UNIVERSITÀ DEGLI STUDI DI TRIESTE

Elementi di geofisica per la Protezione Civile

GMPE

Giovanni Costa - costa@units.it

Estimation of regression laws for ground motion parameters using as case of study the Amatrice earthquake.

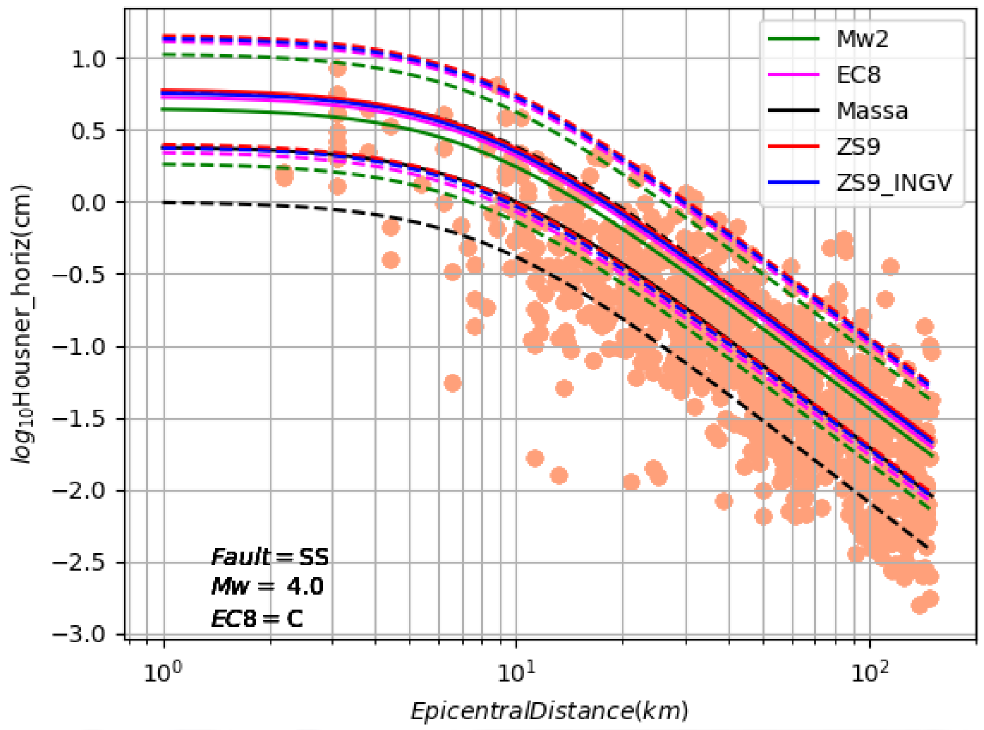
L. Tiberi[1], G. Costa[1]

1 University of Trieste, DMG, Trieste, SeisRaM group

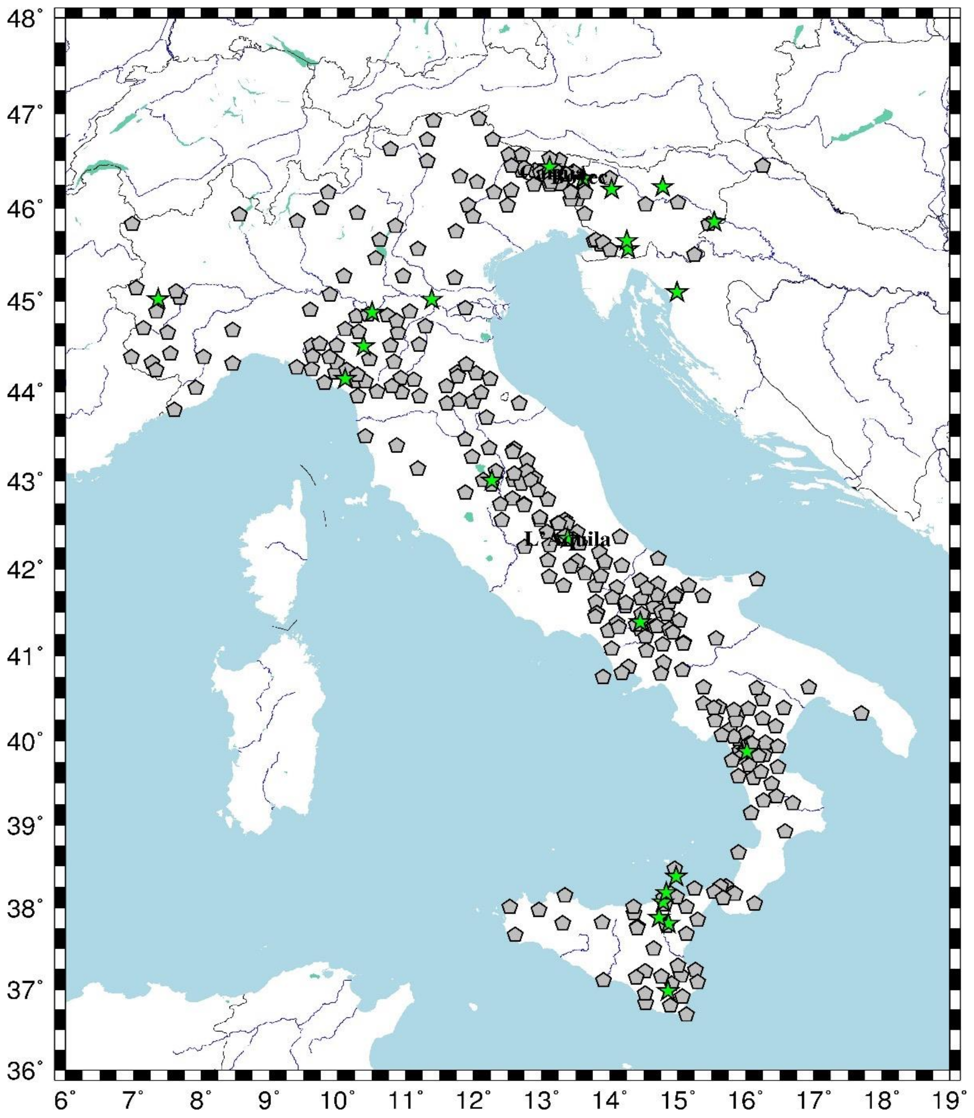
Introduction

The possibility to directly associate the damages to the ground motion parameters is always a great challenge, in particular for civil protections.

Even if there are few regression law estimations in literature for the Italian territory (e.g. Faccioli and Cauzzi (2007) and Faenza and Michelini (2010)), the availability of new accelerometric data allows us to estimate a new set of high quality regression laws.



Input Data



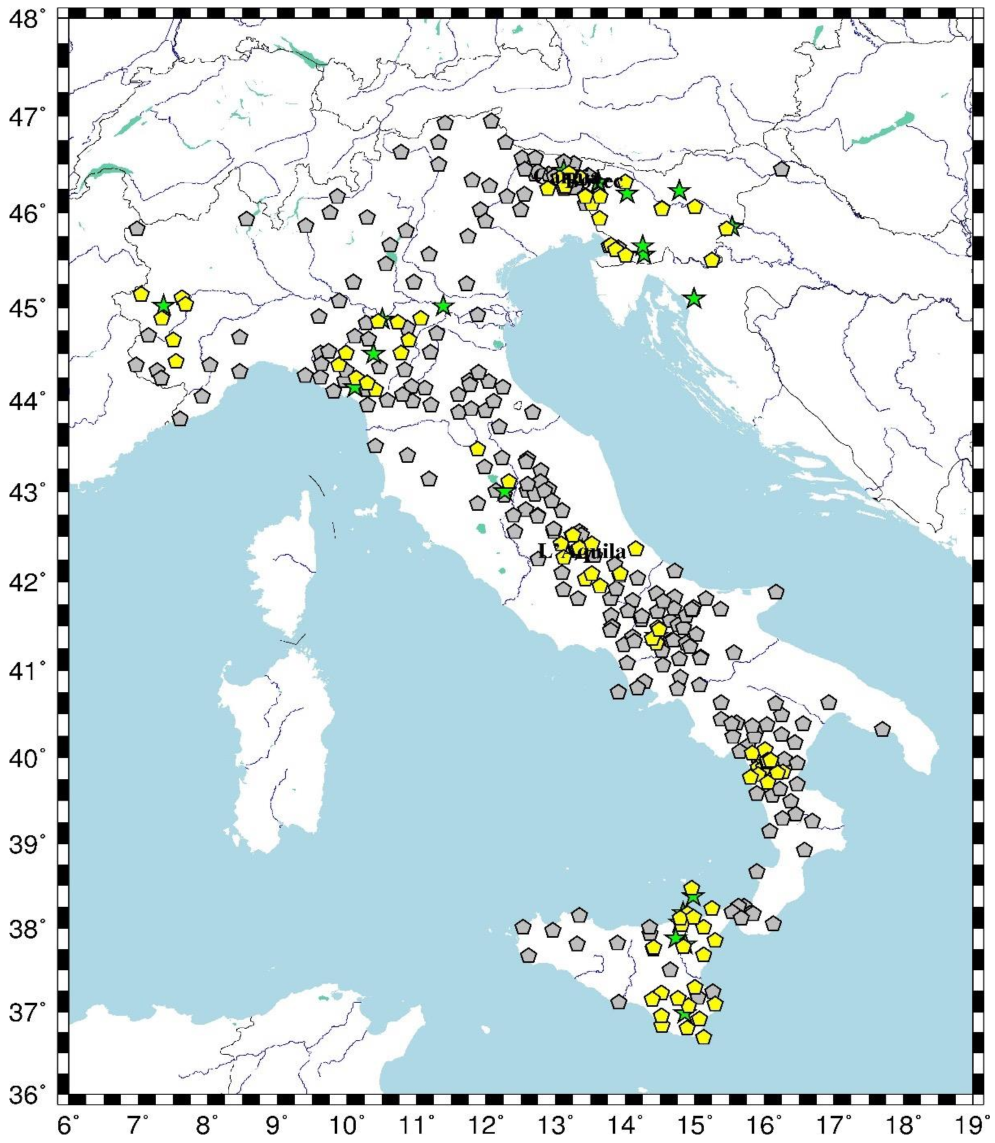
Data collected using the CE3RN (Central Eastern European Earthquake and Research Network) and the RAN (National Accelerometric Network managed by the Civil Defence of Rome) stations

ML >= 3.8

GMPs (ground motion parameters) estimated using an automatic procedure that works daily in a real time mode. (Gallo et al. (2014))

The green stars are the epicentral location of the studied events and the grey pentagons are the station sites, where we have calculated the GMPs values.

Input Data



Data collected using the CE3RN (Central Eastern European Earthquake and Research Network) and the RAN (National Accelerometric Network managed by the Civil Defence of Rome) stations

Macroseismic data collected from the ARSO macroseismic archive (for the slovenian events) and from the DBMI15 (for the italian events).

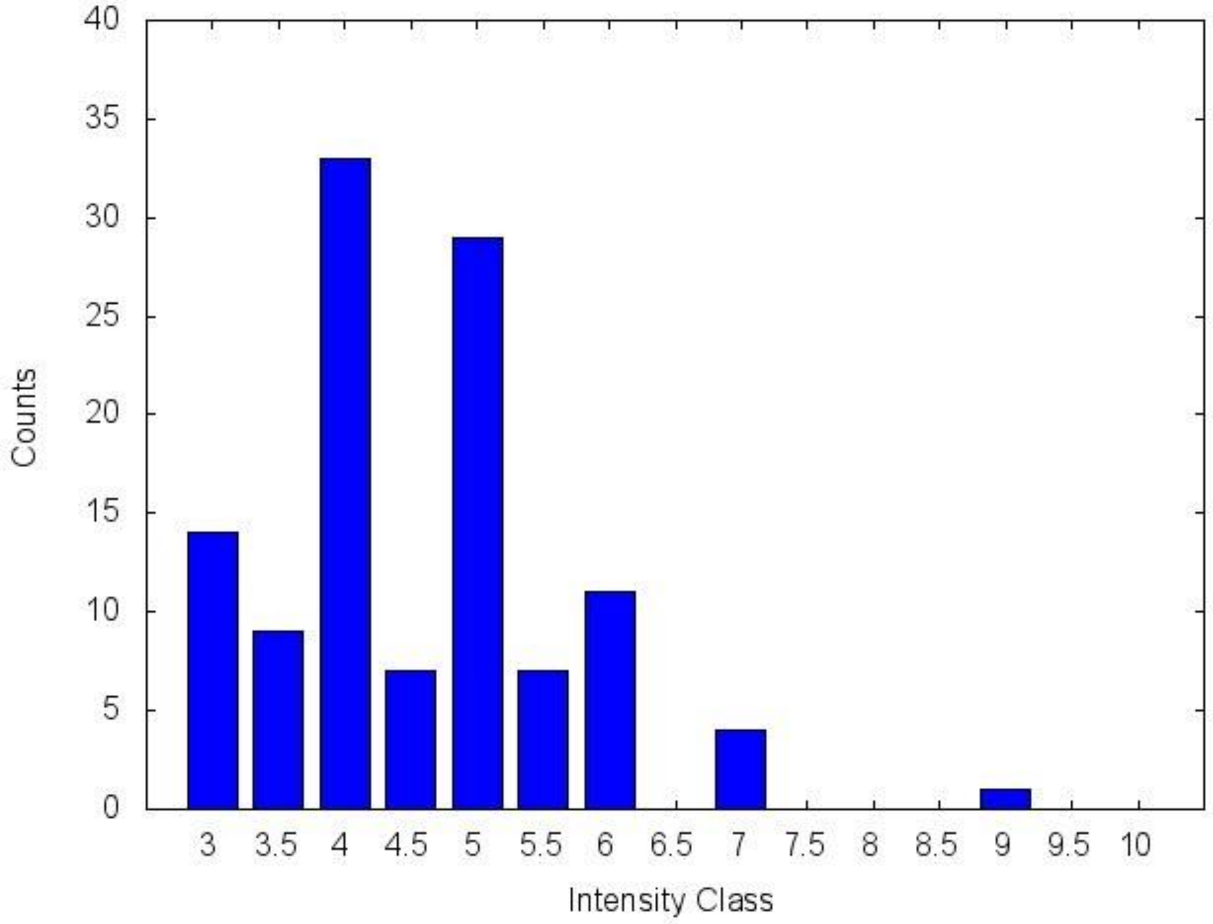
Maximum distance of 4 km, with an average value of :

(1.8 ± 1.8) km

115 pairs of intensity - GMPs values

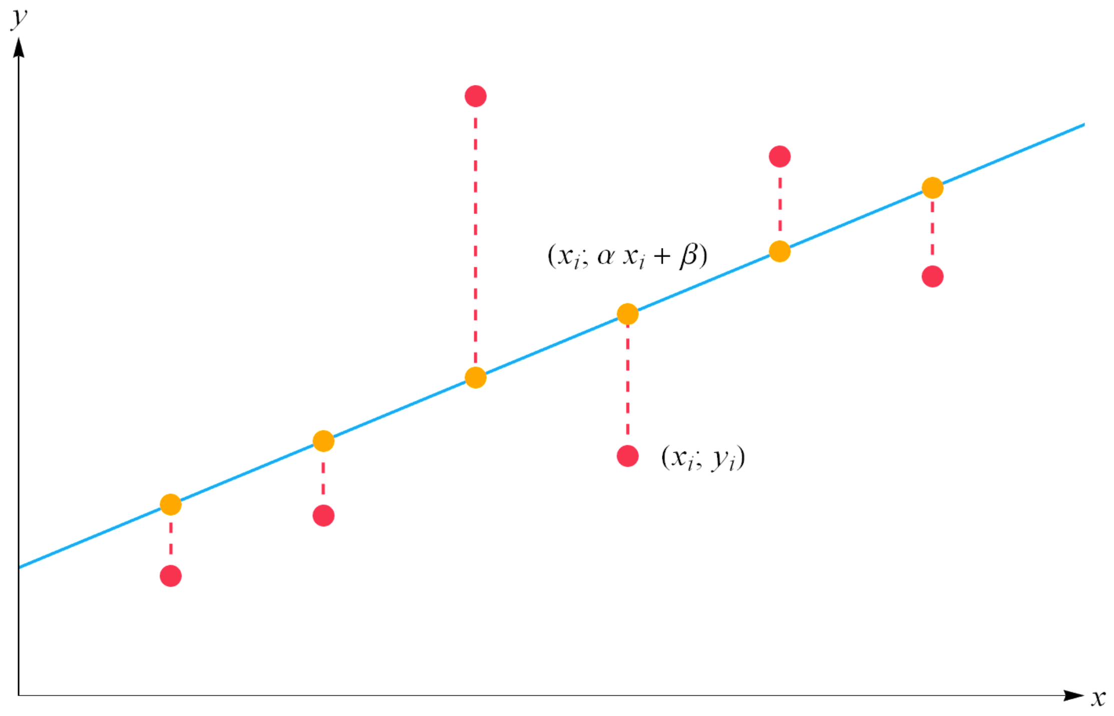
Data set used for the regression law estimation. The green stars are the epicentral location of the studied events and the grey pentagons are the station sites, where we have calculated the GMPs values and the yellow one are those with an observed intensity associated.

