Macroseismic intensity attenuation models calibrated in Mw for Italy

Bulletin of Earthquake Engineering

A. A. Gomez-Capera[1], M. Santulin[2], M. D'Amico[1], V. D'Amico[3], M. Locati[1], C. Meletti[3], E. Varini[4]

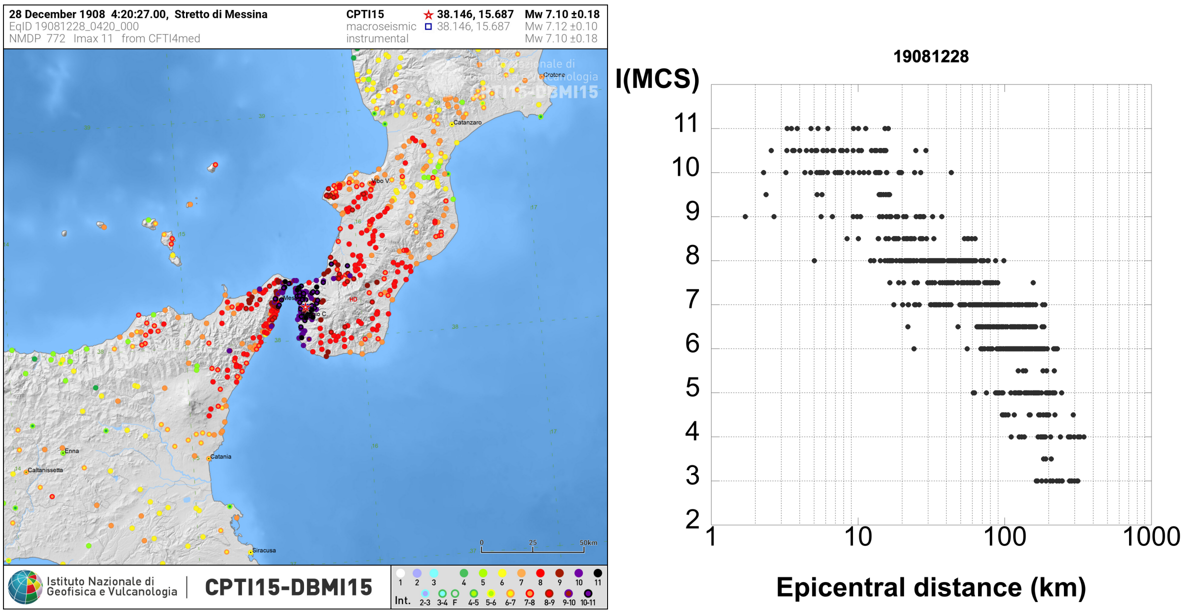
[1] Istituto Nazionale di Geofisica e Vulcanologia, sezione di Milano
[2]Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste
[3] Istituto Nazionale di Geofisica e Vulcanologia, sezione di Pisa
[4]Consiglio Nazionale delle Ricerche, Istituto di Matematica Applicata e Tecnologie Informatiche "Enrico Magenes", Milano

Corresponding author

Augusto Antonio Gomez-Capera

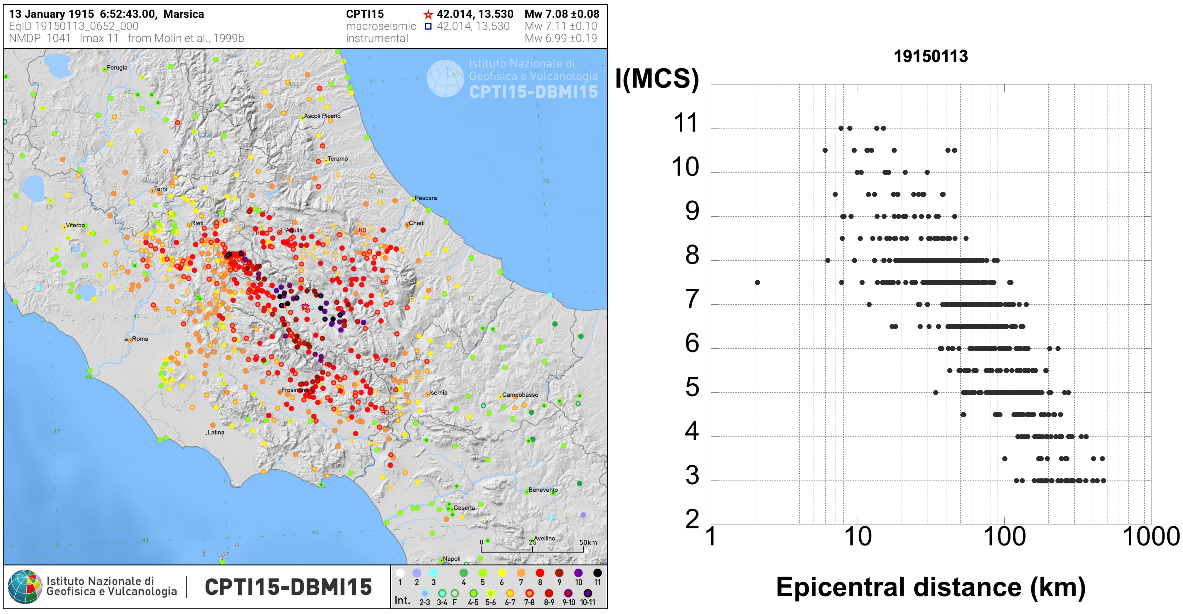
Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano, via Corti 12, 20133, Milan, Italy

