# Evaluating the performance of Italian intensity prediction equations and analysis of directivity using macroseismic data

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SECURE Mid-term - 19-20 Giugno 2025, Milano

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

# INTRODUCTION

The **macroseismic intensity data expresses the level of ground shaking** generated at a given site by an earthquake

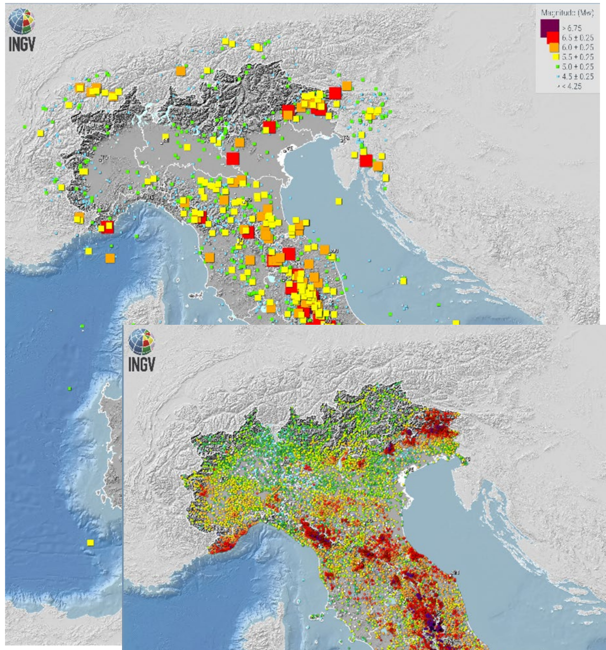

In Italy a large amount of macroseismic data that has greatly improved the **Italian Macroseismic Database – DBMI** and the **Italian Parametric Earthquake Catalogue - CPTI**

This allowed the development of several **Intensity Prediction Equations (IPEs)** and their continuous updating

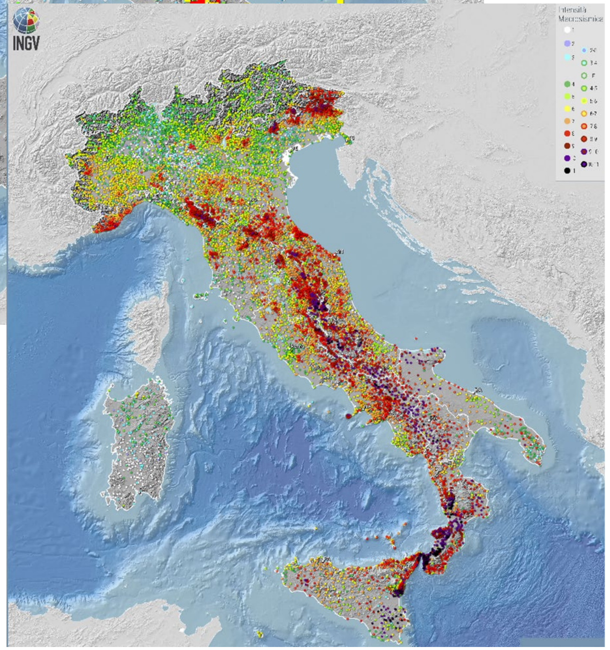
# GOAL

We evaluated the performance of the Italian attenuation models by comparing **the documented intensity data** of **DBMI15** with **the predicted values** computed from the epicentral parameters collected in the **CPTI15**

Rovida et al. (2022)




1. We selected the **most recent IPEs** valid for the Italian area
2. We considered **four datasets** derived from the last version of CPTI15 and DBMI15
3. We **predicted the intensity value** at a given site of the selected datasets
4. We analyzed the results to define the **best predictive model** following the GMMs strategy (Lanzano et al., 2020)




Locati et al. (2022)

# 1) IPEs selection

## We selected 5 intensity attenuation

$$D = \sqrt{R^2 + h^2}$$

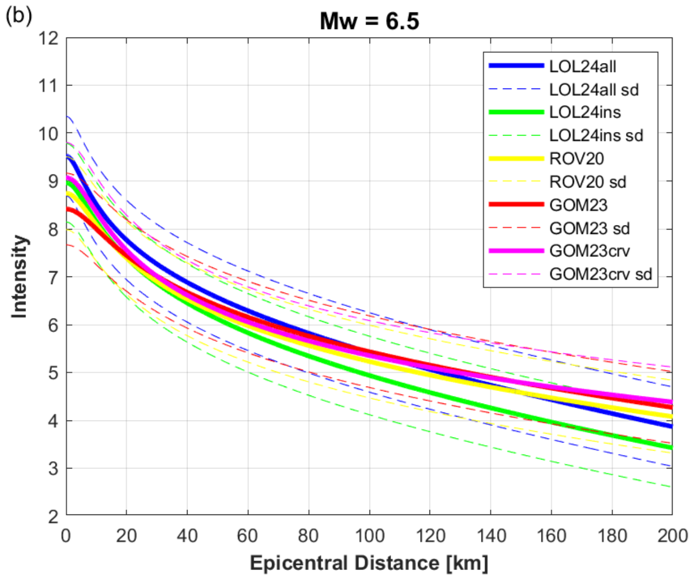
| ID | Reference |
|---|---|
| ROV20 | Rovida et al. 2020 |
| LOL24all | Lolli et al. 2024 |
| LOL24ins | Lolli et al. 2024 |
| GOM24 | Gomez-Capera et al. 2024 |
| GOM24crv | Gomez-Capera et al. 2024 |

