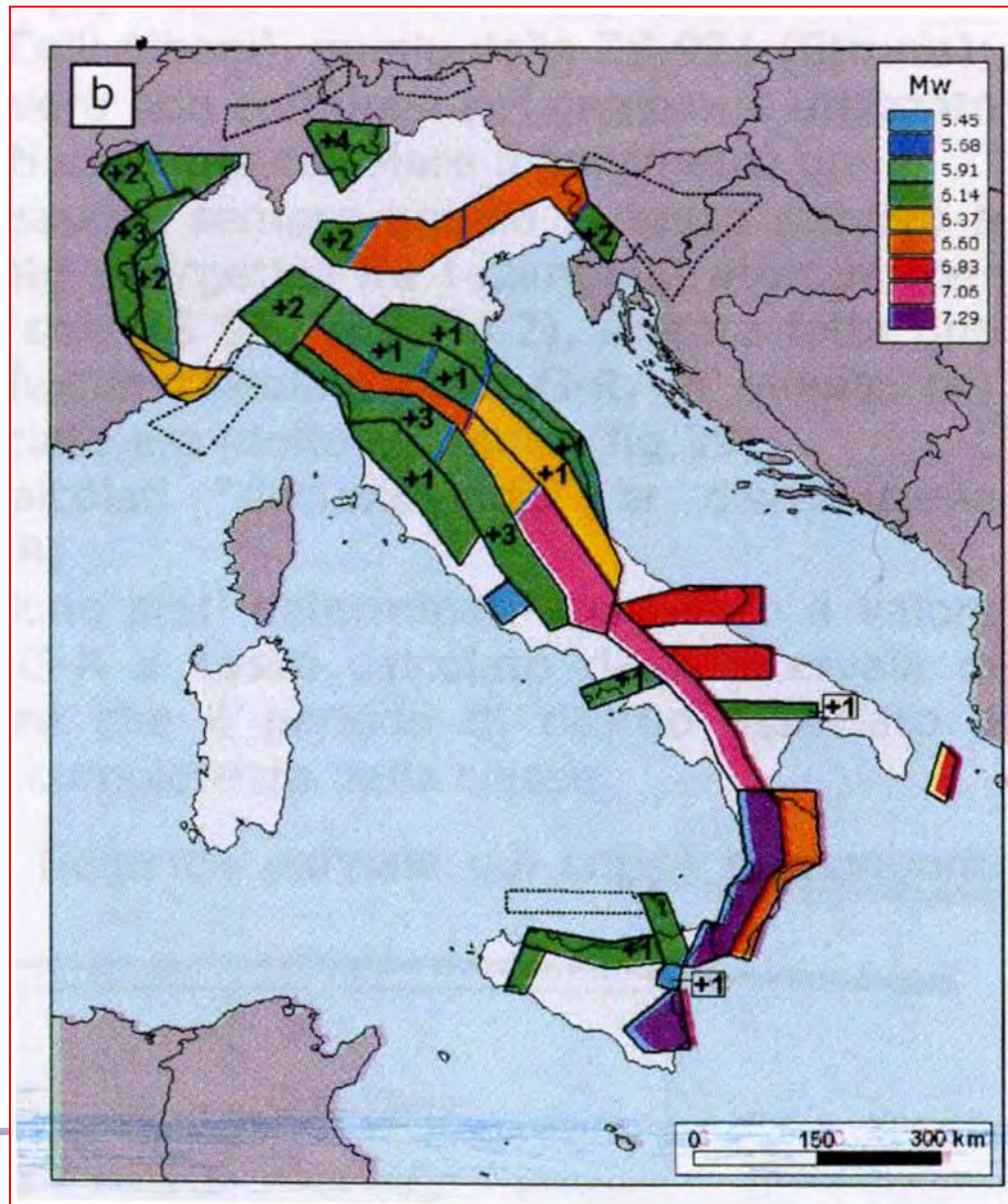
Classi di magnitudo

N	Mw	Ms	Msp	Io(MCS)
1	4.76 ± 0.115	4.3 ± 0.15	4.49 ± 0.14	6
2	4.99 ± 0.115	4.6 ± 0.15	4.77 ± 0.14	6/7
3	5.22 ± 0.115	4.9 ± 0.15	5.05 ± 0.14	7
4	5.45 ± 0.115	5.2 ± 0.15	5.33 ± 0.14	7/8
5	5.68 ± 0.115	5.5 ± 0.15	5.61 ± 0.14	8
6	5.91 ± 0.115	5.8 ± 0.15	5.89 ± 0.14	8/9
7	6.14 ± 0.115	6.1 ± 0.15	6.17 ± 0.14	9
8	6.37 ± 0.115	6.4 ± 0.15	6.45 ± 0.14	9/10
9	6.60 ± 0.115	6.7 ± 0.15	6.73 ± 0.14	10
10	6.83 ± 0.115	7.0 ± 0.15	7.01 ± 0.14	10/11
11	7.06 ± 0.115	7.3 ± 0.15	7.29 ± 0.14	11
12	7.29 ± 0.115	7.6 ± 0.15	7.57 ± 0.14	11/12