antonio.gomez@ingv.it



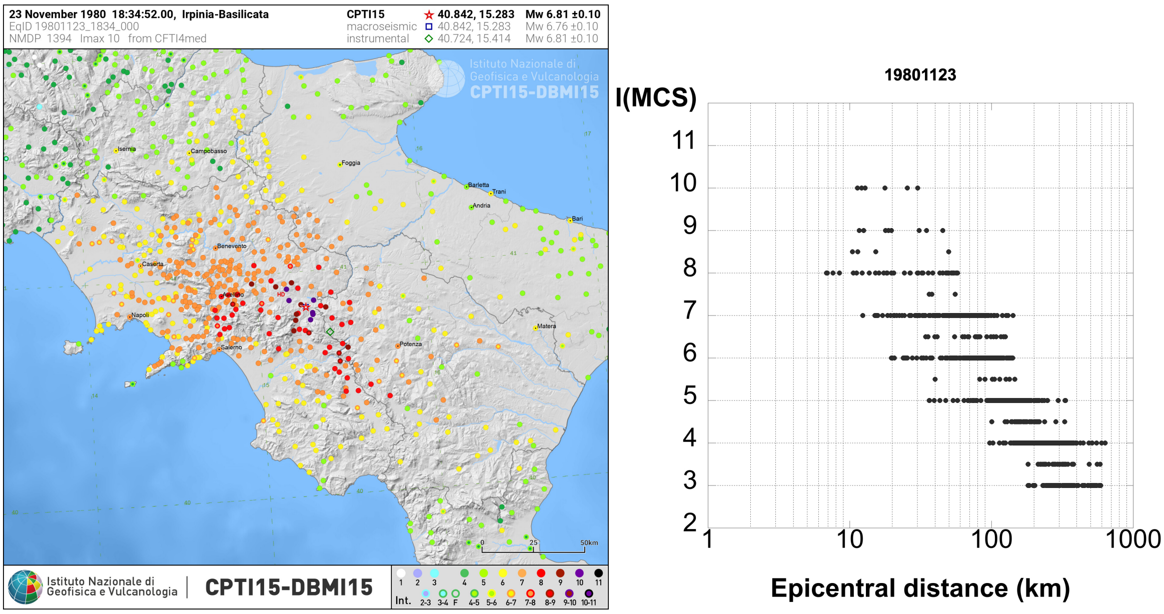
28 December 1908 4:20:27.00, Stretto di Messina
EqID 19081228_0420_000
NMDP 772 Imax 11 from CFTI4med
CPTI15
macroseismic
instrumental
38.146, 15.687
38.146, 15.687
Mw 7.10 ±0.18
Mw 7.12 ±0.10
Mw 7.10 ±0.18
Istituto Nazionale di Geofisica e Vulcanologia
CPTI15-DBMI15
Int.
19081228
I(MCS)
Epicentral distance (km)

a)

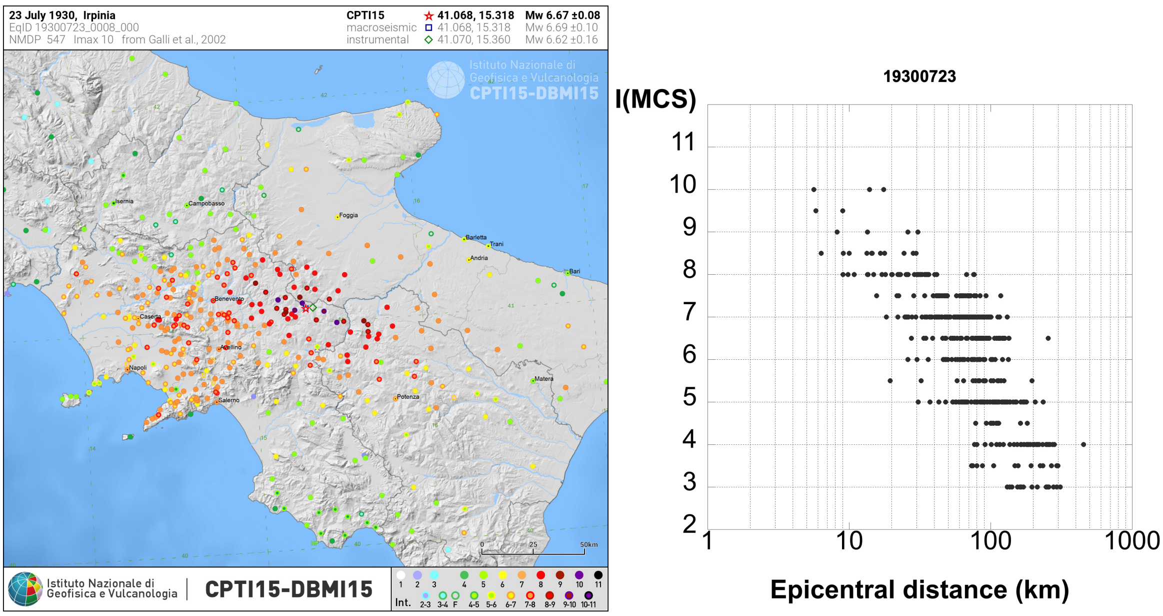


13 January 1915 6:52:43.00, Marsica
EqID 19150113_0652_000
NMDP 1041 Imax 11 from Molin et al., 1999b
CPTI15
macroseismic
instrumental
42.014, 13.530
42.014, 13.530
Mw 7.08 ±0.08
Mw 7.11 ±0.10
Mw 6.99 ±0.19
Istituto Nazionale di Geofisica e Vulcanologia
CPTI15-DBMI15
Int.
19150113
I(MCS)
Epicentral distance (km)

