



SECURE

REGIONAL-SCALE EARTHQUAKE GROUND MOTION PREDICTIONS
THROUGH PHYSICS-BASED AND EMPIRICAL APPROACHES:
A CASE STUDY CENTRAL ITALY

Macroseismic intensity attenuation models calibrated in Mw for Italy

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- State-of-the-art
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- Data
- Results
 - ✓ The best regressions assuming h as free parameter
 - ✓ Sensitivity analysis
 - ✓ Residuals
- Validation
 - ✓ MAE
 - ✓ BW97



Macroseismic intensity attenuation models calibrated in M_w for Italy

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Abstract

This study aims at developing new macroseismic intensity attenuation models valid for Italy by exploiting the most updated macroseismic dataset and earthquakes catalogue, as well as the information obtained from a critical analysis of the most recent models in the literature. Several different attenuation models have been calibrated as a function of the moment magnitude (M_w) and epicentral distance from 16,260 intensity data points, that are related to 119 earthquakes occurred after 1900. According to trends and residuals analysis, the preferred calibrated intensity attenuation function is a Log-Linear model for epicentral distance (R_{epi} in km) and a linear model for M_w as:

$$I(MCS) = 1.81 - 2.61 \log R - 0.0039R + 1.42M_w$$

with pseudo hypocentral distance $R = \sqrt{R_{epi}^2 + (9.87)^2}$; the estimated standard deviation is $\sigma = 0.75$. Also noteworthy is another model for macroseismic intensity attenuation that proved to be as good as the best model and shows higher sensitivity to physical parameters, such as focal depth and magnitude, especially in the epicentral area. Performance of all calibrated models was also checked on an independent set of 15 post-1900 Italian earthquakes. One of the results of the present work is the opportunity to define earthquake scenarios (e.g. probabilistic seismic hazard maps) in terms of Macroseismic Intensity and its related standard deviation, avoiding the uncertainties due to the conversion of various ground shaking parameters into intensity values.

Keywords Macroseismic intensity · Intensity attenuation · Macroseismic data · Italy

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State-of-the-art

Table 1 Examples of functional types of macroseismic intensity attenuation models

References	Functional	Properties
Kövesligethy (1906)	$I_o - I_i = 3\text{Log}\left(\frac{R}{h}\right) + 3\alpha\text{Log}(e)(R - h)$ $R = \sqrt{R_{epi}^2 + h^2}$	I_o is the macroseismic intensity in the epicentre; I is the site intensity; R is the pseudo hypocentral distance; h is the pseudo focal depth; e is Euler's constant, α is an anelastic attenuation coefficient
Blake (1937)	$I_o - I_i = b\text{Log}(R/h)$	Montana
Gutenberg and Richter (1942)	$I_o - I_i = b\text{Log}(R_i/h)$	California
Cornell (1968)	$I = a - b\text{Ln}R + dM$ $[a=6; b=2.5; c=1.5]$	California
Milne and Davenport (1969)	$I = I_o + a - cR_{epi} + dM + frM$	Canada
Howell and Schultz (1975)	$I = I_o + a - b\text{Ln}R - cR$ $I = -b\text{Ln}R - cR + dM + fI_o/R$ $\text{Ln}I = \text{Ln}I_o + a - b\text{Ln}R - cR$ $I = I_o e^a R^{-b} e^{-cR}$ $\text{Ln}I = \text{Ln}(1.5M - 1.5) + a - b\text{Ln}R - cR$ $I = (1.5M - 1.5)e^a R^{-b} e^{-cR}$	[Isoseismals Input] USA
Gupta and Nuttli (1976)	$I = I_o + a - b\text{Log}R_{epi} - cR_{epi}$ $\text{with } R_{epi} \geq R_o \text{ km}$	R_{epi} : epicentral distance; R_o isoseismal radius average to maximum Intensity Central USA
Chandra et al. (1979)	$I = I_o + a - b\text{Log}(R_{epi} + R_o) - cr$	Iran
Kaila and Sarkar (1982)	$\text{Ln}(I/I_o) = -mR_{epi}$ $I = (dM - fh + a)e^{aR_{epi}} e^{-\beta r/h^2}$	USA
Ambraseys (1985)	$I_o - I = a + b\text{Log}(R/h) + c(R - h)$	Northwest Europe
Greenhalgh et al. (1989)	$I = I_o e^{-aR/2} / R$	Australia
Grandori et al. (1991)	$I_o - I = \frac{1}{\ln\psi} \ln \left[1 + \frac{\psi-1}{\psi_0} \left(\frac{D_i}{D_0} - 1 \right) \right]$	Central Italy
Dowrick and Rhoades (1992)	$I = a - b\text{Ln}R_{epi} - cR_{epi} + dM$	[r is the mean radius of the isoseismal line for intensity I in km] [Isoseismals Input] New Zealand
Berardi et al. (1993)	$I_o - I = \alpha + \beta \sqrt[3]{D_i}$	[Isoseismals Input] Italy
Papazachos and Papaioannou (1997)	$I - I_o = -b\text{Log}\sqrt{1 + \frac{R_{epi}^2}{h^2}} - c\sqrt{R_{epi}^2 + h^2} - h$ $h=9.5 \text{ km}$	[Isoseismals Input] Balkan area

Table 2 Examples of macroseismic intensity attenuation models calibrated in magnitude

References	Attenuation relationship	σ	Area	Time interval [N events] used	Distance metric [macroseismic data type]	Input parameters range
Bakun and Wentworth (1997)	$I = -3.29 - 0.0206R_{epi} + 1.68M_w$ to $M_w > 5.5$	–	California	1966–1994 [11]	Repi [IDPs]	$5.6 \leq M_w \leq 6.9$ $3 \leq I(MM) \leq 9$
Hinzen and Oemish (2001)	$I = -0.7374 - 0.0184R_{epi} + 1.26$ $73 M_L$	–	Northern Rhine Area	1993–1998 [14]	Repi [IDPs]	$2.9 \leq M_w \leq 5.9$ $2 \leq I(MSK) \leq 7$
Gomez-Capera and Salcedo Hurtado (2002)	$I = I_0 - 0.76 \ln(R_{epi} - 15) - 0.019(R_{epi} - 15)$ to $h \leq 20 \text{ km}$ $I = (2.3mb - 6.8)1.1 R_{epi}$ $-0.06e^{-0.001R_{epi}}$ to $h \leq 60 \text{ km}$ $I = I_0 1.26e^{-0.004R_{epi}}$ to $h > 60 \text{ km}$	0.3 0.5 0.9	Colombia	1812–1995 [34]	Repi [Isoseismals]	$5 \leq mb \leq 7.4$ $2 \leq I(MM) \leq 11$
Mezcua et al. (2004)	$I = 1.96 - 2.93 \text{Log} R_{epi} + 1.41M_w$	0.3	Spain	1993–1999 [5]	Repi [IDPs]	$4.8 \leq I(MSK) \leq 7.9$ $3 \leq I(MM) \leq 7$
Bakun (2005)	$I_{JMA} = -1.89 - 1.66 \text{Log} R$ $-0.00887R + 1.42M_{JMA}$ $R = \sqrt{R_{epi}^2 + 5^2}$	–	Japan (shallow crustal)	1930–1990 [14]	Repi [IDPs]	$3.5 \leq M_{JMA} \leq 6.1$ $1 \leq I(JMA) \leq 4$
Bakun (2006)	$I = 0.44 - 2.73 \text{Log} R - 0.0048$ $R + 1.70M_w$ $R = \sqrt{R_{epi}^2 + 10^2}$	–	Southern California	1968–1999 [13]	Repi [IDPs]	$5.5 \leq M_w \leq 7.3$ $3 \leq I(MM) \leq 8$
Bakun and Scotti (2006)	$I = 2.26 - 4.05 \text{Log} R + 1.27M_w$	–	French Alps	1866–2003 [7]	Rhyp [IDPs]	$3.6 \leq M_w \leq 5.37$ $3 \leq I(MSK) \leq 7$
Gomez-Capera et al. (2013)	$I = 3.11 - 3.17 \text{Log} R - 0.0017R + 1.4M_w$ $R = \sqrt{R_{epi}^2 + 10^2}$	0.5	Eastern Cuba	1978–2007 [8]	Repi [IDPs]	$5.2 \leq M_w \leq 6.8$ $3 \leq I(MSK) \leq 8$
Le Goff et al. (2014)	$I = -9.5763 - 1.9438 \ln R_{epi} + 4$ $.1M_w$	0.6	Portugal	1909–1997 [25]	Repi [IDPs]	$4.4 \leq M_w \leq 6.2$ $2 \leq I(MM) \leq 10$
Quadros et al (2019)	$I = 2.08 - 1.505 \text{Log} R - 0.00116R$ $+ 0.995M_w$	0.8	Brazil	1922–2017 [20]	Rhyp [IDPs]	$3.5 \leq mb \leq 6.2$ $1 \leq I(MM) \leq 7-8$
Gomez-Capera et al. (2020)	$I = -1.92 - 3.68 \text{Log} R - 0.0021R$ $+ 2.33M_w$ $R = \sqrt{R_{epi}^2 + 10^2}$	0.5	Colombia	1917–2008 [8]	Repi [IDPs]	$5.1 \leq M_w \leq 7$ $4 \leq I(EMS-98) \leq 10$
Mezcua et al. (2020)	$I = -0.66 - 1.544 \text{Log} R - 0.0022$ $R + 1.528M_w$	0.6	Spain	post-1884 [105]	Rhyp [IDPs]	$3.3 \leq M_w \leq 5.3$ $2 \leq I(EMS-98) \leq 9-10$

Table 3 The most recent macroseismic intensity attenuation models referenced in literature for Italy

References	Attenuation relationship	σ	Catalogue	Time interval [N events] used	Database [NIDPs] used	Input parameters range
Berardi et al. (1993)	$I_o - I = -0.729 + 1.12R_{epi}^{1/3}$	1.08	ENEL (1975) Postpischl ed. (1985) ING (1981)	1450 a.C.-1980 [44]	Margottini e Molin (1983) [6.188]	$I_o \geq 9$ $1 \leq R_{epi} \leq 500$
Gasperini (2001)	$\Delta I = \begin{cases} 0.445 + 0.059R & (R \leq 45km) \\ 0.445 + 0.059 \cdot 45 + 0.0207(R - 45) & (R > 45km) \end{cases}$ $\Delta I = I_o - I, h = 10km$	1.04	CPTI99	1801–1990	DOM4.1 Boschi et al. (1997) [~20.000]	$10 \leq R \leq 180$
Albarelo and D'Amico (2004)	$I = 3.6 - 0.98LnR - 0.003R + 0.705I_o$ $h = 10km$	1.25	CPTI99	217 a.C.-1992 [369]	DOM4.1 [14.870]	$15 \leq R \leq 300$
Gomez-Capera et al. (2006, 2010)	$I_o - I = -1.31 + 1.18R_{epi}^{1/3}$ whole Italy $I_o - I = -1.35 + 1.23R_{epi}^{1/3}$ FM Normal $I_o - I = -0.89 + 1.02R_{epi}^{1/3}$ FM Reverse + Strike – Slip $I_o - I = -0.49 + 1.41R_{epi}^{1/3}$ Etna	0.94 0.88 1.00 1.15	CPTI04	1279–2002[212]	DBMI04 [20.873] [13.393] [5.020] [1.328]	$7 \leq I_o \leq 11$ $3 \leq I \leq 11$ $R_{epi} < 453$ $R_{epi} < 453$ $R_{epi} < 453$ $R_{epi} < 40.0$
Gomez-Capera et al. (2008a, b)	$I = 2.343 - 2.87LogR_{epi} + 1.35Mw$	0.72	CPTI04	1989–2002 [9]	DBMI04 [6.495]	$4.6 \leq Mw \leq 6.9$ $1 \leq R_{epi} \leq 250$ $4 \leq I \leq 10$
Pasolini et al. (2008b)	$I = I_E - 0.0086(R - h) - 1.037(LnR - Lnh)$ $I_E = -5.862 + 2.460Mw$ $I_E = -0.893 + 1.118I_o$ $h = 3.91km$ $I = -5.86 - 1.037(LnR - Lnh) - 0.0086(R - h) + 2.46Mw$	*0.98 **0.87	CPTI04	1200–2002 [470]	DBMI04 [21.932]	$4.4 \leq Mw \leq 7.4$ $R \leq 200$ $4 \leq I \leq 11$
Gomez-Capera et al. (2009)	$I = 2.18 - 3.52LnR - 0.011R + 1.65Mw$ $h = 10km$	0.64	CPTI04	1908–2005 [18]	DBMI04 [7.991]	$3.7 \leq Mw \leq 7.1$ $R < 400$ $4 \leq I \leq 11$

R_{epi} : Epicentral distance (km); R : pseudo hypocentral distance (km); h : pseudo focal depth (km)

I : Macroseismic Intensity (MCS); Mw : moment Magnitude; I_o : Epicentral macroseismic intensity

σ : standard deviation

NIDPs: Number of Macroseismic Data Points; *: The $\sigma=0.98$ to Attenuation relationship for I_o ; **: The $\sigma=0.87$ to Attenuation relationship for Mw

CPTI99: Gruppo di lavoro CPTI (1999); DOM4.1: Monachesi and Stucchi (1997); CPTI04: Gruppo di lavoro CPTI (2004); DBMI04: Stucchi et al. (2007)

Method: Howell and Schultz (1975)

$$E = \left(\frac{E_0}{4\pi} \right) R_{hyp}^{-b} 10^{-cR_{hyp}}$$

$$I = k_1 + k_2 \text{Log} E$$

i. Macroseismic intensity attenuation model type 1

$$I = a_1 - b_1 \text{Log} R - c_1 R + d_1 M_w$$

$$I = k_3 + k_4 E^{k_4}$$

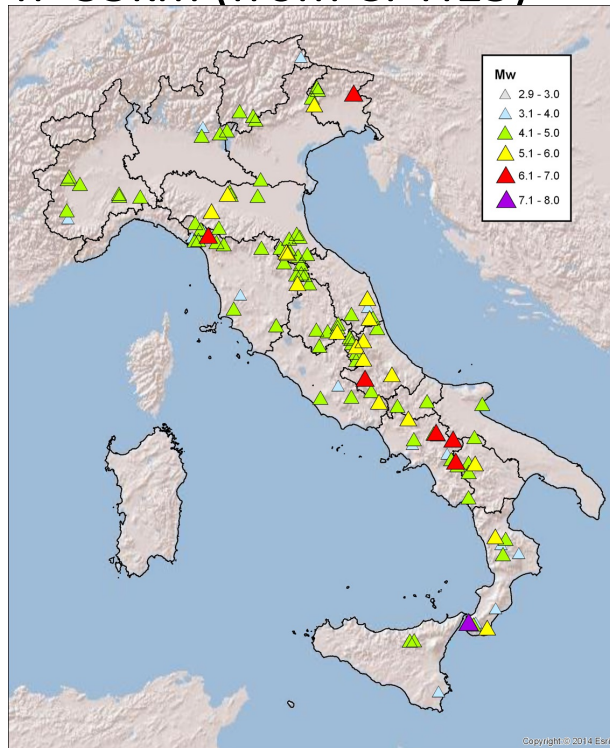
ii. Macroseismic intensity attenuation model type 2

$$\text{Log} I = a_2 - b_2 \text{Log} R - c_2 R + d_2 \text{Log} M_w$$

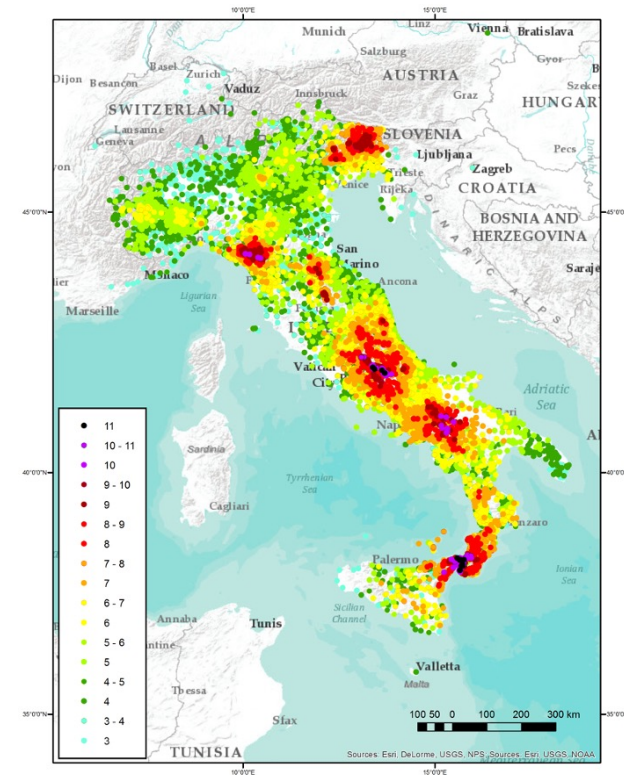
$$I = a'_2 R^{-b_2} 10^{-c_2 R} M_w^{d_2}$$

Data

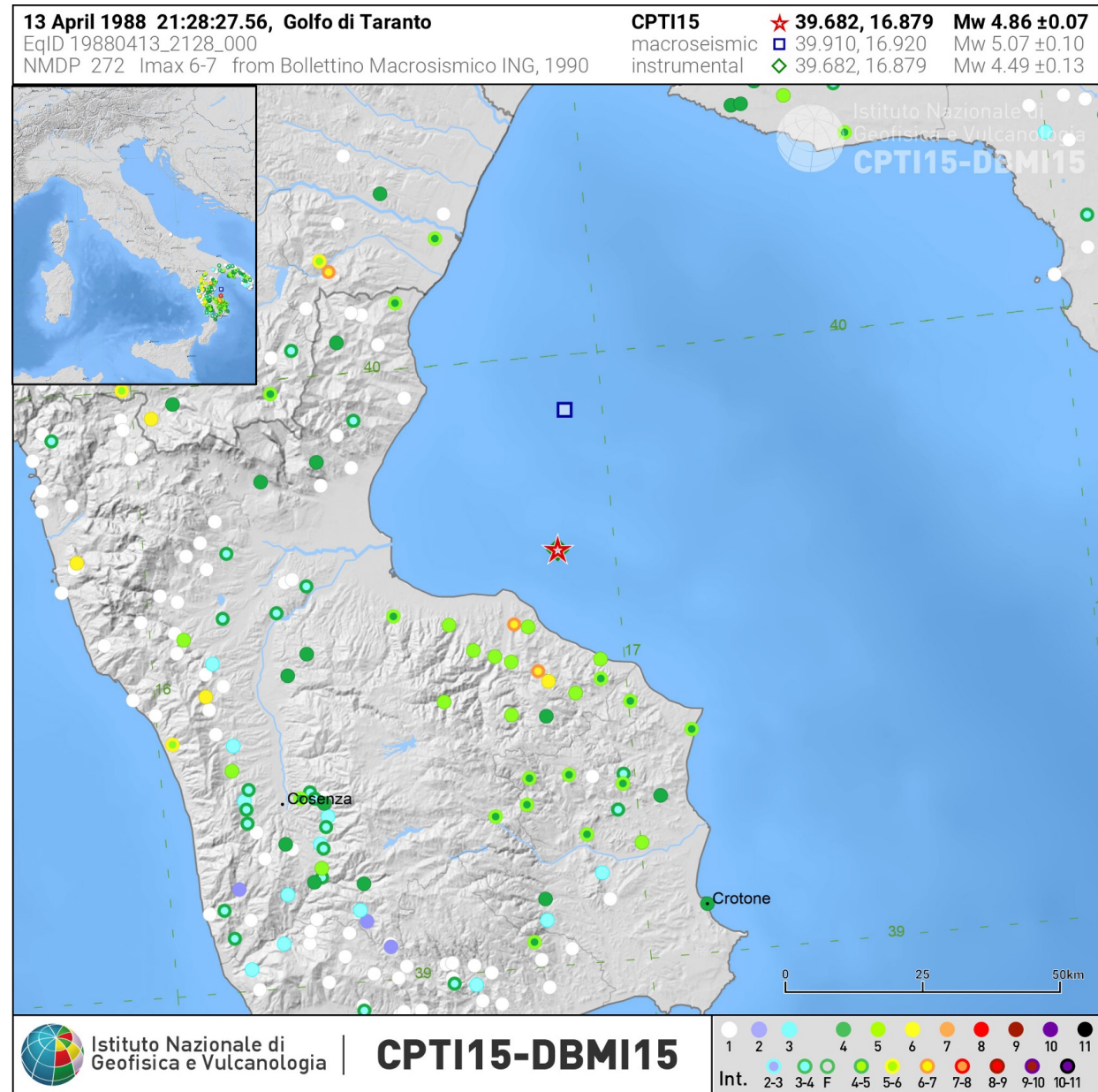
119 earthquakes [1908-2013]
[3.8 - 7.1]Mw
h<35km (from CPTI15)



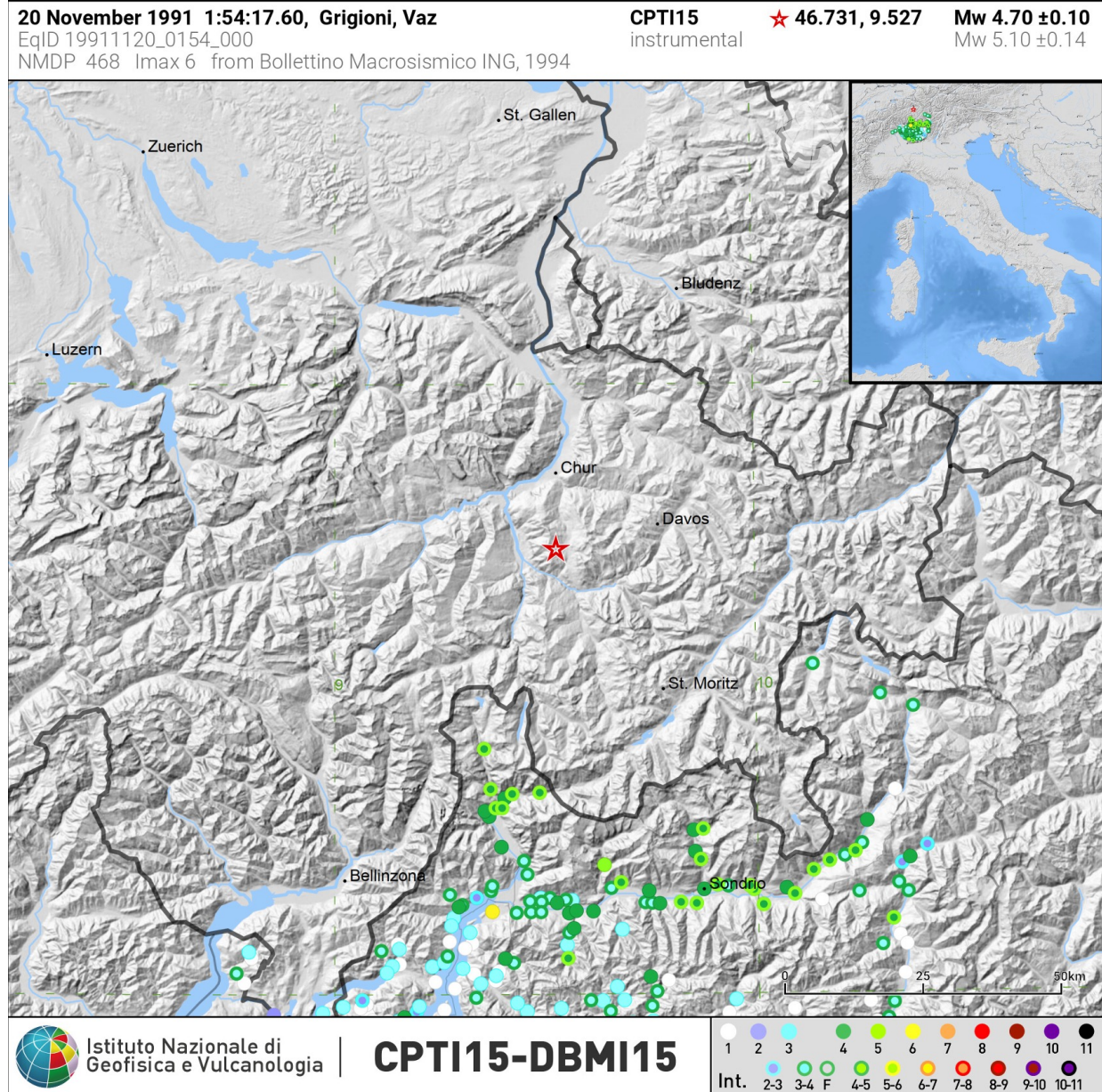
16.260 IDPs (from DBMI15)
[3-11]MCS ; [5-11]Imax
[0.1-634km]