Input Data



GMPs data divided into 0.5 intensity classes

Regression (least-squares)



Example of linear regression with one dependent and one independent variable

$$A = \{x_1, \ldots\ldots, x_n\} \qquad B = \{y_1, \ldots\ldots, y_n\}$$

A regression or least squares line is defined as the line of equation

$$y = \alpha x + \beta$$

for which the quantity is minimum

$$E = \sum_{i=1}^{n} \left(\alpha x_i + (\beta - y_i)\right)$$

representing the sum of the squares of the distances of each pair $(x_i - y_i)$ from the corresponding point on the line, $\alpha x_i + \beta$

$$\alpha = \frac{cov(A,B)}{\sigma_A^2} \qquad \beta = \mu_B - \alpha\mu_A$$

$$cov(A,B) = \frac{(x_1 - \mu_A)(x_1 - \mu_B) + \cdots . + (x_n - \mu_A)(x_n - \mu_B)}{n-1}$$

$$\sigma_A = \sqrt{\frac{(x_1 - \mu_A)^2 + \cdots . + (x_n - \mu_A)^2}{n-1}}$$

R^2

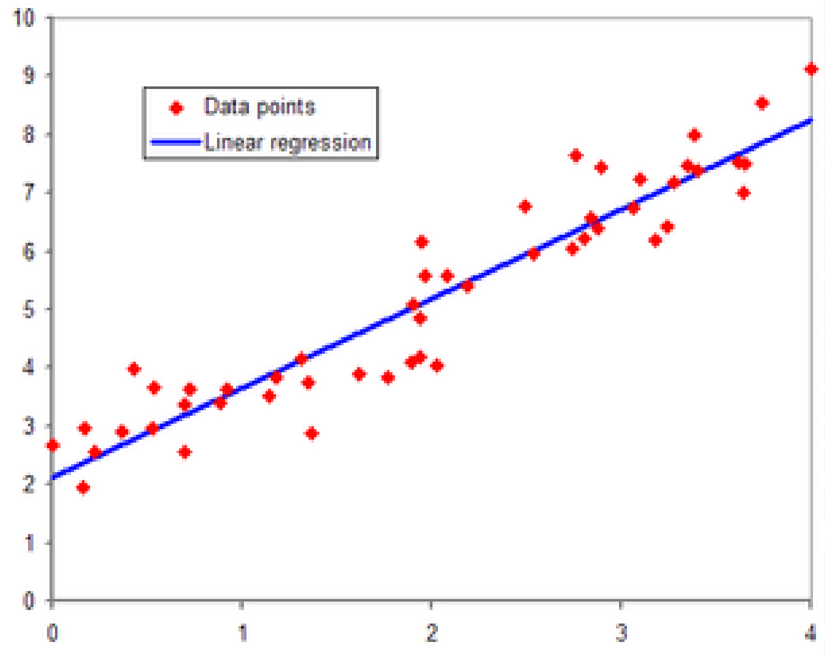
In statistics, the coefficient of determination, most commonly R^2, is an index that measures the link between the variability of the data and the correctness of the statistical model used.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \mu_B)^2}$$

$\hat{y} = predicted\ values$

$y = observed\ values$

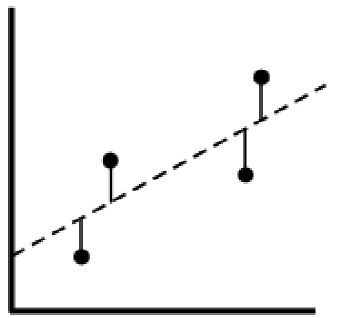
$\mu_B = mean\ of\ the\ observed\ data$



Regression laws and used algorithms

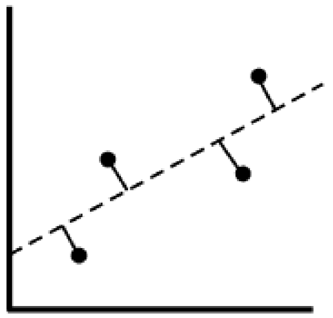
$$I = \mathbf{a} * \log_{10}(GMP) + \mathbf{b}$$

Not linear least-squares (NLLS) (Levenberg, 1944) needs initial values for a and b (set 1.0 in this study) and the independent variable must be known with greater accuracy than the dependent one.



vertical offsets

Orthogonal distance regression (ODR) (Boggs et al., 1987) estimates errors perpendicularly to the line not vertically. So it takes into account the errors of both variables. So it is possible to invert the relation.



perpendicular offsets

Results

	NLLS				ODR			
GMPs	a	b	R^2	σ	a	b	R^2	σ
max PGD	1.60 ± 0.17	6.27 ± 0.21	0.93	0.55	1.71 ± 0.18	6.35 ± 0.22	0.92	0.28
max PGV	1.84 ± 0.24	4.85± 0.23	0.89	0.66	2.03 ± 0.27	4.82 ± 0.25	0.89	0.3
max PGA	2.03 ± 0.34	2.11 ± 0.59	0.84	0.8	2.39 ± 0.39	1.55 ± 0.70	0.92	0.28
max Arias	1.07 ± 0.15	5.35 ± 0.23	0.88	0.7	1.17 ± 0.16	5.38 ± 0.25	0.88	0.46
max Housner	1.81 ± 0.23	3.82 ± 0.28	0.9	0.63	1.98 ± 0.25	3.70 ± 0.30	0.9	0.29
max PSA03	1.94 ± 0.34	1.83 ± 0.67	0.83	0.84	2.31 ± 0.41	1.19 ± 0.80	0.82	0.35
max PSA10	1.69 ± 0.22	3.36 ± 0.33	0.89	0.65	1.86 ± 0.24	3.17 ± 0.35	0.9	0.31
max PSA30	1.64 ± 0.17	4.89 ± 0.19	0.92	0.54	1.76 ± 0.18	4.87 ± 0.19	0.93	0.27

a, b and R^2 values are consistent between the two different algorithms.

The main differences are the standard deviations lower using ODR than the NLLS.

Test on input data

How much are the data close to the regression line, so how much does the line represent well the data used?

$$diff = \sum_{i=1}^{N} (I^i_{OBS} - I^i_{CALC})/N$$

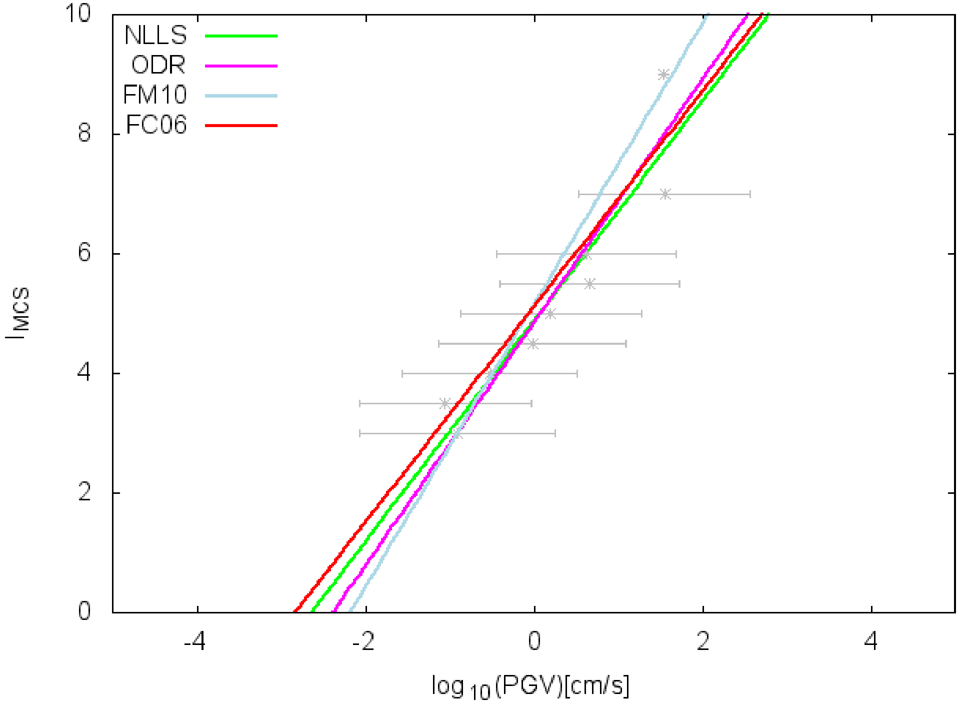
$$misfit = \sum_{i=1}^{N} (|I^i_{OBS} - I^i_{CALC}|)/N$$

	NLLS		ODR	
	Diff	Misfit	Diff	Misfit
PGD	0.0 ± 0.5	0.5 ± 0.5	0.0 ± 0.5	1.0 ± 0.5
PGV	0.0 ± 0.5	0.5 ± 0.5	0.0 ± 0.5	0.5 ± 0.5
PGA	0.0 ± 0.5	0.5 ± 0.5	0.0 ± 0.5	1.0 ± 0.5
Arias	0.0 ± 0.5	0.5 ± 0.5	0.0 ± 0.5	0.5 ± 0.5
Housner	0.0 ± 0.5	0.5 ± 0.5	0.0 ± 0.5	0.5 ± 0.5
PSA03	0.0 ± 0.5	0.5 ± 0.5	0.0 ± 0.5	1.0 ± 0.5
PSA10	0.0 ± 0.5	0.5 ± 0.5	0.0 ± 0.5	0.5 ± 0.5
PSA30	0.0 ± 0.5	1.0 ± 0.5	0.0 ± 0.5	1.0 ± 0.5

Test using the data set of estimation of the laws.

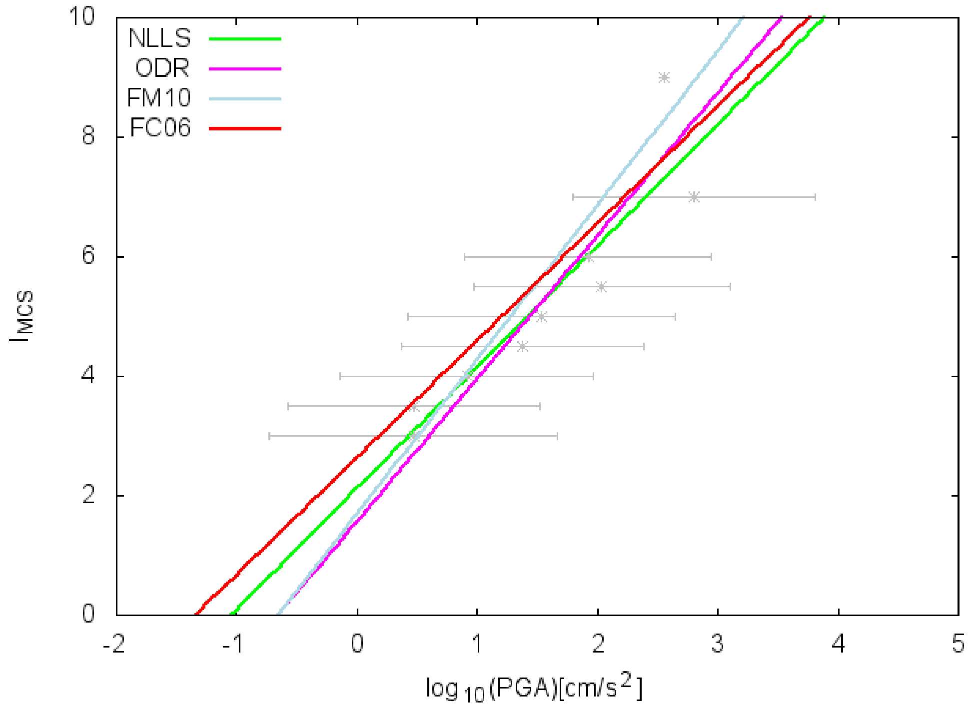
Comparisons: PGV relations

$I_{MCS} = (1.84 \pm 0.24) * \log PGV + (4.85 \pm 0.23)$, $\sigma = 0.66$, $R^2 = 0.89$	NLLS
$I_{MCS} = (2.03 \pm 0.27) * \log PGV + (4.82 \pm 0.25)$, $\sigma = 0.30$, $R^2 = 0.89$	ODR
$I_{MCS} = (2.35 \pm 0.09) * \log PGV + (5.11 \pm 0.07)$, $\sigma = 0.26$	Faenza and Michelini (2010)
$I_{MCS} = (1.80 \pm 0.17) * \log PGV + (5.09 \pm 0.22)$, $\sigma = 0.71$, $R^2 = 0.61$	Faccioli and Cauzzi (2006)



Comparisons: PGA relations

$I_{MCS} = (2.03 \pm 0.34) * \log PGA + (2.11 \pm 0.59)$, $\sigma = 0.80$, $R^2 = 0.84$	NLLS
$I_{MCS} = (2.39 \pm 0.39) * \log PGA + (1.55 \pm 0.70)$, $\sigma = 0.28$, $R^2 = 0.92$	ODR
$I_{MCS} = (2.58 \pm 0.14) * \log PGA + (1.68 \pm 0.22)$, $\sigma = 0.35$	Faenza and Michelini (2010)
$I_{MCS} = (1.96 \pm 0.29) * \log PGA + (2.62 \pm 0.10)$, $\sigma = 0.89$, $R^2 = 0.38$	Faccioli and Cauzzi (2006)