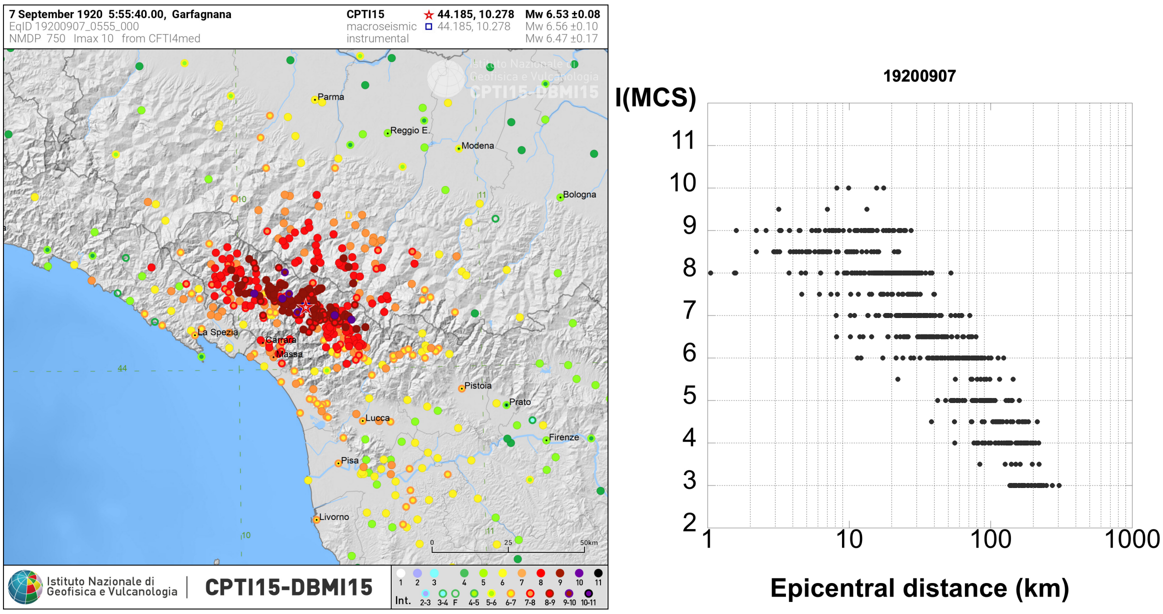
b)


23 November 1980 18:34:52.00, Irpinia-Basilicata
EqID 19801123_1834_000
NMDP 1394 Imax 10 from CFTI4med
CPTI15
macroseismic
instrumental
40.842, 15.283 Mw 6.81 ±0.10
40.842, 15.283 Mw 6.76 ±0.10
40.724, 15.414 Mw 6.81 ±0.10
Istituto Nazionale di Geofisica e Vulcanologia
CPTI15-DBMI15
19801123
I(MCS)
Epicentral distance (km)

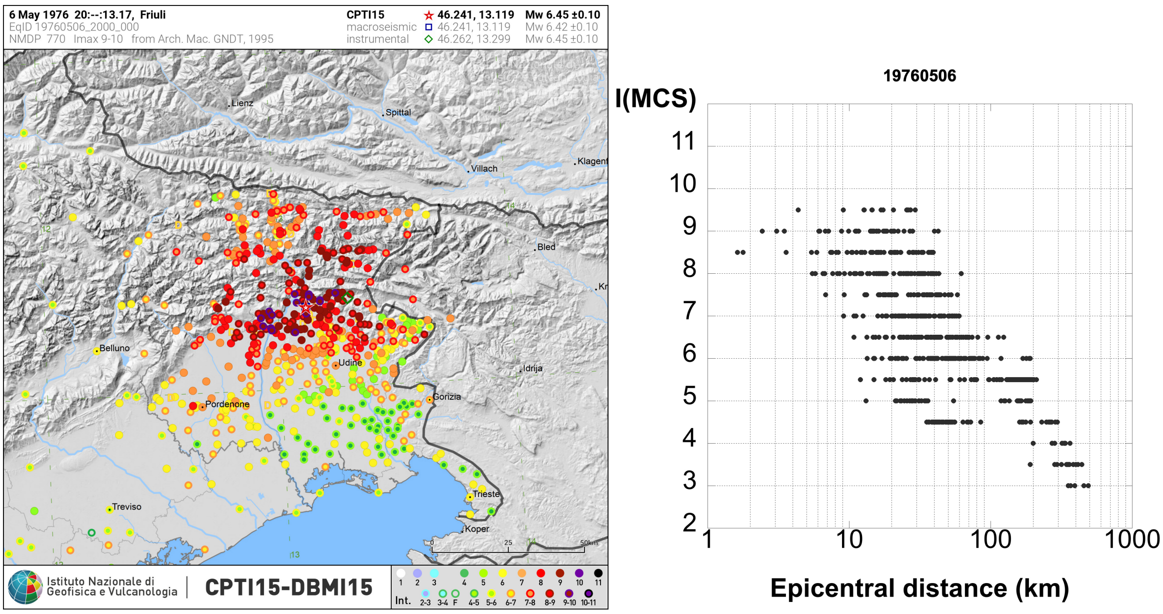
c)