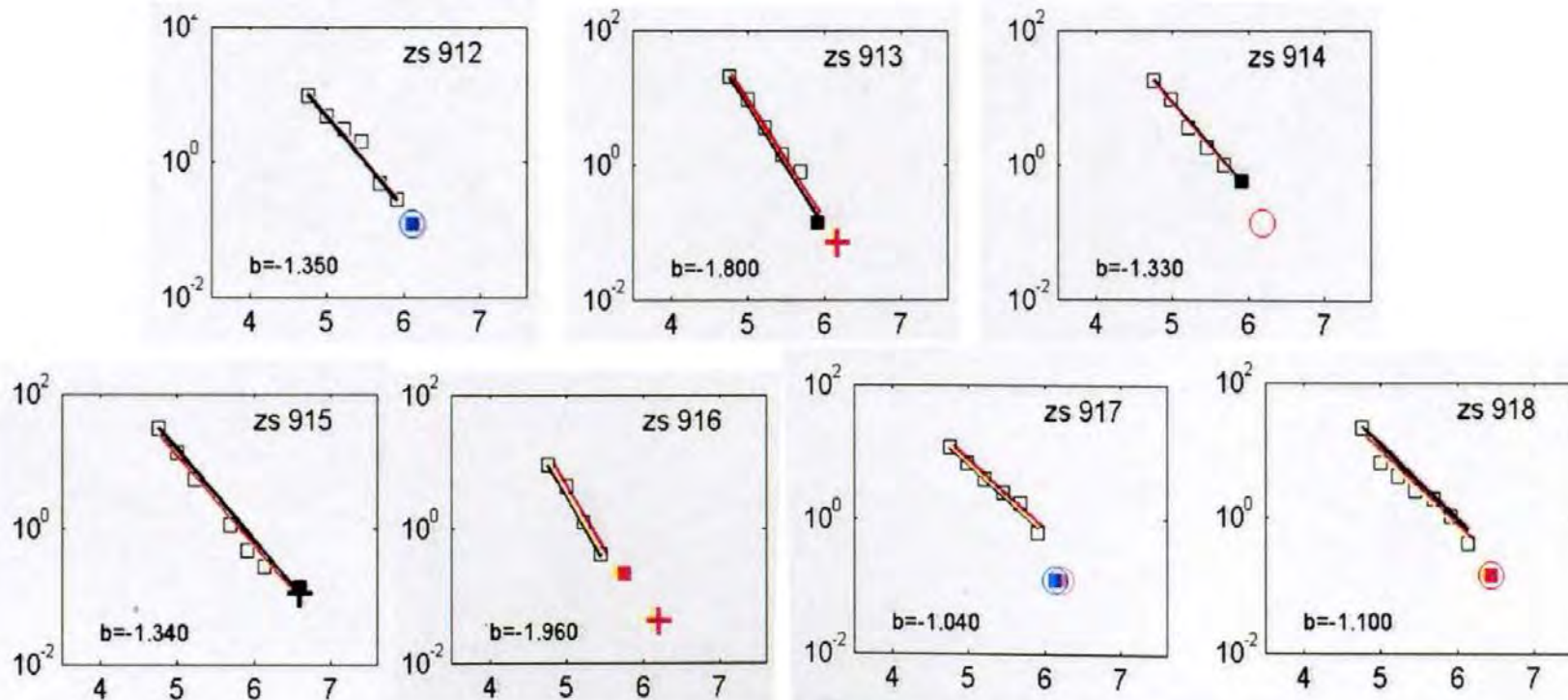
Intervalli di completezza dei cataloghi sismici