L. Tiberi[1], G. Costa[1]

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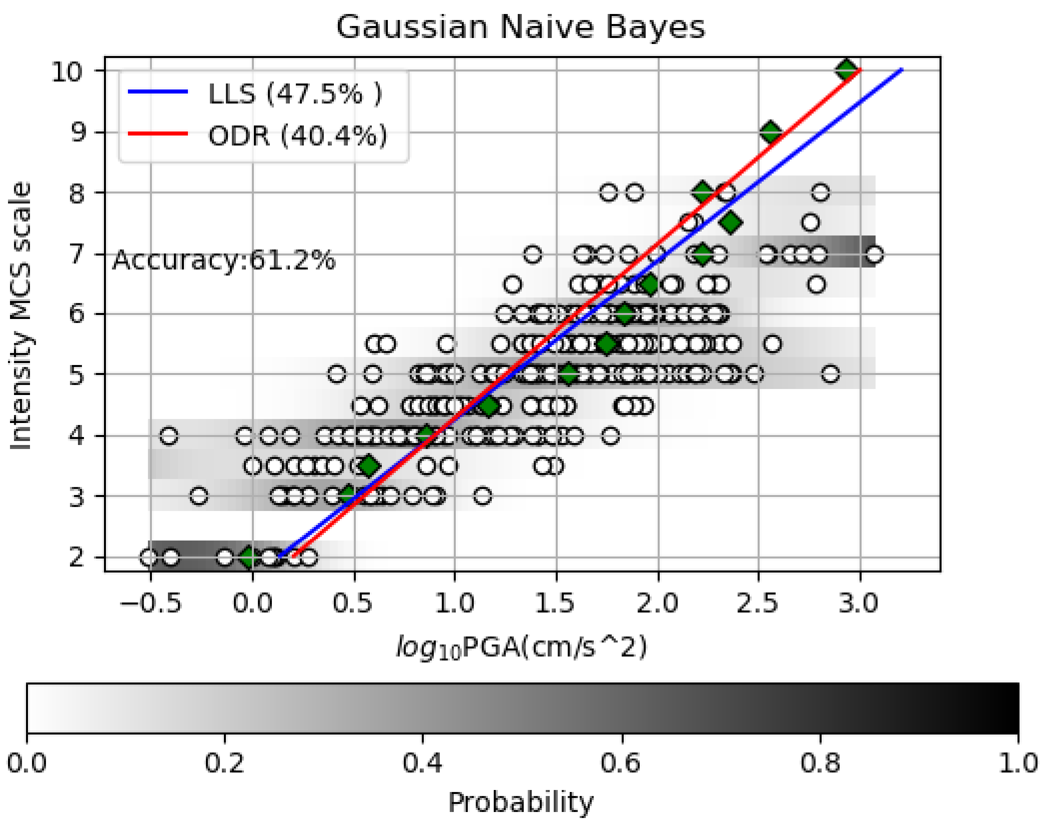
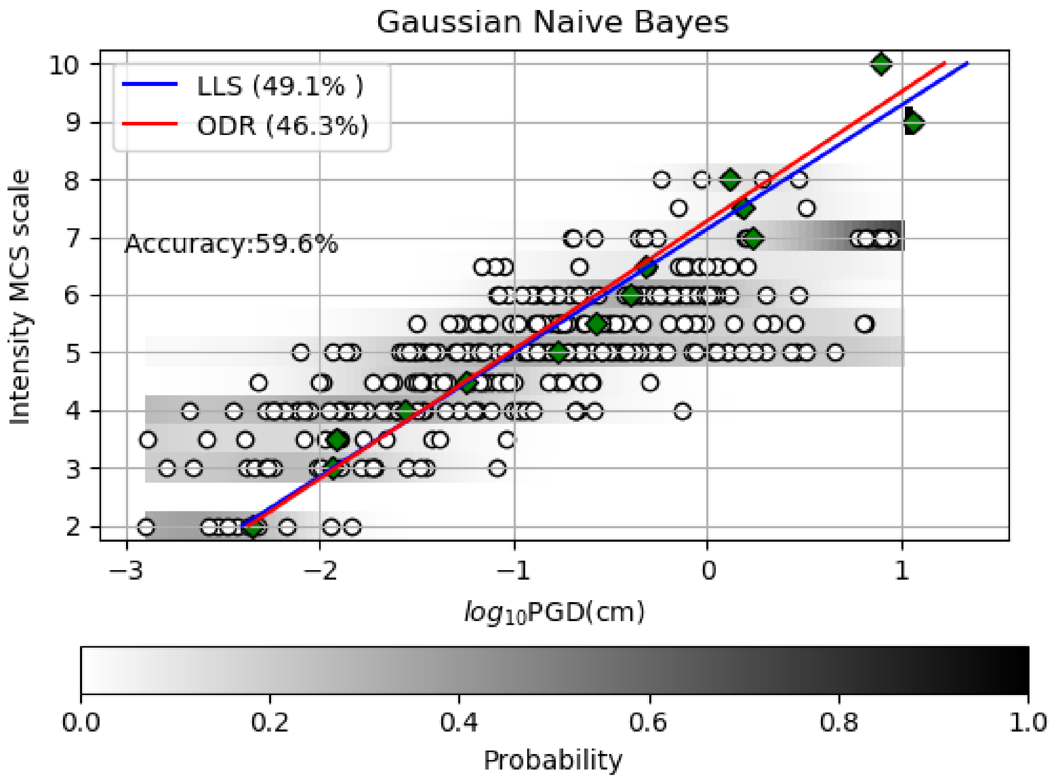
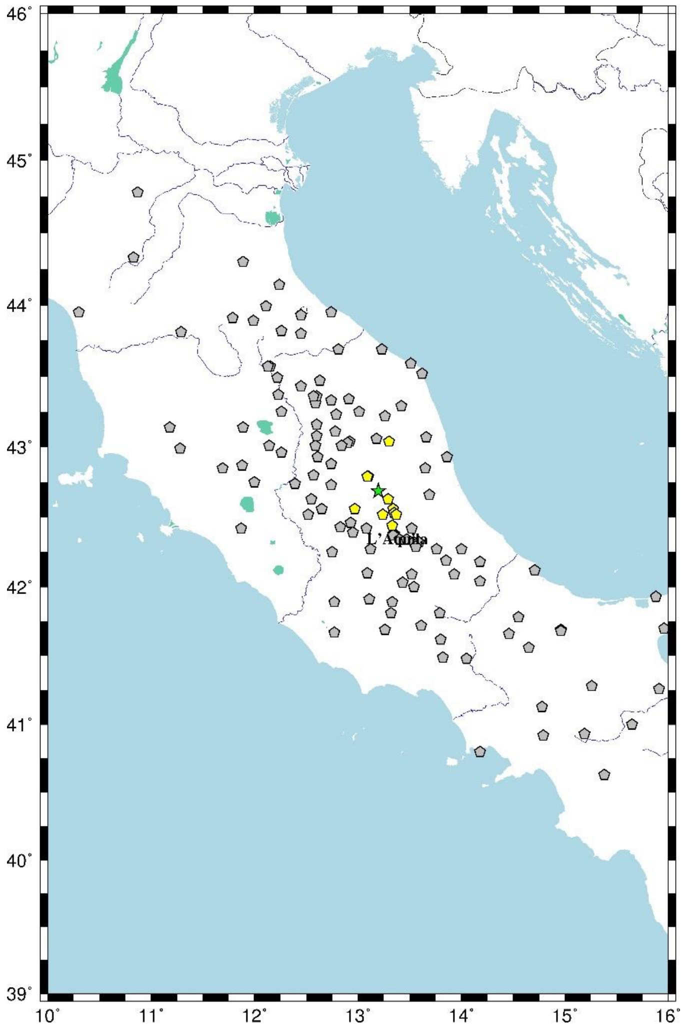




Gaussian Naive Bayes probabilities fo each ground motion parameters in a grey scale with the accuracy percentage; the LLS (blue line) and ODR (red line) of the previous estimation, with the associated accuracy.

Amatrice earthquake



Amatrice earthquake occurred the 24th August of 2016, 01:36 UTC with a Mw of 6.1.

Data collected using the RAN (National Accelerometric Network managed by the Civil Defence of Rome) stations.

Macroseismic data collected from Albini et al. (2016).

The green star is the epicentral location of Amatrice event and the grey pentagons are the station sites, where we have calculated the GMPs values, and the yellow one are those with an observed intensity associated.

Test using Amatrice earthquake data

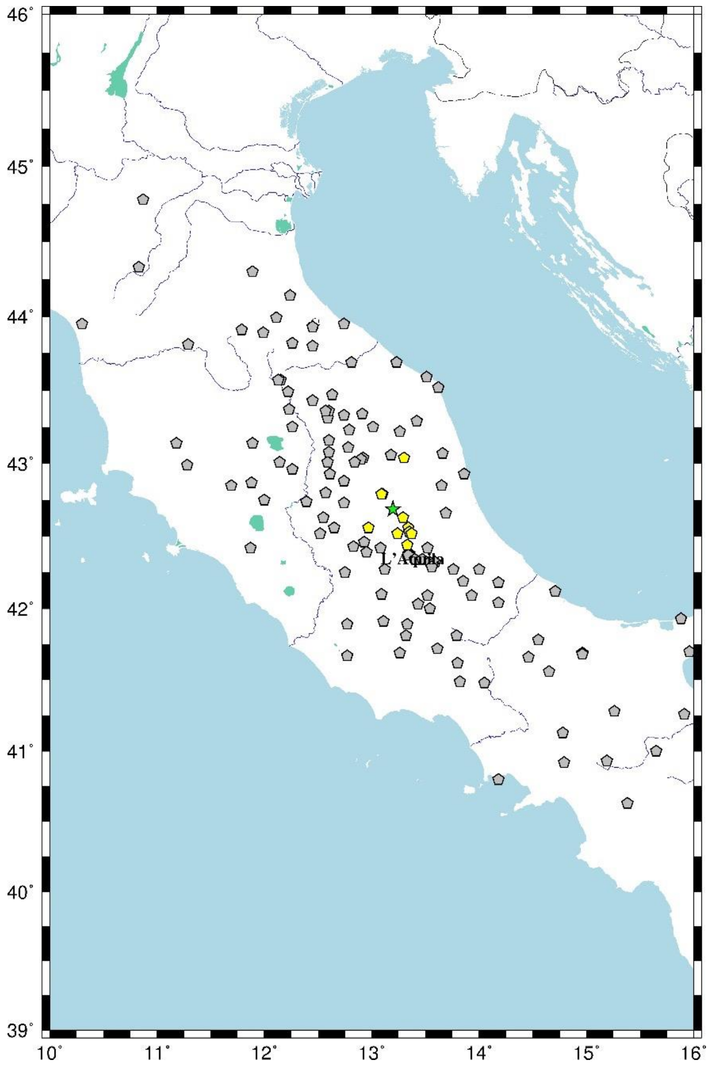
$$diff = \sum_{i=1}^{N} (I^i_{OBS} - I^i_{CALC})/N$$

$$misfit = \sum_{i=1}^{N} (|\, I^i_{OBS} - I^i_{CALC} \,|)/N$$

	NLLS		ODR	
	Average diff	Misfit	Average diff	Misfit
PGD	-1.0 ± 0.5	1.5 ± 0.5	-1.5 ± 0.5	1.5 ± 0.5
PGV	-1.0 ± 0.5	1.5 ± 0.5	-1.0 ± 0.5	1.5 ± 0.5
PGA	-0.5 ± 0.5	1.0 ± 0.5	-1.0 ± 0.5	1.0 ± 0.5
PSA03	-1.0 ± 0.5	1.5 ± 0.5	-1.0 ± 0.5	1.5 ± 0.5
PSA10	-1.0 ± 0.5	1.5 ± 0.5	-1.0 ± 0.5	1.5 ± 0.5
PSA30	-1.5 ± 0.5	2.0 ± 0.5	-1.5 ± 0.5	2.0 ± 0.5
Arias	-0.5 ± 0.5	1.0 ± 0.5	-1.0 ± 0.5	1.5 ± 0.5
Housner	-1.0 ± 0.5	1.5 ± 0.5	-1.0 ± 0.5	1.5 ± 0.5

	PGV		PGA	
	Diff	Misfit	Diff	Misfit
NLLS	-1.0 ± 0.5	1.5 ± 0.5	-0.5 ± 0.5	1.0 ± 0.5
ODR	-1.0 ± 0.5	1.5 ± 0.5	-1.0 ± 0.5	1.0 ± 0.5
FC06	-1.0 ± 0.5	1.5 ± 0.5	-1.0 ± 0.5	1.5 ± 0.5
FM10	-2.0 ± 0.5	2.0 ± 0.5	-1.5 ± 0.5	1.5 ± 0.5

Adding Amatrice earthquake to the initial dataset



Amatrice earthquake occurred the 24th August of 2016, 01:36 UTC with a Mw of 6.1.

Data collected using the RAN (National Accelerometric Network managed by the Civil Defence of Rome) stations.

Maximum distance of 4 km, with an average value of :

(1.8 ± 1.8) km

125 pairs of intensity - GMPs values

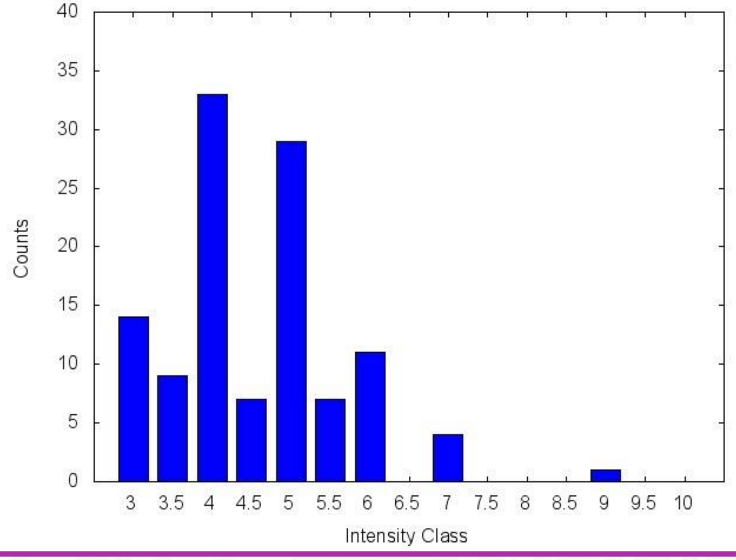
The green stars are the epicentral location of the studied events and the grey pentagons are the station sites, where we have calculated the GMPs values, and the yellow one are those with an observed intensity associated.

Adding Amatrice earthquake to the initial dataset

Original dataset

Average distance of :
(1.8 ± 1.8) km

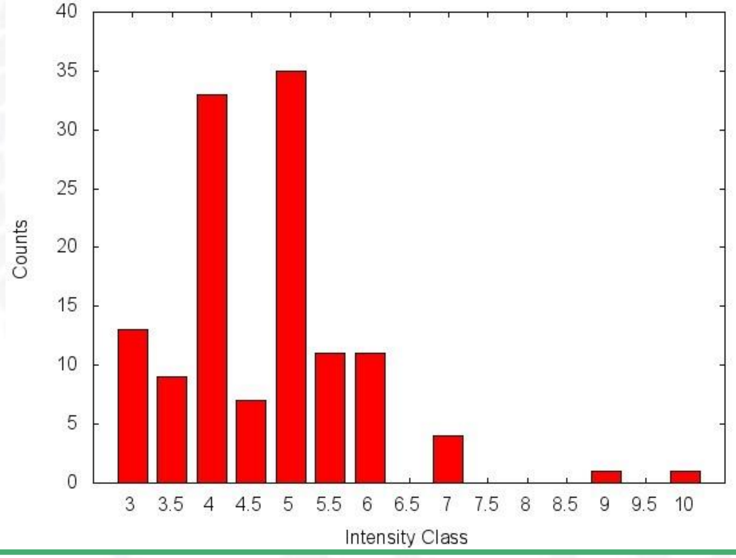
115 pairs of intensity - GMPs values



Original dataset + Amatrice data

Average distance of :
(1.8 ± 1.8) km

125 pairs of intensity - GMPs values



Regression laws including Amatrice:

without Amatrice

	NLLS				ODR			
GMPs	a	b	R^2	σ	a	b	R^2	σ
max PGD	1.60 ± 0.17	6.27 ± 0.21	0.93	0.55	1.71 ± 0.18	6.35 ± 0.22	0.92	0.28
max PGV	1.84 ± 0.24	4.85± 0.23	0.89	0.66	2.03 ± 0.27	4.82 ± 0.25	0.89	0.3
max PGA	2.03 ± 0.34	2.11 ± 0.59	0.84	0.8	2.39 ± 0.39	1.55 ± 0.70	0.92	0.28
max Arias	1.07 ± 0.15	5.35 ± 0.23	0.88	0.7	1.17 ± 0.16	5.38 ± 0.25	0.88	0.46
max Housner	1.81 ± 0.23	3.82 ± 0.28	0.9	0.63	1.98 ± 0.25	3.70 ± 0.30	0.9	0.29
max PSA03	1.94 ± 0.34	1.83 ± 0.67	0.83	0.84	2.31 ± 0.41	1.19 ± 0.80	0.82	0.35
max PSA10	1.69 ± 0.22	3.36 ± 0.33	0.89	0.65	1.86 ± 0.24	3.17 ± 0.35	0.9	0.31
max PSA30	1.64 ± 0.17	4.89 ± 0.19	0.92	0.54	1.76 ± 0.18	4.87 ± 0.19	0.93	0.27

with Amatrice

	NLLS				ODR			
GMPs	a	b	R^2	σ	a	b	R^2	σ
max PGD	1.82 ± 0.27	6.53 ± 0.32	0.85	0.94	2.13 ± 0.31	6.64 ± 0.34	0.85	0.41
max PGV	2.12 ± 0.32	4.89 ± 0.33	0.85	0.96	2.46 ± 0.37	4.76 ± 0.37	0.85	0.37
max PGA	2.33 ± 0.35	1.77 ± 0.68	0.84	0.97	2.75 ± 0.42	1.03 ± 0.82	0.84	0.34
max Arias	1.23 ± 0.19	5.53 ± 0.31	0.84	0.98	1.41 ± 0.22	5.49 ± 0.34	0.84	0.58
max Housner	2.07 ± 0.32	3.75 ± 0.44	0.84	0.97	2.44 ± 0.37	3.39 ± 0.51	0.84	0.39
max PSA03	2.22 ± 0.35	1.46 ± 0.74	0.84	0.99	2.61 ± 0.41	0.72 ± 0.87	0.84	0.37
max PSA10	1.96 ± 0.29	3.18 ± 0.49	0.85	0.96	2.29 ± 0.34	2.72 ± 0.57	0.85	0.4
max PSA30	1.87 ± 0.27	4.92 ± 0.32	0.85	0.94	2.18 ± 0.31	4.78 ± 0.36	0.85	0.39

The quality of the regression laws decreases including Amatrice data, probably due to the near fault effects in some points.