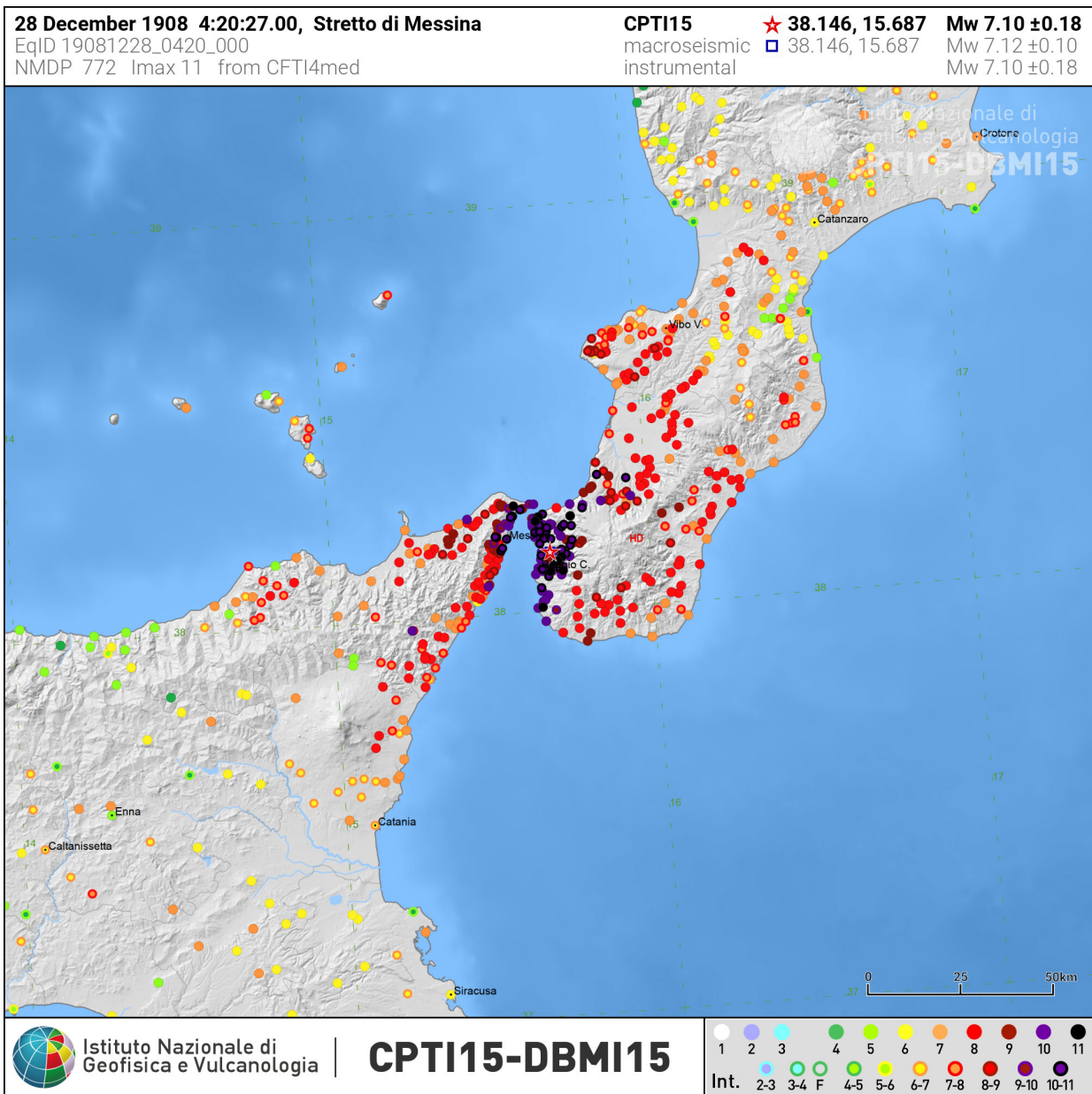


Examples of Events Excluded in the Calibration Process

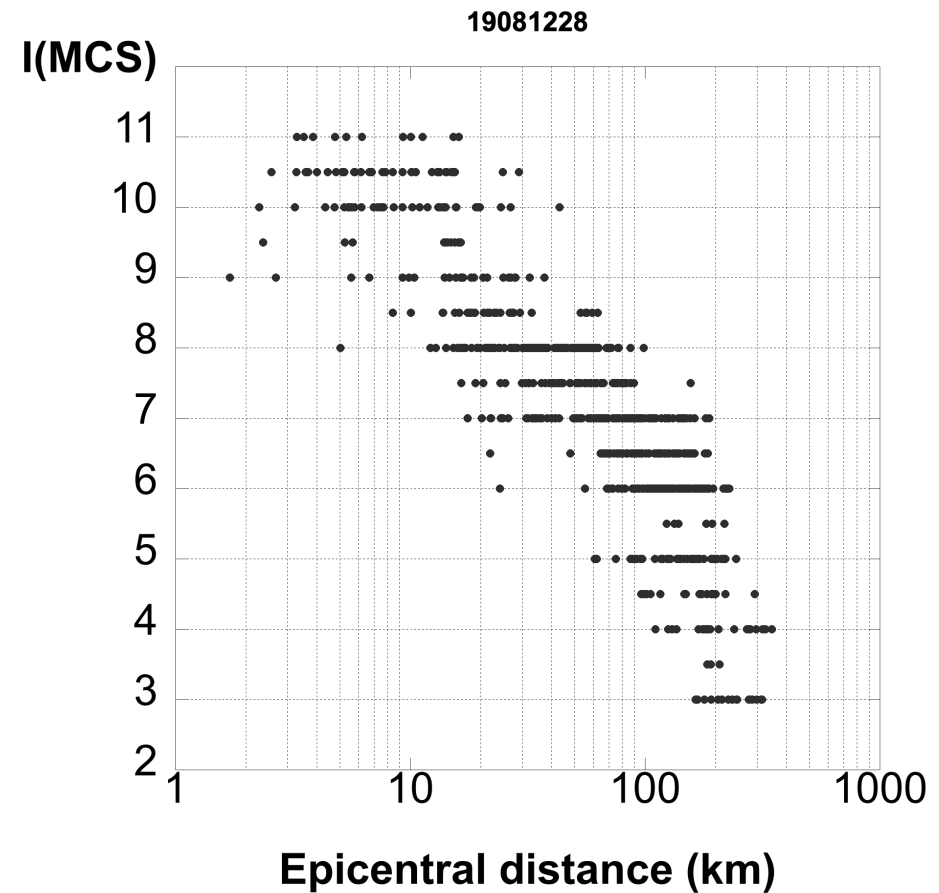


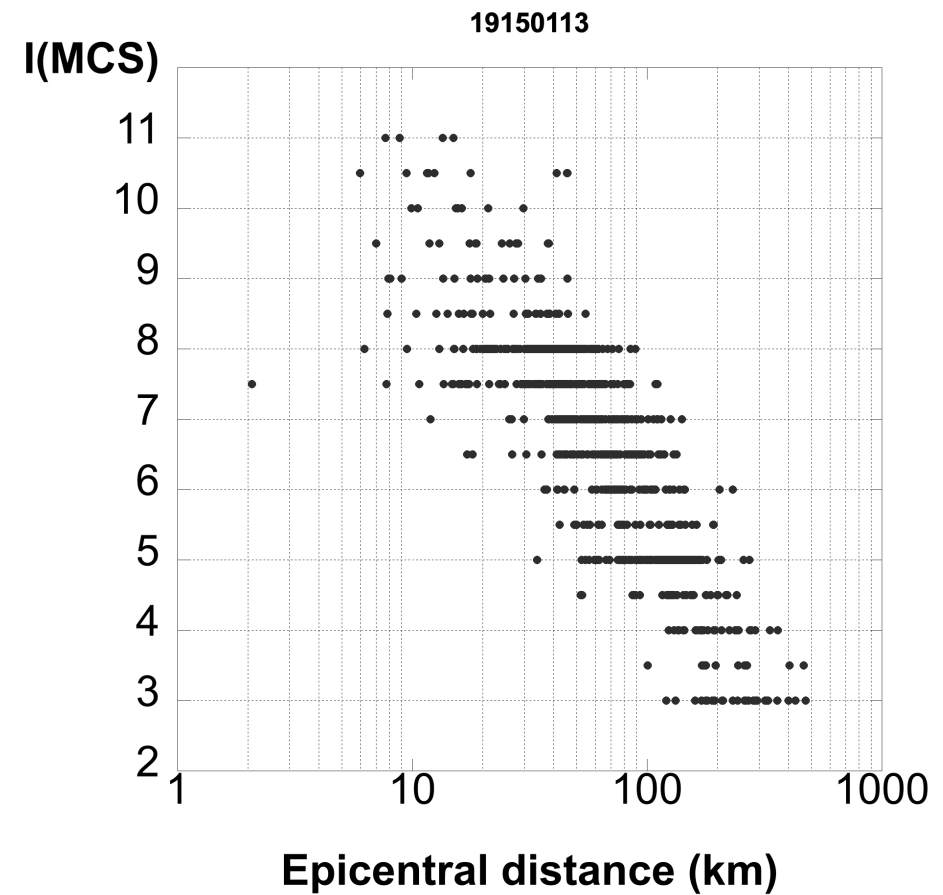
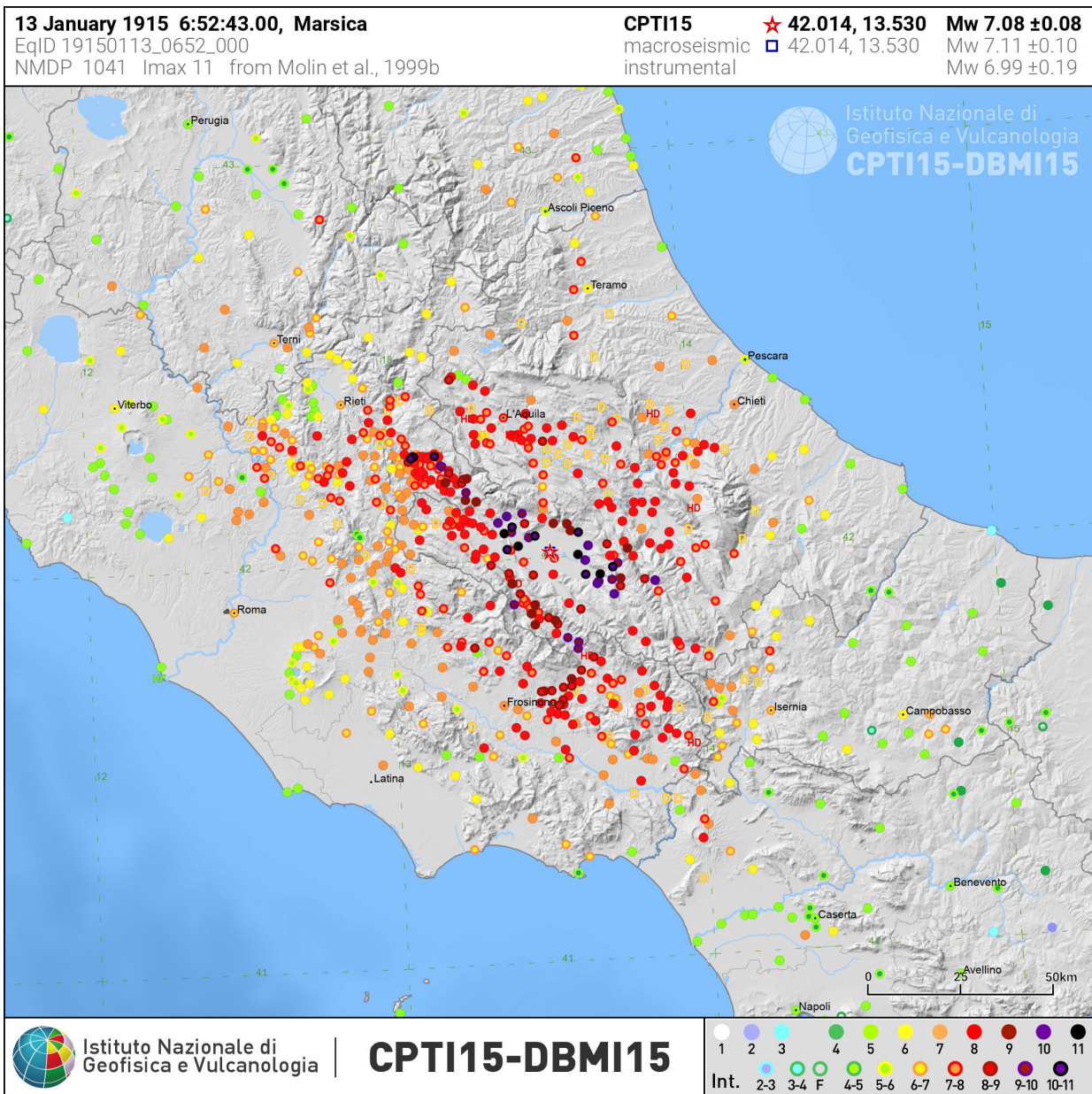
Examples of Events Excluded in the Calibration Process





Examples of Events Used

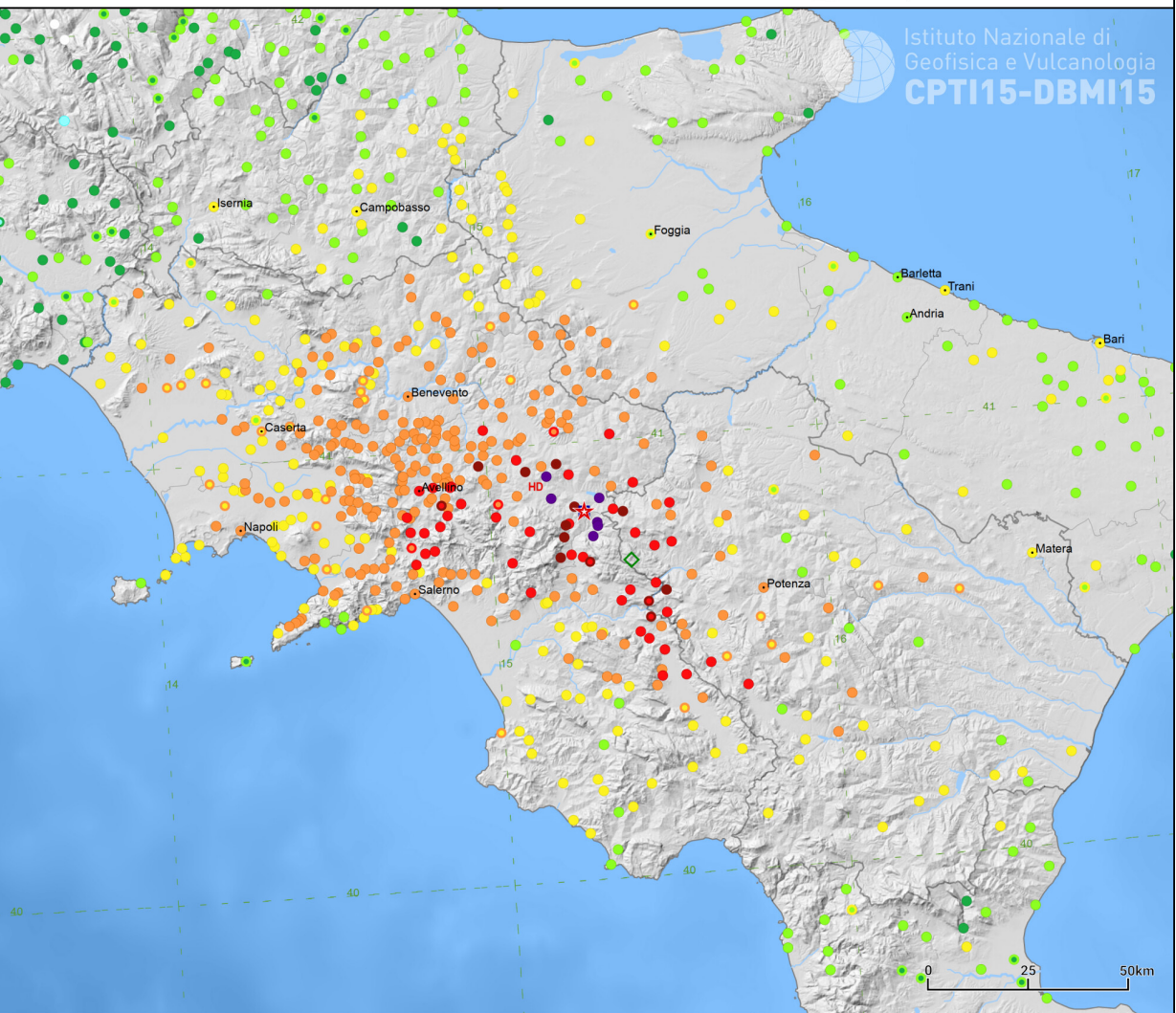




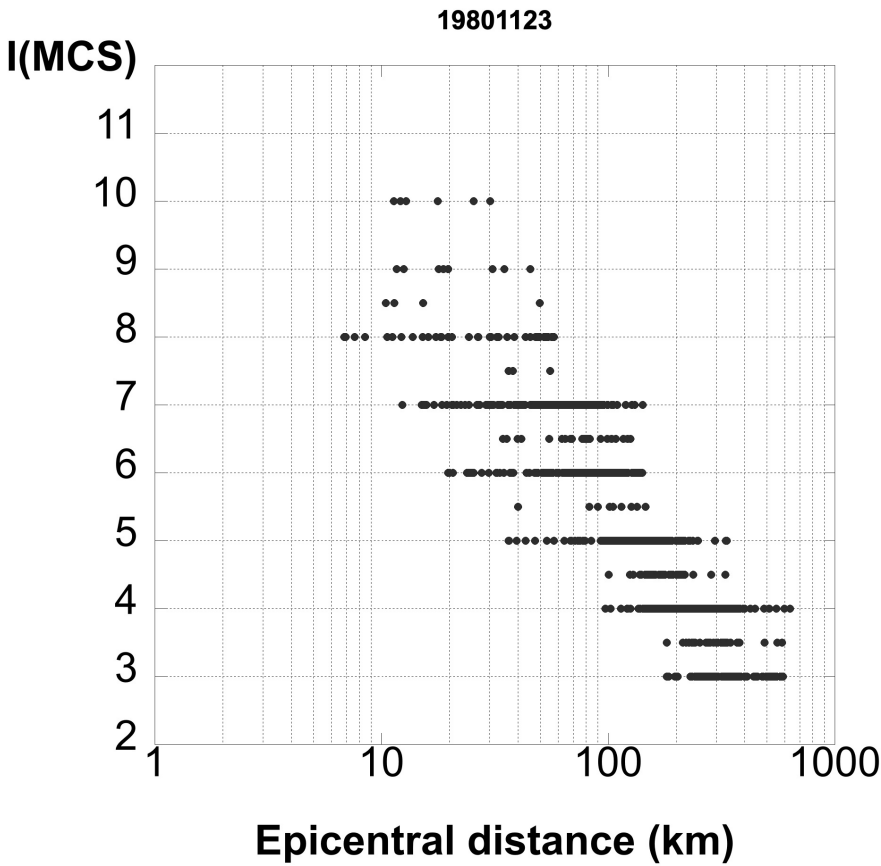
23 November 1980 18:34:52.00, Irpinia-Basilicata
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NMDP 1394 lmax 10 from CFTI4med

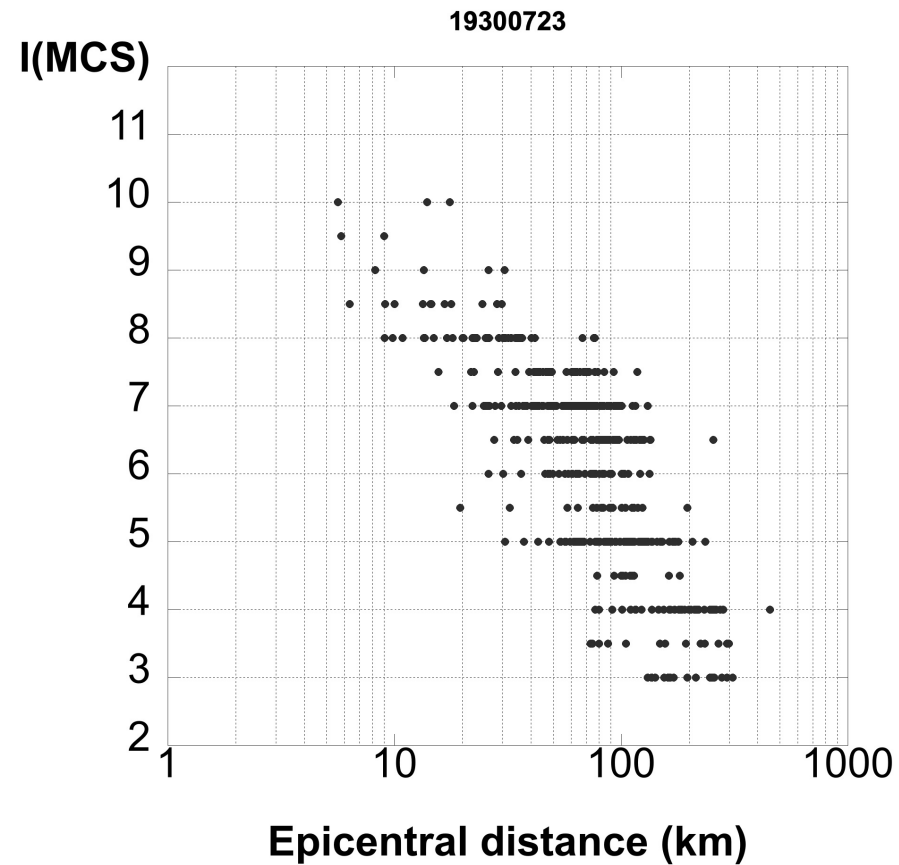
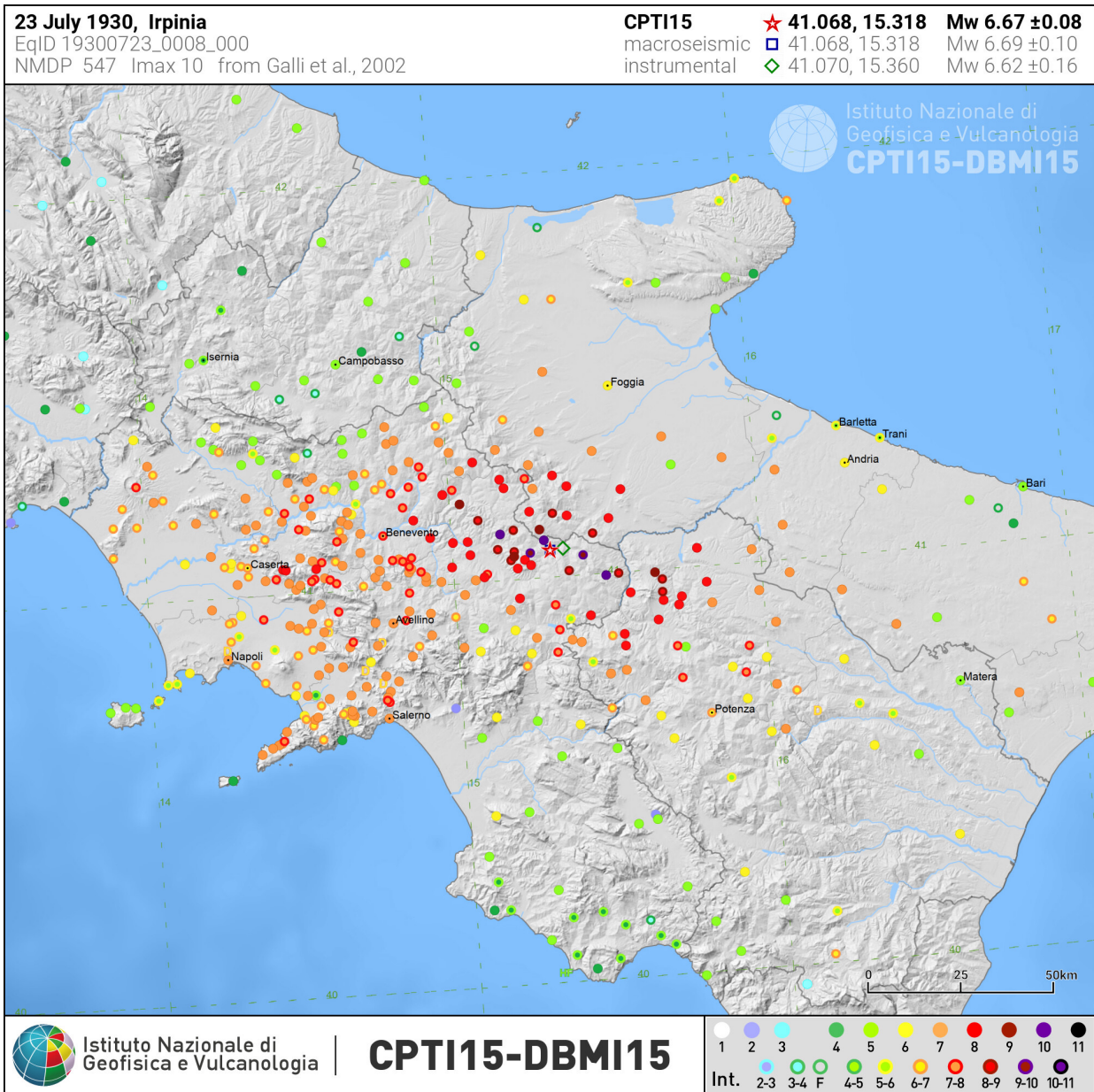
CPTI15
macroseismic
instrumental