Dorsale Ferrarese	912	1910	1871	1871	1700	1700	1530	1530	1400	1400	1300	1300	1300
App. Emiliano-Romagn.	913	1910	1871	1871	1700	1700	1530	1530	1400	1400	1300	1300	1300
Forlivese	914	1910	1871	1871	1700	1700	1530	1530	1400	1400	1300	1300	1300
Garfagnana-Mugello	915	1920	1871	1871	1700	1700	1700	1530	1530	1300	1300	1300	1300
Versilia-Chianti	916	1920	1871	1871	1700	1700	1700	1530	1530	1300	1300	1300	1300
Rimini-Ancona	917	1920	1871	1871	1700	1700	1700	1530	1530	1300	1300	1300	1300
Medio-Marchigiana/Abruzz.	918	1920	1871	1871	1700	1700	1700	1530	1530	1300	1300	1300	1300

Magnitudo massima attesa



Tasso di sismicità annuale

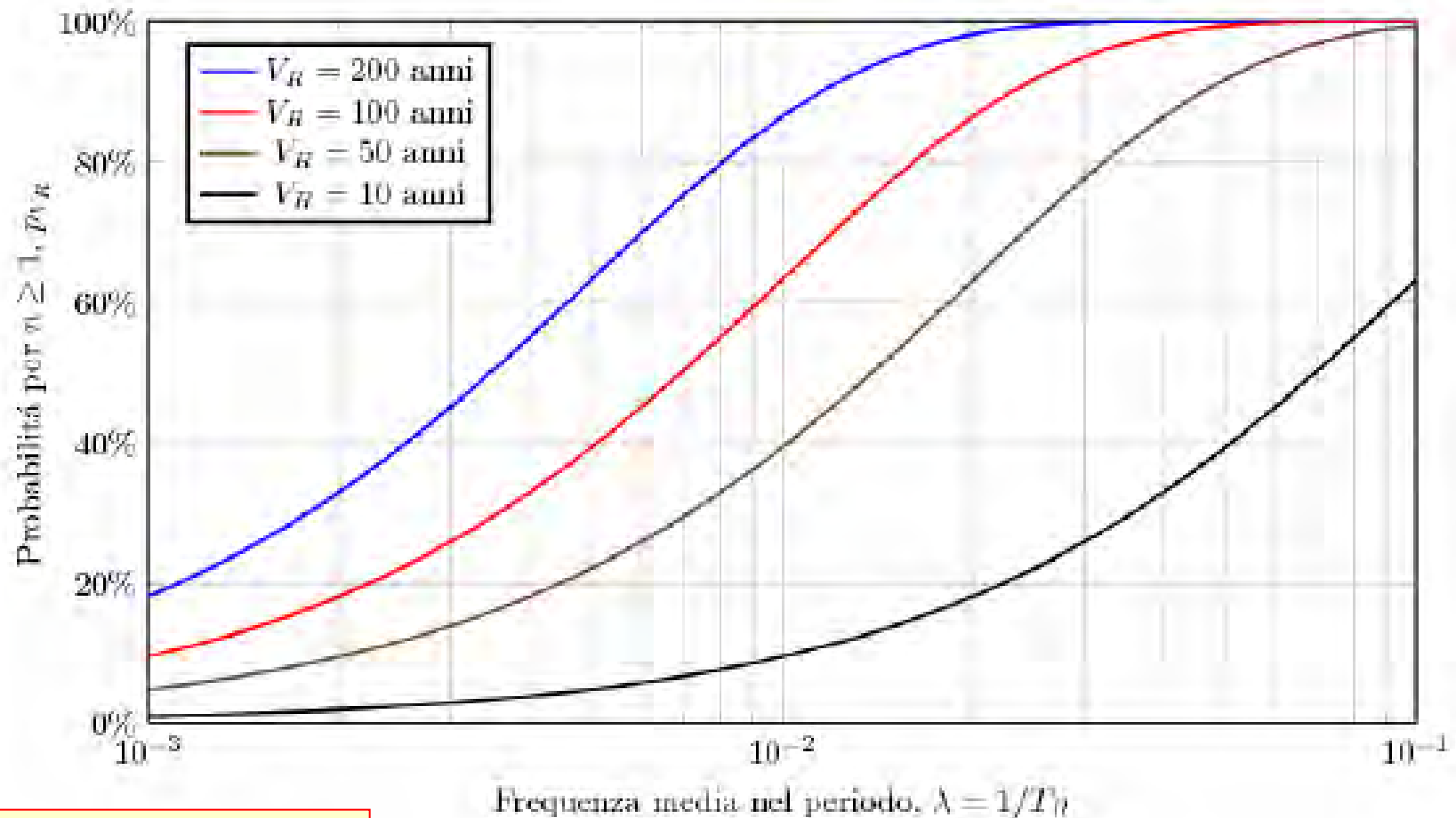


Dorsale Ferrarese	912	6.14	0.12	6.14	-1.35	0.12	0.13	A	0.12
Appennino Emiliano-Romagn.	913	5.91	0.14	6.14	-1.80	0.14	0.07	A	0.07
Forlivese	914	5.91	0.57	6.14	-1.33	0.14	0.26	A	0.14
Garfagnana-Mugello	915	6.60	0.14	6.60	-1.34	0.14	0.11	A	0.11
Versilia-Chianti	916	5.68	0.21	6.14	-1.96	0.14	0.02	C	0.04
Rimini-Ancona	917	6.14	0.12	6.14	-1.04	0.12	0.43	A	0.12
Medio-Marchigiana/Abruzz.	918	6.37	0.14	6.37	-1.10	0.14	0.37	A	0.14