Regression laws including Amatrice:

without Amatrice

	NLLS				ODR			
GMPs	a	b	R^2	σ	a	b	R^2	σ
max PGD	1.60 ± 0.17	6.27 ± 0.21	0.93	0.55	1.71 ± 0.18	6.35 ± 0.22	0.92	0.28
max PGV	1.84 ± 0.24	4.85± 0.23	0.89	0.66	2.03 ± 0.27	4.82 ± 0.25	0.89	0.3
max PGA	2.03 ± 0.34	2.11 ± 0.59	0.84	0.8	2.39 ± 0.39	1.55 ± 0.70	0.92	0.28
max Arias	1.07 ± 0.15	5.35 ± 0.23	0.88	0.7	1.17 ± 0.16	5.38 ± 0.25	0.88	0.46
max Housner	1.81 ± 0.23	3.82 ± 0.28	0.9	0.63	1.98 ± 0.25	3.70 ± 0.30	0.9	0.29
max PSA03	1.94 ± 0.34	1.83 ± 0.67	0.83	0.84	2.31 ± 0.41	1.19 ± 0.80	0.82	0.35
max PSA10	1.69 ± 0.22	3.36 ± 0.33	0.89	0.65	1.86 ± 0.24	3.17 ± 0.35	0.9	0.31
max PSA30	1.64 ± 0.17	4.89 ± 0.19	0.92	0.54	1.76 ± 0.18	4.87 ± 0.19	0.93	0.27

with Amatrice no AMT

	NLLS				ODR			
GMPs	a	b	R^2	σ	a	b	R^2	σ
max PGD	1.56 ± 0.19	6.17 ± 0.23	0.91	0.58	1.71 ± 0.21	6.26 ± 0.24	0.91	0.31
max PGV	1.81 ± 0.26	4.79 ± 0.25	0.87	0.67	2.04 ± 0.29	4.74 ± 0.28	0.87	0.33
max PGA	2.00 ± 0.34	2.12 ± 0.60	0.83	0.77	2.38 ± 0.41	1.53 ± 0.73	0.83	0.34
max Arias	1.05 ± 0.16	5.33 ± 0.24	0.87	0.68	1.16 ± 0.17	5.34 ± 0.26	0.87	0.48
max Housner	1.77 ± 0.24	3.79 ± 0.31	0.88	0.64	1.98 ± 0.27	3.63 ± 0.34	0.88	0.31
max PSA03	1.91 ± 0.35	1.87 ± 0.68	0.82	0.81	2.28 ± 0.41	1.21 ± 0.82	0.81	0.37
max PSA10	1.67 ± 0.23	3.31 ± 0.35	0.88	0.64	1.87 ± 0.25	3.07 ± 0.39	0.88	0.33
max PSA30	1.61 ± 0.19	4.79 ± 0.22	0.91	0.58	1.77 ± 0.21	4.74 ± 0.23	0.9	0.3

Without considering the AMT data, above the fault, the regression laws quality increased.
These parameters are not significant for the near-fault intensity estimation.

To conclude

We estimated a set of regression laws between Intensity and 8 different ground motion parameters. Using two different algorithms the results are basically coincident.

We used the Amatrice earthquake as test and we found a great correspondence between the observed and the calculated intensities,even if the number of the data is not statistically significant but better than the regression laws found in literature.

Using the Amatrice data in the estimation of the regression laws, the quality of the laws slightly decreases. This is probably due to the near fault effects. The used ground motion parameters seem not be significant in near fault. We will try to express the damages with a multi-component and multi-parametric relation.

RAN accelerometric data trend in a GMPE shape.

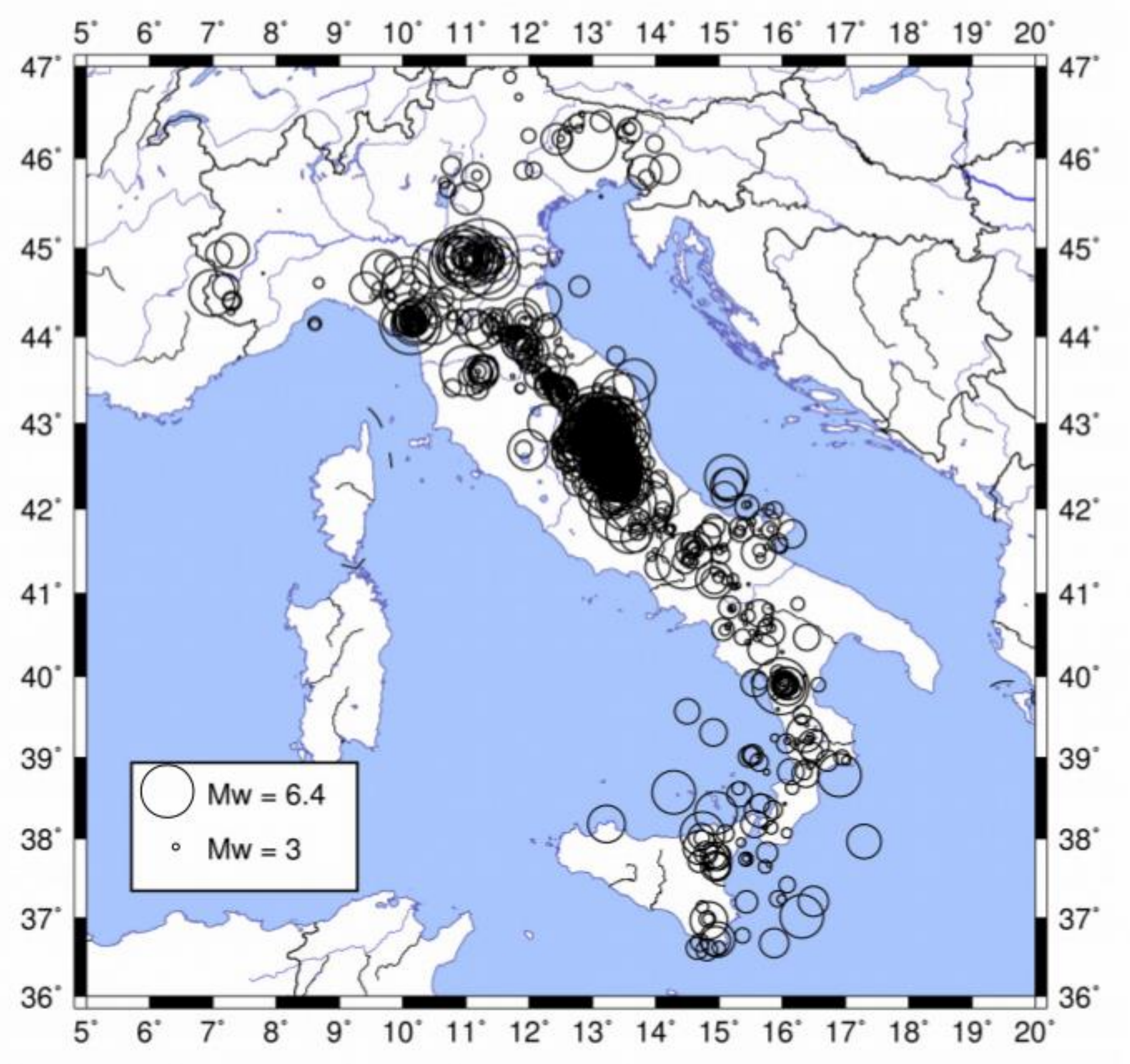
L. Tiberi[1], **G. Costa**[1]

[1] Università di Trieste, DMG, Trieste, SeisRaM group

The goal of this study is to present a new set of GMPEs for the italian territory using a huge input dataset composed by 2313 earthquakes with moment magnitude values included in 3.0-6.4, considering the stations sites up to 150 km, we obtained 121878 records to process.

These GMPEs are valid for PGD, PGV, PGA, PSA0.3, 1.0 and 3.0 seconds, Arias and Housner intensities, for the maximum between the two horizontal components, the geometrical mean between them and for the vertical component.

Dataset

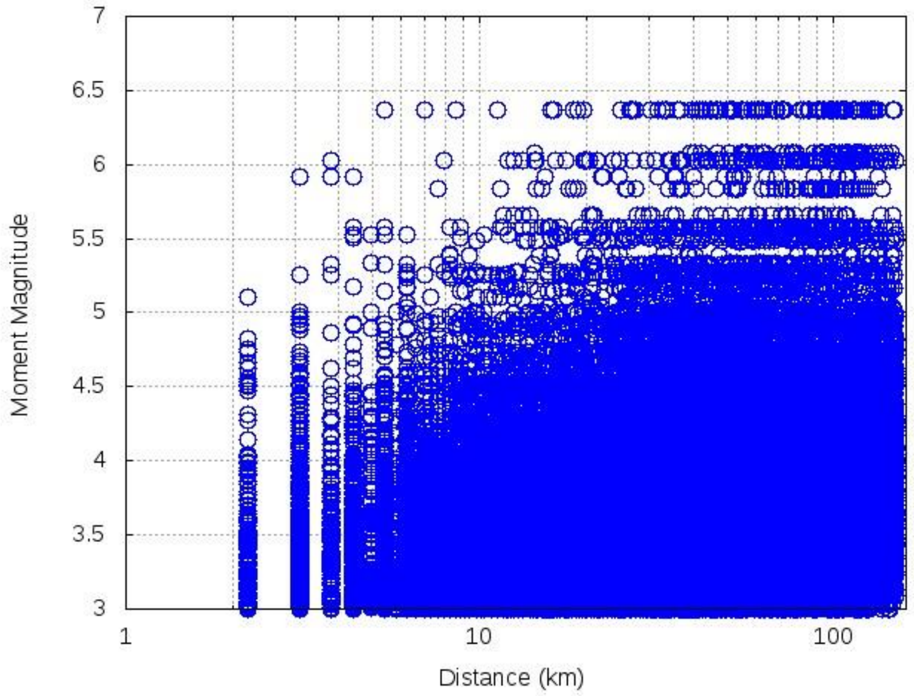


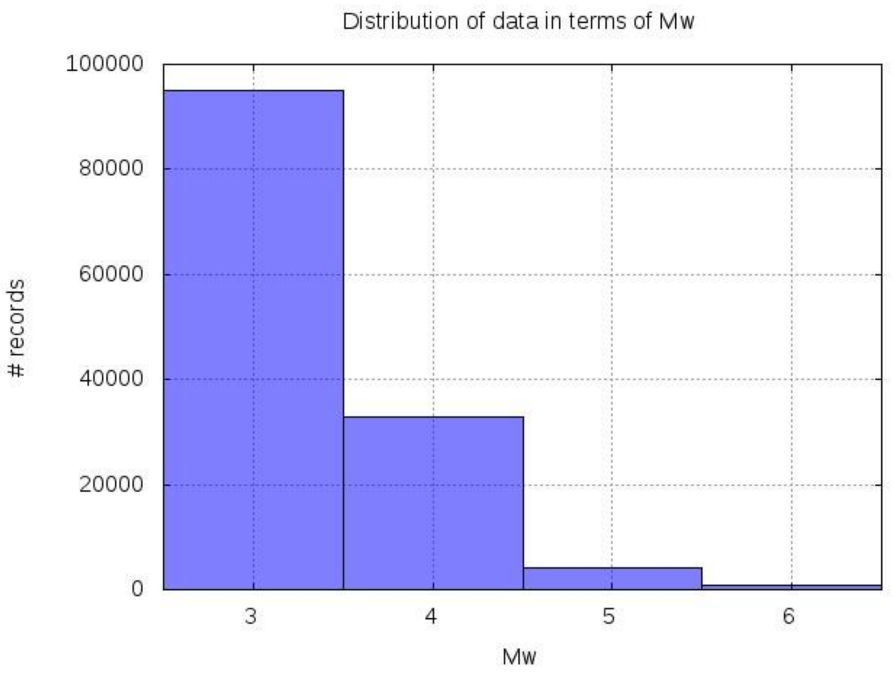
Time-span : 2009-2017

The entire database counts 2313 earthquakes with a moment magnitude between 3.0 and 6.4 of the strongest event of Amatrice sequence occurred the 30th of October, 2016.

Dataset

The total number of records are 121878 up to 150 km.





Tests:

1) $\log_{10} Y = a + b \cdot Mw + c \cdot \log_{10}(\mathrm{sqrt}(R^2 + d^2)) + s1 \cdot SA + s2 \cdot SB$ (from Massa et al., 2008);

Ground motion parameters:

PGD;
PGV;
PGA;
PSA0.3
PSA1.0
PSA3.0
Arias;
Housner.

L. Tiberi[1], G. Costa[1]

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Tests:

1) $Log_{10}Y = a + b*Mw + c* log_{10}(sqrt(R^2 + d^2)) + s1*SA + s2*SB$ (from Massa et al., 2008);

↓

Moment magnitude value (estimated with an automatic procedure from Gallo et al., 2014)

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Tests:

1) $Log_{10}Y = a + b*Mw + c*log_{10}(sqrt(R^2 + d^2)) + s1*SA + s2*SB$ (from Massa et al., 2008);

Epicentral Distance

Tests:

1) $Log_{10}Y = a + b*Mw + c* log_{10}(sqrt(R^2 + d^2)) + s1*SA + s2*SB$ (from Massa et al., 2008);

Site condition terms:
SA is 1 if rock (SB=0), otherwise SB is 1 (SA=0).

Tests:

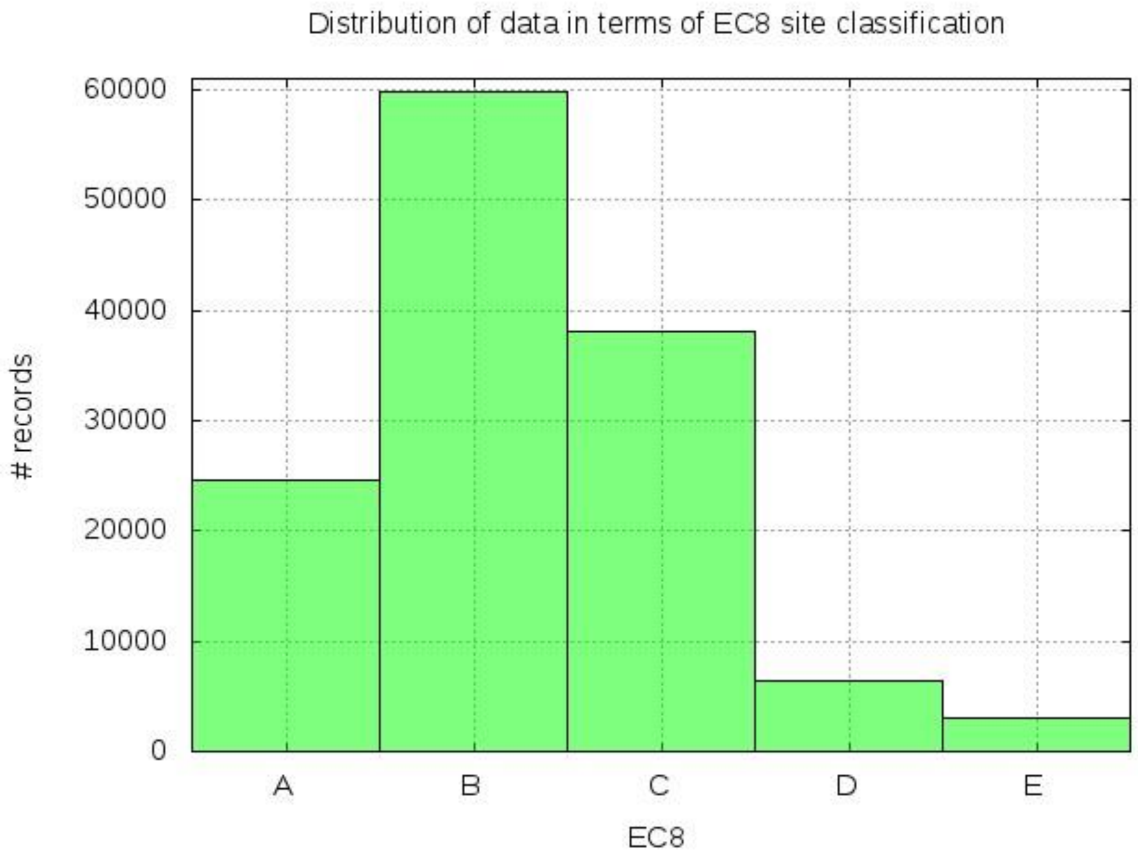
1 - $\text{Log}_{10}Y = a + b*Mw + c* \log_{10}(\text{sqrt}(R^2 + d^2)) + s1*SA + s2*SB$ (from Massa et al., 2008);

2 - $\text{Log}_{10}Y = a + b*Mw + c* \log_{10}(\text{sqrt}(R^2 + d^2)) + s1*SA + s2*SB +$ **s3*SC + s4*SD + s5*SE**

EC8 classes:

class A: Vs30 > 800 m/s
class B: Vs30 = 360 − 800 m/s
class C: Vs30 = 180 - 360 m/s
class D: Vs30 < 180 m/s
class E: 5 to 20 m of C- or D-type alluvium underlain by stiffer material with Vs30 > 800 m/s.