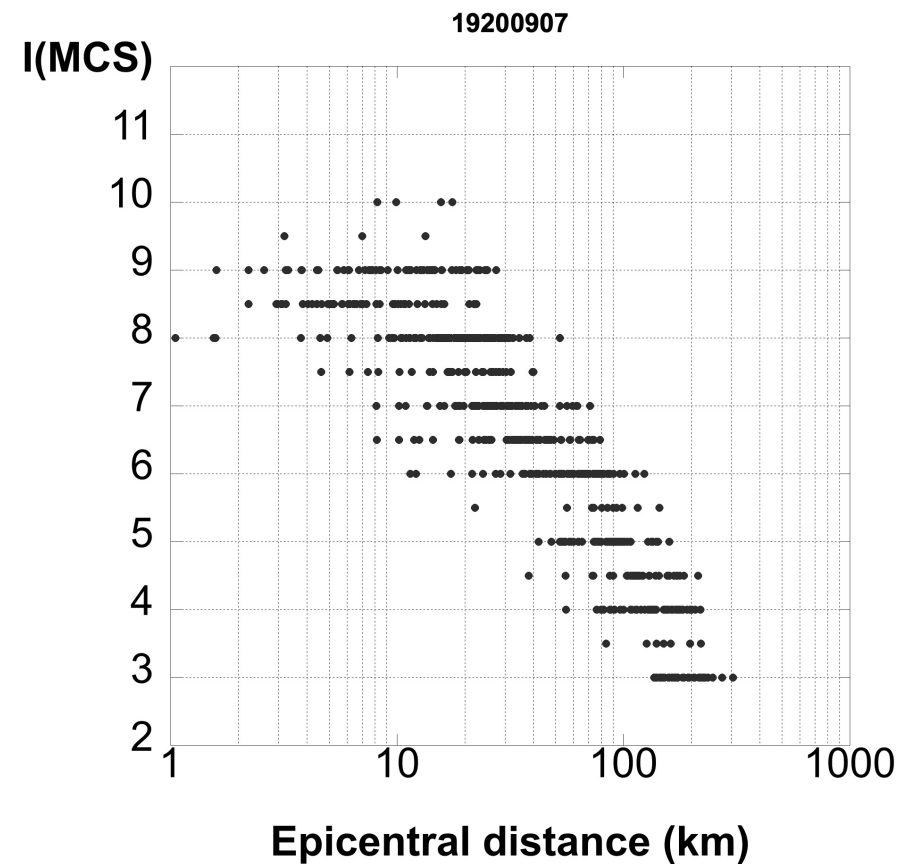
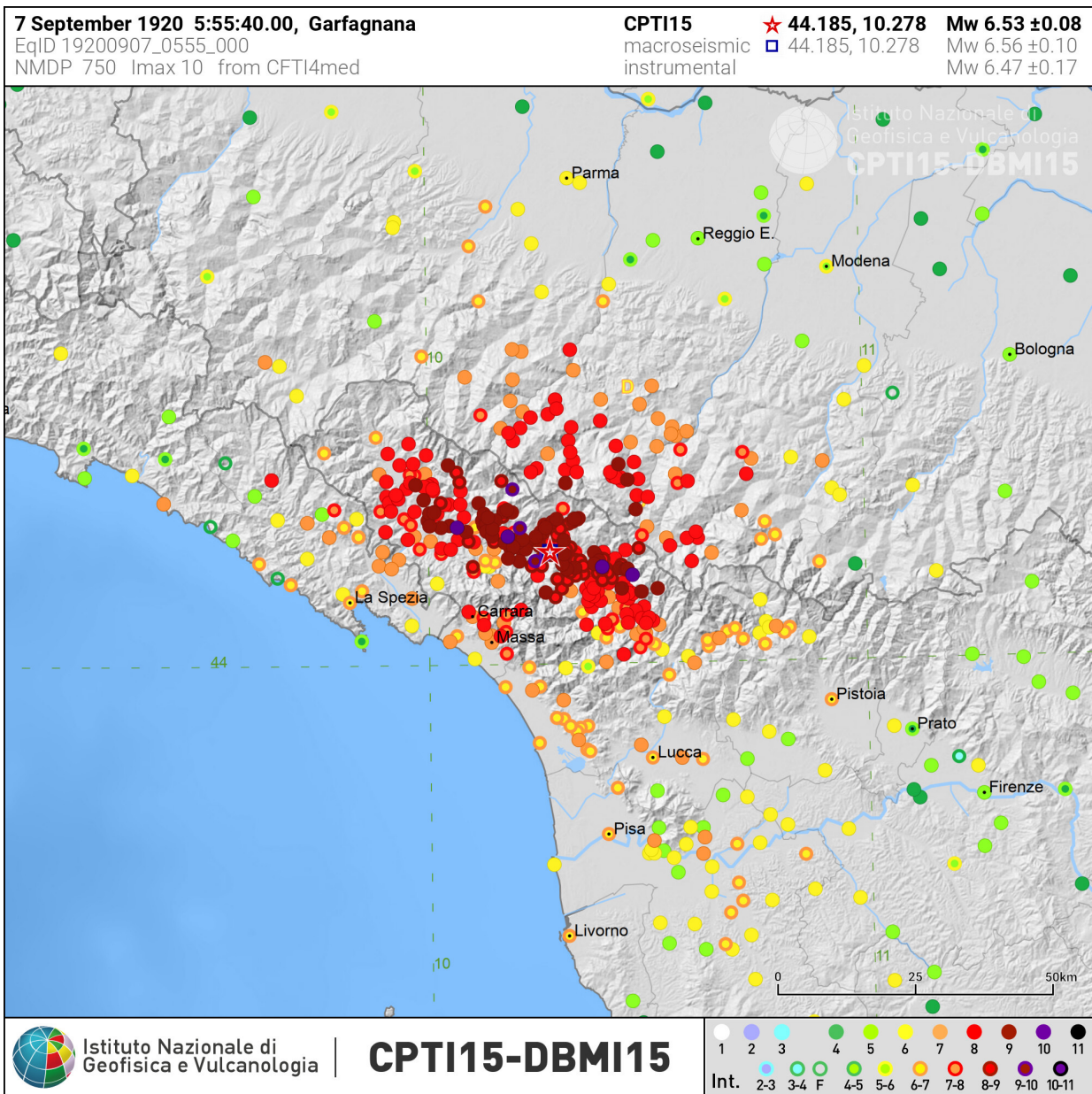
★ 40.842, 15.283 Mw 6.81 ±0.10
□ 40.842, 15.283 Mw 6.76 ±0.10
◇ 40.724, 15.414 Mw 6.81 ±0.10

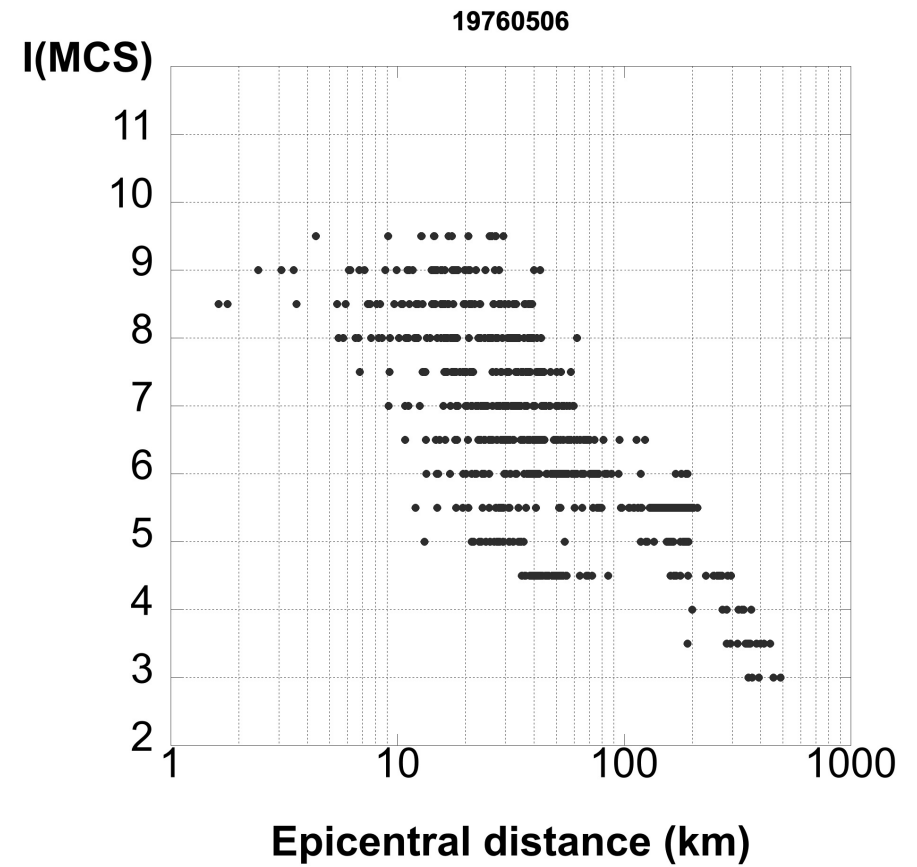
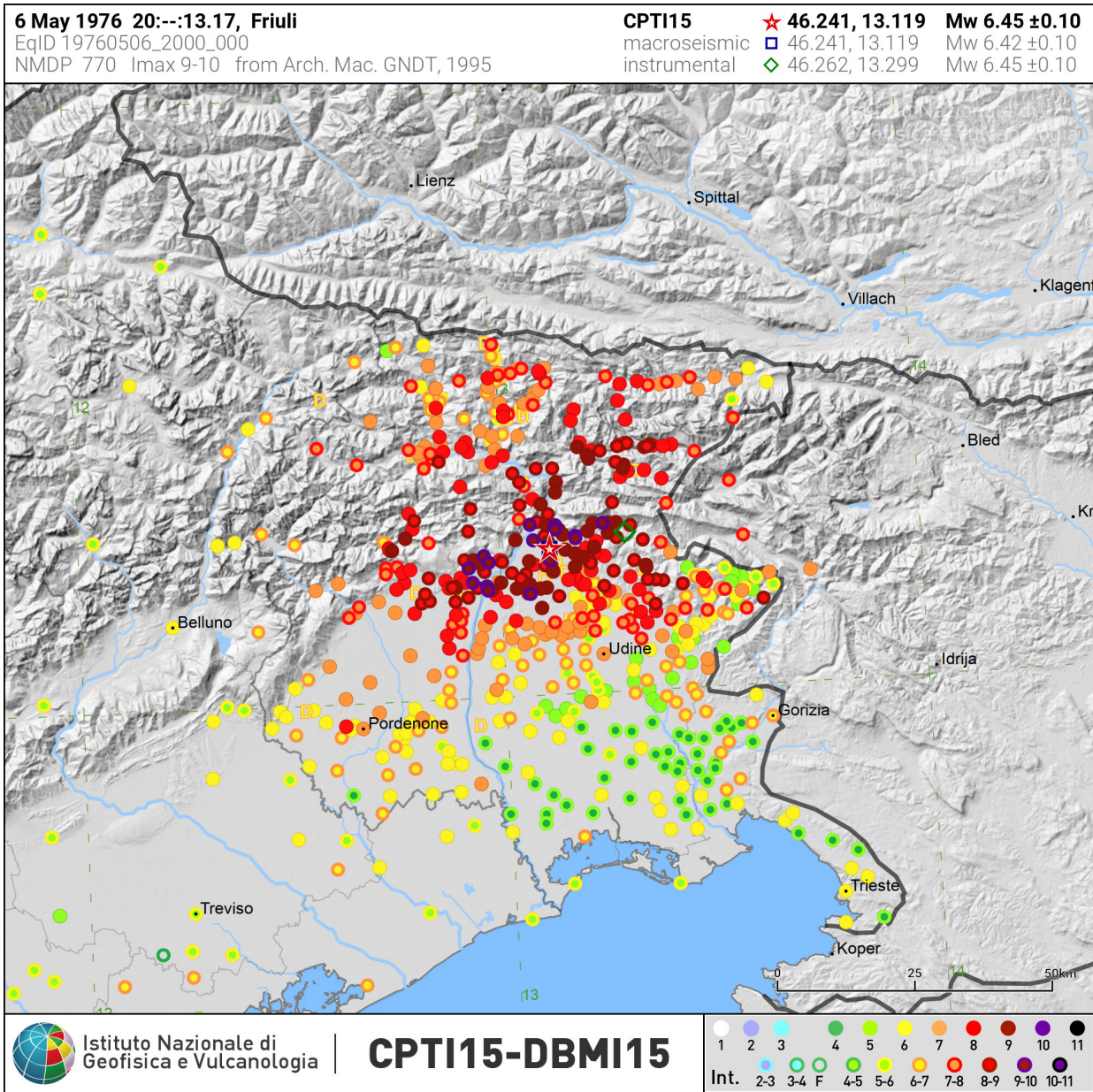


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CPTI15-DBMI15



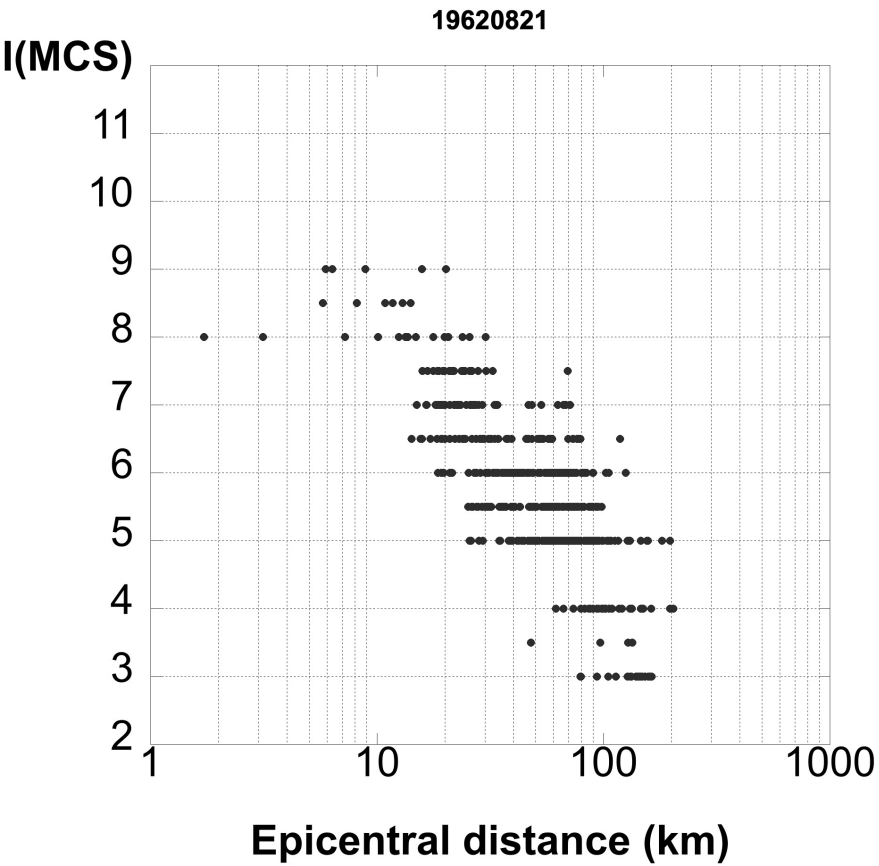
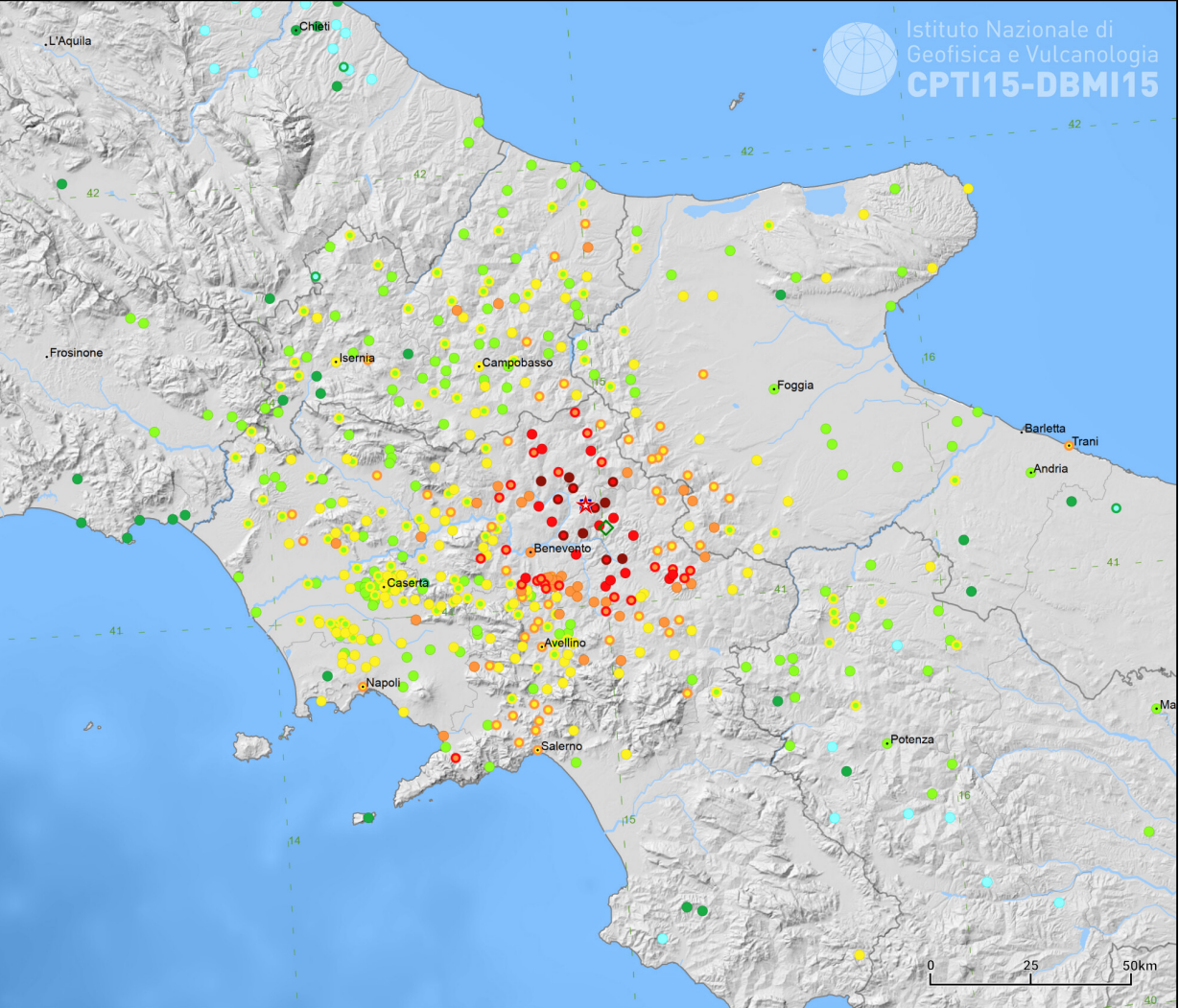




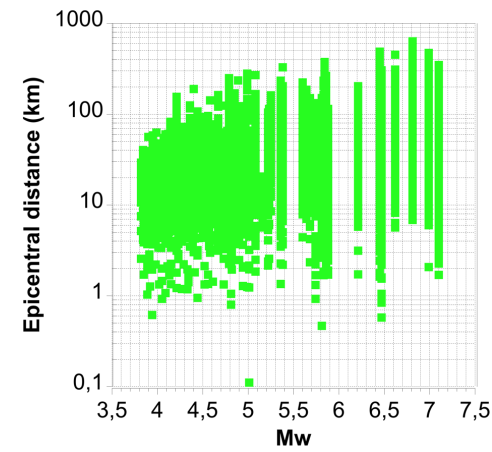
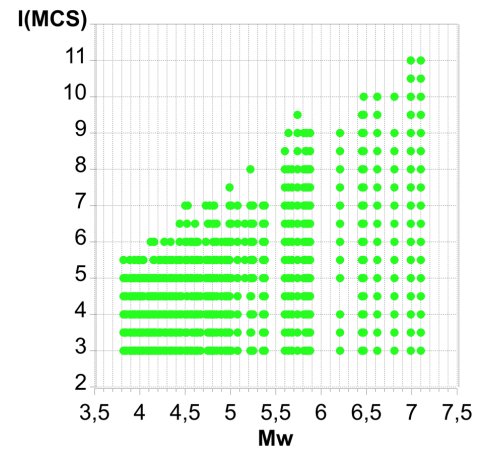
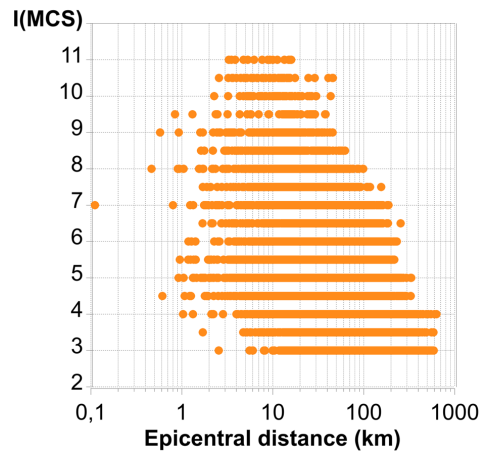
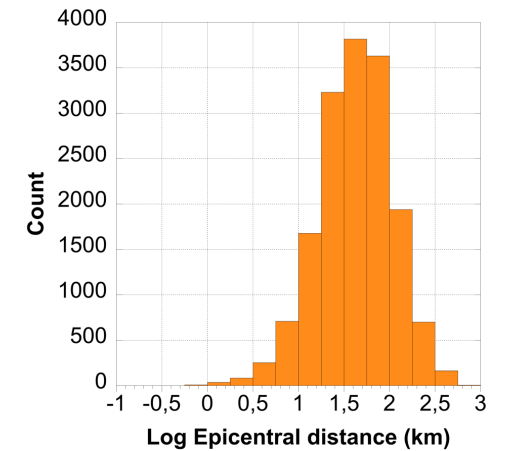
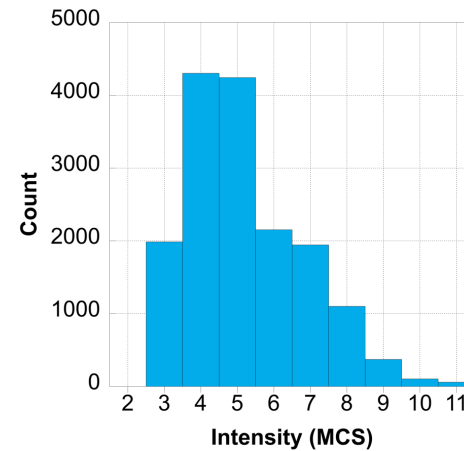
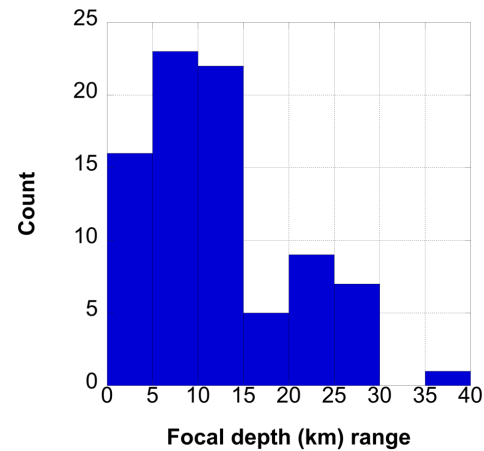
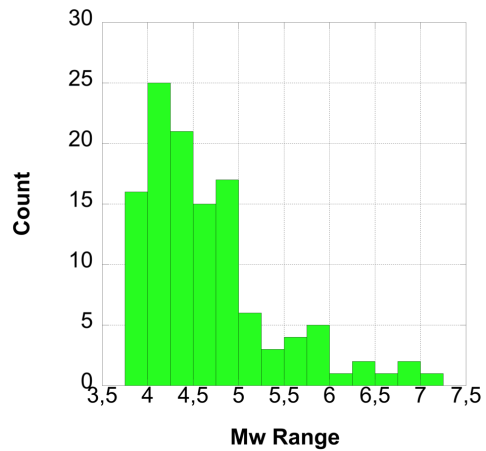