Probabilità dei terremoti (processo di Poisson)

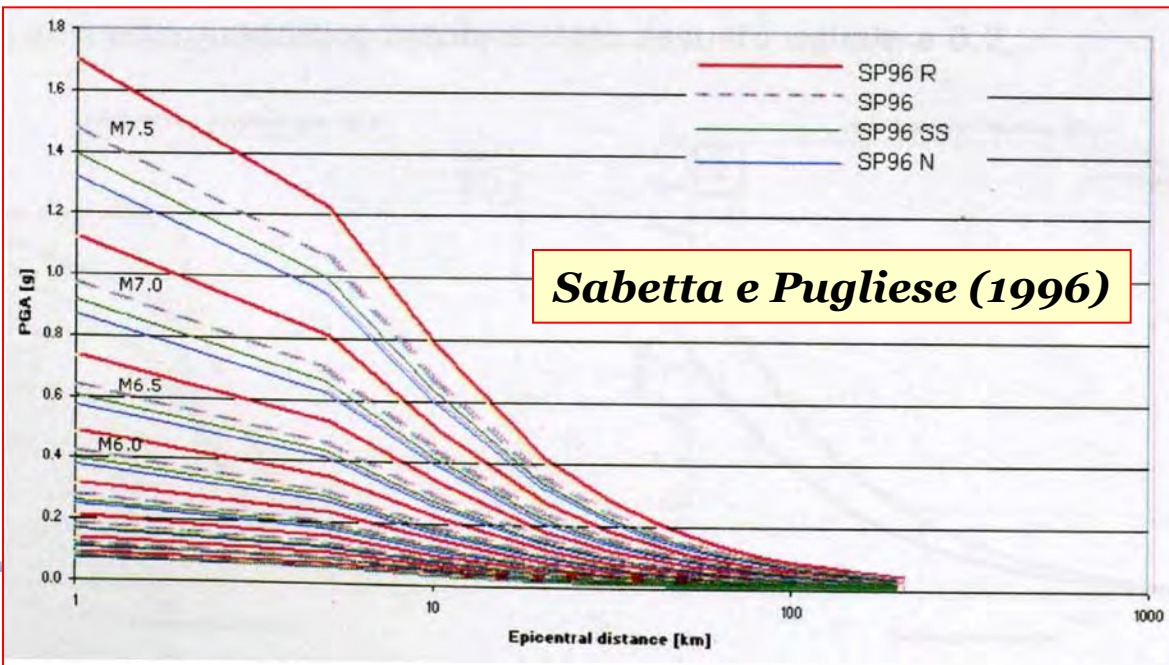
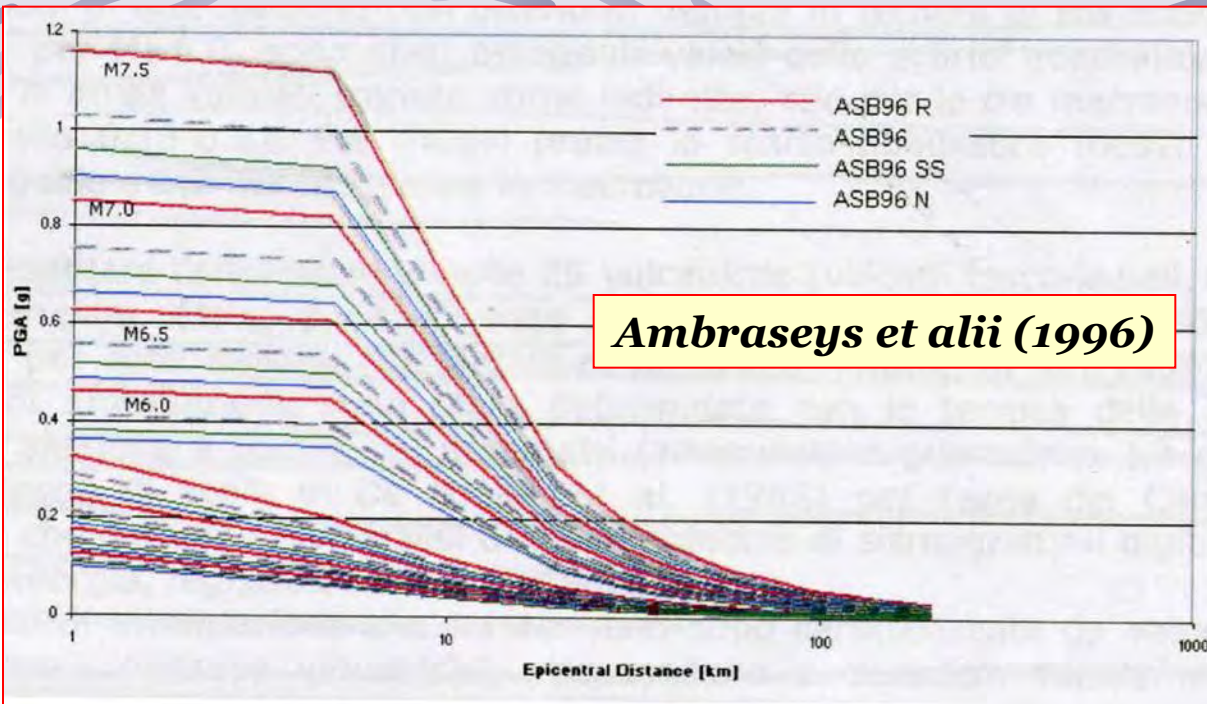
$$p_n = \frac{y^n}{n!} e^{-y}$$