Dataset



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class C: Vs30 = 180 - 360 m/s
class D: Vs30 < 180 m/s
class E: 5 to 20 m of C- or D-type alluvium underlain by stiffer material with Vs30 > 800 m/s.

Tests:

1 - $\text{Log}_{10}Y = a + b{*}Mw + c{*}\log_{10}(\text{sqrt}(R^2 + d^2)) + s1{*}SA + s2{*}SB$ (from Massa et al., 2008);

2 - $\text{Log}_{10}Y = a + b{*}Mw + c{*}\log_{10}(\text{sqrt}(R^2 + d^2)) + s1{*}SA + s2{*}SB + s3{*}SC + s4{*}SD + s5{*}SE$;

3 - Log10Y = a + b*Mw + e*Mw2 + c* log10(sqrt(R2 +d2)) + s1*SA + s2*SB + s3*SC + s4*SD + s5*SE

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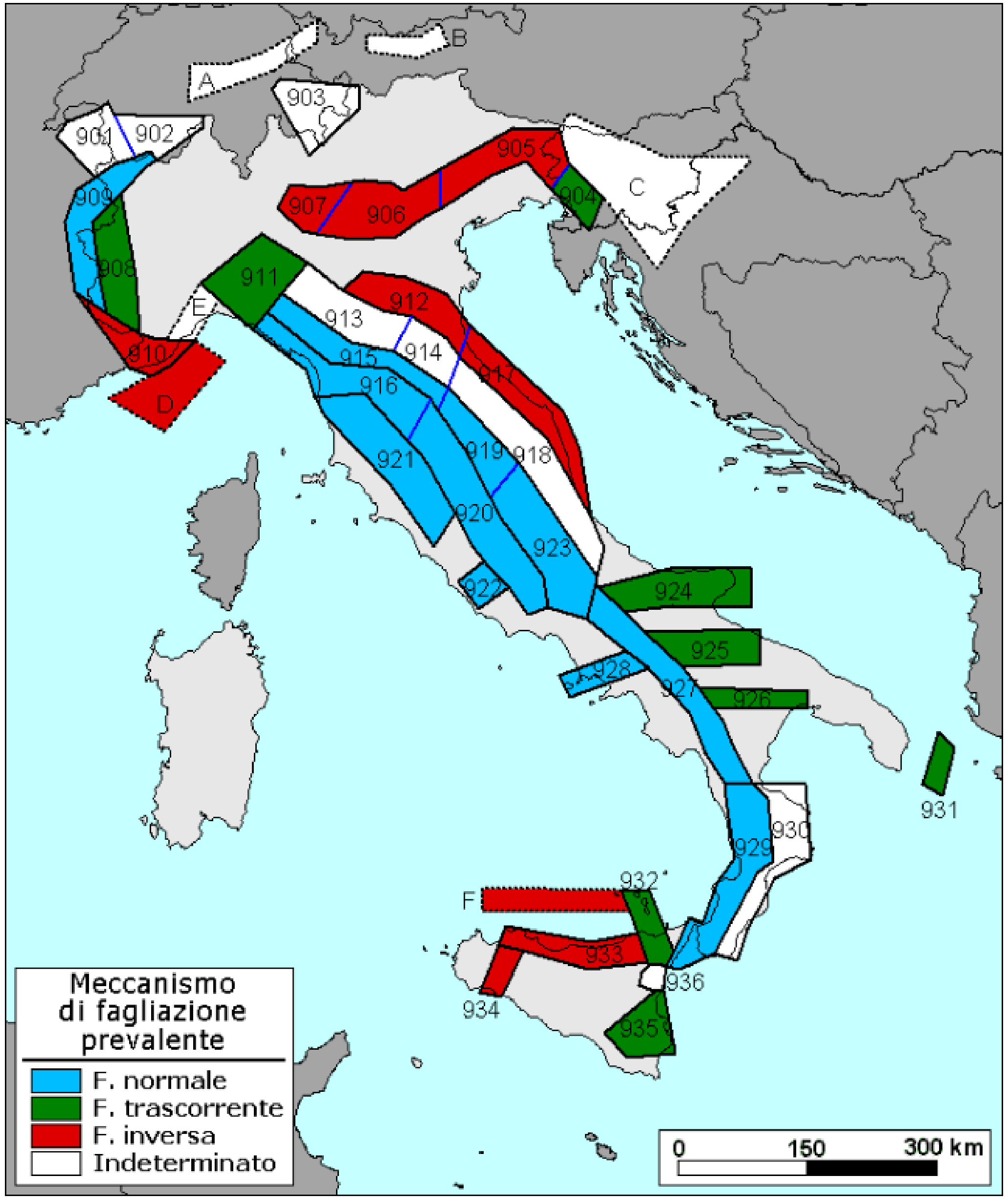
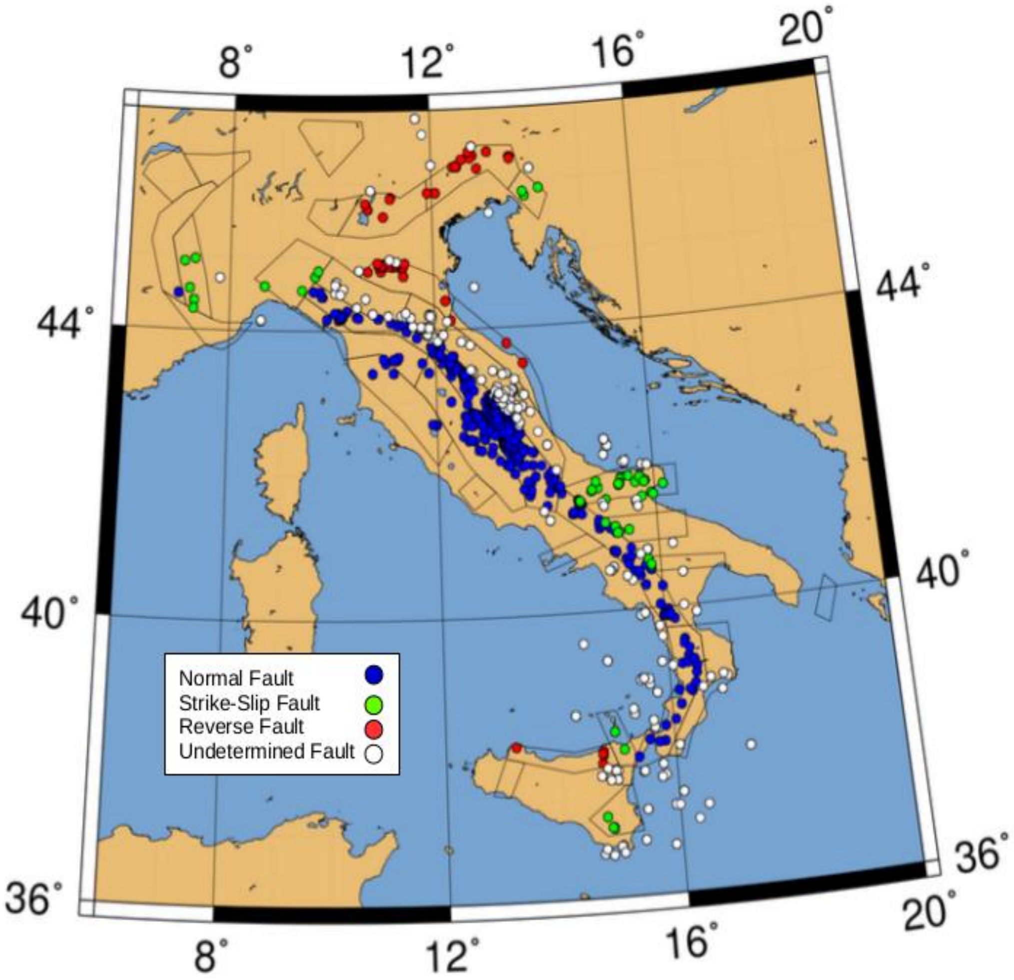
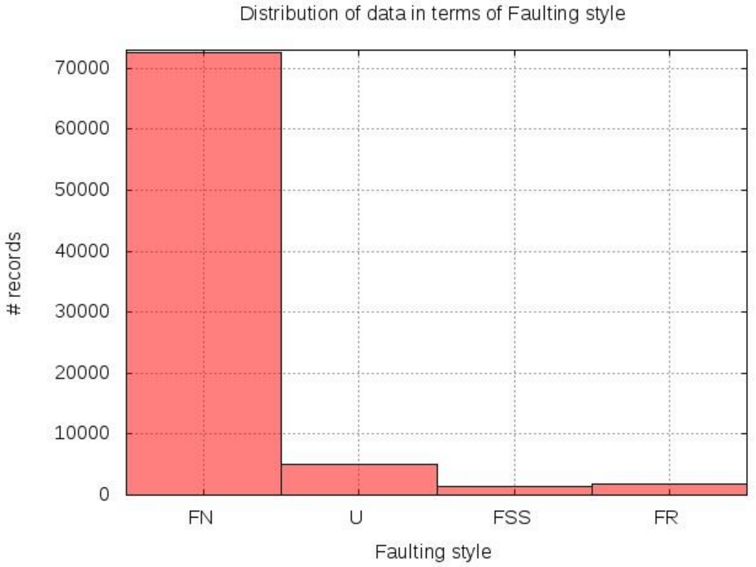
Zonazione sismogenetica ZS9

Meccanismo di fagliazione prevalente atteso per le diverse zone sismogenetiche che compongono ZS9. L'assegnazione è basata su una combinazione dei meccanismi focali osservati con dati geologici a varie scale.



Seismogenic zonation ZS9





Tests:

1 - $Log_{10}Y = a + b*Mw + c* log_{10}(sqrt(R^2 +d^2)) + s1*SA + s2*SB$ (from Massa et al., 2008);

2 - $Log_{10}Y = a + b*Mw + c* log_{10}(sqrt(R^2 +d^2)) + s1*SA + s2*SB + s3*SC + s4*SD + s5*SE$;

3 - Log10Y = a + b*Mw + e*Mw2 + c* log10(sqrt(R2 +d2)) + s1*SA + s2*SB + s3*SC + s4*SD + s5*SE;

4 - Log10Y = a + b*Mw + e*Mw2 + c* log10(sqrt(R2 +d2)) + s1*SA + s2*SB + s3*SC + s4*SD + s5*SE + fn*FN + fR*FR + fss*FSS

Tests:

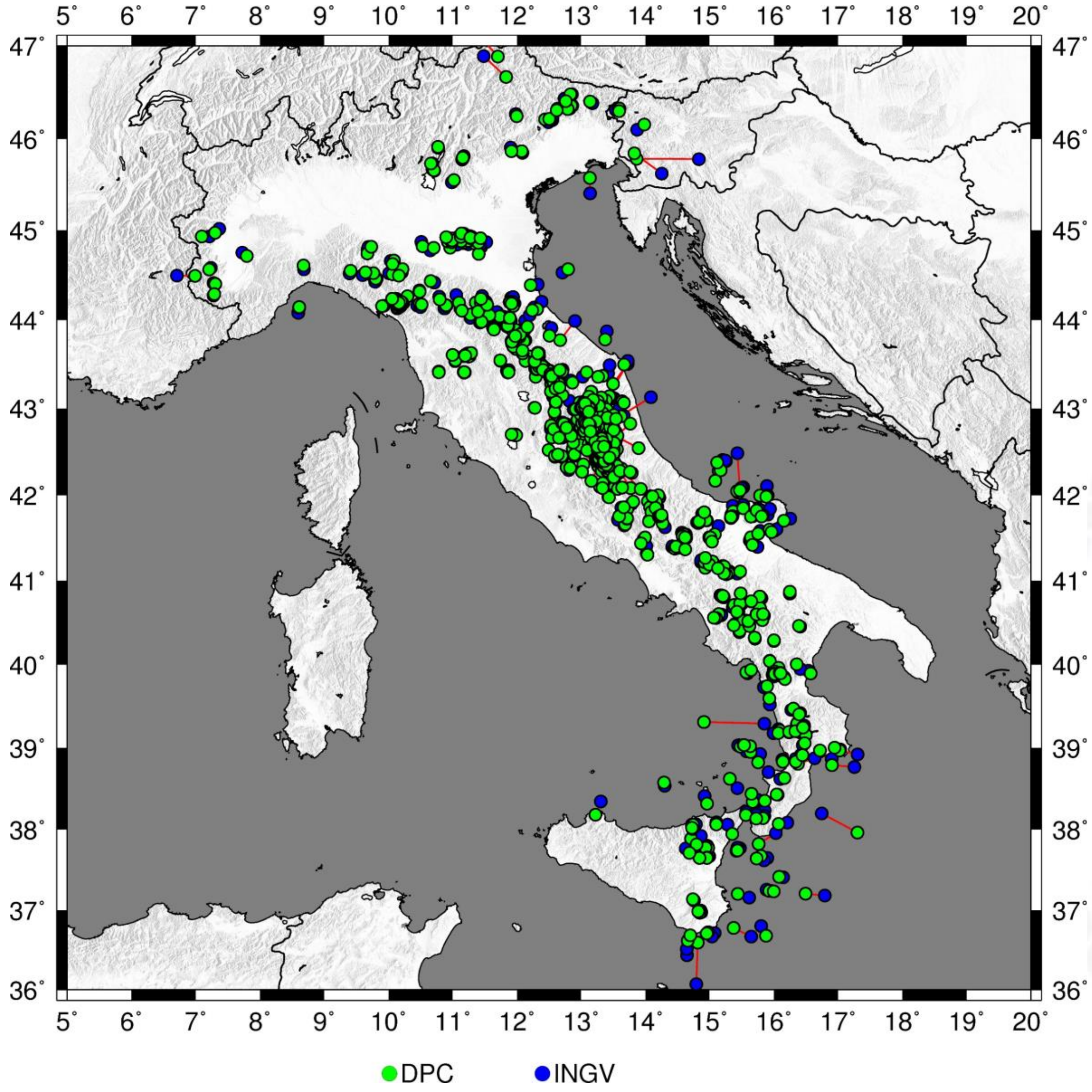
1 - $Log_{10}Y = a + b*Mw + c* log_{10}(sqrt(R^2 +d^2)) + s1*SA + s2*SB$ (from Massa et al., 2008);

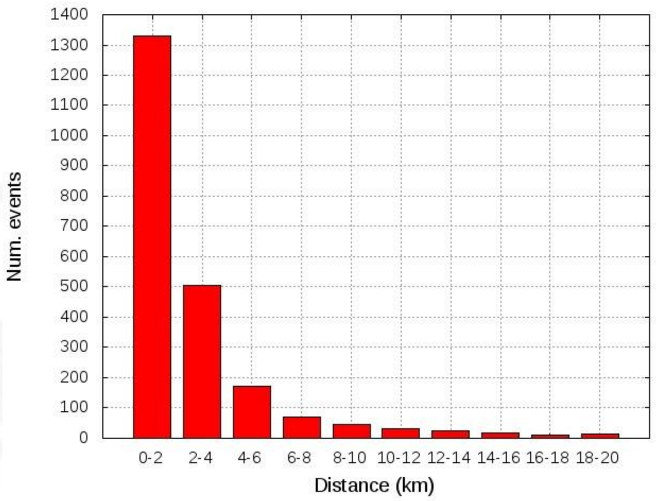
2 - $Log_{10}Y = a + b*Mw + c* log_{10}(sqrt(R^2 +d^2)) + s1*SA + s2*SB + s3*SC + s4*SD + s5*SE$;