21 August 1962 18:19:-- , Irpinia
EqID 19620821_1819_000
NMDP 562 lmax 9 from Gizzi, 2012

CPTI15 ★ 41.230, 14.953 Mw 6.15 ±0.08
macroseismic ◻ 41.230, 14.953 Mw 6.13 ±0.10
instrumental ◊ 41.175, 15.009 Mw 6.21 ±0.15

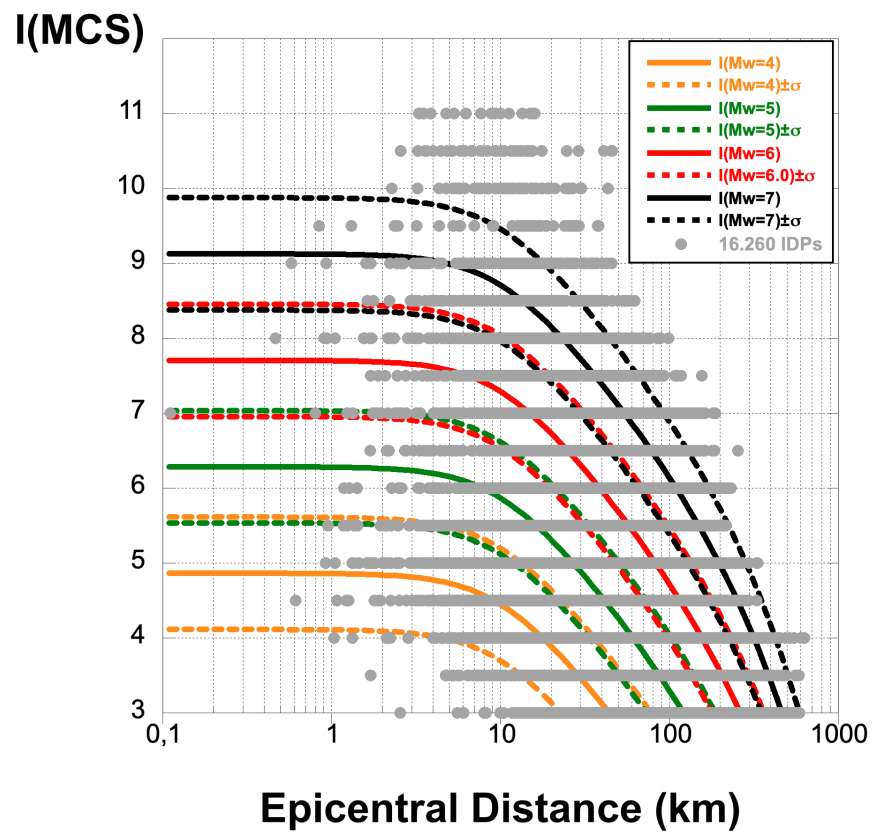


Histograms and distribution of the input data in the calibration dataset



Results: The best regressions assuming h as free parameter

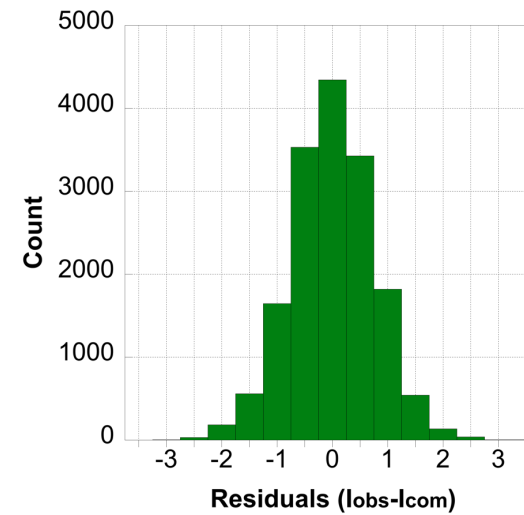
Type 1 model Log-Lin_10



$$I = 1.81 - 2.61 \log R - 0.0039R + 1.42Mw$$

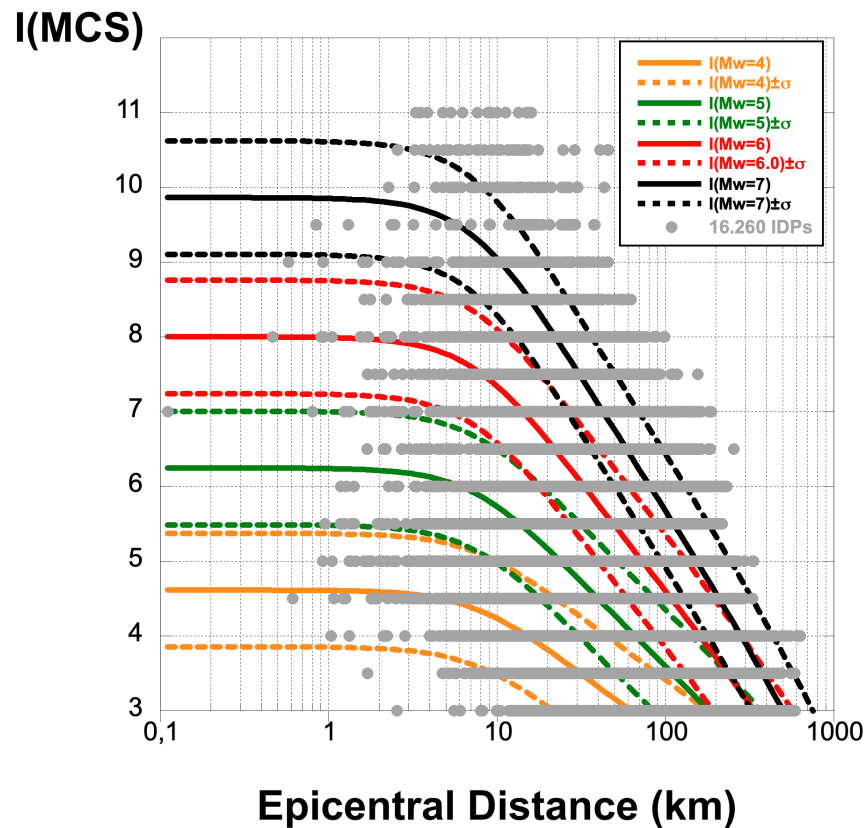
$$R = (R_{epi}^2 + 9.87^2)^{1/2}$$

$\sigma = 0.748$



Results: The best regressions assuming h as free parameter

Type 2 model CRV9

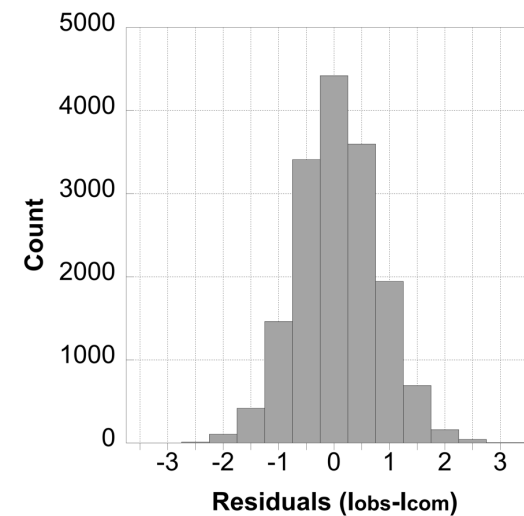


$$\text{Log} I = 0.032 - 0.19 \text{Log} R - 0.0003R + 1.36M_w$$

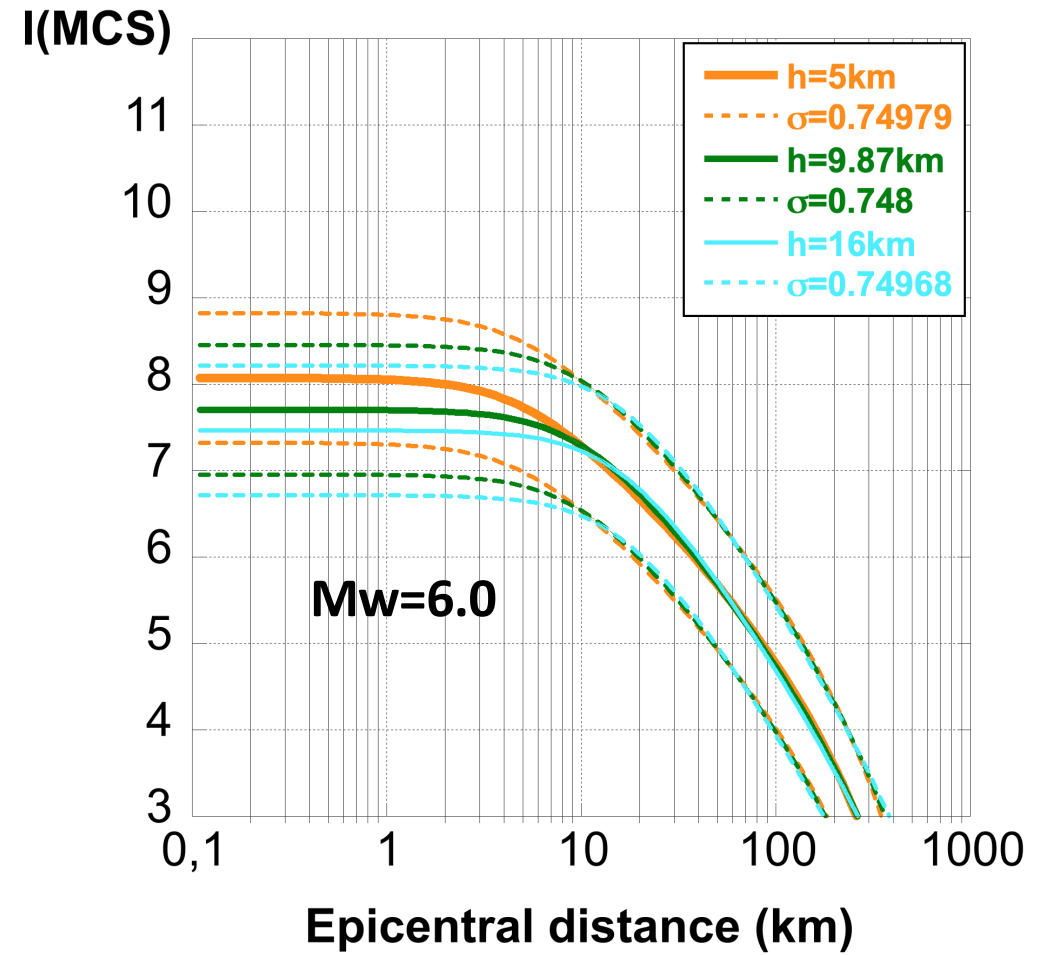
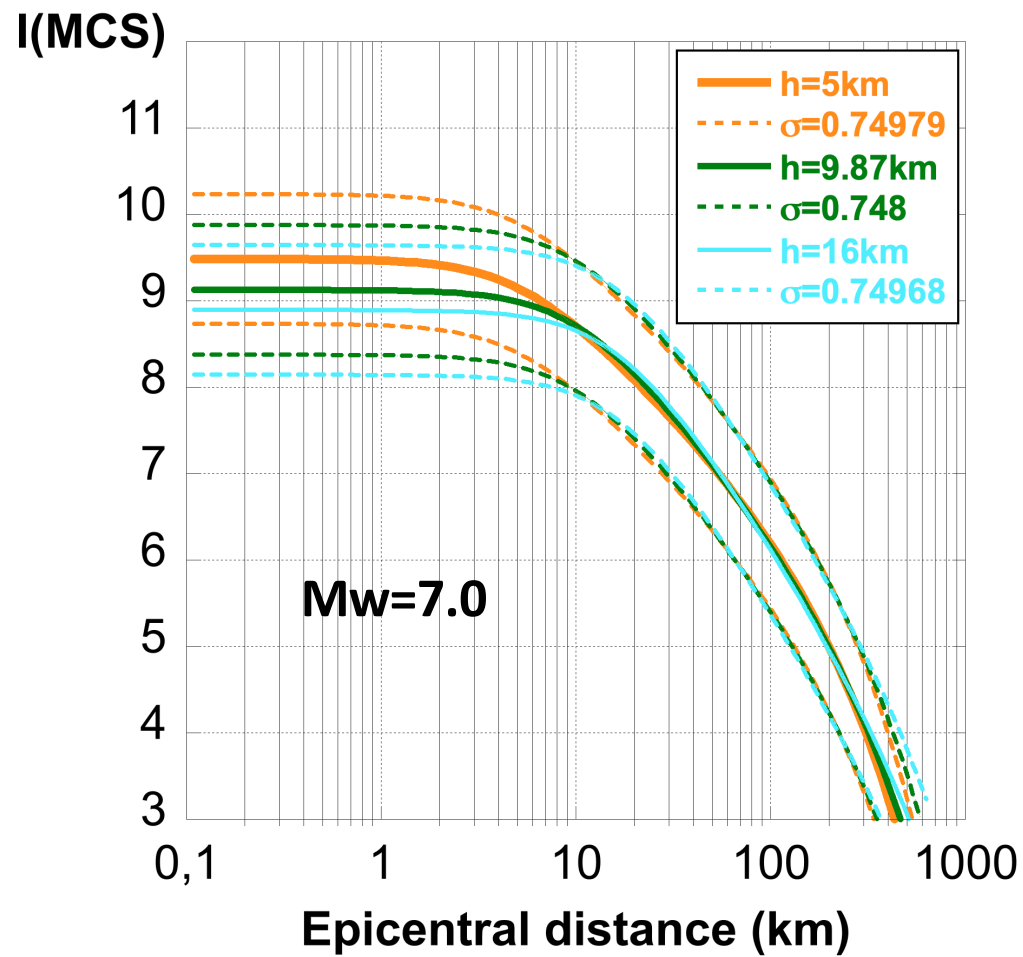
$$I = 1.08R^{-0.19} 10^{-0.0003R} M_w^{1.36}$$

$$R = (R_{\text{epi}}^2 + 8.72^2)^{1/2}$$

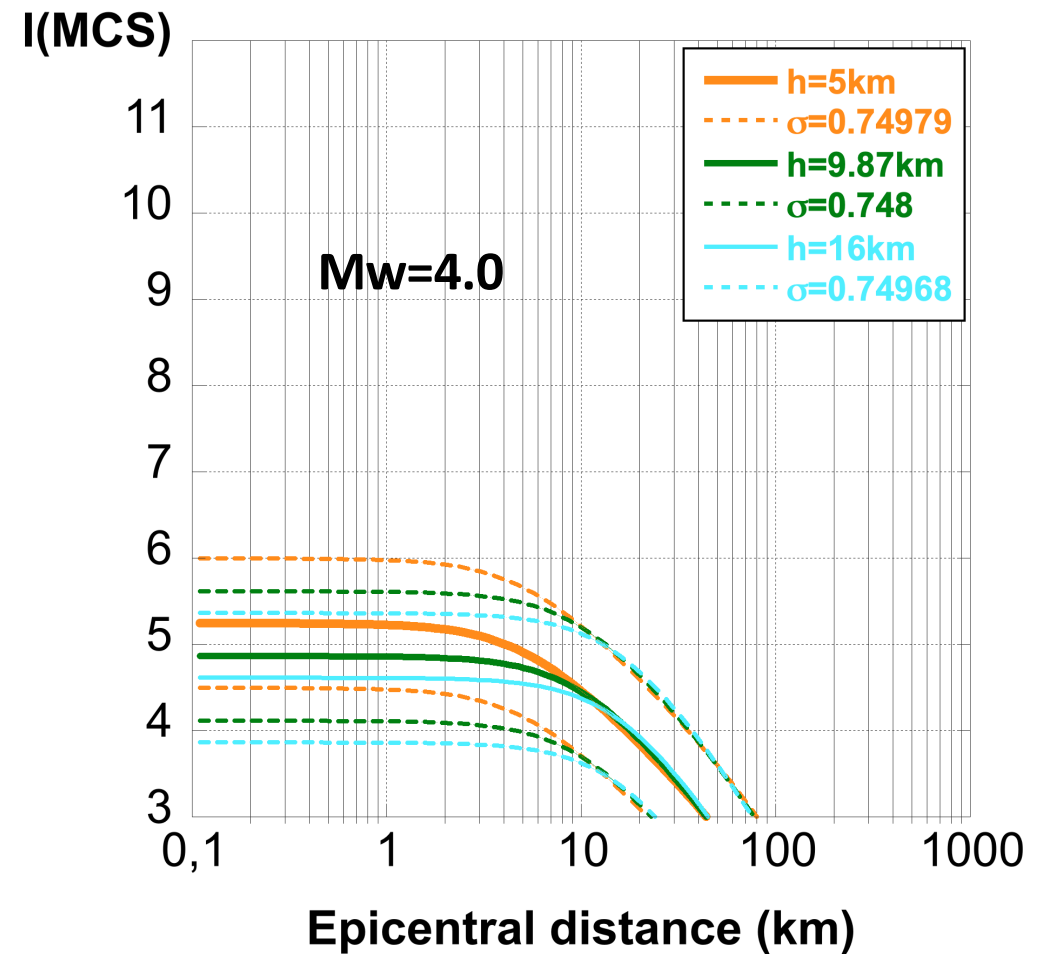
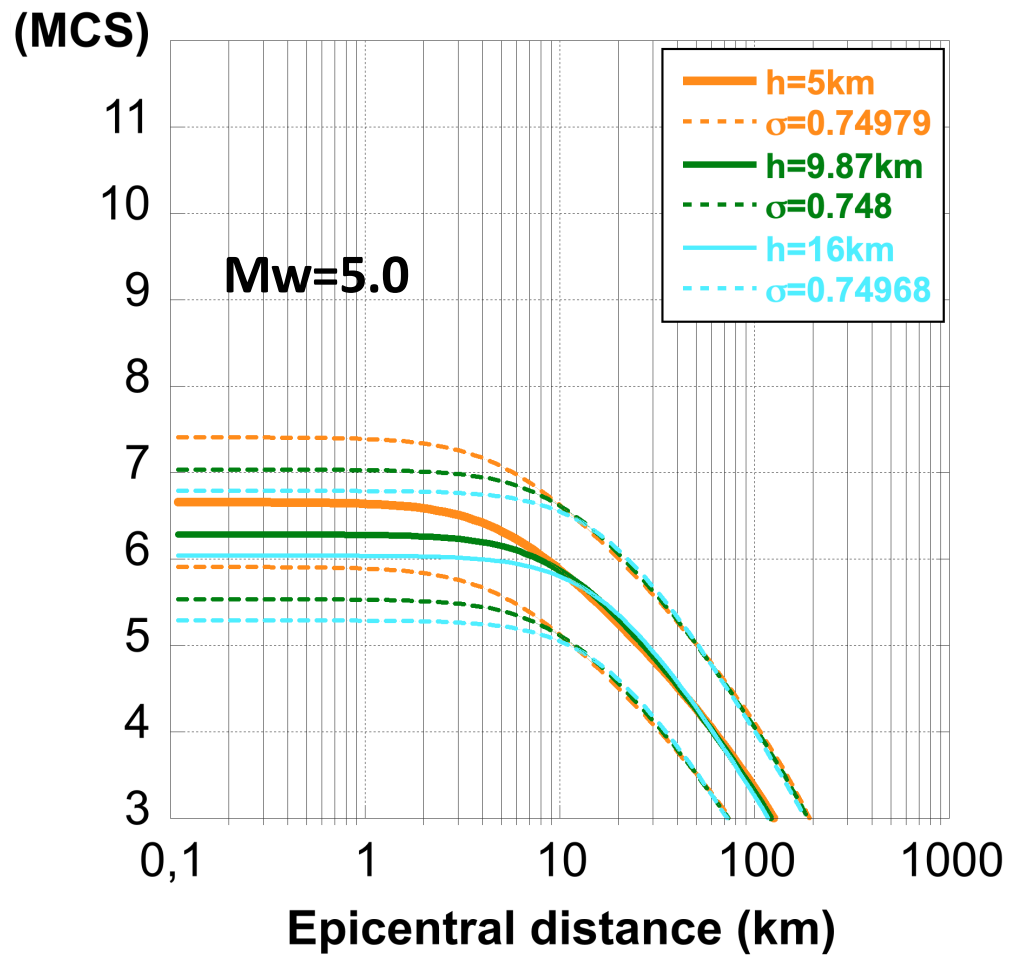
$$\sigma = 0.731$$



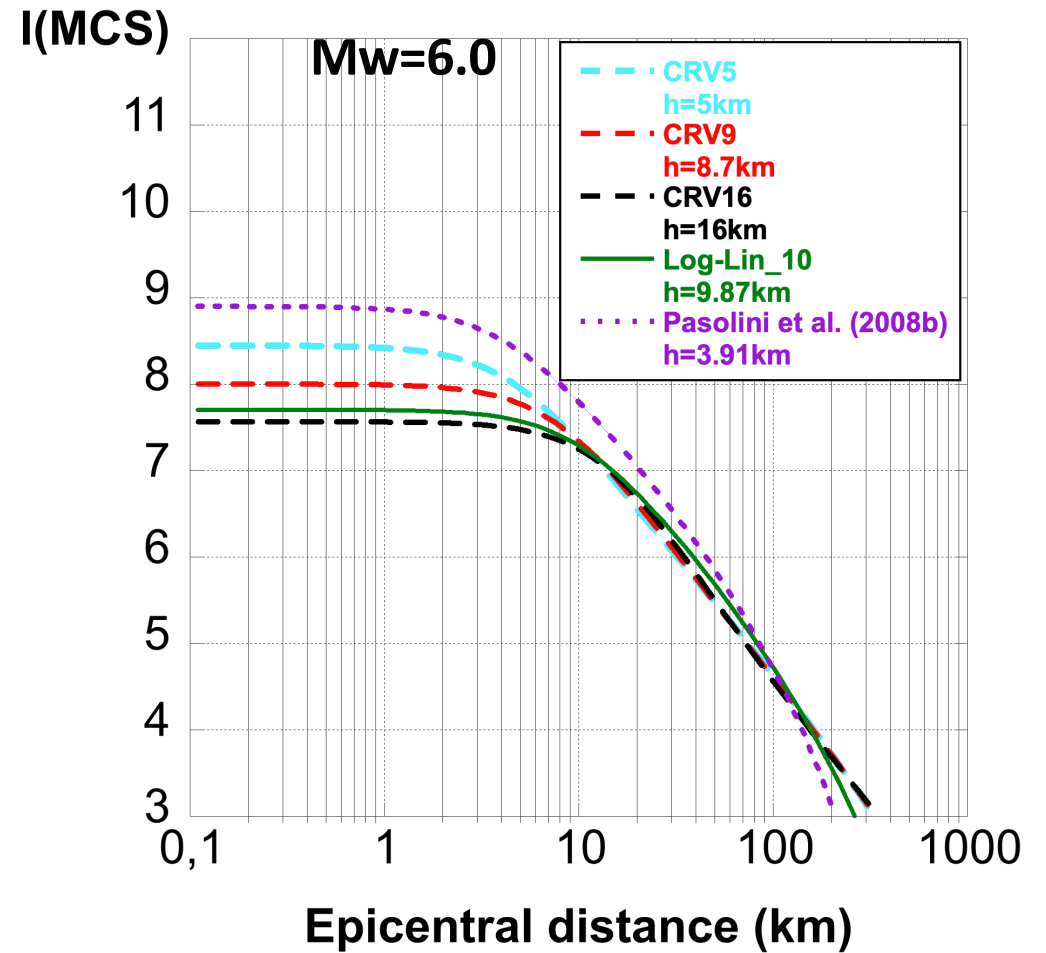
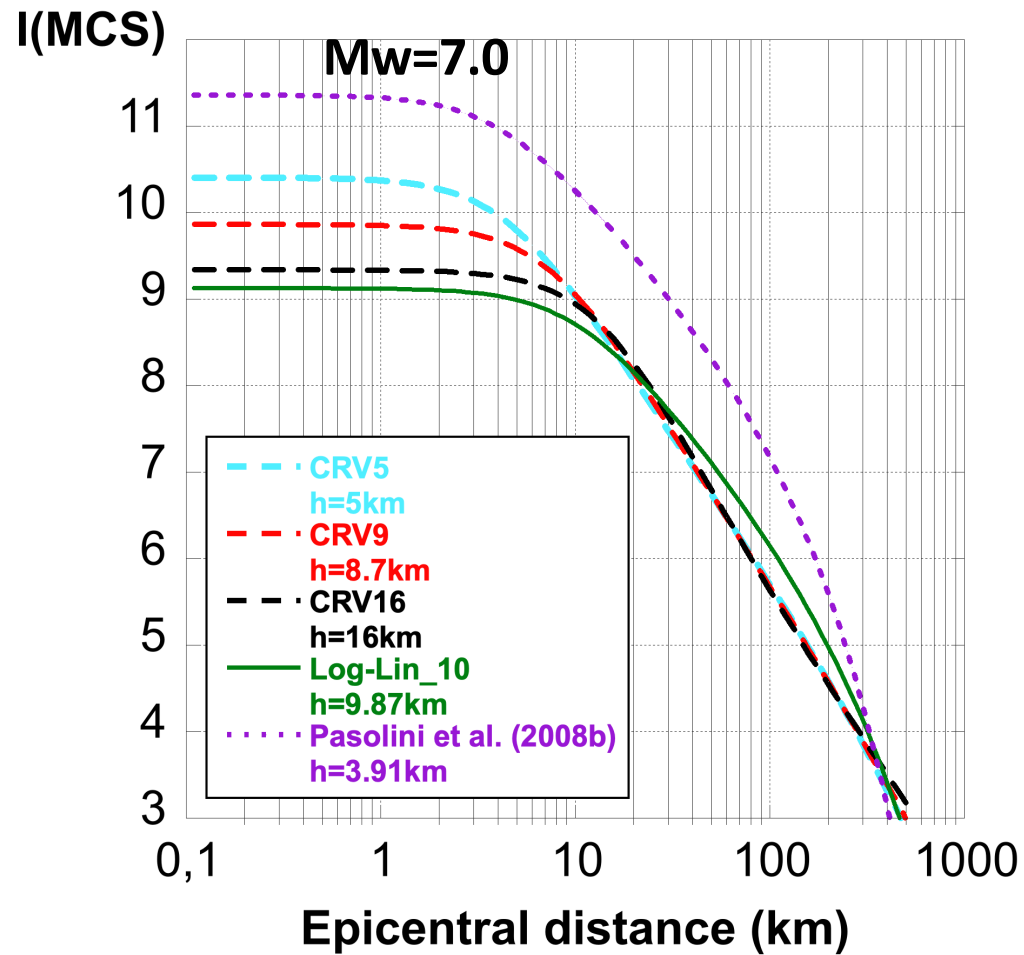
Varying the pseudo focal depth ($h=5\text{km}$ and 16km – Type 1)