$$I = I_E - b * (D - h) - c * [ln\ (D)\ - ln\ (h)]$$

$$I_E = a + d * M_w$$

$$I = a - b * D - c * Log\,(D) + d * M_w$$

$$LogI = a - b * D - c * Log\,(D) + d * LogM_w$$




| ID | N° Events | Time range | Mw range | Focal Depth | N° IDPs | Int range |
|---|---|---|---|---|---|---|
| ROV20 | 354 | 1903–2013 | 2.7–7.1 | <30 km | 30,138 | 2–11 |
| LOL24all | 744 | 1200–2017 | * | * | 33,038 | 3–11 |
| LOL24ins | 338 | 1904–2017 | * | * | 20,029 | 3–11 |
| GOM24 | 119 | 1908–2013 | 3.8–7.1 | <35 km | 16,260 | 3–11 |
| GOM24crv | 119 | 1908–2013 | 3.8–7.1 | <35 km | 16,260 | 3–11 |

# 2) Testing Datasets

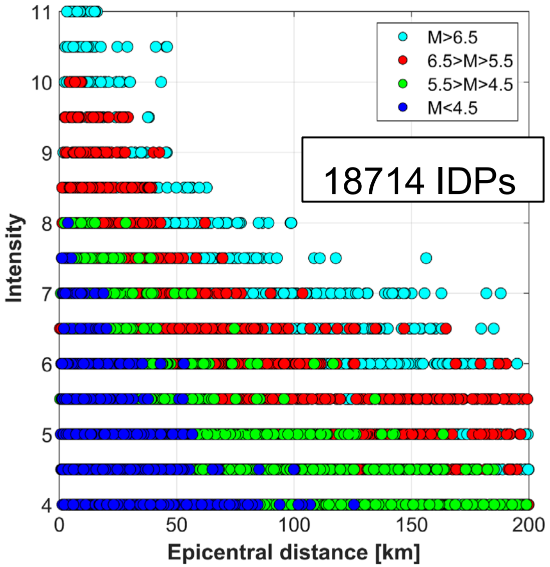
**We selected 4 different datasets:**

- Number of associated IDPs ≥ 10
- Moment magnitude Mw ≥ 4.0
- No volcanic and subduction earthquakes

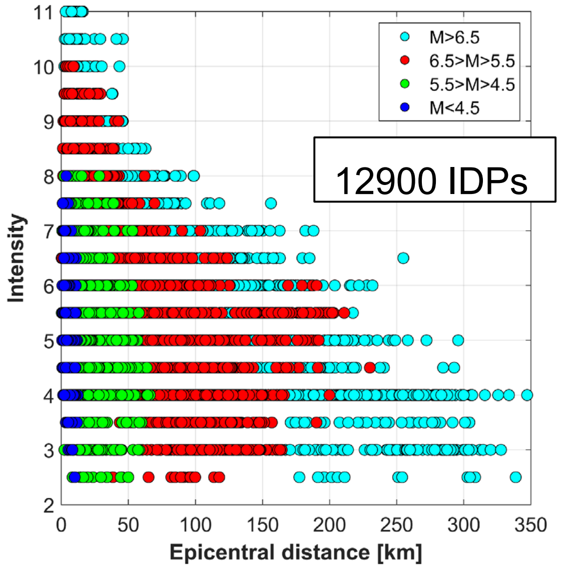
1. Two datasets with **213 earthquakes** with **instrumental magnitudes and location** from 1907 to 2020