3 - Log10Y = a + b*Mw + e*Mw2 + c* log10(sqrt(R2 +d2)) + s1*SA + s2*SB + s3*SC + s4*SD + s5*SE;

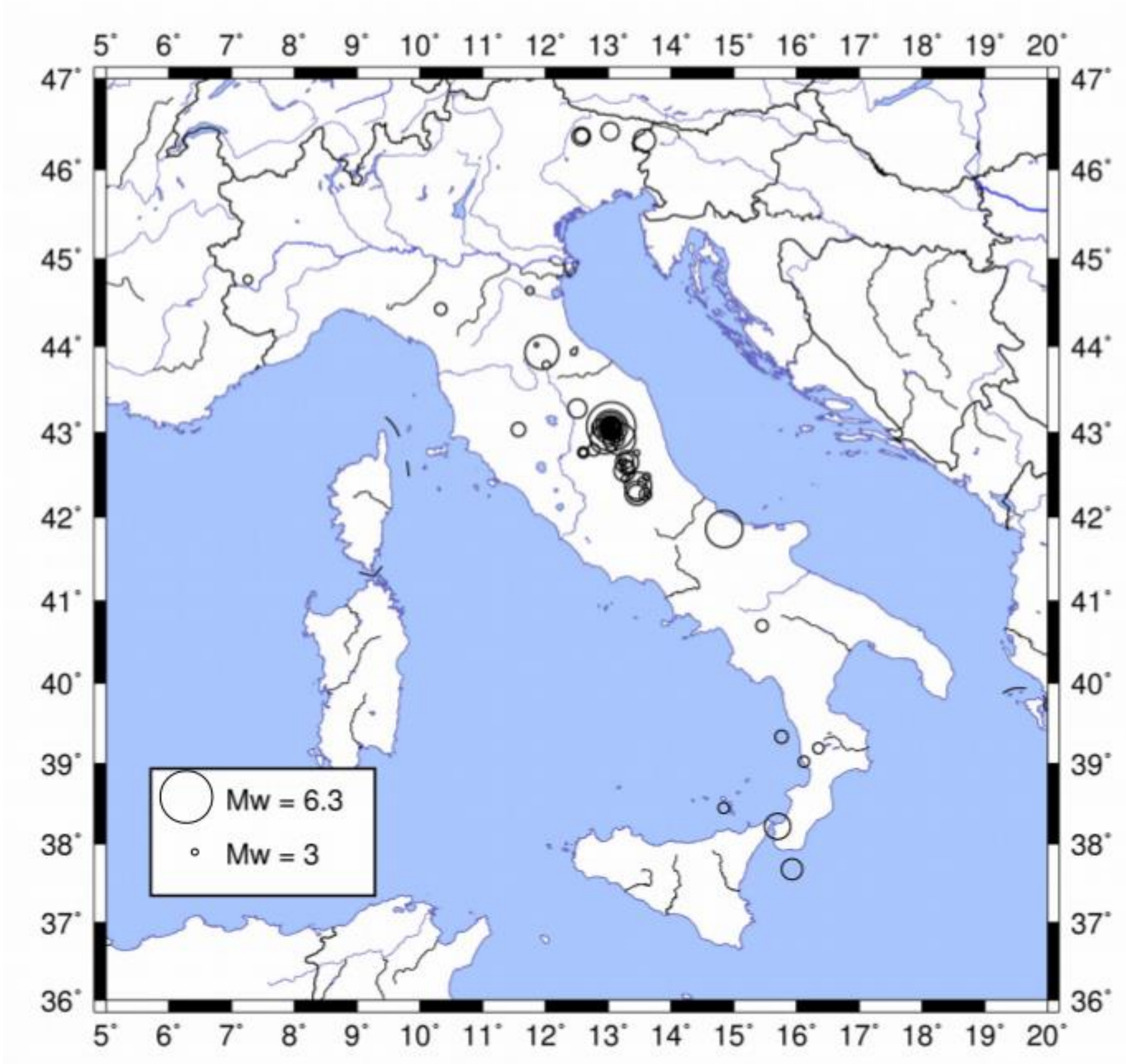
4 - Log10Y = a + b*Mw + e*Mw2 + c* log10(sqrt(R2 +d2)) + s1*SA + s2*SB + s3*SC + s4*SD + s5*SE + fn*FN + fR*FR + fss*FSS;

Automatic and Manually revised (INGV) locations:





90% of the events have epicentral differences up to 4 km.



Time-span : 4 months 2018

N° events: 95

N° records: 3859

Mw : 3.0-4.9

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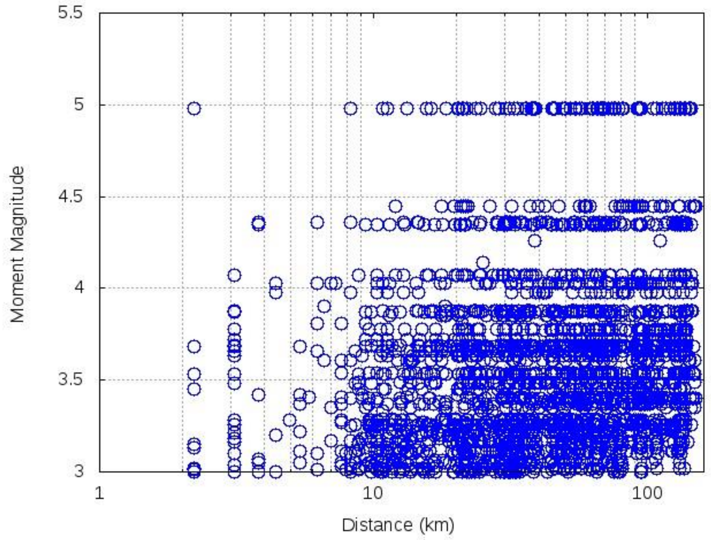
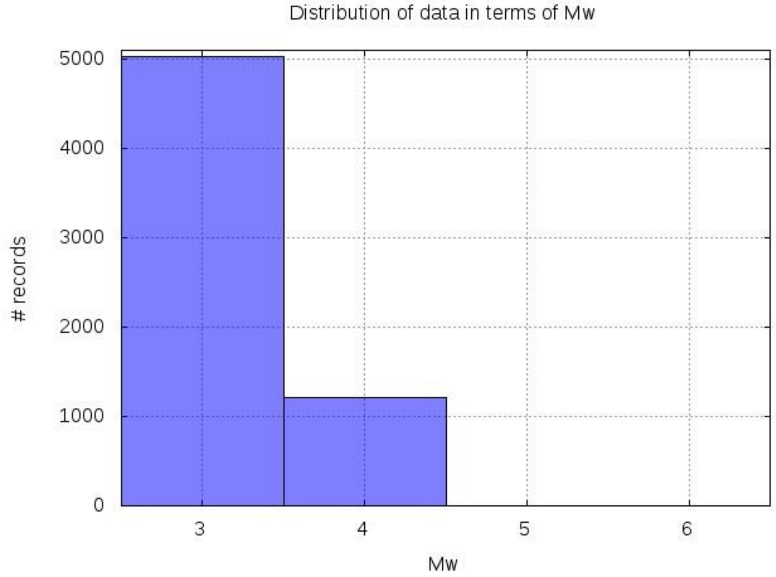
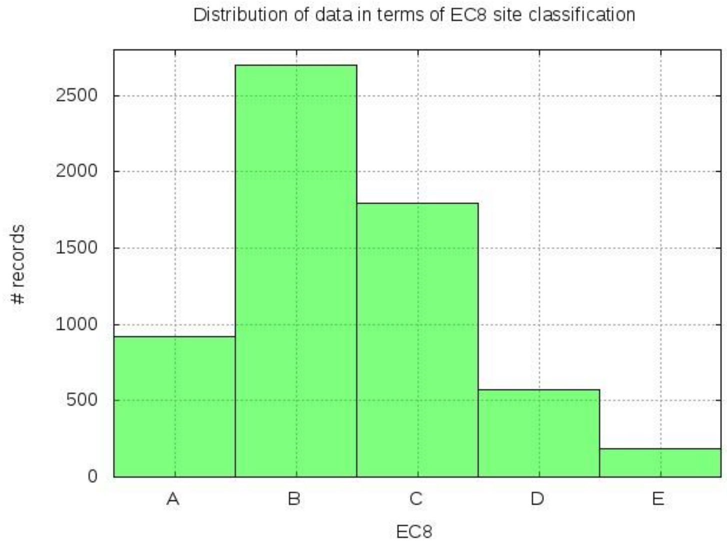
Dataset - test







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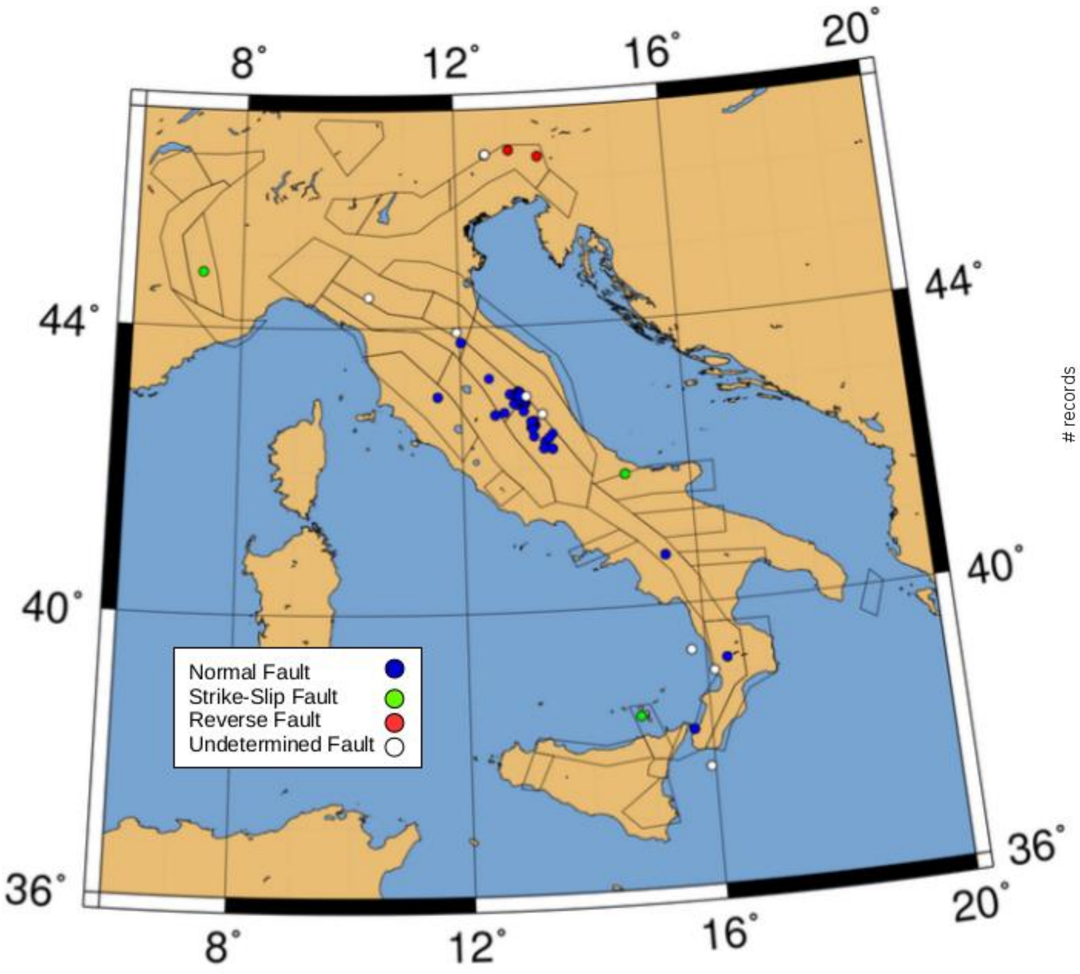
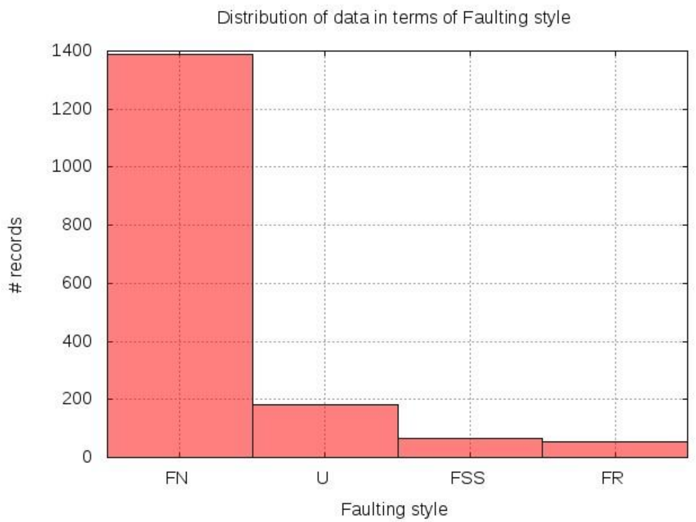
Dataset - test





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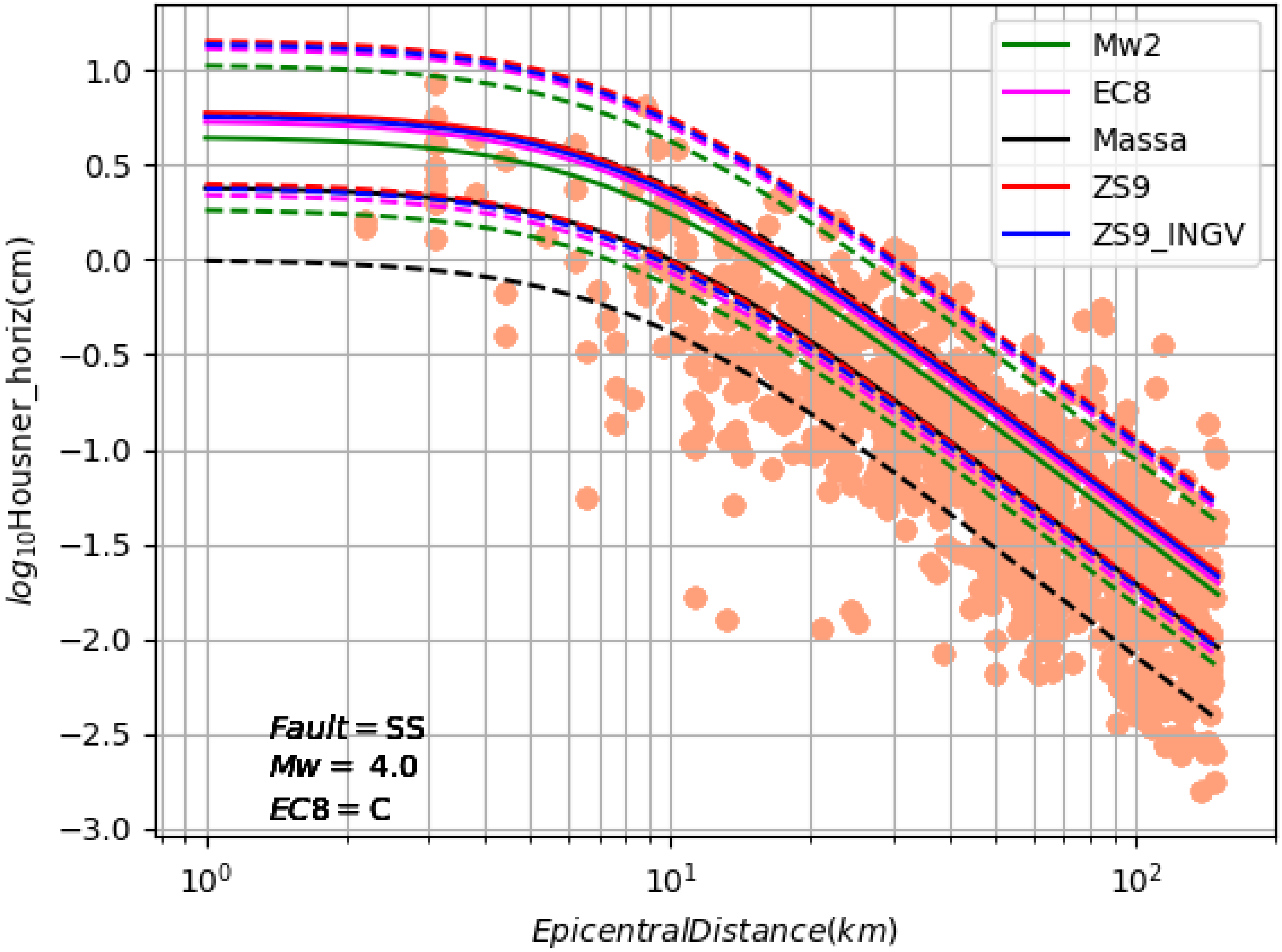
Results