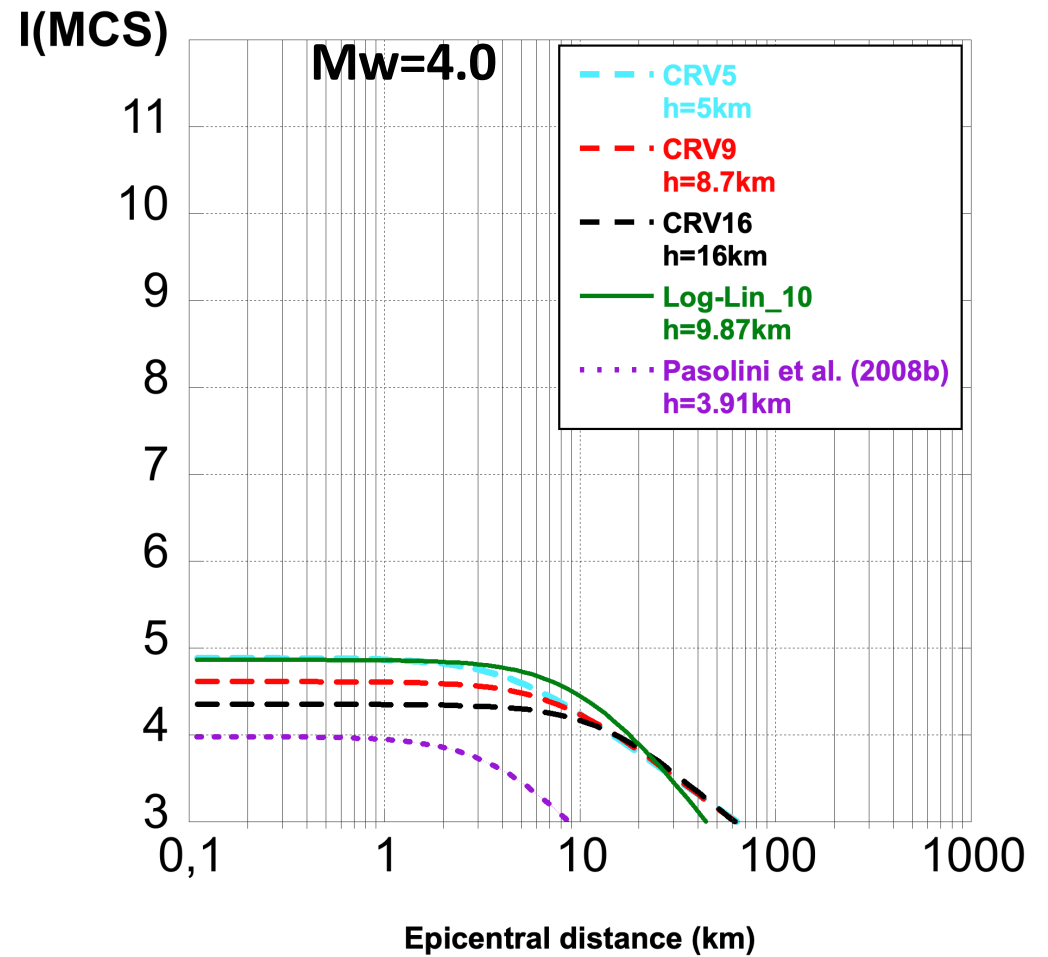
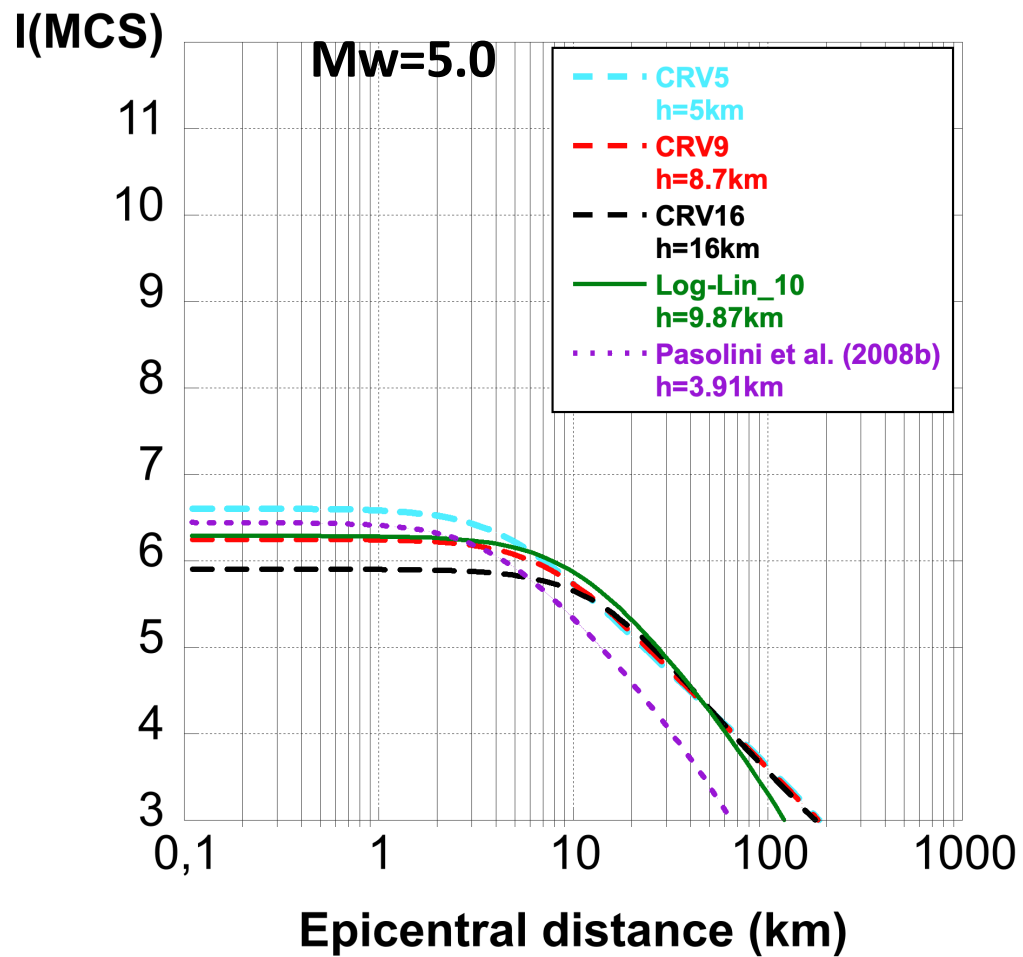
Varying the pseudo focal depth ($h=5\text{km}$ and 16km – Type 1)



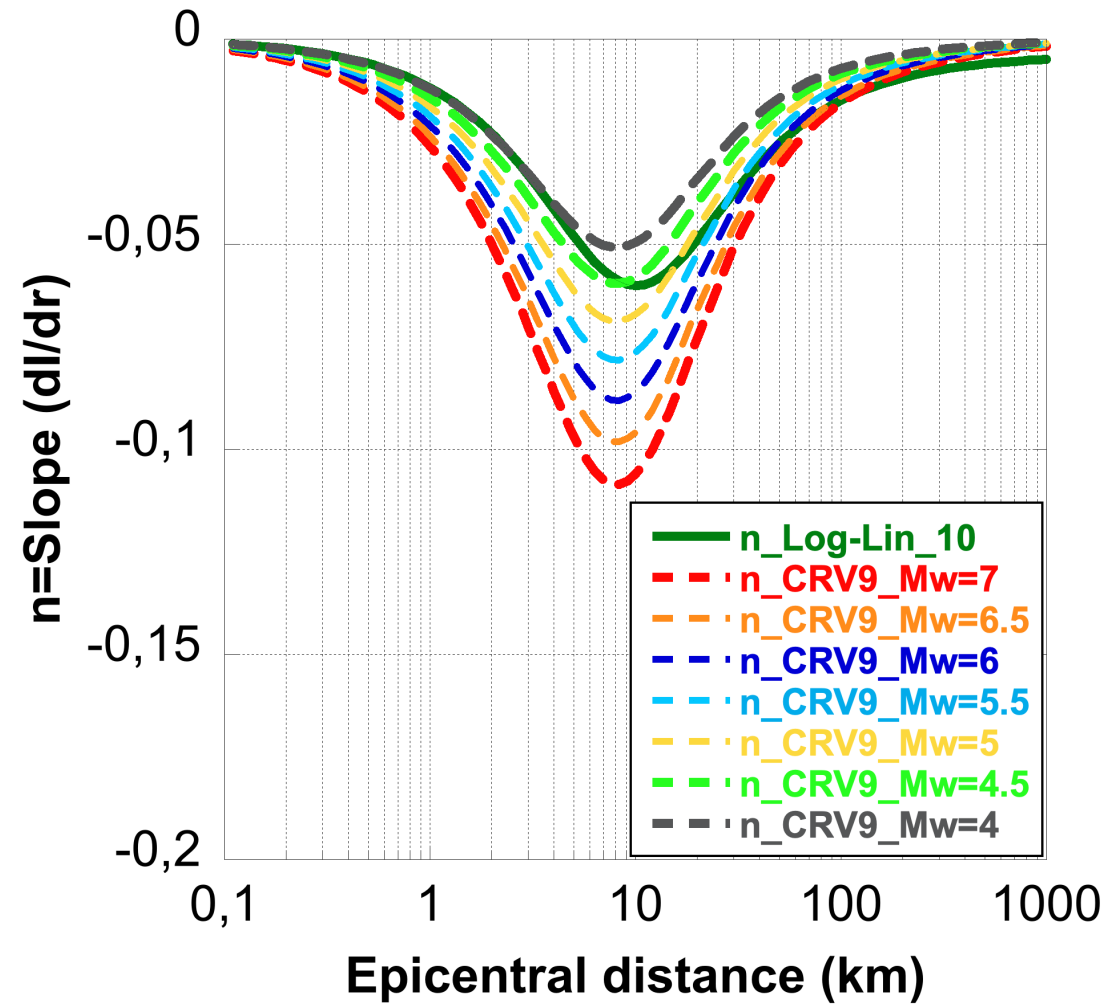
Varying the pseudo focal depth ($h=5\text{km}$ and 16km – Type 2)



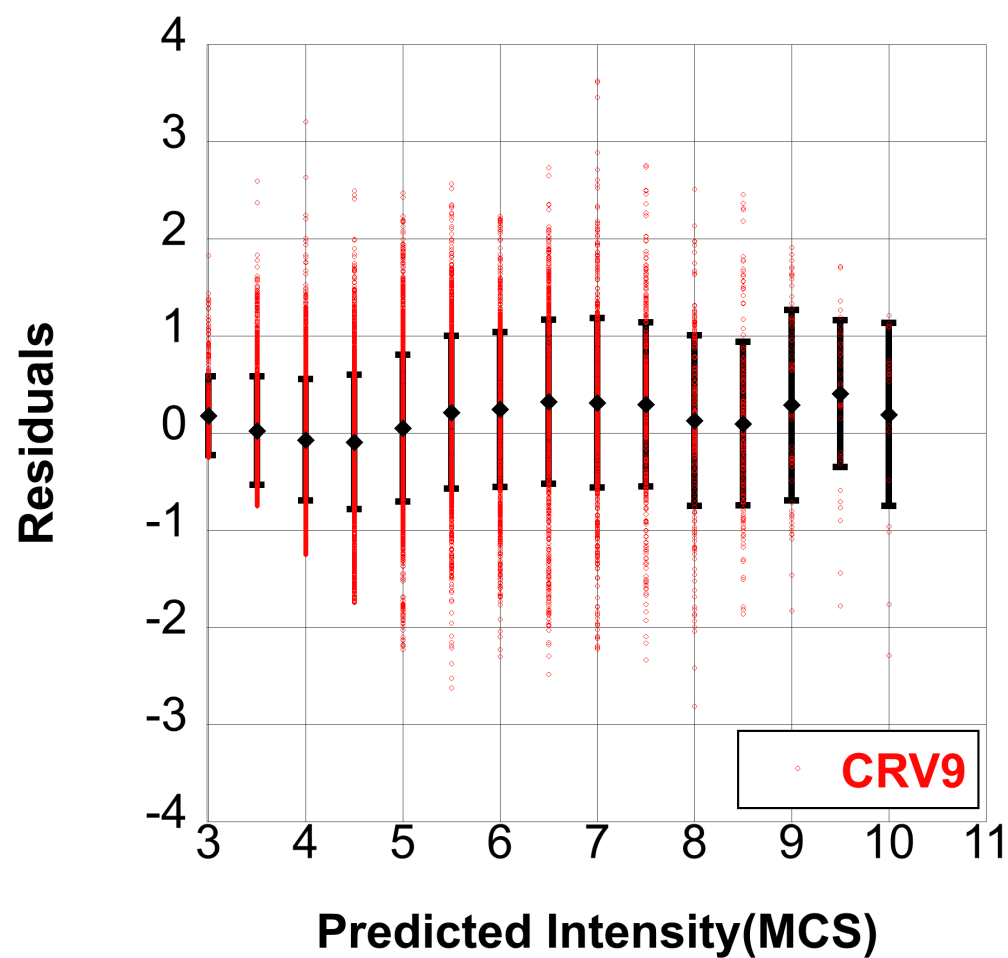
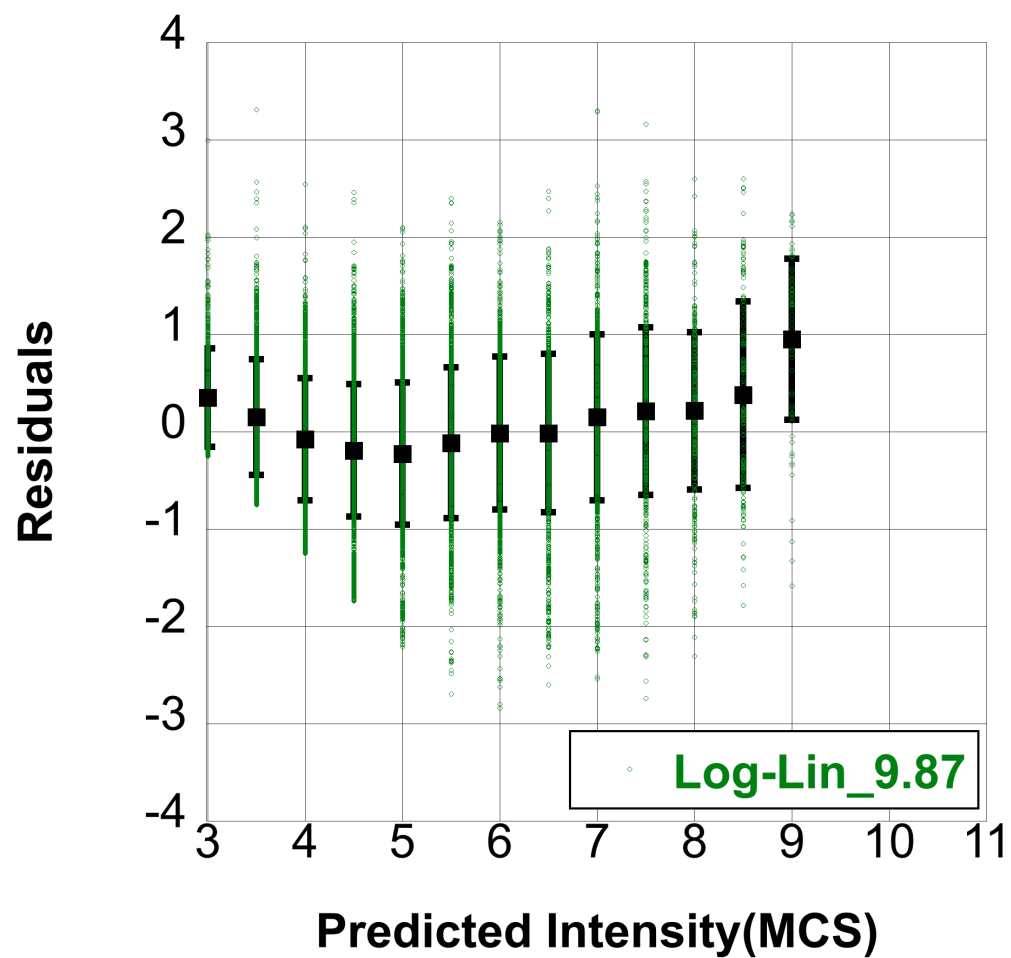
Varying the pseudo focal depth ($h=5\text{km}$ and 16km – Type 2)

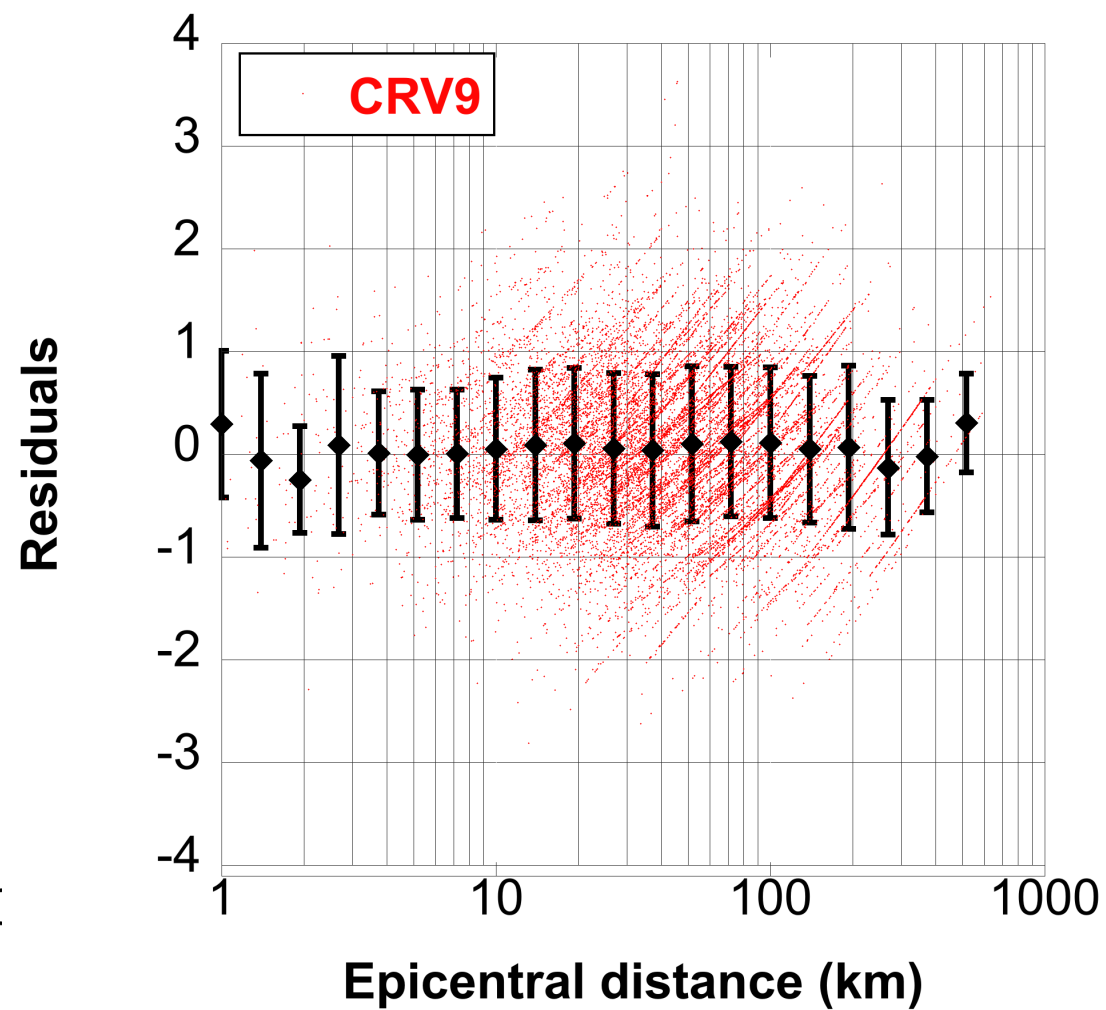
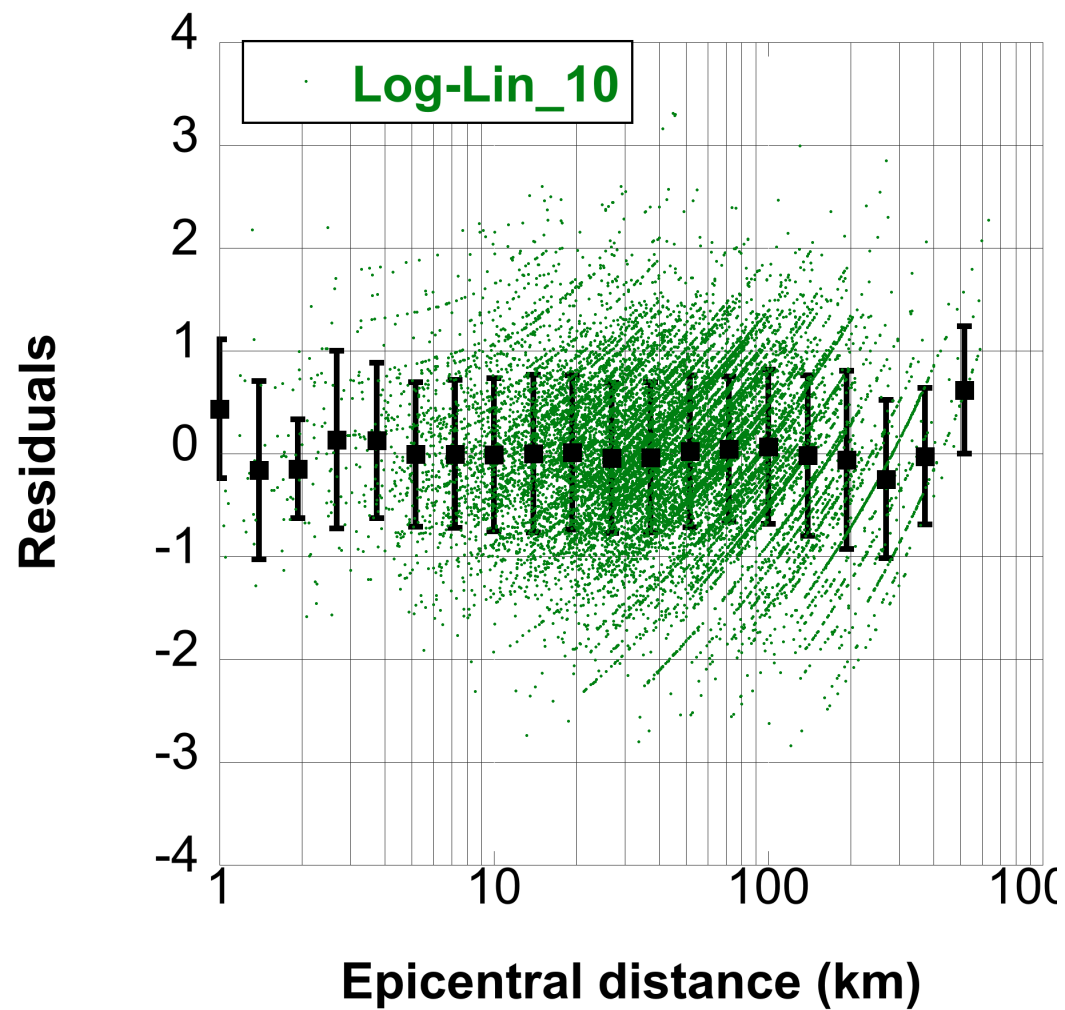