$$y = \lambda V_R$$

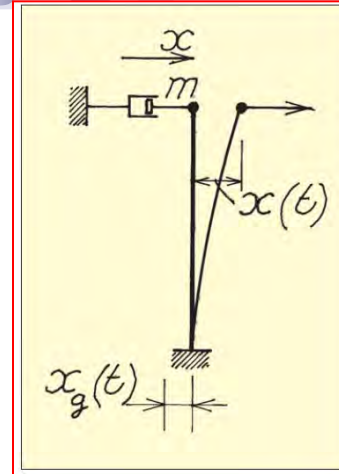
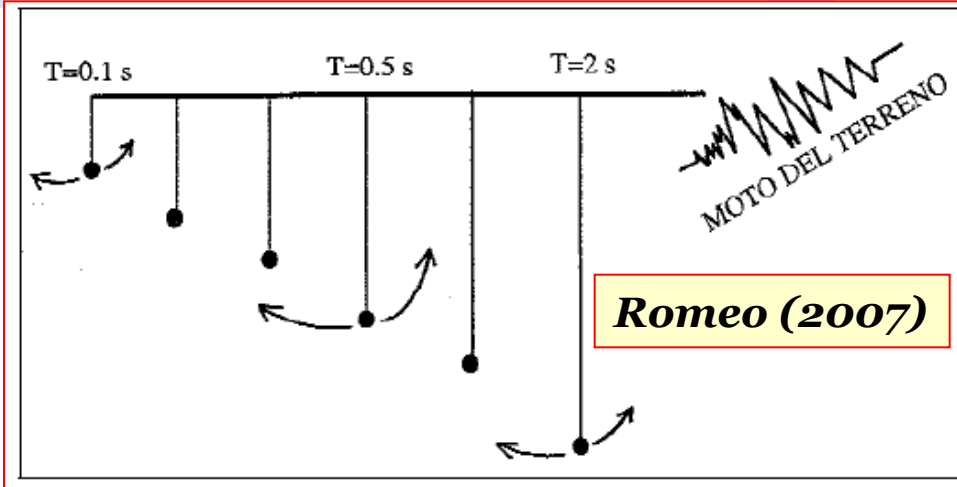


Giacometti (2011)