23 July 1930, Irpinia
EqID 19300723_0008_000
NMDP 547 Imax 10 from Galli et al., 2002
CPTI15
macroseismic
instrumental
41.068, 15.318 Mw 6.67 ±0.08
41.068, 15.318 Mw 6.69 ±0.10
41.070, 15.360 Mw 6.62 ±0.16
Istituto Nazionale di Geofisica e Vulcanologia
CPTI15-DBMI15
19300723
I(MCS)
Epicentral distance (km)

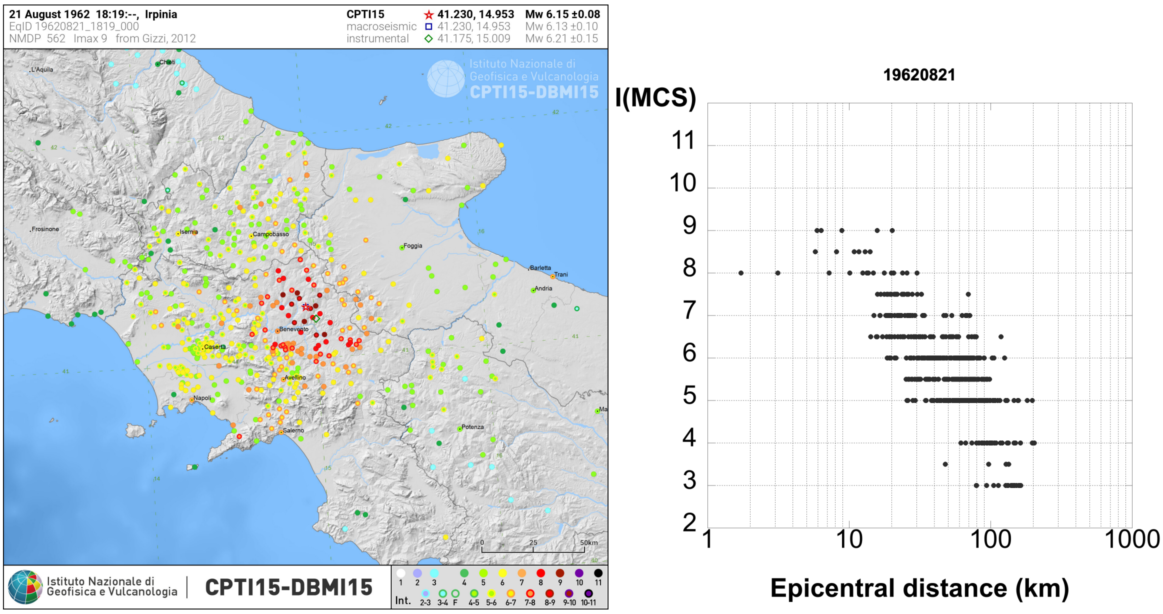
d)


7 September 1920 5:55:40.00, Garfagnana
EqID 19200907_0555_000
NMDP 750 Imax 10 from CFTI4med
CPTI15
macroseismic
instrumental
44.185, 10.278
44.185, 10.278
Mw 6.53 ±0.08
Mw 6.56 ±0.10
Mw 6.47 ±0.17
Parma
Reggio E.
Modena
Bologna
La Spezia
Massa
Pistoia
Prato
Lucca
Firenze
Pisa
Livorno
Istituto Nazionale di Geofisica e Vulcanologia
CPTI15-DBMI15
19200907
I(MCS)
Epicentral distance (km)

e)


6 May 1976 20:--:13.17, Friuli
EqID 19760506_2000_000
NMDP 770 Imax 9-10 from Arch. Mac. GNDT, 1995
CPTI15
macroseismic
instrumental
46.241, 13.119
46.241, 13.119
46.262, 13.299
Mw 6.45 ±0.10
Mw 6.42 ±0.10
Mw 6.45 ±0.10
Lienz
Spittal
Villach
Bled
Belluno
Udine
Idrija
Pordenone
Gorizia
Treviso
Trieste
Koper
Istituto Nazionale di Geofisica e Vulcanologia
CPTI15-DBMI15
19760506
I(MCS)
Epicentral distance (km)

f)



g)

Fig. A1 Spatial distribution of IDPs (left panels) and macroseismic intensity versus epicentral distance obtained from instrumental epicentre (right panels) of seven events with *Mw* greater than 6.0: a) 1908.12.28 *Stretto di Messina* (*Mw* 7.1); b) 1915.01.13 *Marsica* (*Mw* 7.0); c) 1980.11.23 *Irpinia-Basilicata* (*Mw* 6.8); d) 1930.07.23 *Irpinia* (*Mw* 6.6); e) 1920.09.07 *Garfagnana* (*Mw* 6.5); f) 1976.05.06 *Friuli* (*Mw* 6.4); g) 1962.08.21 *Irpinia* (*Mw* 6.2)