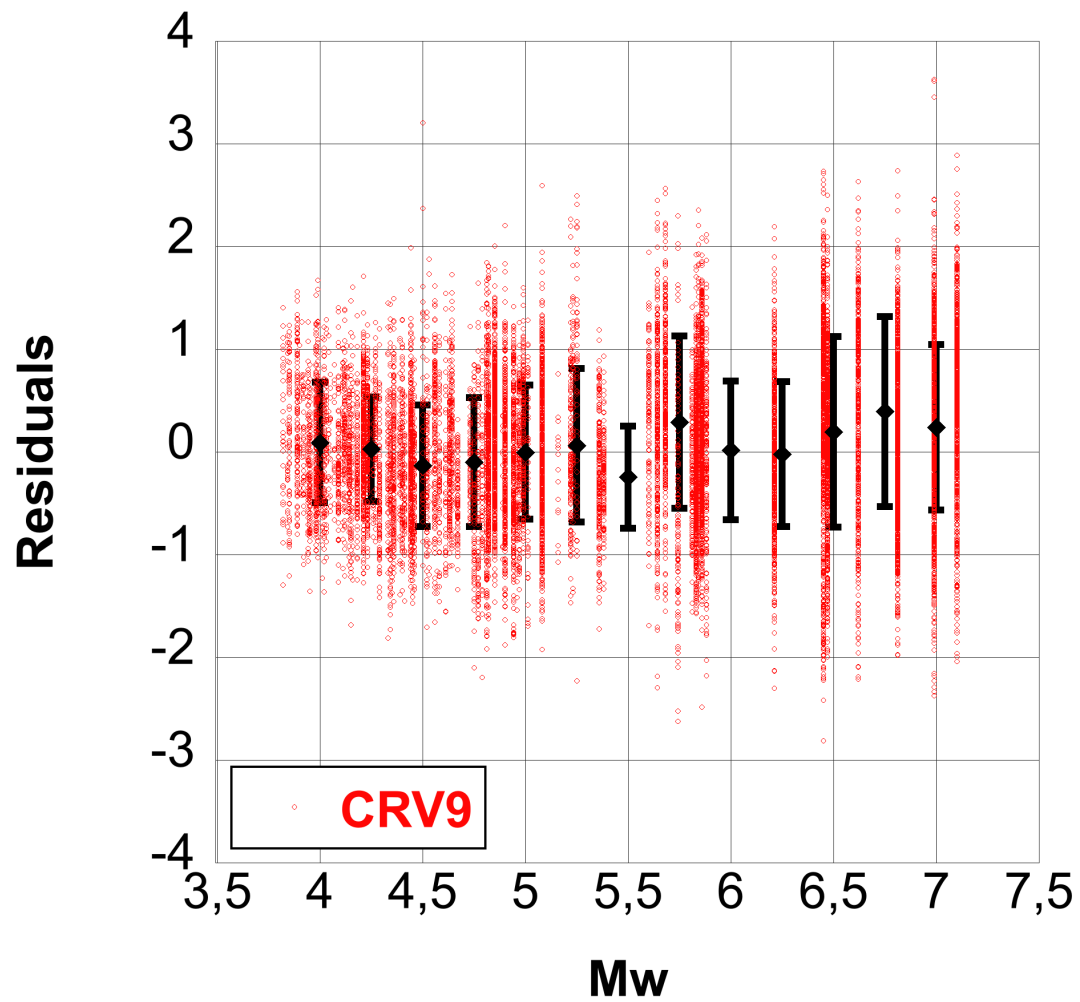
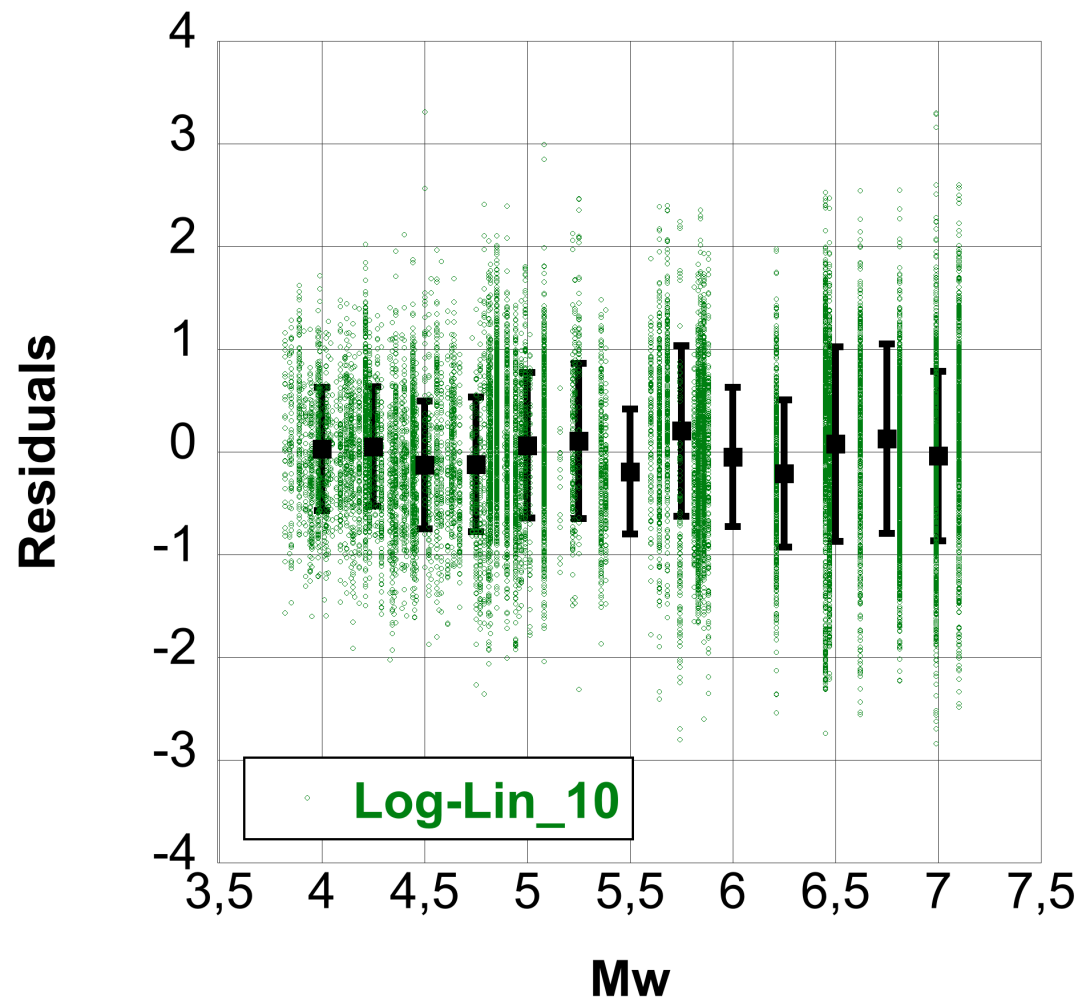
Comparison of the slopes

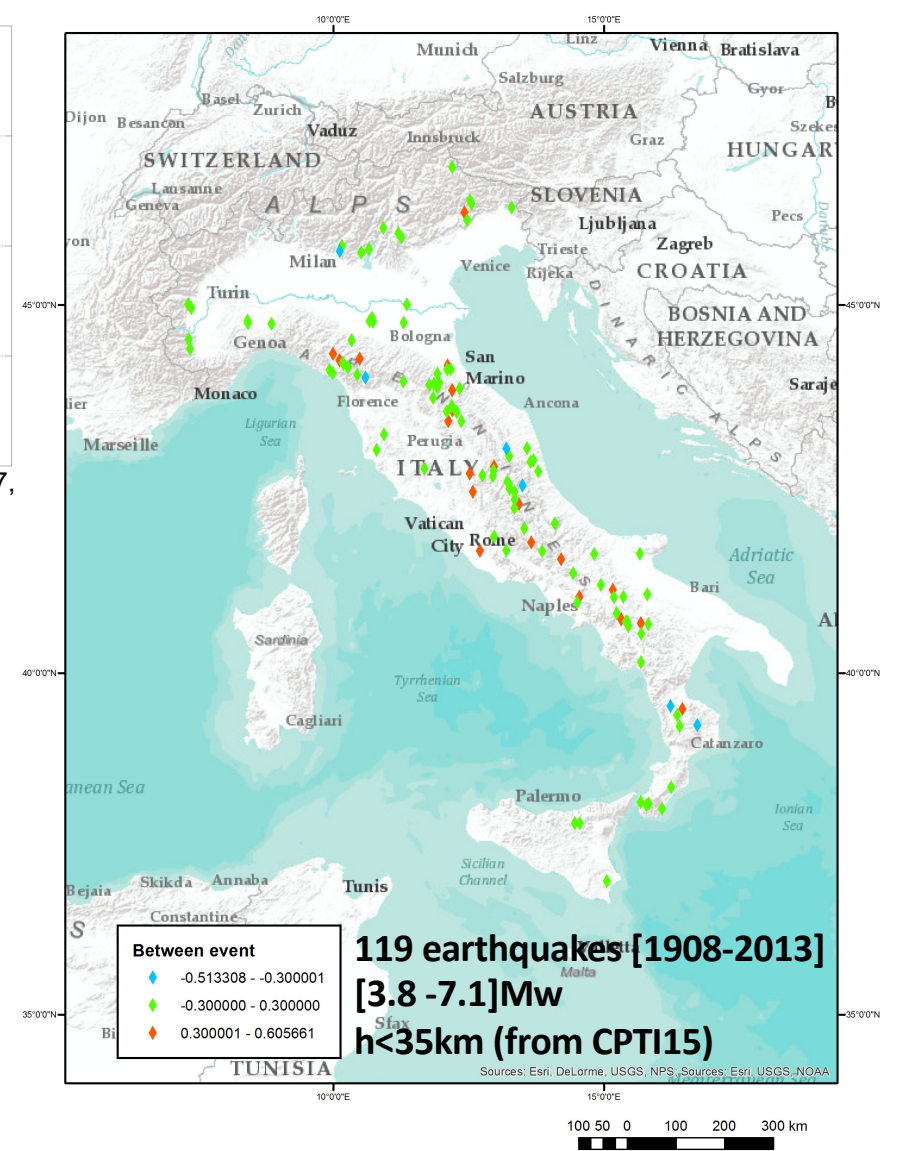
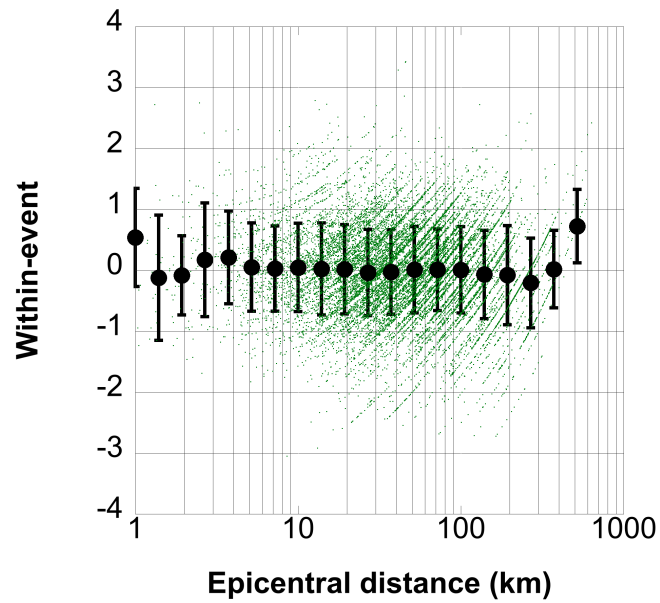
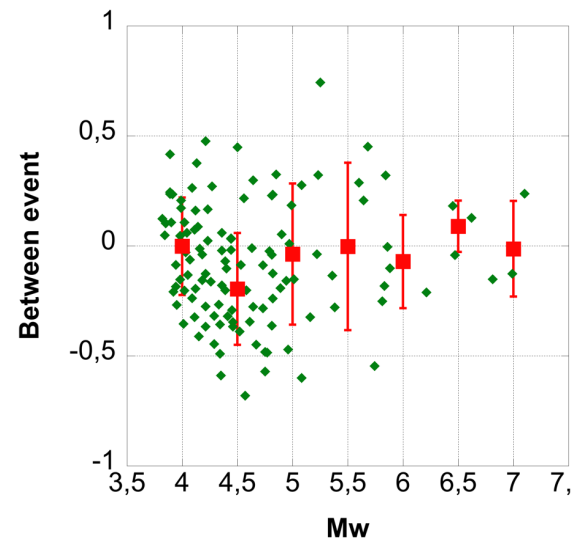
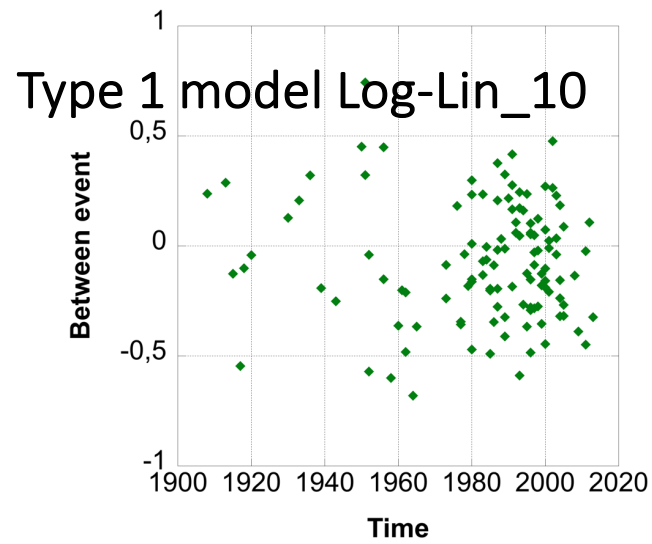


Residuals



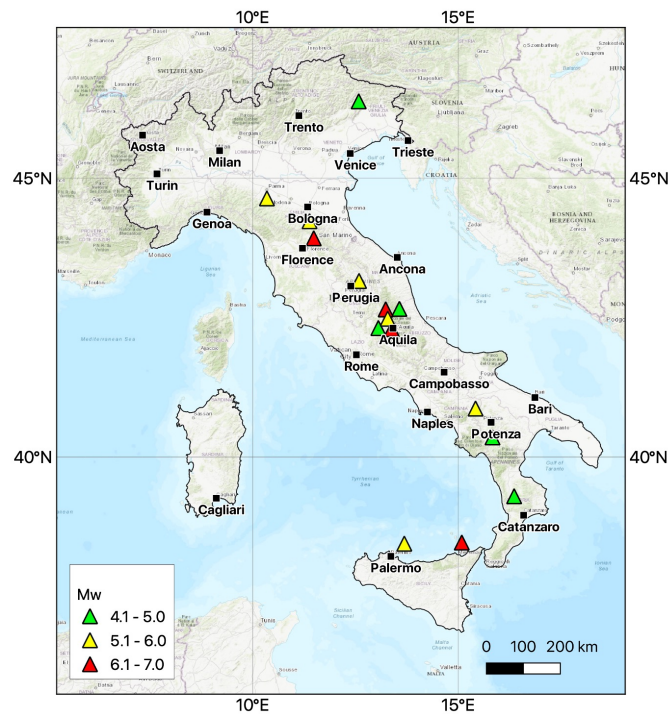




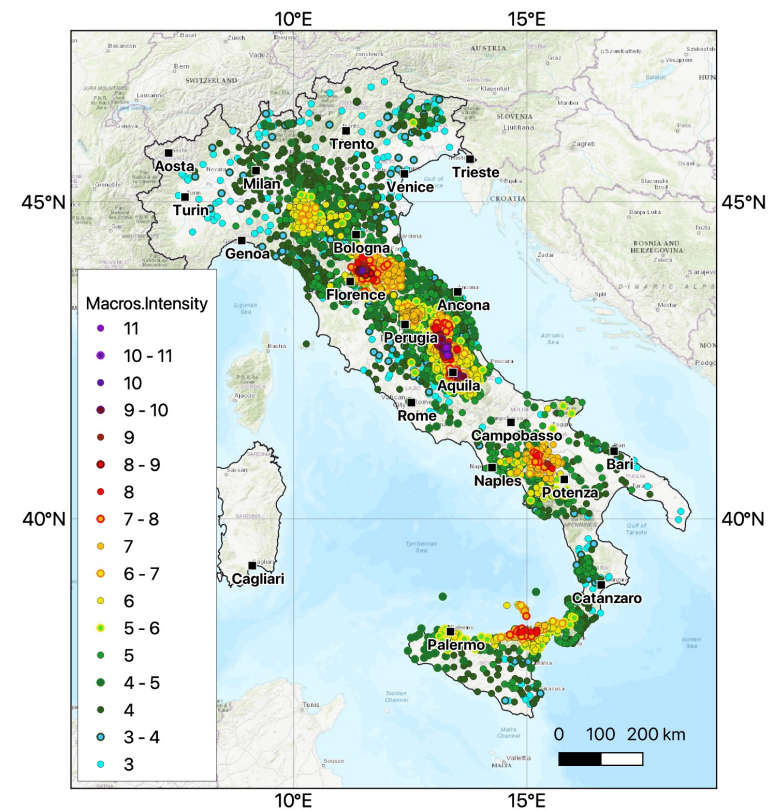


Validation: Data

15 earthquakes [1910-2017]
[4.2 -6.3]Mw
h<35km (from CPTI15)



4.533 IDPs (from DBMI15)
[3-10]MCS ; [5-10]Imax



Validation: MAE & BW97 (Residual Analysis)

i. Mean Absolute Error, Mak *et al.* (2015)

(About Prediction Macroseismic Intensity)

$$wMAE = \left(\sum_{j=1}^P w_j |res_j| \right) / \left(\sum_{j=1}^P w_j \right)$$

$$res_j = I_{obs,j} - I_{pre,j}$$

ii. Mw from IDPs and IPE (Bakun and Wentworth, 1997)

(About Prediction Macroseismic Mw)

$$MI_i = f(I_i, R_i)$$

$$rms[MI^k] = rms[MI^k - M_i] - rms_0[MI^k - M_i]$$

$$MI^k = \left(\sum_{i=1}^P MI_i^k \right) / P$$

$$rms[MI^k - M_i] = \sqrt{\sum_{i=1}^P [w_i (MI^k - MI_i^k)]^2 / \sum_{i=1}^P w_i^2}$$

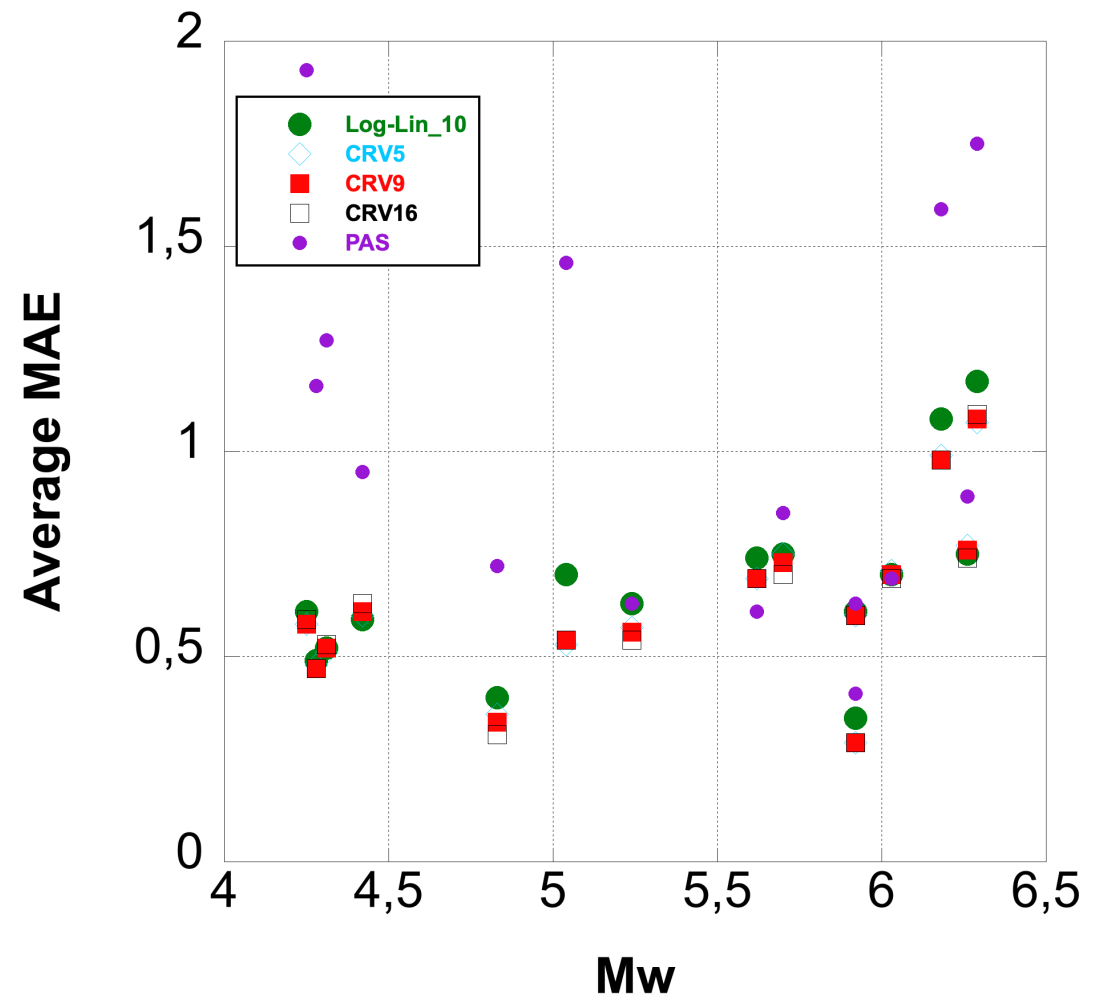
$$rms[MI^k - M_i] - rms_0[MI^k - M_i] = 0$$

MAE (Mak *et al.*, 2015)

Median

Log-Lin_10, CRV5, CRV9, CRV16: 0.6

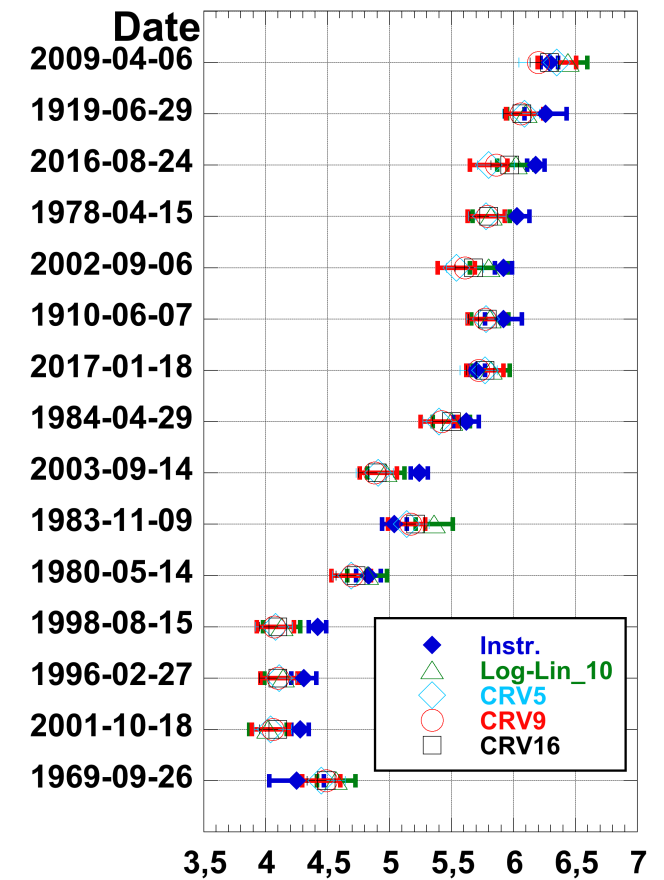
PAS (Pasolini *et al.*, 2008): 0.9



Mw from IDPs
using Bakun and Wentworth (1997) and the IPEs calibrated in Mw

Comparison with Mw (Instrumental from CPTI15, Diamond blue)