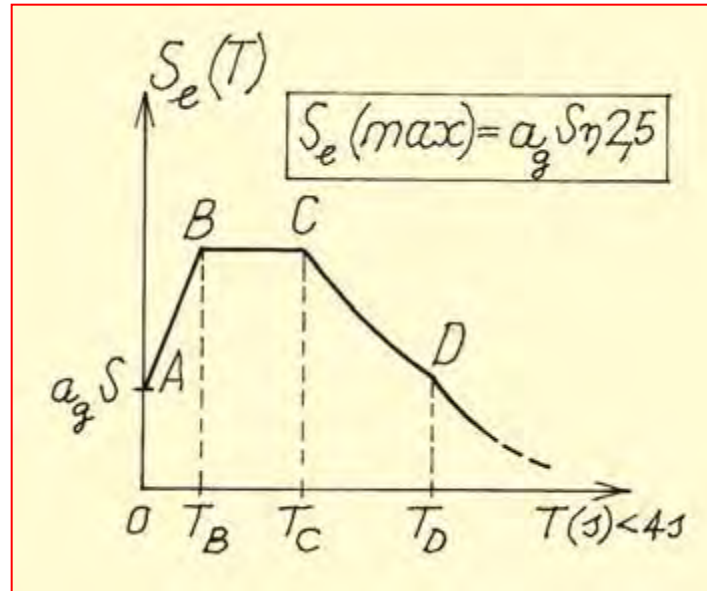
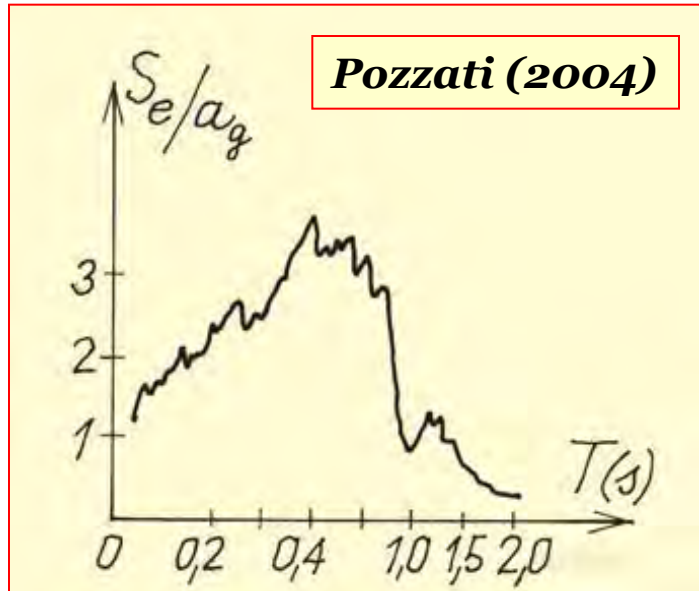
Attenuazione dello scuotimento con la distanza