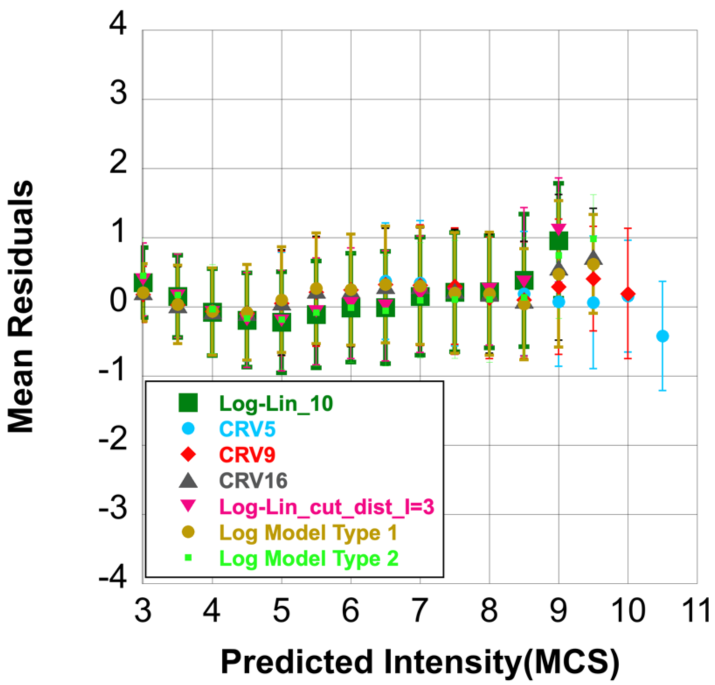


Fig. A2 Comparison of mean residuals and standard deviation (error bars) versus predicted macroseismic intensities for all macroseismic intensity attenuation model

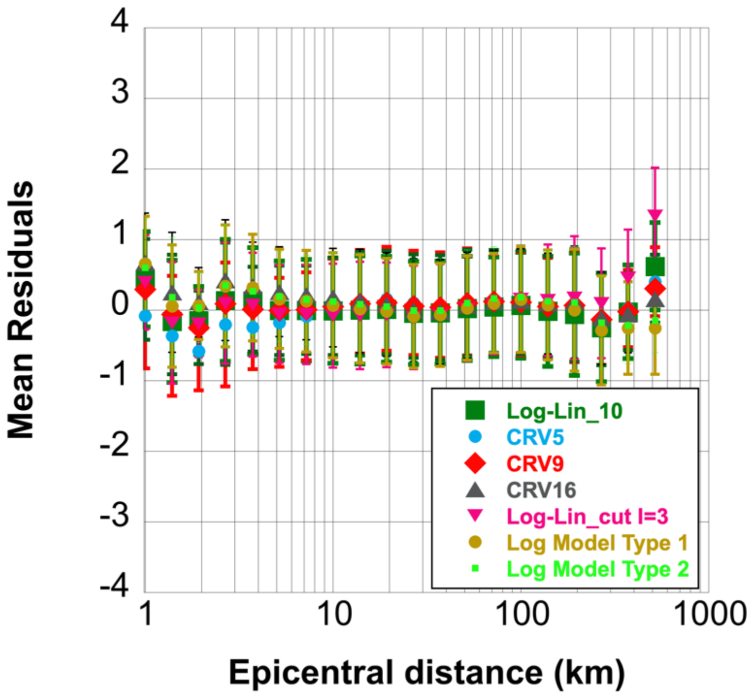


Fig. A3 Comparison of mean residuals and standard deviation (error bars) versus epicentral distance for all macroseismic intensity attenuation models

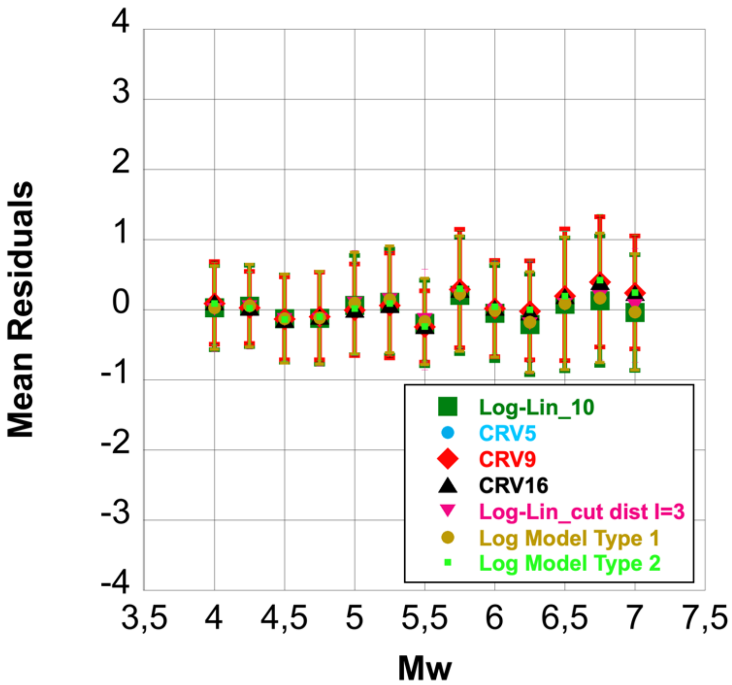


Fig. A4 Comparison of mean residuals and standard deviation (error bars) versus magnitude *Mw* for all macroseismic intensity attenuation models