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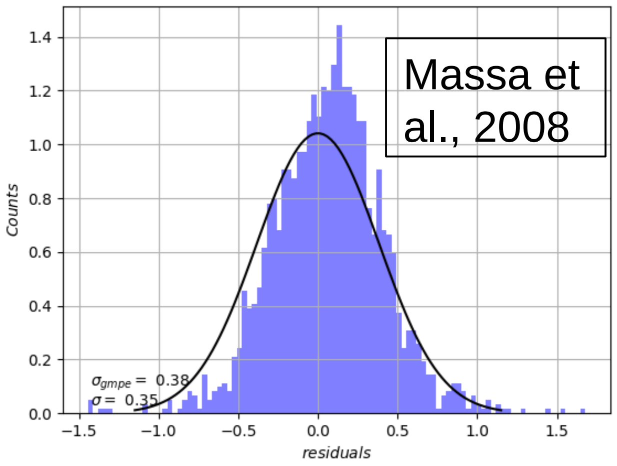
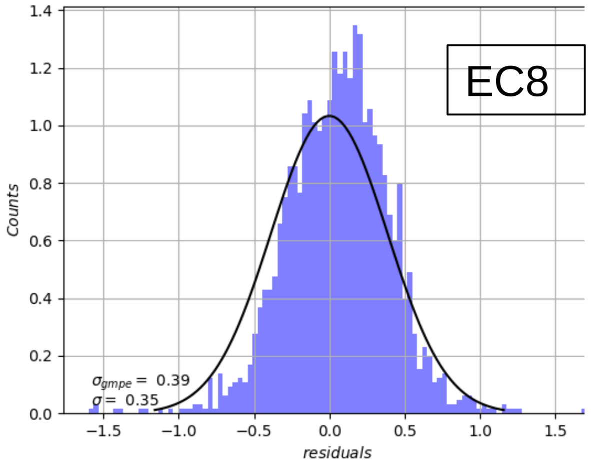
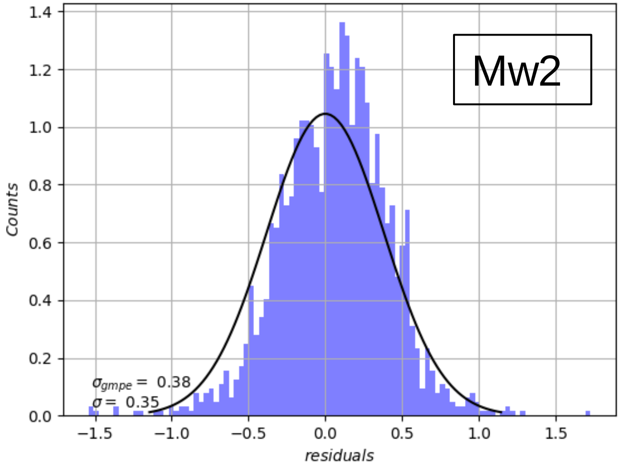
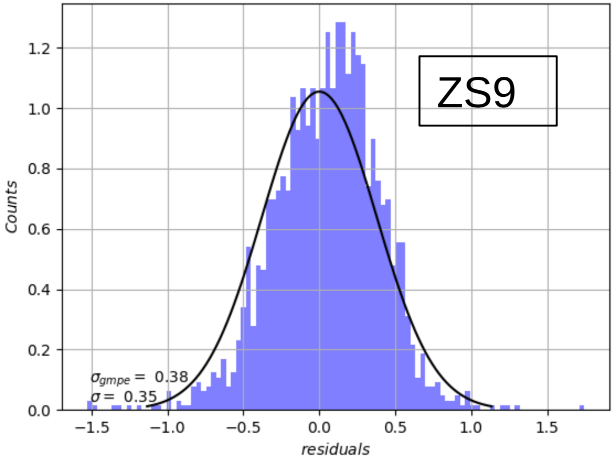
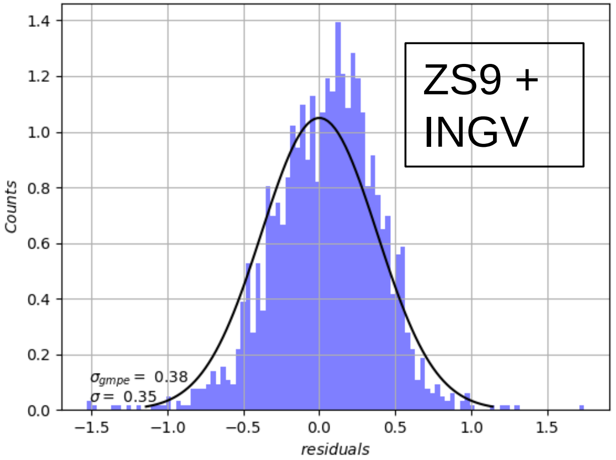
Results


Massa et al., 2008
σ_{gmpe} = 0.38
σ = 0.35
Counts
residuals

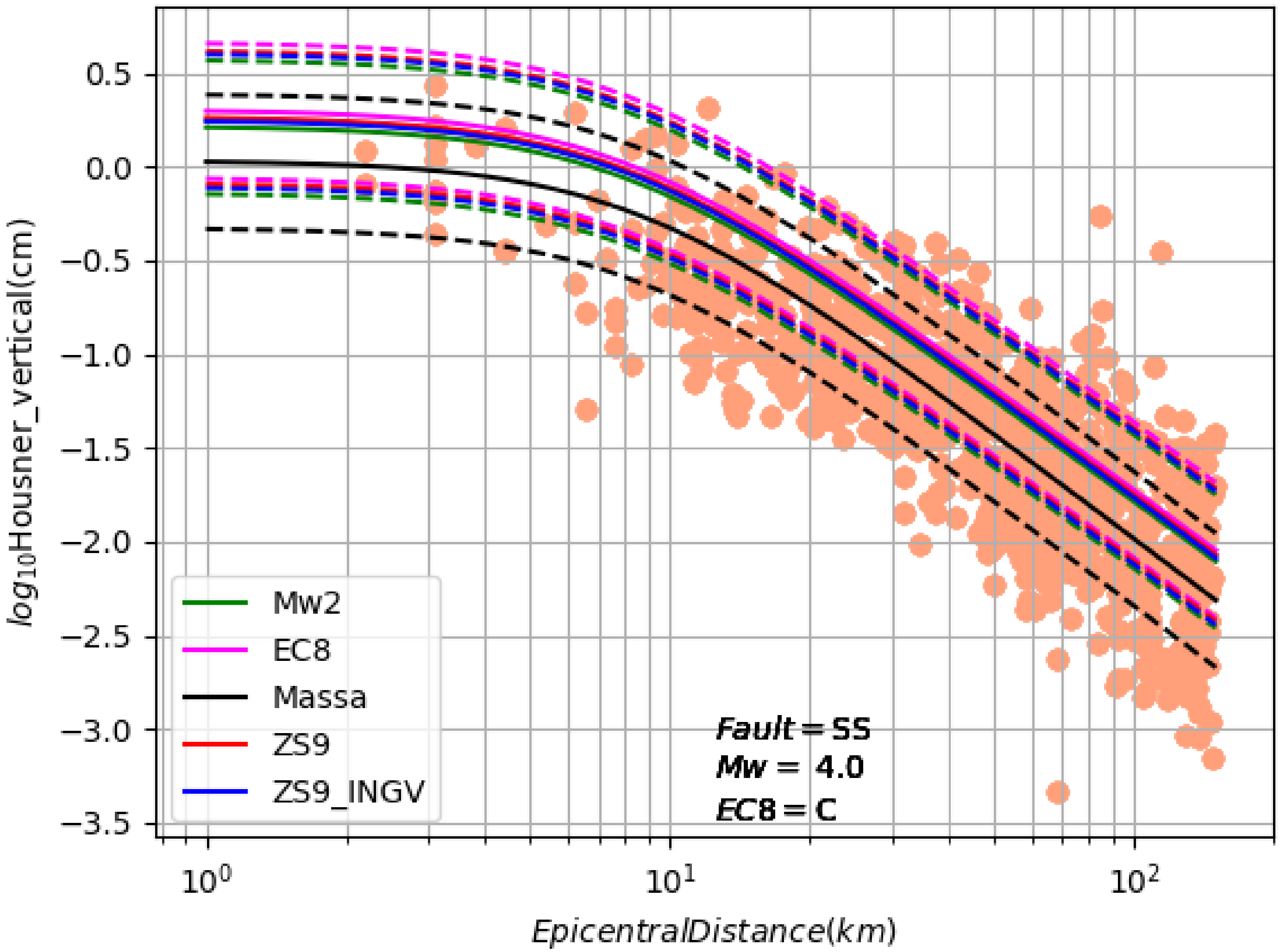

EC8
σ_{gmpe} = 0.39
σ = 0.35
Counts
residuals


Mw2
σ_{gmpe} = 0.38
σ = 0.35
Counts
residuals


ZS9
σ_{gmpe} = 0.38
σ = 0.35
Counts
residuals


ZS9 + INGV
σ_{gmpe} = 0.38
σ = 0.35
Counts
residuals

Results



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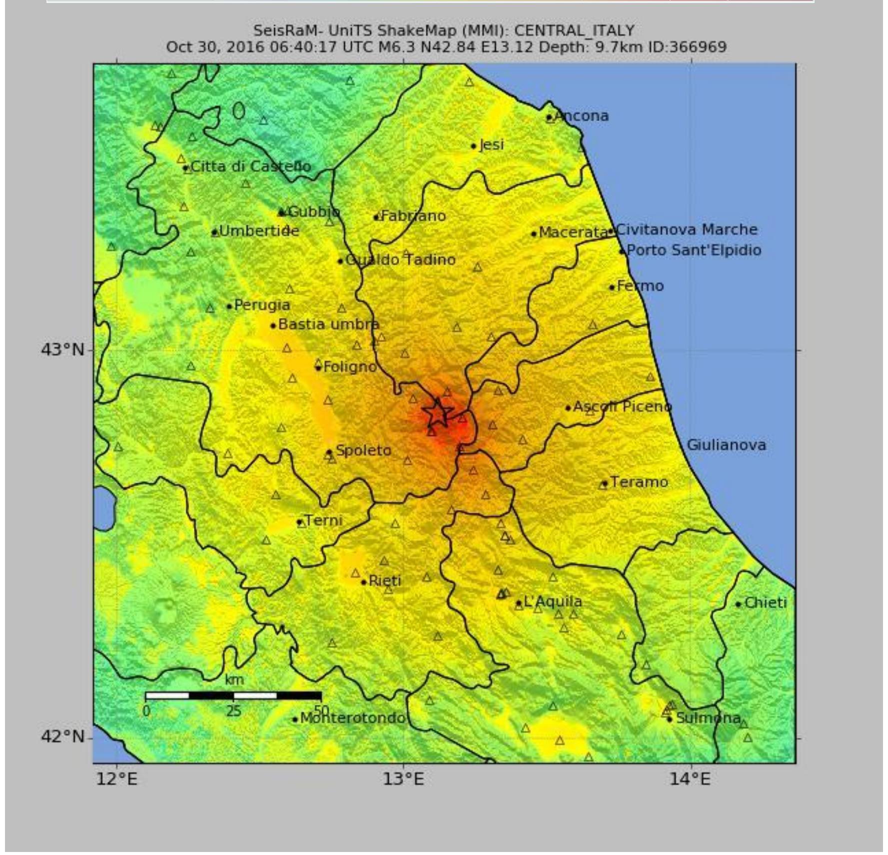
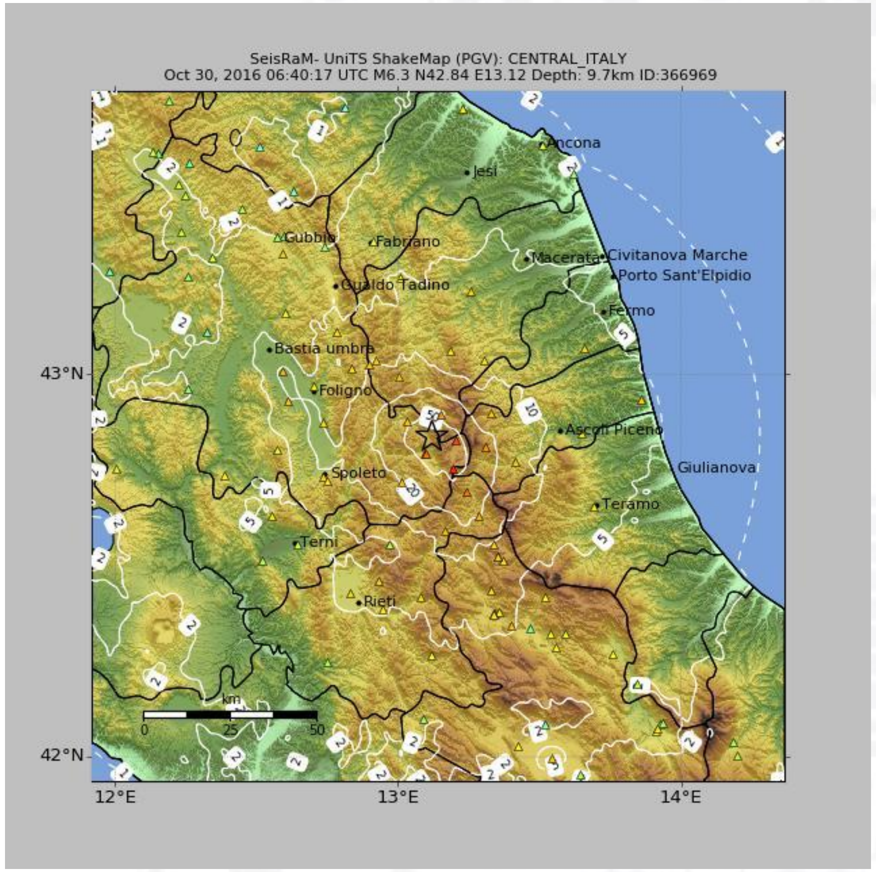
ShakeMap Implementation:

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod/Heavy	Heavy	Very Heavy
PEAK ACC (%g)	< 0.04	0.31	0.8	2.29	6.2	16.8	45.5	123	> 333
PEAK VEL (cm/s)	< 0.03	0.16	0.39	0.96	2.4	5.9	14.5	35.9	> 89
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