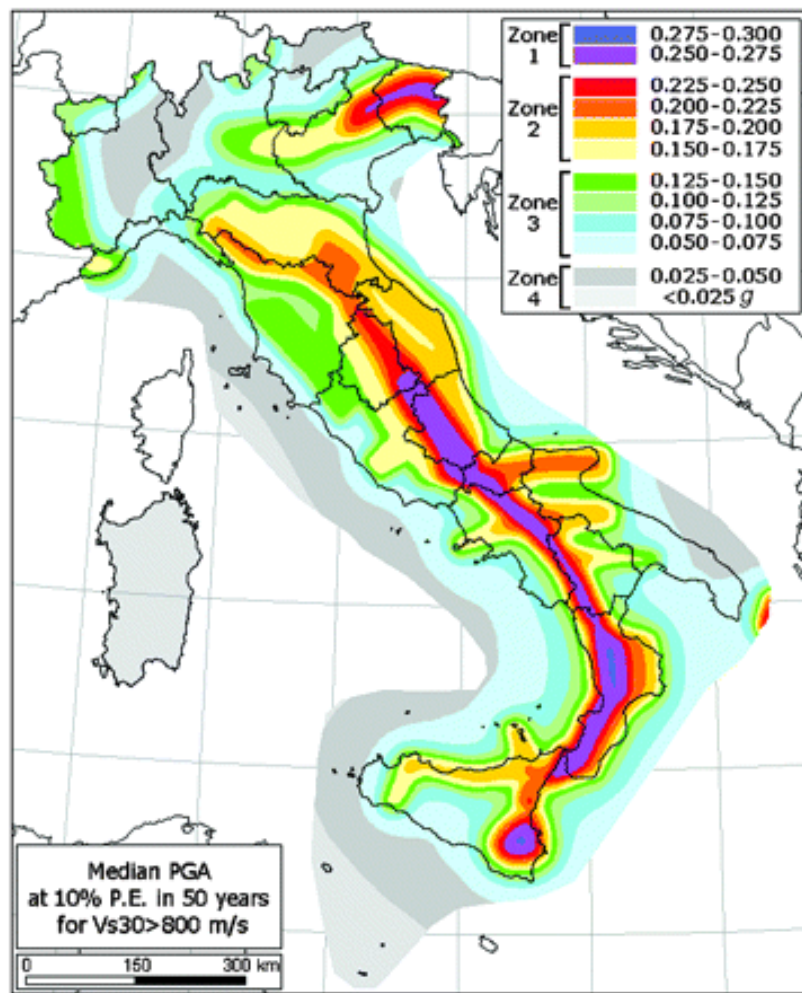


Spettro di risposta elastico

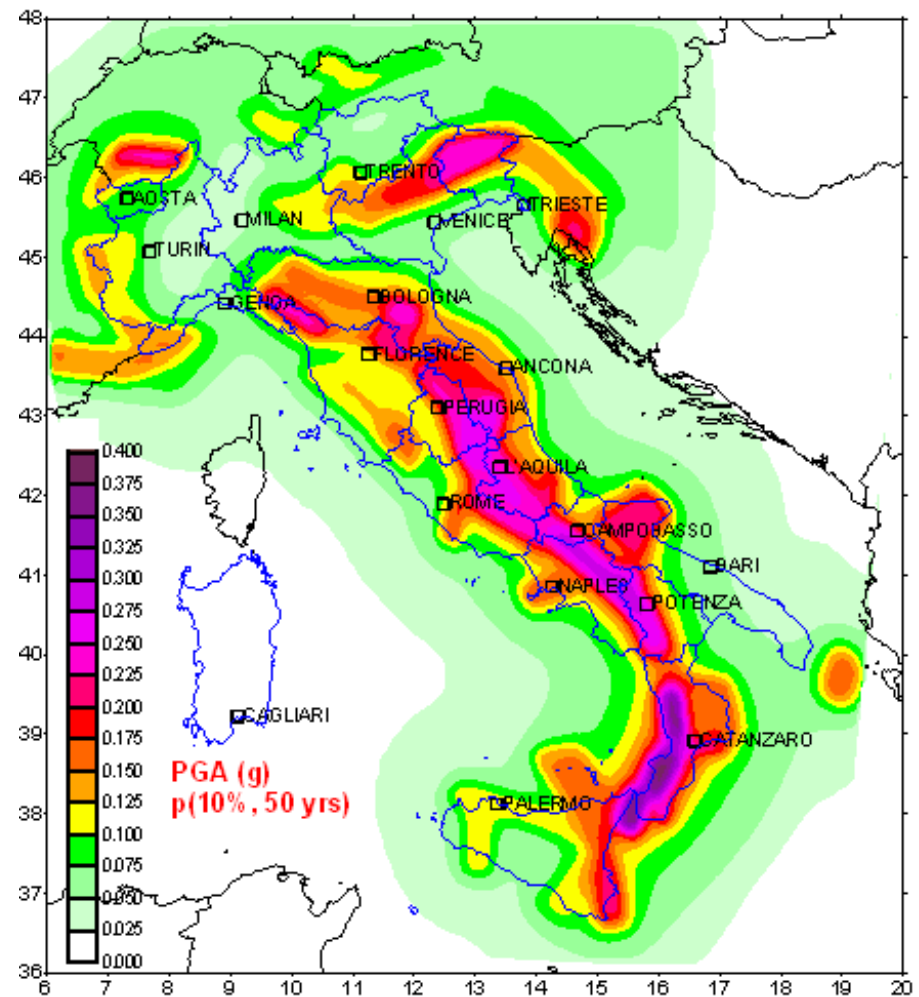


Parametri dello spettro di risposta (a_g , F_0 e T_c) nei 10571 nodi del reticolo nazionale, per 9 valori di probabilità di superamento in 50 anni (81%, 63%, 50%, 39%, 30%, 22%, 10%, 5% e 2%)