Median of all events-based Abs. Res
Log-Lin_10, CRV5, CRV9, CRV16: 0.2



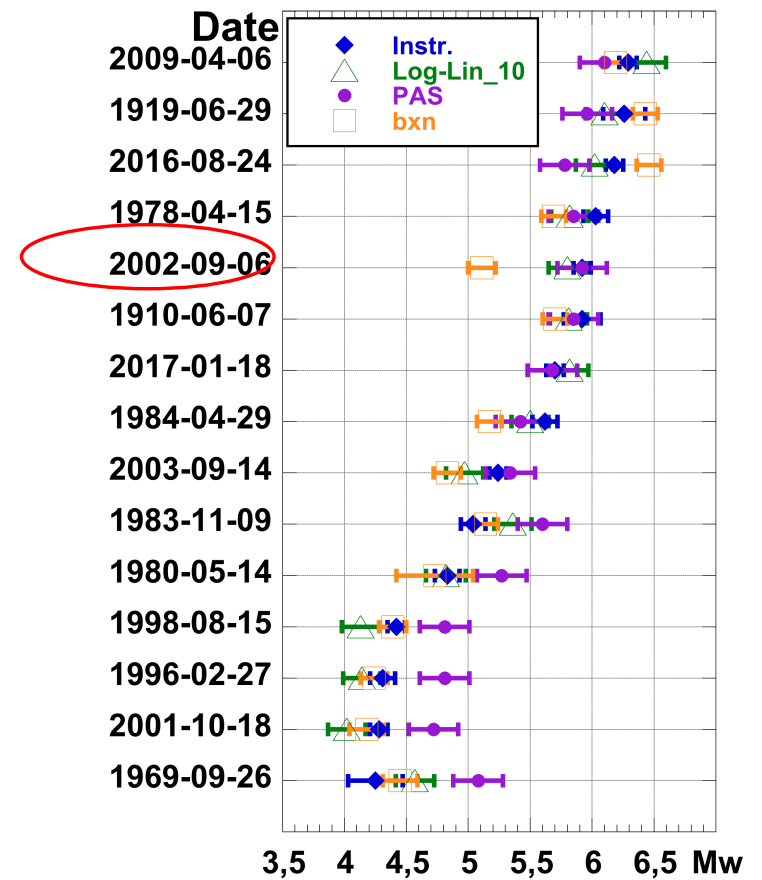
Event not used in calibration set

$M_w = 5.92 \pm 0.07$ (CPTI15)

Comparison with M_w (Instrumental from CPTI15, Diamond blue)

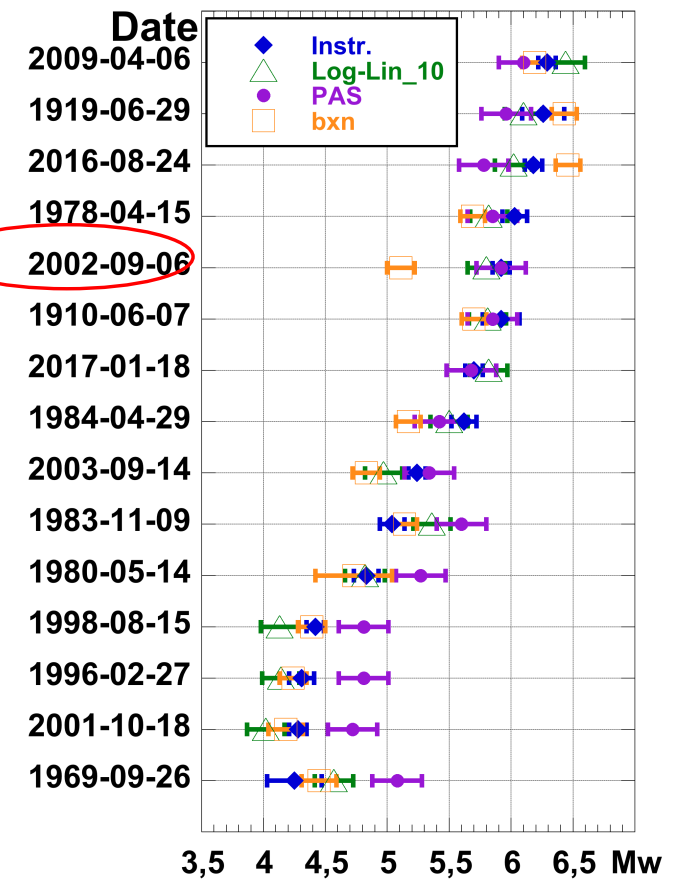
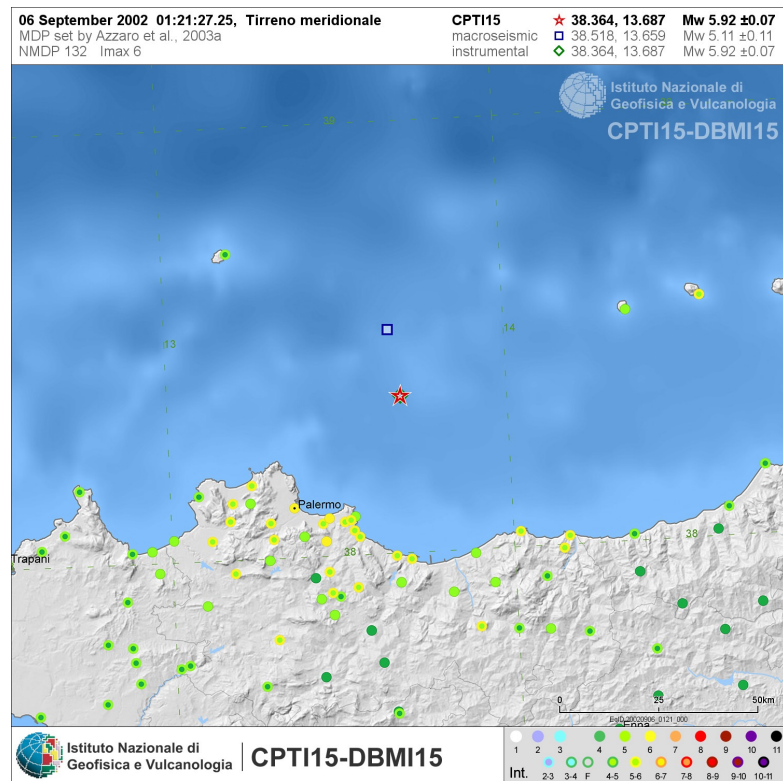
Median of all events-based Abs. Res
Log-Lin_10, CRV5, CRV9, CRV16: 0.2

PAS(Pasolini *et al.*, 2008): 0.3



Event not used in calibration set

$M_w = 5.92 \pm 0.07$ (CPTI15)

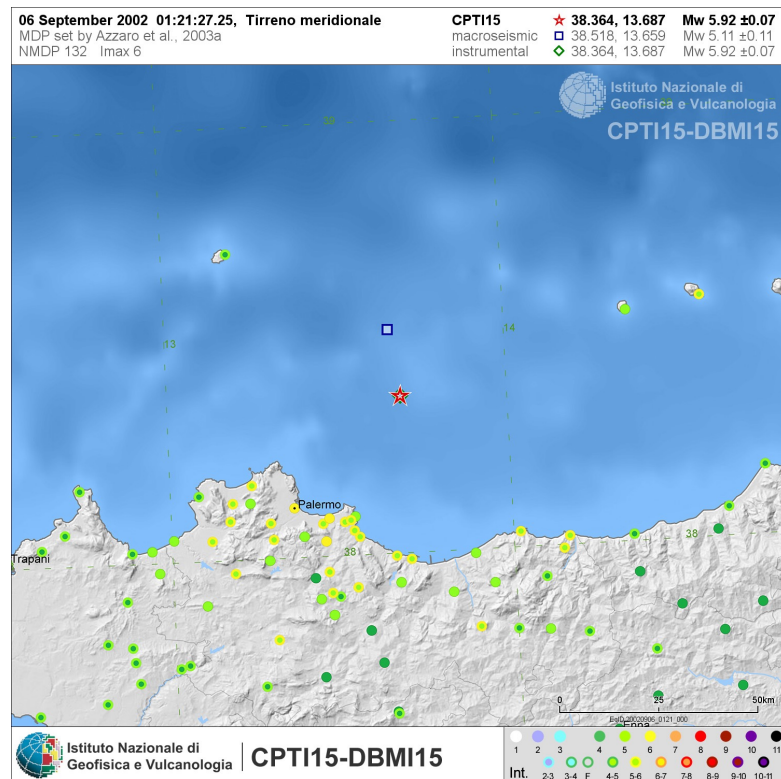


Event not used in calibration set

2002.09.06; Earthquake Parameters in CPTI15

$M_w = 5.92 \pm 0.07$ (Instr)

$M_w = 5.11 \pm 0.11$ (macroseismic)

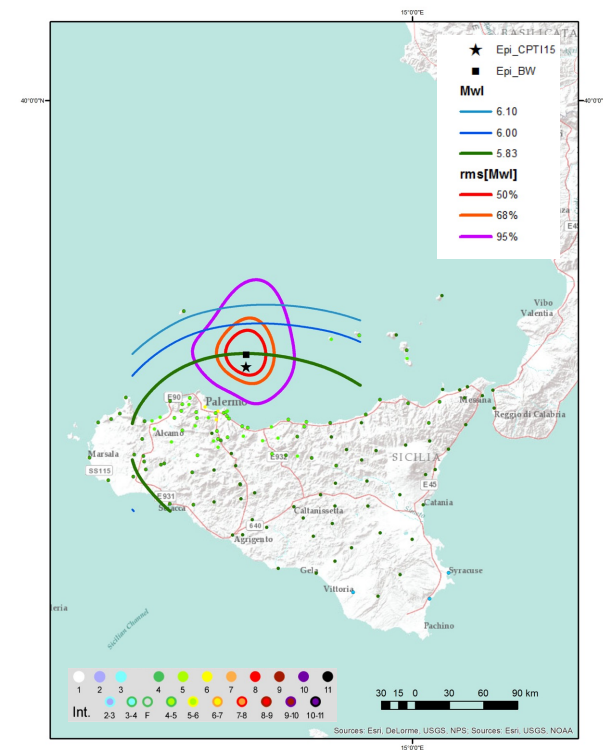


M_w in the present study using

IDPs (DBMI15, Azzaro *et al.*, 2003),

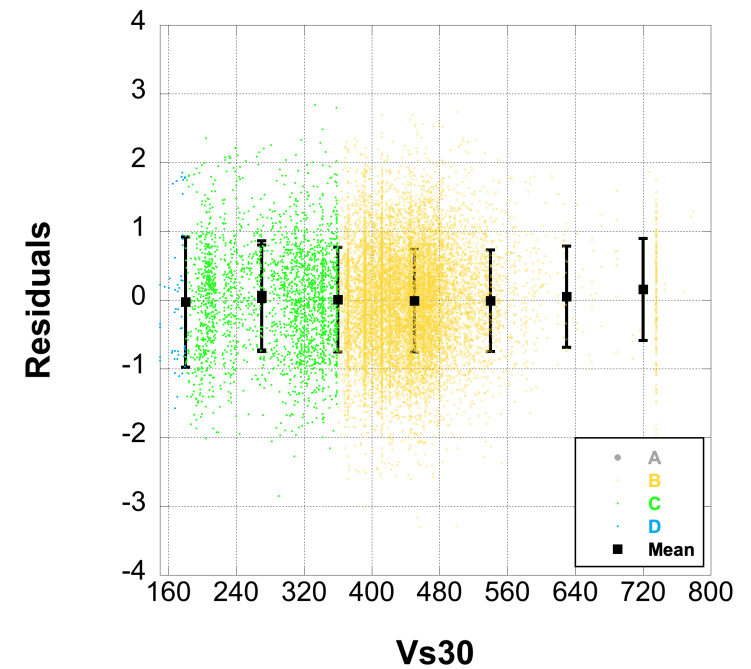
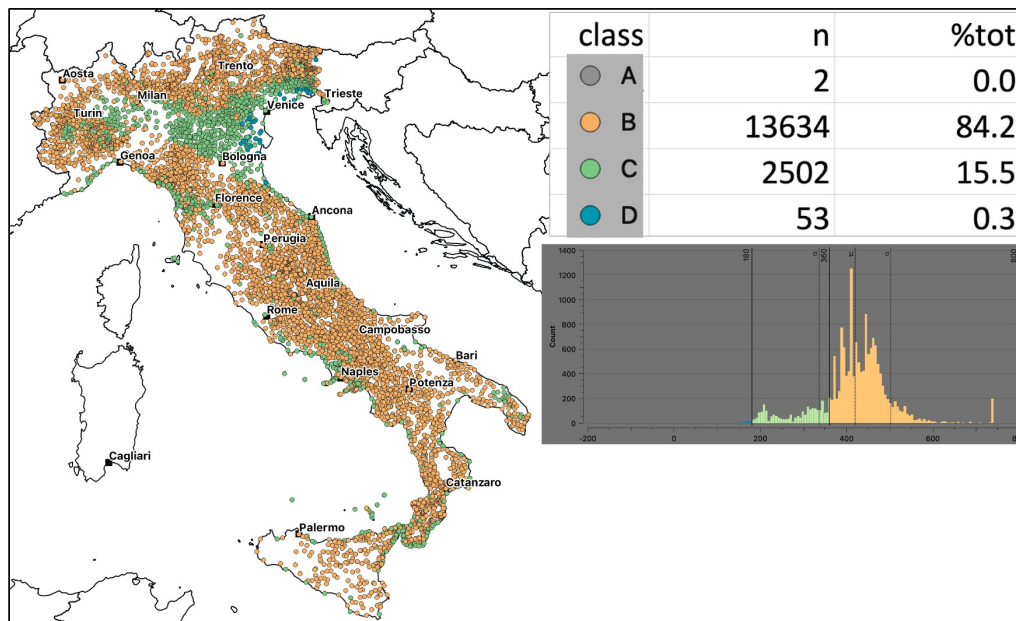
IPE (Log-Lin₁₀) and BW97 method:

$M_w = 5.8 \pm 0.2$



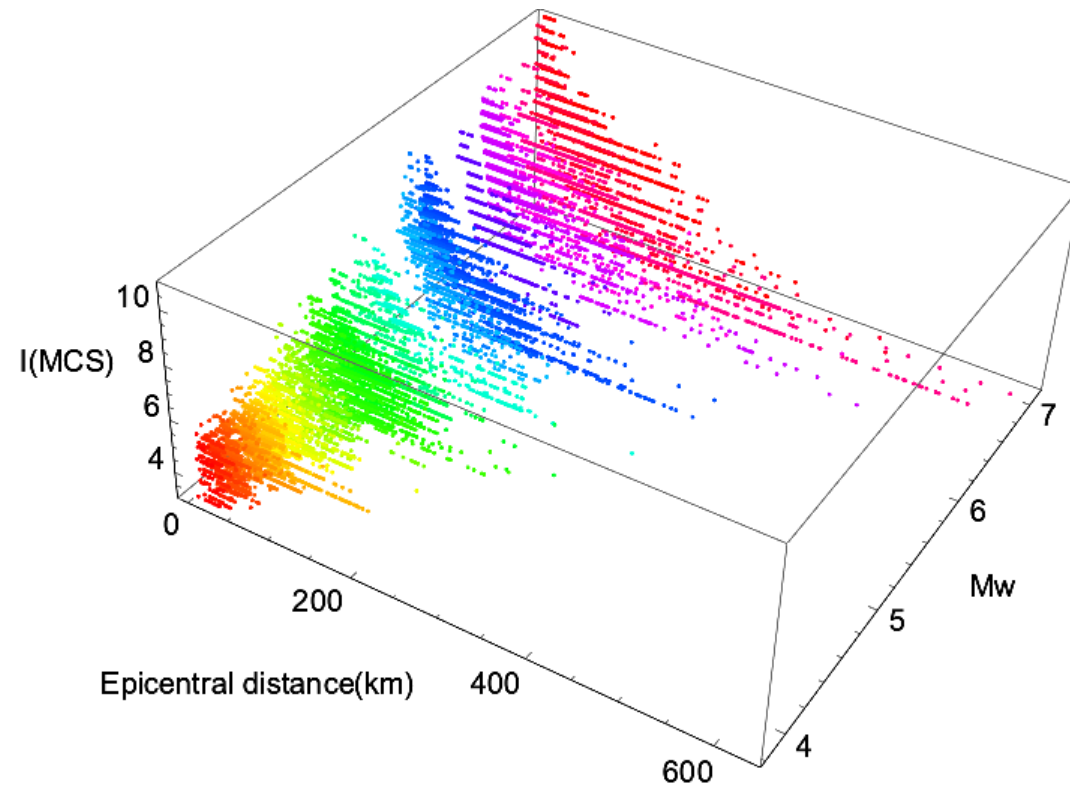
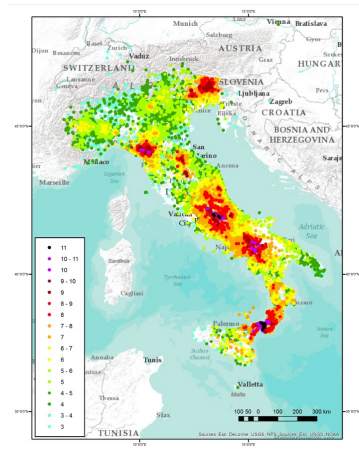
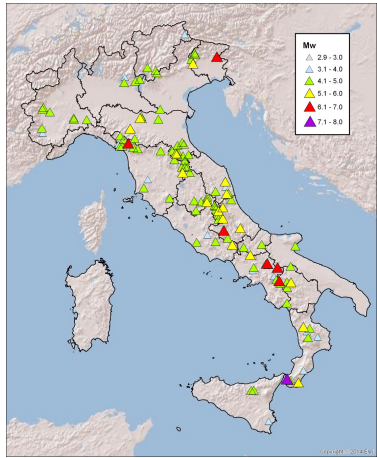
Preliminary analysis of the possible correlation between model residuals and broad scale seismic site conditions

Input 16.260IDPs + raster Vs30 map with spatial resolution of 50 x 50 m defined in Mori et al. (2020)



Conclusions

We have an updated calibration dataset

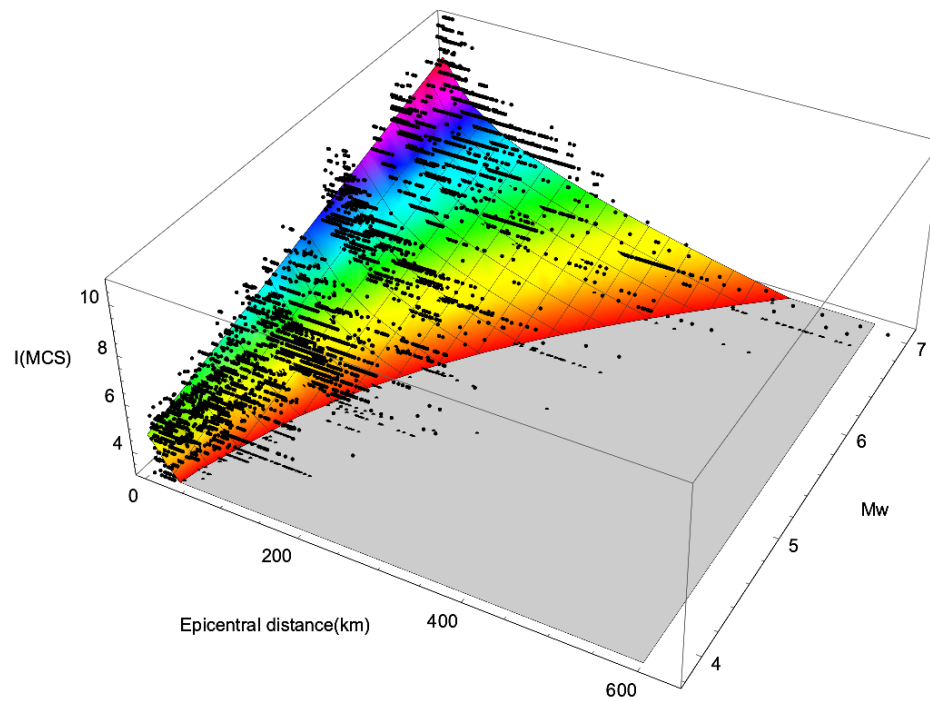


Conclusions Two IPEs are calibrated Mw and are validated

1. A "classic" attenuation model
and we consider it as the first option:

$$I = 1.81 - 2.61 \log R - 0.0039 R + 1.42 M_w$$

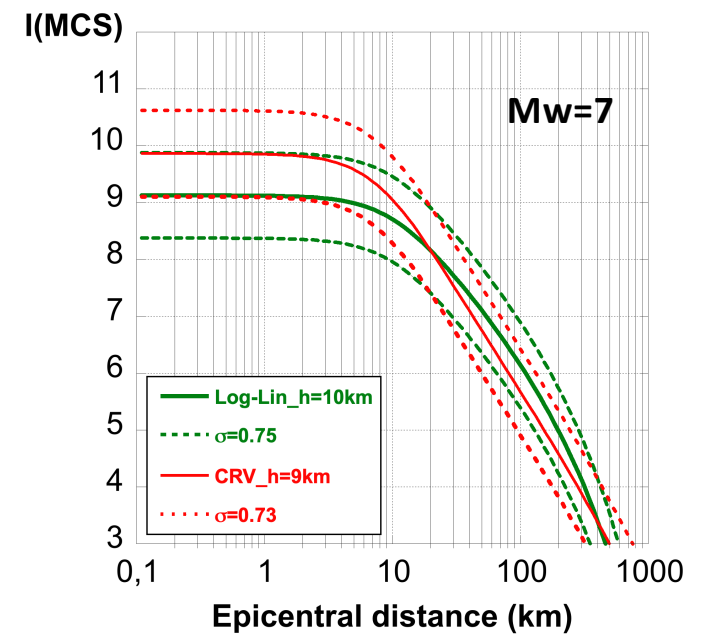
$$R = (R_{\text{epi}}^2 + 9.87^2)^{1/2} \quad \sigma = 0.75$$



A second model as an alternative (CRV9), with a different function, which is more sensitive in the epicentral zone for $M_w > 6$ events, but which on average (Distance $> 10 \text{ km}$) has a similar performance to the classic model (Log-Lin₁₀)

$$I = 1.08 R^{-0.19} 10^{-0.0003 R} M_w^{1.36}$$

$$R = (R_{\text{epi}}^2 + 8.72^2)^{1/2} \quad \sigma = 0.73$$





Macroseismic intensity attenuation models calibrated in Mw for Italy

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Abstract

This study aims at developing new macroseismic intensity attenuation models valid for Italy by exploiting the most updated macroseismic dataset and earthquakes catalogue, as well as the information obtained from a critical analysis of the most recent models in the literature. Several different attenuation models have been calibrated as a function of the moment magnitude (M_w) and epicentral distance from 16,260 intensity data points, that are related to 119 earthquakes occurred after 1900. According to trends and residuals analysis, the preferred calibrated intensity attenuation function is a Log-Linear model for epicentral distance (R_{epi} in km) and a linear model for M_w as:

$$I(MCS) = 1.81 - 2.61 \log R - 0.0039R + 1.42M_w$$

with pseudo hypocentral distance $R = \sqrt{R_{epi}^2 + (9.87)^2}$; the estimated standard deviation is $\sigma = 0.75$. Also noteworthy is another model for macroseismic intensity attenuation that proved to be as good as the best model and shows higher sensitivity to physical parameters, such as focal depth and magnitude, especially in the epicentral area. Performance of all calibrated models was also checked on an independent set of 15 post-1900 Italian earthquakes. One of the results of the present work is the opportunity to define earthquake scenarios (e.g. probabilistic seismic hazard maps) in terms of Macroseismic Intensity and its related standard deviation, avoiding the uncertainties due to the conversion of various ground shaking parameters into intensity values.

Keywords Macroseismic intensity · Intensity attenuation · Macroseismic data · Italy

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For the two proposed models, a sensitivity analysis is performed by varying the depth ($H=5$ and 16 km), simplifying the functional that considers only geometric attenuation and eliminating large epicentral distances in the input data.