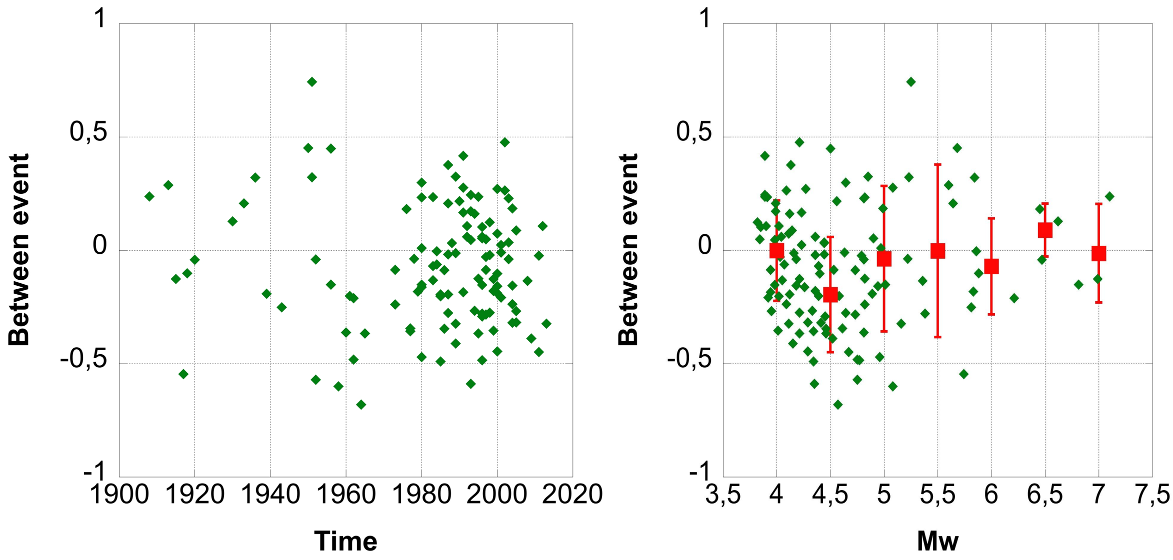


Fig. A5 Between event residuals versus Time and *Mw* of the calibration earthquakes

In CPTI15, various methods were applied to determine the magnitudes (*Mw*) of smaller earthquakes. This study utilised 119 events (electronic supplement Tab. A1), and the methods and time periods for *Mw* determination are as follows:

i) 31 earthquakes with *Mw* ranging from 3.8 to 4.8 between 1983 and 2005. The magnitude is calculated as the mean of *Mw* values determined from *Ml*, *Ms*, and *mb* estimates, with weights inversely proportional to their associated variances;

ii) 14 earthquakes with *Mw* in the range of 3.9 to 4.4 between 1983 and 1998. *Mw* is directly converted from local magnitude;

iii) 24 earthquakes with *Mw* ranging from 4.4 to 7.0. The magnitude is calculated as the mean of *Mw* values converted from *Ms* and *mb* estimates, with weights inversely proportional to their variances;

iv) 2 events with *Mw* ranging from 4.5 to 4.8. *Mw* is the mean of values converted from *Ms*, *mb*, and *Ml* Wood-Anderson estimates, with weights inversely proportional to their variances;

v) 2 events (1977-1980) with *Mw* ranging from 4.26 to 4.34. *Mw* is determined from *Ml* Wood-Anderson;

vi) The 1908 Messina earthquake has its *Mw* determined from S-waves amplitude;

vii) For 45 earthquakes with *Mw* ranging from 3.9 to 6.8, *Mw* is obtained from moment tensor solutions;

The use of diverse methods for calculating *Mw* may contribute to the observed bias in the between-event residuals.