PGV



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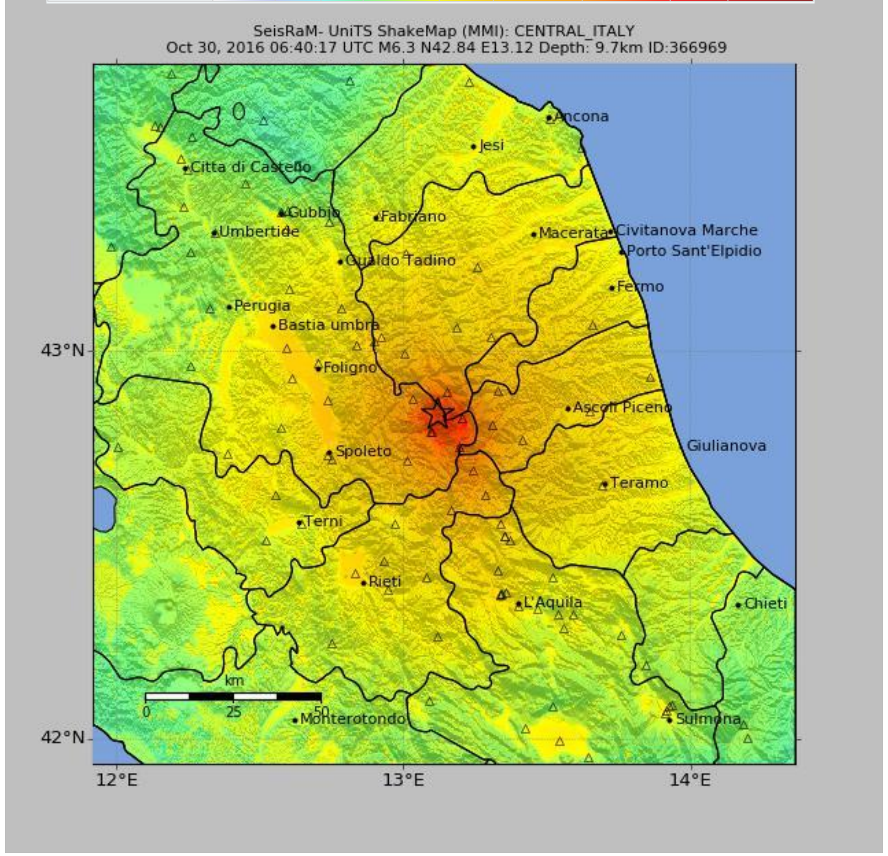
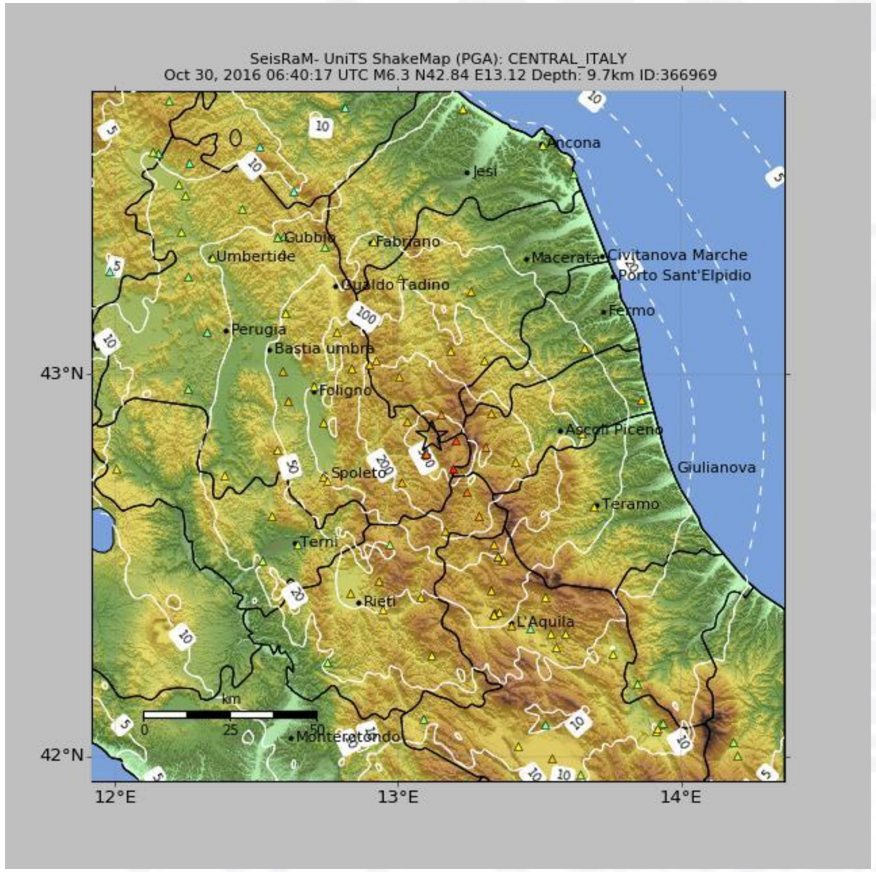


PGA



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Plus squared moment magnitude term:

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
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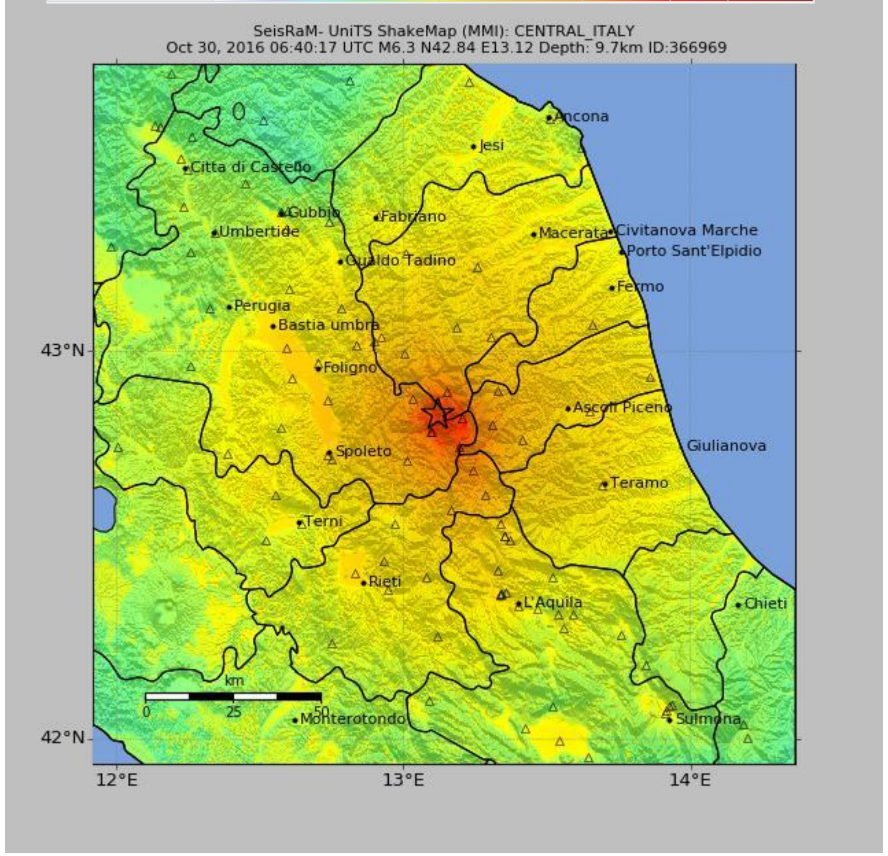
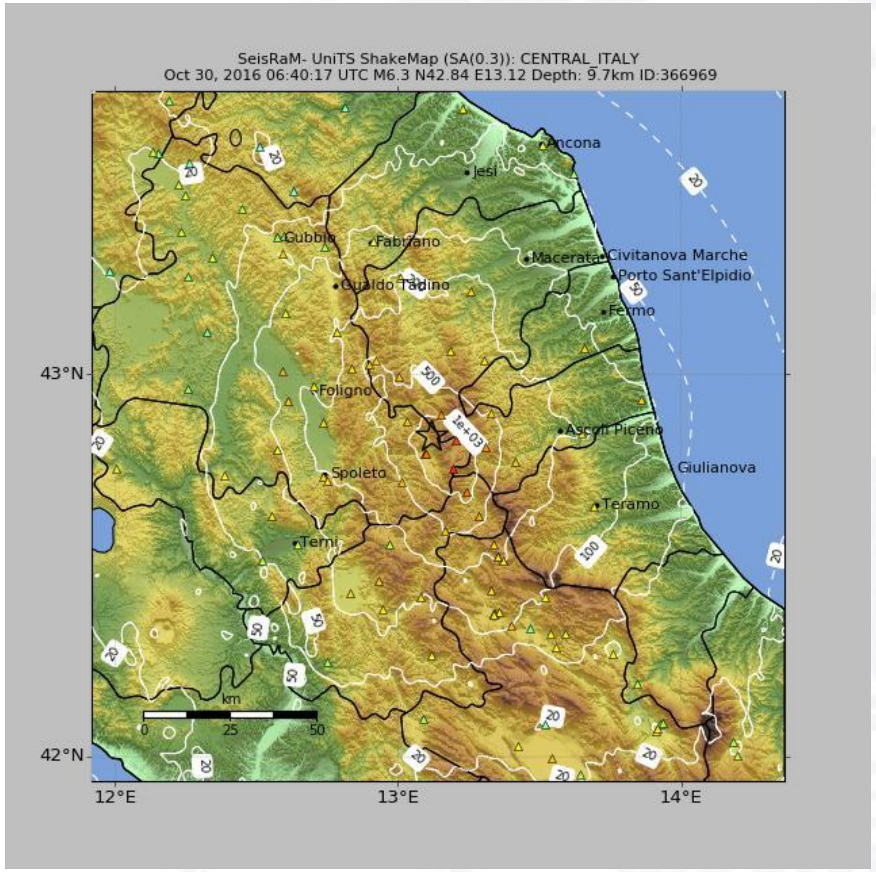


PSA0.3



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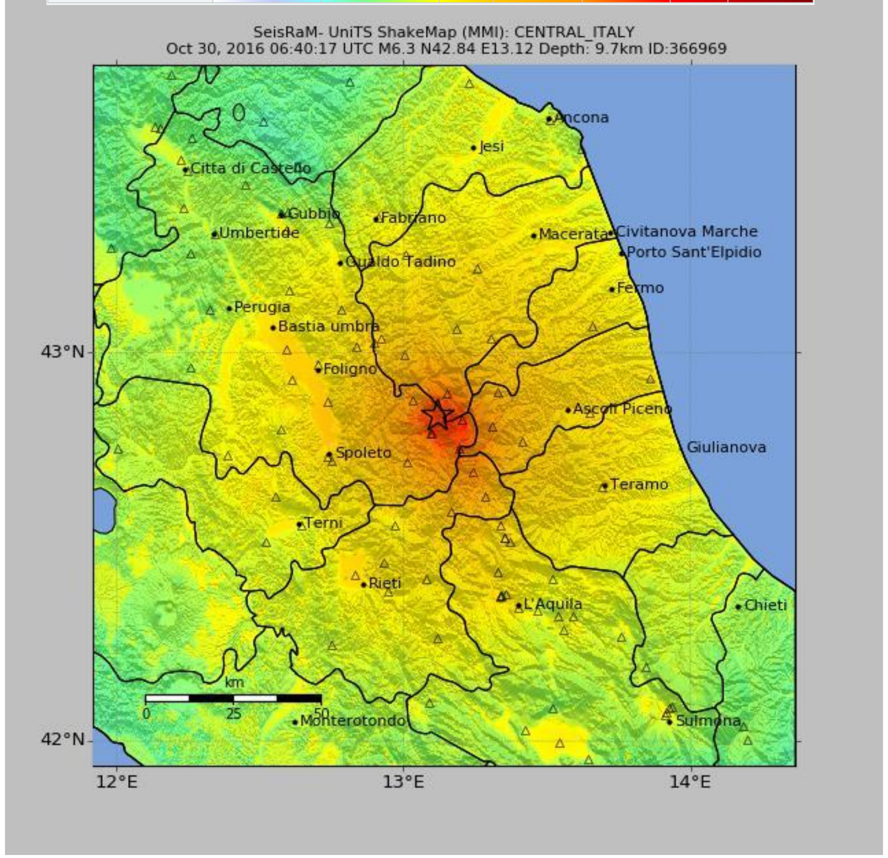
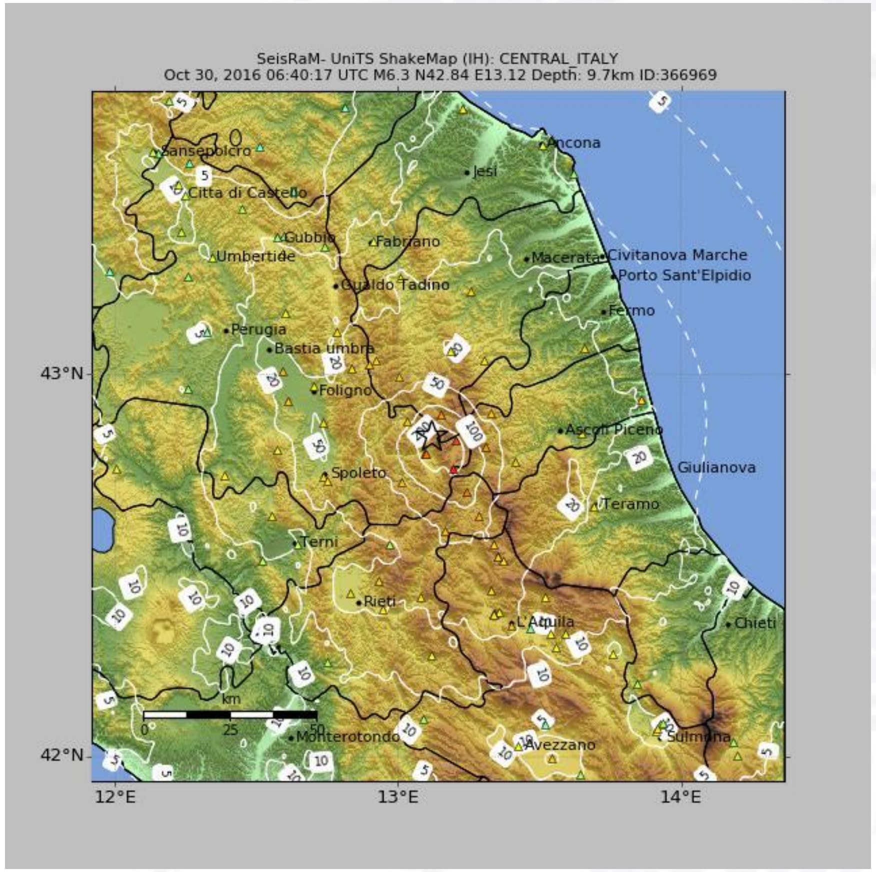


Housner intensity



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EC8 Categorie del suolo

Tipo di Terreno	Descrizione profilo stratigrafico	Vs_{30} (m/s)	N_{SPT} (colpi/30 cm)	cu (kPa)
A	Roccia o altre formazioni geologiche tipo-roccia, che includono strati superficiali di materiale più debole di spessore massimo di 5 m.	>800		
B	Depositi di sabbia molto densa, ghiaia, o argilla molto consistente, con spessore di almeno parecchie decine di metri, caratterizzati da un graduale aumento delle proprietà meccaniche con la profondità.	360-800	>50	>250
C	Depositi profondi di sabbia densa o mediamente addensata, ghiaia o argilla consistente con spessore variabile da parecchie decine di metri a molte centinaia di metri.	180-360	15-50	70-250
D	Depositi di terreni sciolti o poco addensati (con o senza alcuni strati coesivi di bassa consistenza), o di terreni per la maggior parte coesivi da poco a mediamente consistenti.	<180	<15	<70
E	n profilo di terreno costituito da strati superficiali alluvionali con valori di Vs simili a quelli dei tipi C o D e spessore che varia tra circa 5 m e 20 m, giacente su un substrato di materiale più rigido con V_s > 800 m/s			
S_1	Depositi costituiti da, o che includono, uno strato spesso almeno 10 m di argille/limi di bassa consistenza con elevato indice di plasticità (PI > 40) ed elevato contenuto di acqua.	<100 (indicativo)		10-20
S_2	Depositi di terreni soggetti a liquefazione, di argille sensibili o qualsiasi alltro profilo di terreno non incluso nei tipi A o S_1			

Intensità di Arias *[Ia]*
Parametro che è indice dell' intensità delle onde sismiche e della frequenza. Essa è definita, a meno di una costante, come l'integrale del quadrato dell'accelerogramma (esteso a tutta la durata del sisma).

Intensità degli incroci dell'accelerogramma con l'asse dei tempi $[v_0]$.
In pratica si calcola come rapporto tra il numero di volte che l'accelerogramma interseca l'asse dei tempi e la durata dell'evento sismico.

Durata del moto sismico *[TD]*
Durata del moto sismico definita da Trifunac (Trifunac & Brady 1975). E' calcolata come l'intervallo di tempo che intercorre tra il raggiundimento del 5% di Ia ed il 95% di Ia (Ia è l'intensità di Arias).