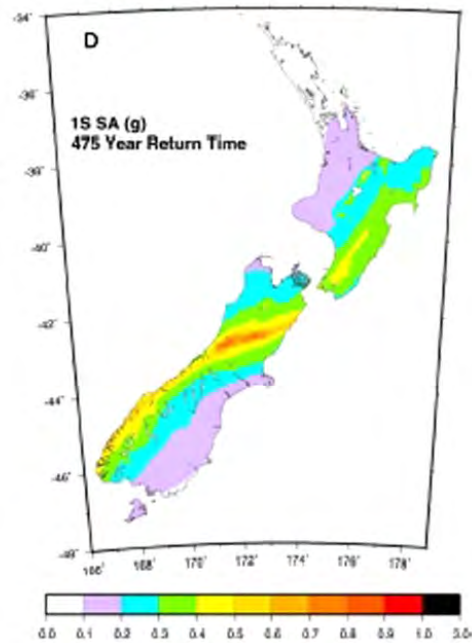
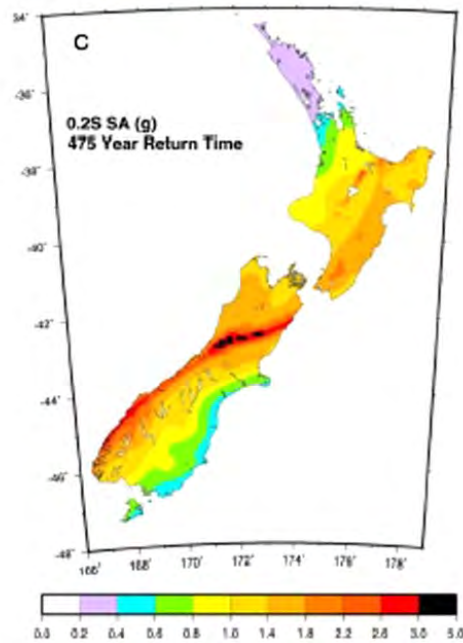
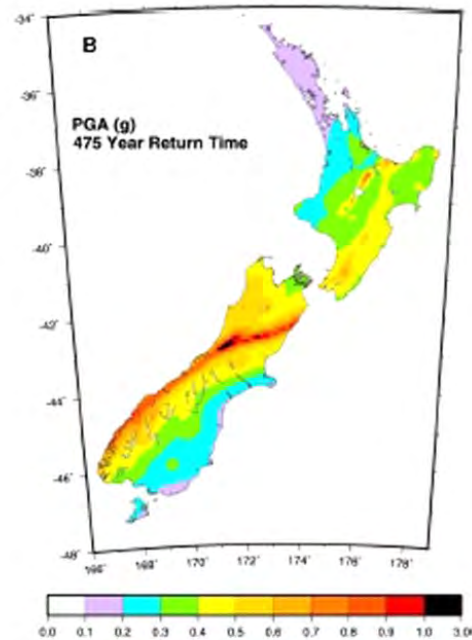
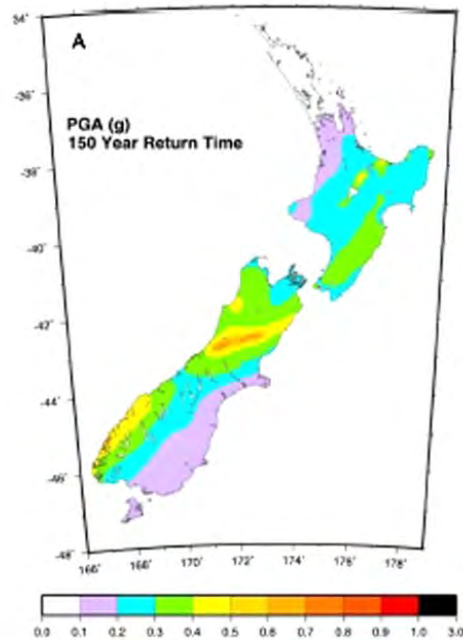




Stucchi et alii (2011)



Romeo (2009)



Stirling et al., 2002

“This network has recorded an exceptional set of strong ground motions, with vertical peak ground accelerations reaching 1.26 g close to the September rupture and 2.20 g close to the February rupture.

...Prior to the September rupture of the Greendale fault, no past surface ruptures had been recognized in the immediate region. But the possibility of large earthquakes had been incorporated in the probabilistic seismic hazard model for New Zealand by assigning a maximum magnitude (M_{max}) of 7.2 to distributed seismicity in the Canterbury region. The problem is that the extreme ground motions recorded for both the M 7.1 mainshock and M 6.3 aftershock were greater than this model predicted (even at 10,000-year return periods for the case of the M 6.3 aftershock).

The reason for this is that both these events radiated anomalously high levels of seismic energy relative to their magnitudes...This can be understood in terms of the anomalous crustal structure of the region...Because of this crustal structure, there is no shallow brittle-ductile transition beneath the Canterbury region— small earthquakes extend down to 35 km depth in the mafic Hikurangi Plateau...The high levels of radiated seismic energy from the events indicate high stress drop and high fault friction.” [Reyners, 2011]

“The issues confronting the makers of hazard maps are somewhat similar to those arising in the development and testing of new medicines or therapies. A new treatment or pharmaceutical cannot be approved for general use unless it passes a clinical trial on humans. However, earthquake hazard maps were incorporated into public policy before their limitations were explored and characterized. Not surprisingly, the results are sometimes poor, showing the need to improve hazard mapping methods and to be cautious in using present hazard maps as the basis for public policy.” [Stein et al., 2013]