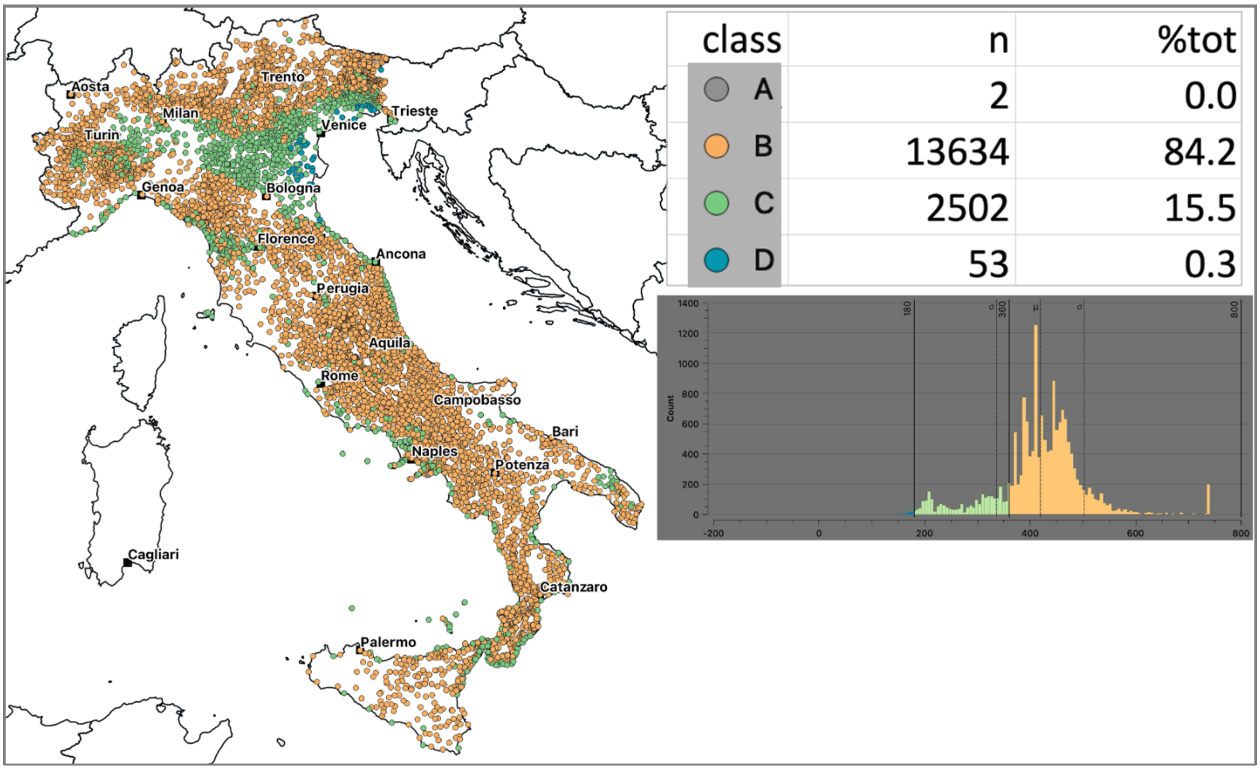


Fig. A6a

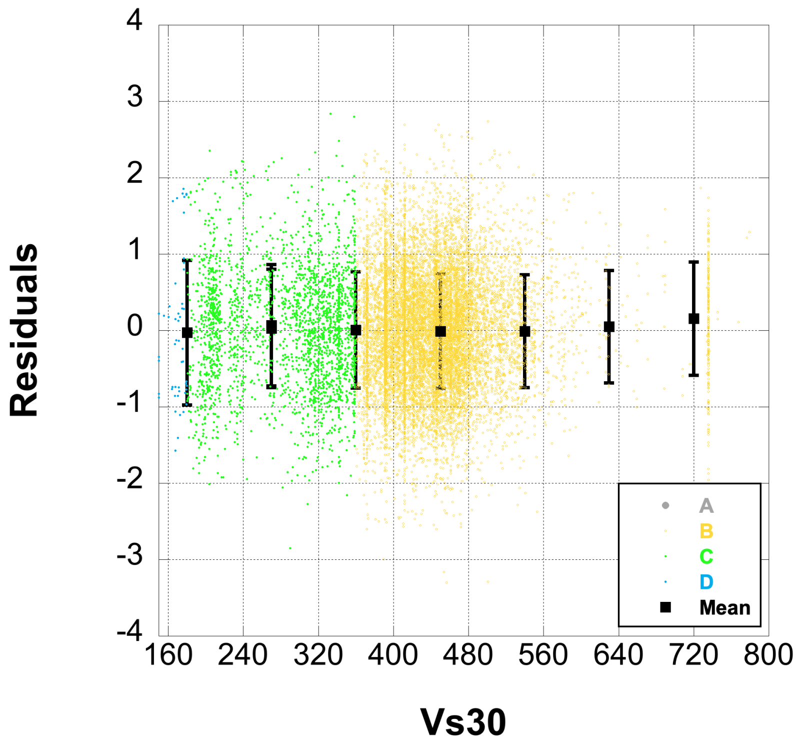


Fig. 6b

Fig. A6a The map is plotted using 4 classes of Vs30 (m/s), following the EC8 classification (CEN, 2004); n=number of IDPs. **Fig. A6b** Distribution of residuals (coloured dots) versus Vs30 considering 90 m/s bins, its mean (square dots) and standard deviation (error bars), for the Log-Lin_10 model

Table A2 Coefficients and standard errors of the macroseismic intensity attenuation models analysed in the present study. Type 1 models (Eq. 4) are denoted by N=1, 2, 3, 7, 8 and type 2 models (Eq. 5) by N=4, 5, 6, 9. All models are fitted to 16,260 IDPs, except Log-Lin$_{\text{cut dist I=3}}$ (N=7) which is fitted to 12,587 IDPs with $I \geq 3$. Column *Comp h* specifies if the pseudo focal depth *h* is a fixed (fix) or estimated (fit) parameter. The standard deviation of the intensity (*σ_I*), given by the root mean square of intensity residuals (Eq. 11), is provided for all models. For all type 2 models, the last column reports the standard deviation (*σ_LogI*) given by the root mean square of the log-intensity residuals for the additive model (5), as well as the standard deviation (*σ_Iobs/Icomp*) of the intensity residuals given by the theoretical formula (A1.4) for the equivalent multiplicative model (6)