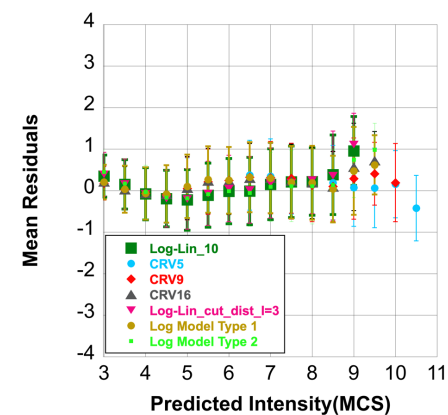
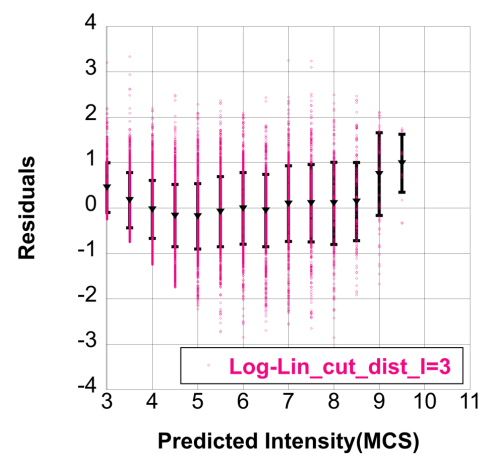
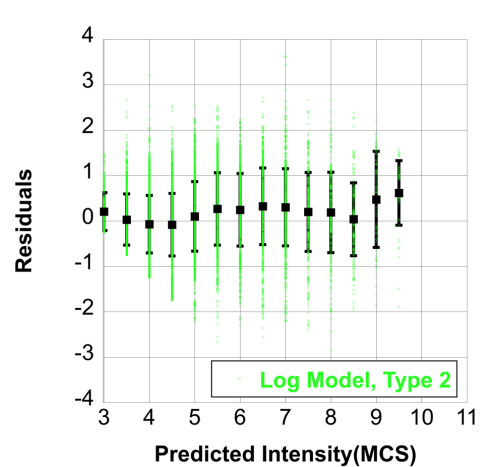
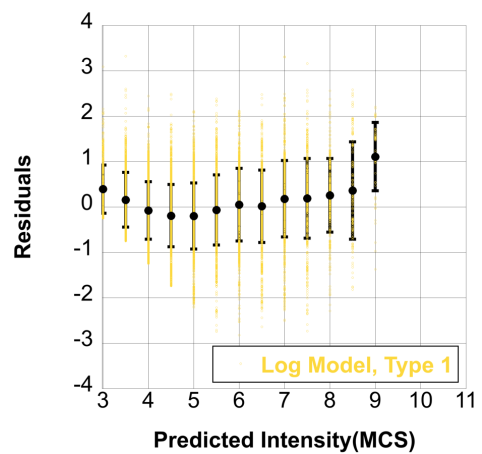
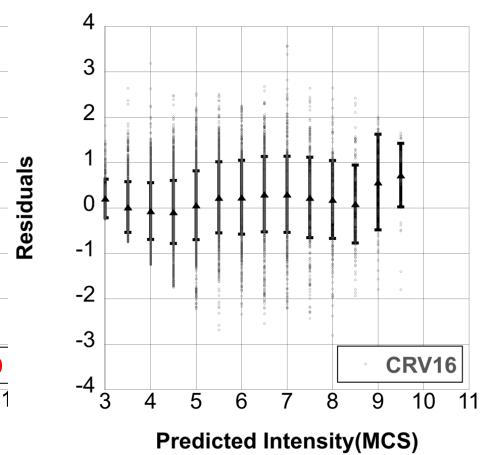
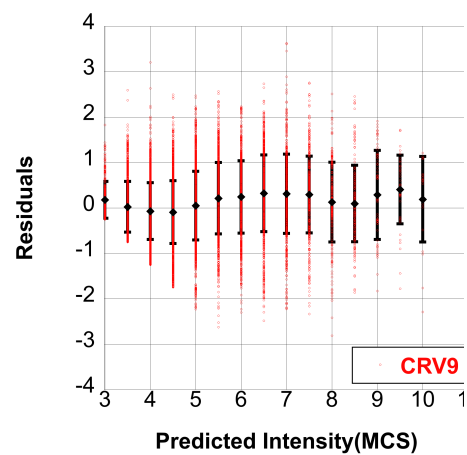
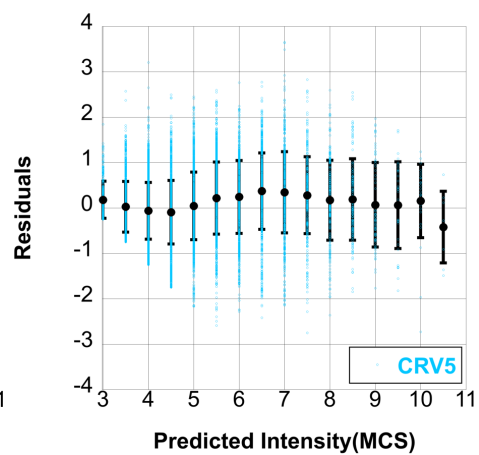
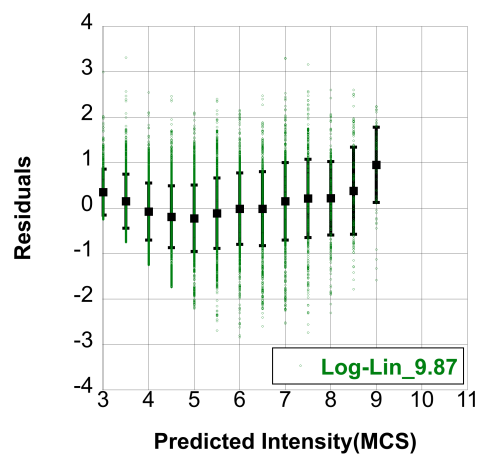
Table 4 Two types of macroseismic intensity attenuation models proposed in the present study (the two best models are in bold): $I = f(R, M_w)$ and $\log I = f(R, M_w)$ where $R = \sqrt{R_{epi}^2 + h^2}$

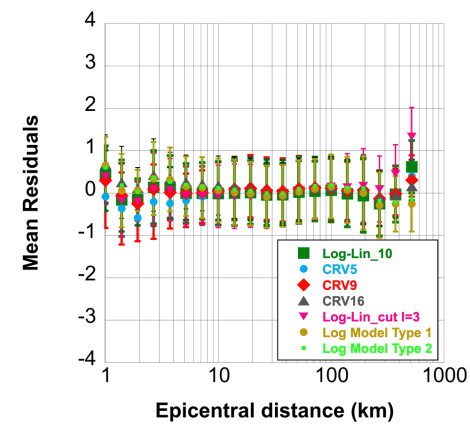
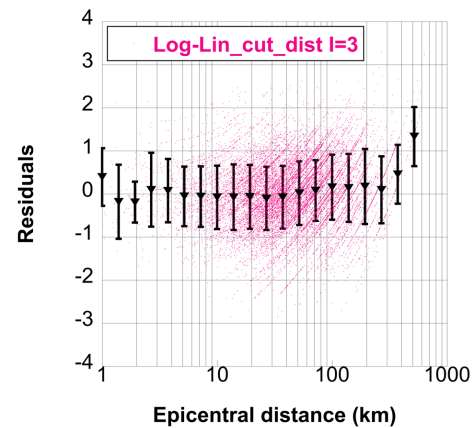
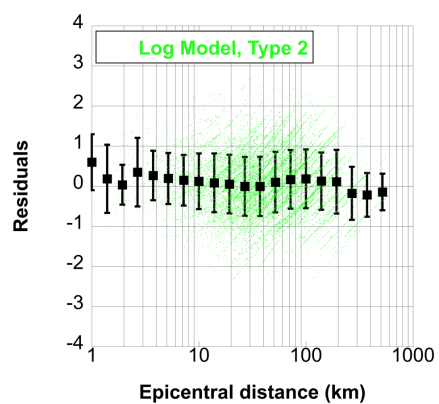
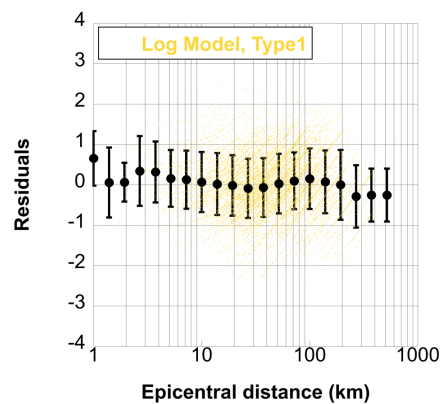
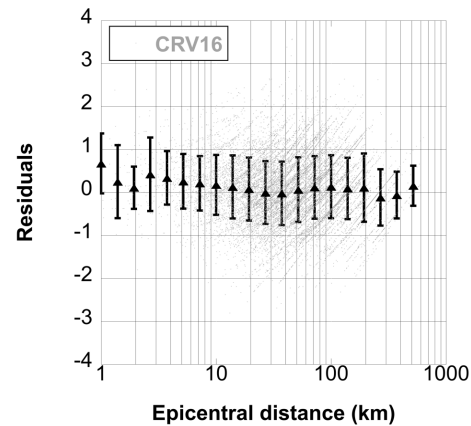
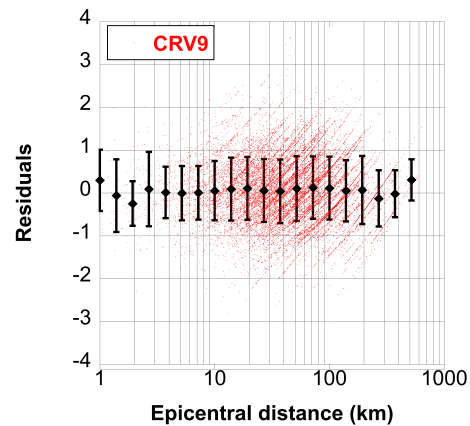
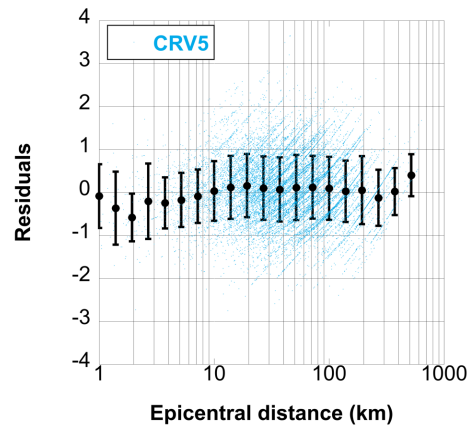
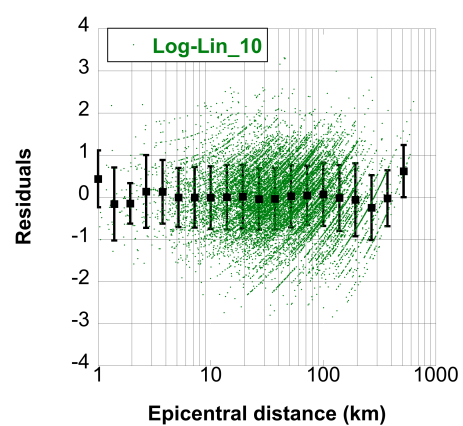
N	Model	H (km)	Comp. h	σ	Name [Type]
1	$I = 1.11 - 2.14 \log R - 0.0054R + 1.41M_w$	5	Fix	0.749	Log-Lin ₅ [Type 1]
2	$I = 1.81 - 2.61 \log R - 0.0039R + 1.42M_w$	9.87	Fit	0.748	Log-Lin₁₀ [Type 1]
3	$I = 2.86 - 3.26 \log R - 0.0020R + 1.43M_w$	16	Fix	0.754	Log-Lin ₁₆ [Type 1]
4	$\log I = -0.006 - 0.17 \log R - 0.0004R + 1.35 \log M_w$ $I = 0.99 R^{-0.17} 10^{-0.0004R} M_w^{1.35}$	5	Fix	0.0657 0.735	CRV ₅ [Type 2]
5	$\log I = 0.032 - 0.19 \log R - 0.0003R + 1.36 \log M_w$ $I = 1.08 R^{-0.19} 10^{-0.0003R} M_w^{1.36}$	8.72	Fit	0.0655 0.731	CRV₉ [Type 2]
6	$\log I = 0.125 - 0.25 \log R - 0.0002R + 1.37 \log M_w$ $I = 1.33 R^{-0.25} 10^{-0.0002R} M_w^{1.37}$	16	Fix	0.0657 0.738	CRV ₁₆ [Type 2]
7	$I = 2.12 - 2.84 \log R - 0.0051R + 1.45M_w$	11.3	Fit	*0.771	Log-Lin _{cut_dist_I=3} [Type 1]
8	$I = 3.39 - 3.63 \log R + 1.42M_w$	16.6	Fit	0.751	Log Dist. Model [Type 1]
9	$\log I = 0.171 - 0.29 \log R + 1.36M_w$ $I = 1.48 R^{-0.29} M_w^{1.36}$	16.2	Fit	0.0659 0.735	Log-Dist. Model [Type 2]

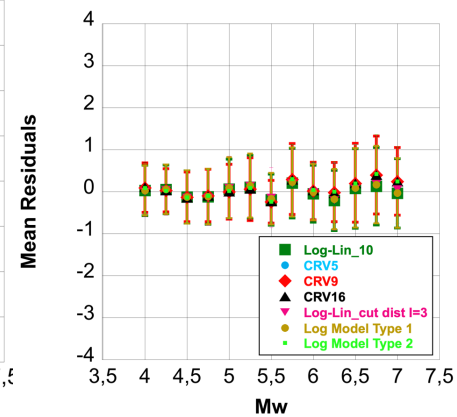
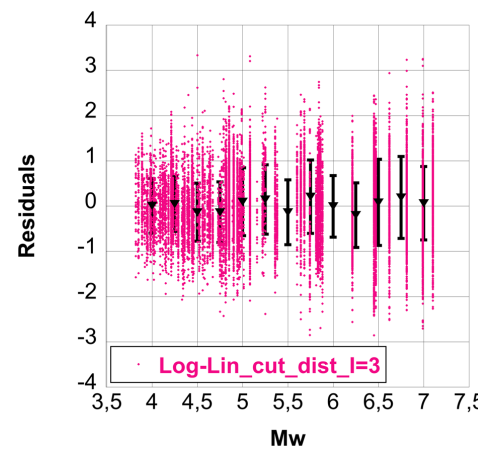
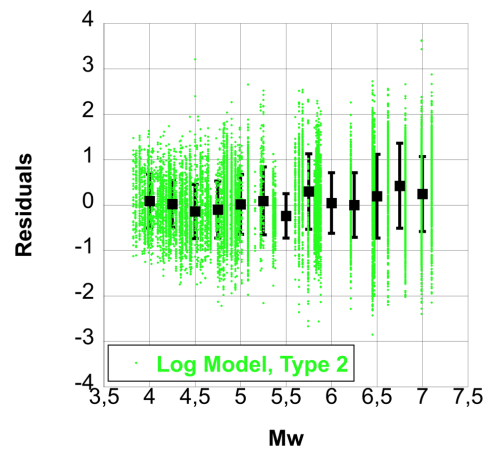
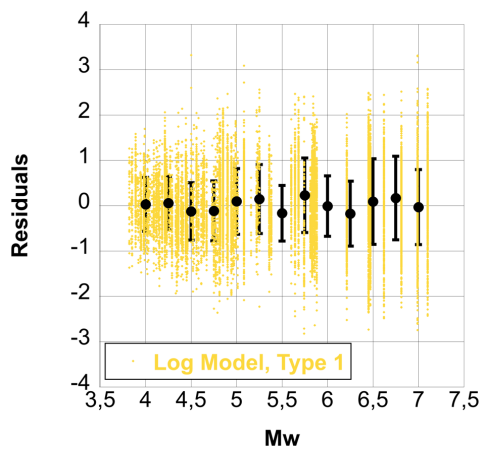
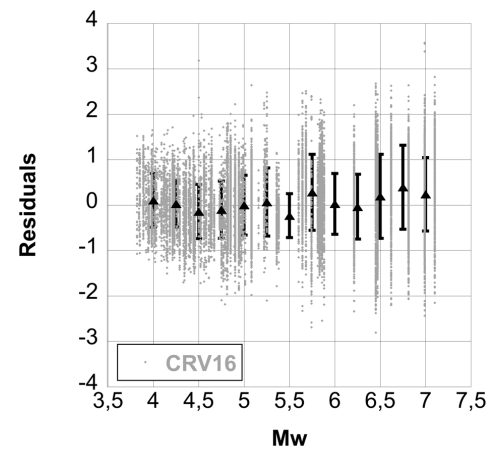
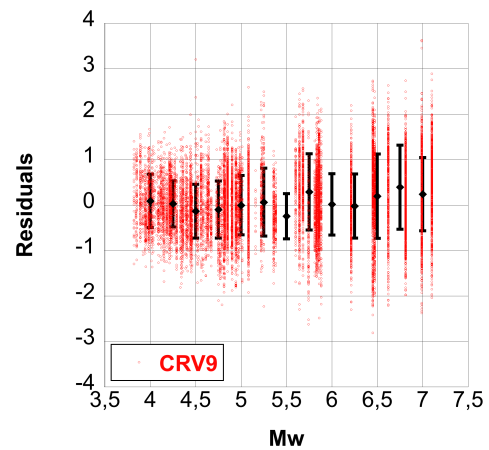
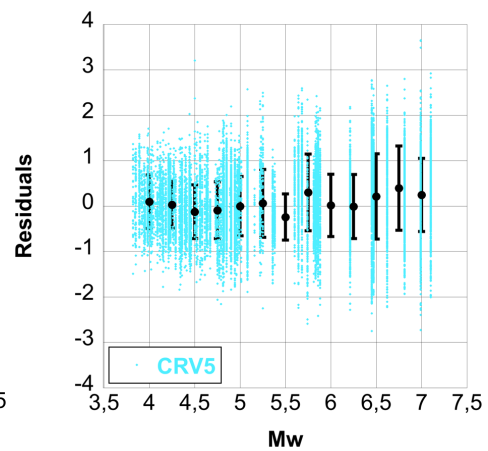
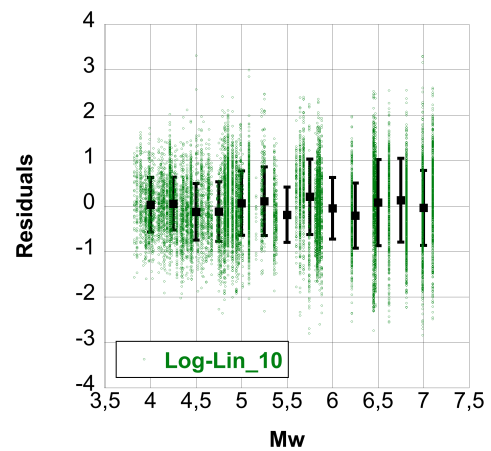
Comp Computation pseudo focal depth (h) as fixed parameter in the regression or fitting parameter in the regression. The models are fitting from 16,260 IDPs

*The Log-Lin model cut distance [$N=7$] at $I=3$ is fitting with 12.587 IDPs

Materiale complementare







1919 Mugello

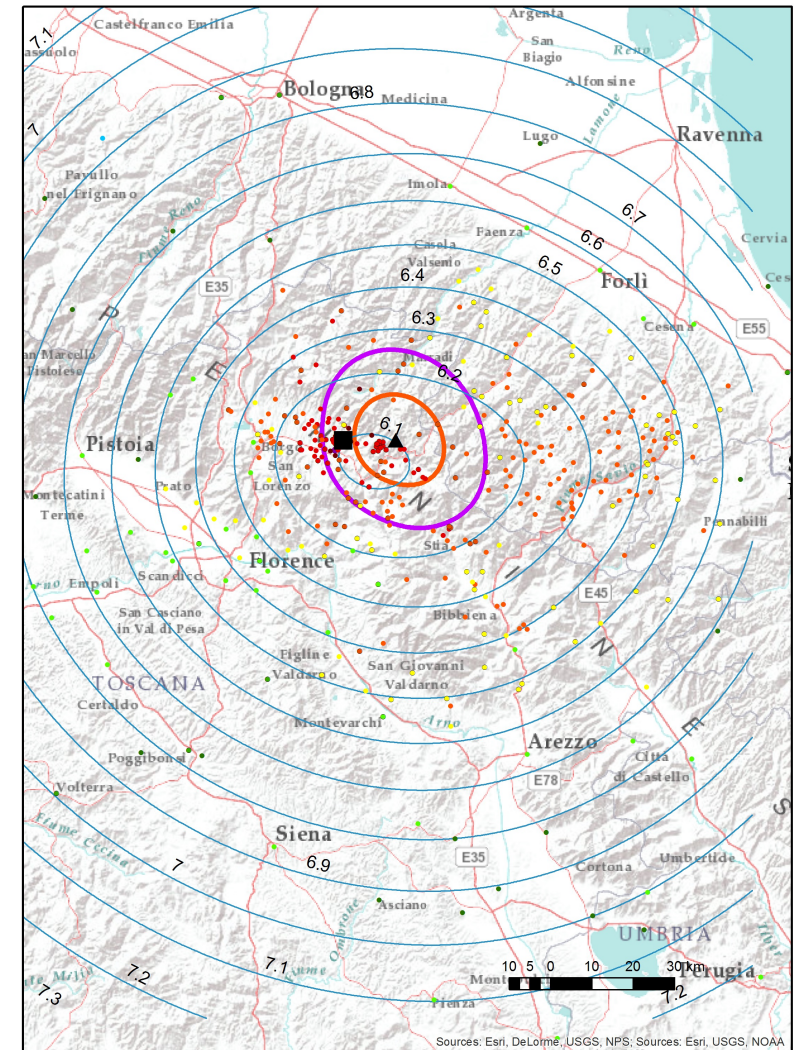


Table 6 Instrumental parameters (CPTI15) of the earthquakes used for validation process and M_w estimations among the macroseismic intensity attenuation models and BW97 method for each event

N	Year	Mo	Da	Ho	Mi	Se	MdpN	Imax	DepIns	MwIns	ErMwIns	Mw Log- Lin	error	Mw CRV5	error	Mw CRV9	error	Mw CRV16	error	Mw PAS	error	AbsRes Log-Lin	AbsRes CRV5	AbsRes CRV9	AbsRes CRV16	AbsRes PAS
1	1910	06	07	02	04		376	9		5.92	0.15	5.81	0.2	5.85	0.2	5.83	0.2	5.84	0.2	5.85	0.2	0.11	0.07	0.09	0.08	0.07
2	1919	06	29	15	06	13.00	565	10		6.26	0.17	6.10	0.2	6.14	0.2	6.12	0.2	6.11	0.2	5.96	0.2	0.16	0.12	0.14	0.15	0.30
3	1969	09	26	23	40	39.00	97	5		4.25	0.22	4.57	0.2	4.52	0.2	4.51	0.2	4.50	0.2	5.08	0.2	0.32	0.27	0.26	0.25	0.83
4	1978	04	15	23	33	48.15	330	8	17.9	6.03	0.10	5.84	0.2	5.85	0.2	5.84	0.2	5.85	0.2	5.85	0.2	0.19	0.18	0.18	0.19	0.18
5	1980	05	14	01	41		26	6		4.83	0.10	4.82	0.2	4.75	0.2	4.75	0.2	4.77	0.2	5.27	0.2	0.01	0.08	0.08	0.06	0.44
6	1983	11	09	16	29	52.00	850	7	18.1	5.04	0.10	5.36	0.2	5.25	0.2	5.25	0.2	5.27	0.2	5.60	0.2	0.32	0.21	0.21	0.23	0.56
7	1984	04	29	05	02	59.00	709	7	8.6	5.62	0.10	5.50	0.2	5.54	0.2	5.50	0.2	5.58	0.2	5.42	0.2	0.12	0.08	0.12	0.04	0.20
8	1996	02	27	11	13	45.90	150	5–6	9.5	4.31	0.10	4.14	0.2	4.11	0.2	4.09	0.2	4.07	0.2	4.81	0.2	0.17	0.20	0.22	0.24	0.50
9	1998	08	15	05	18	08.89	233	6	2.9	4.42	0.07	4.13	0.2	4.07	0.2	4.05	0.2	4.04	0.2	4.81	0.2	0.29	0.35	0.37	0.38	0.39
10	2001	10	18	11	02	46.25	115	5	5.8	4.28	0.07	4.02	0.2	4.07	0.2	4.07	0.2	4.09	0.2	4.72	0.2	0.26	0.21	0.21	0.19	0.44
11	2002	09	06	01	21	27.25	132	6	9.6	5.92	0.07	5.80	0.2	5.77	0.2	5.79	0.2	5.83	0.2	5.92	0.2	0.12	0.15	0.13	0.09	0.00
12	2003	09	14	21	42	53.18	133	7	8.3	5.24	0.07	4.97	0.2	4.97	0.2	4.94	0.2	4.95	0.2	5.34	0.2	0.27	0.27	0.30	0.29	0.10
13	2009	04	06	01	32	40.40	316	9–10	8.3	6.29	0.07	6.44	0.2	6.39	0.2	6.34	0.2	6.36	0.2	6.10	0.2	0.15	0.10	0.05	0.07	0.19
14	2016	08	24	01	36	32.00	221	10	8.1	6.18	0.07	6.02	0.2	5.93	0.2	5.97	0.2	6.04	0.2	5.78	0.2	0.16	0.25	0.21	0.14	0.40
15	2017	01	18	10	14	09.90	280	8	9.6	5.70	0.07	5.82	0.2	5.86	0.2	5.83	0.2	5.84	0.2	5.68	0.2	0.12	0.16	0.13	0.14	0.02
Mean of all events-based Abs. Res																						0.18	0.18	0.18	0.17	0.31
Median																						0.16	0.18	0.18	0.15	0.30
Std deviation																						0.09	0.08	0.09	0.10	0.20
Minimum																						0.01	0.07	0.05	0.04	0.00
Maximum																						0.32	0.35	0.37	0.38	0.83