N	**Model [Type]**	***a* Independent Term (error) [% error]**	***b* Geometric Spreading (error) [% error]**	***c* Anelastic Attenuation (error) [% error]**	***d* Magnitude Coeff. (error) [% error]**	***h* (km) (error) [% error]**	***Comp h***	***RMS_I***	***σ_LogI* *[σ_Iobs/Icomp]***
1	Log-Lin$_{_5}$ [Type 1]	1,11 (0,05) [4,5]	2,14 (0,03) [1,4]	0,0054 (0,0002) [3,7]	1,41 (0,007) [0,5]	5	fix	0,749	
2	Log-Lin$_{_10}$ [Type 1]	1,81 (0,10) [5,5]	2,61 (0,07) [2,7]	0,0039 (0,0003) [7,7]	1,42 (0,007) [0,5]	9,87 (0,56) [5,7]	fit	0,748	
3	Log-Lin$_{_16}$ [Type 1]	2,86 (0,06) [2,1]	3,26 (0,04) [1,2]	0,0020 (0,0002) [10,0]	1,43 (0,007) [0,5]	16	fix	0,754	
4	CRV$_5$ [Type 2]	-0,006 0,007 [117]	0,17 (0,003) [1,8]	0,0004 0,00002 [5]	1,35 (0,008) [0,6]	5	fix	0,735	0,0657 [0,15]
5	CRV$_9$ [Type 2]	0,032 (0,01) [31,2]	0,19 (0,006) [3,2]	0.0003 (0,00003) [10]	1,36 (0,008) [0,6]	8,72 (0,69) [7,9]	fit	0,731	0,0655 [0.15]
6	CRV$_{16}$ [Type 2]	0,125 (0,008) [6,4]	0,25 (0,004) [1,6]	0,0002 (0,00002) [10]	1,37 (0,008) [0,6]	16	fix	0,738	0,0657 [0,15]
7	Log-Lin$_{\text{cut dist I=3}}$ [Type 1]	2,12 (0,18) [8,5]	2,84 (0,12) [4,2]	0,0051 (0,0005) [10]	1,45 (0,010) [0,7]	11,3 (0,80) [7,1]	fit	*0,771	
8	Log Model [Type 1]	3,39 (0,069) [2]	3,63 (0,036) [1,0]	-	1,42 (0,007) [0,5]	16,6 (0,45) [2,7]	fit	0,751	
9	Log Model [Type 2]	0,171 (0,008) [4.7]	0,29 (0,004) [1,4]	-	1,36 (0,008) [0,6]	16,2 (0,57) [3,5]	fit	[0,735]	0,0659 [0,16]

Appendix 1

A1. Some notes on the multiplicative model (6) and its logarithmic transformation (5)

Eq. (6) is a multiplicative model such as:

$$I = f(R_{epi}\,, Mw) \cdot \varepsilon' \tag{A1.1}$$

where the intensity *I* is positive and depends on moment magnitude *Mw* and epicentral intensity R_{epi}, and ε' is a random error.

To exploit computational methods for linear models, a double-log transformation is applied to model (6) and the linear model (5) is obtained:

$$Log\, I = Log\, f\left(R_{epi}\,, Mw\right) + \varepsilon \tag{A1.2}$$

where $Log\, I$ spans the real line (Log denotes the base 10 logarithm) and ε is reasonably assumed to be an additive Gaussian/Normal error with zero mean and standard deviation σ, namely $\varepsilon \sim Normal(0, \sigma)$ and $Log\, I \sim Normal(Log\, f(R_{epi}, Mw), \sigma)$. The advantage of model (A1.2) is that it is linear and its coefficients can be estimated by standard computational methods developed under the Gaussian error hypothesis. Once model (A1.2) has been estimated, empirical probability rules for Normal distribution can be used to quantify the uncertainty on the predicted value (I_{comp}) of the intensity. In this study we consider $Prob\left(Log\, I_{comp} - \sigma \leq Log\, I \leq Log\, I_{comp} + \sigma\right) \approx 0.683$, that is the probability of the true value of $Log\, I$ falling within the uncertainty range $[Log\, I_{comp} - \sigma, Log\, I_{comp} + \sigma]$ is roughly 68.3%.

The model (A1.1) is easily obtainable from the estimated model (A1.2), after making some considerations on its error ε' and on its residuals. Since ε is assumed to be Normally distributed and $\varepsilon' = 10^{\varepsilon} = exp\ (\varepsilon \cdot ln10)$, it turns out that ε' is LogNormally distributed by definition. Moreover, mean and standard deviation of ε' can be obtained from those of ε as follows:

$$mean\ of\ \varepsilon' = e^{(\sigma')^2/2} \tag{A1.3}$$

$$standard\ deviation\ of\ \varepsilon' = \sqrt{e^{(\sigma')^2}(e^{(\sigma')^2} - 1)} \tag{A1.4}$$

where $\sigma' = \sigma \cdot ln10$.

Consequently, the uncertainty on the intensity predicted from the multiplicative model (A1.1) has the following expression: $Prob\left(I_{comp} \cdot 10^{-\sigma} \leq I \leq I_{comp} \cdot 10^{\sigma}\right) \approx 0.683$.

Finally, the residuals in model (A1.2) are defined as the difference $Log\, I_{obs} - Log\, I_{comp}$ between the logarithm of the observed and predicted values of the intensity *I*; these residuals vary around 0, a value which indicates the exact match between observed and predicted intensity. As a consequence, the residuals in the multiplicative model (A1.1) are positive ratios $\frac{I_{obs}}{I_{comp}} = 10^{Log\, I_{obs} - Log\, I_{comp}}$, that vary around 1. In this case, a residual of 1 would imply that the observed intensity exactly matches the predicted one.