2. Two datasets with **357 earthquakes** with **parameters derived only from macroseismic data** from 1117 to 1978

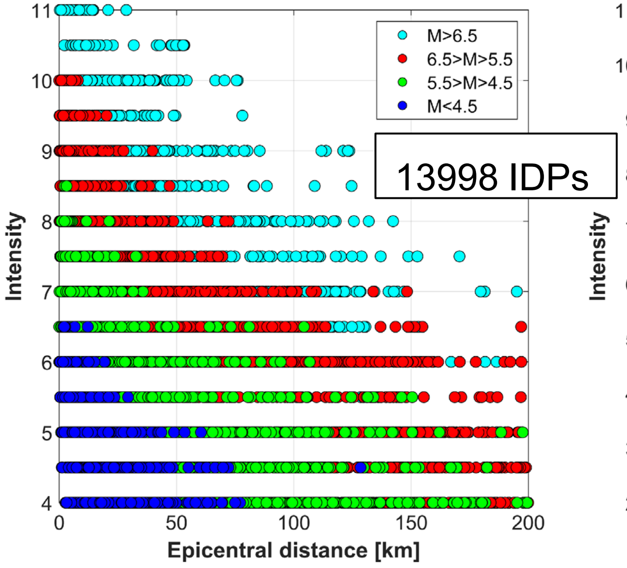
**Dataset #1**



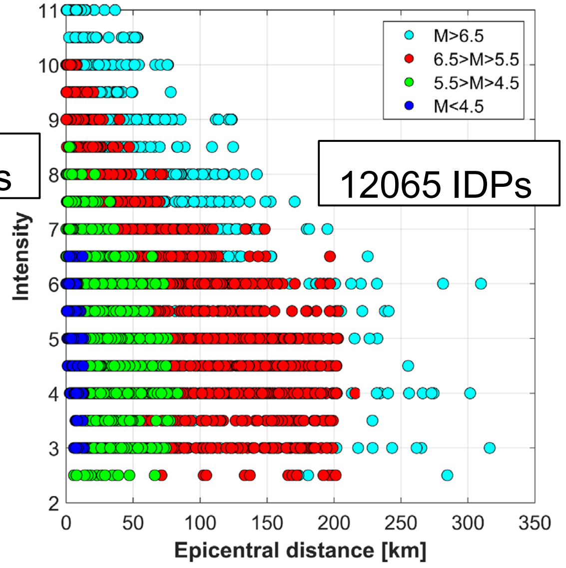

**Dataset #1alt**




**Dataset #2**



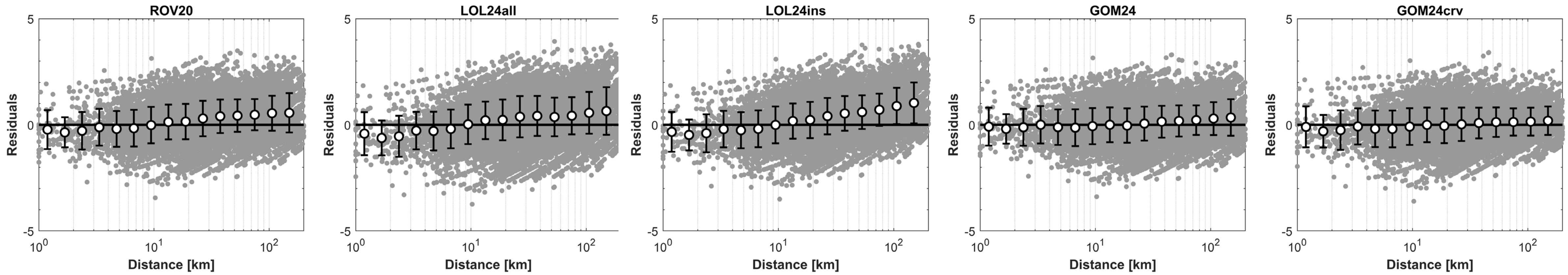

**Dataset #2alt**

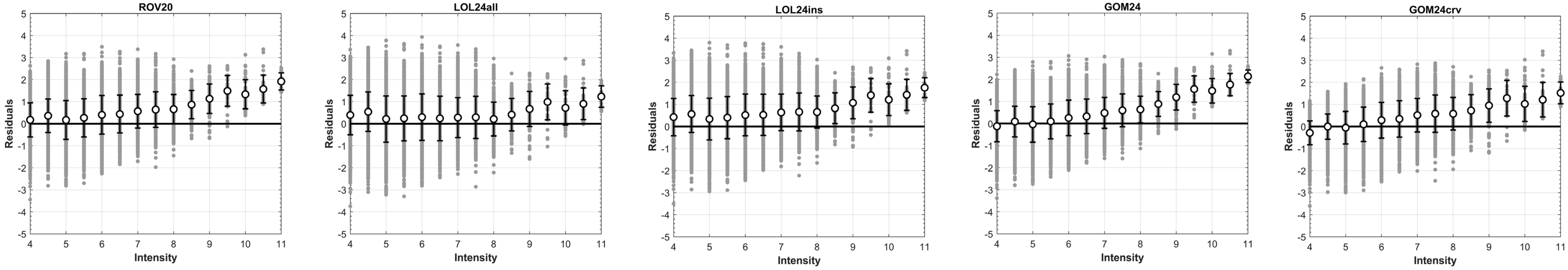


# 3) Analysis of the residuals

The total residual ***Res*** is calculated as the difference between the macroseismic intensity observations ***MI<sub>obs</sub>*** (from the selected datasets) and the predictions at the same sites ***MI<sub>pred</sub>***

$$R_{es} = MI_{obs} - MI_{pred}$$



# 4) Best-performing model

We adopted two metrics to evaluate the performance of the predictive models:

(i) the **log-likelihood (LLH)** proposed by Scherbaum et al. (2009) in the framework of PSH assessment for Europe to rank both IPEs and GMMs

(ii) the **mean absolute error (MAE)**, introduced by Mak et al. (2015) for validating Italian IPEs

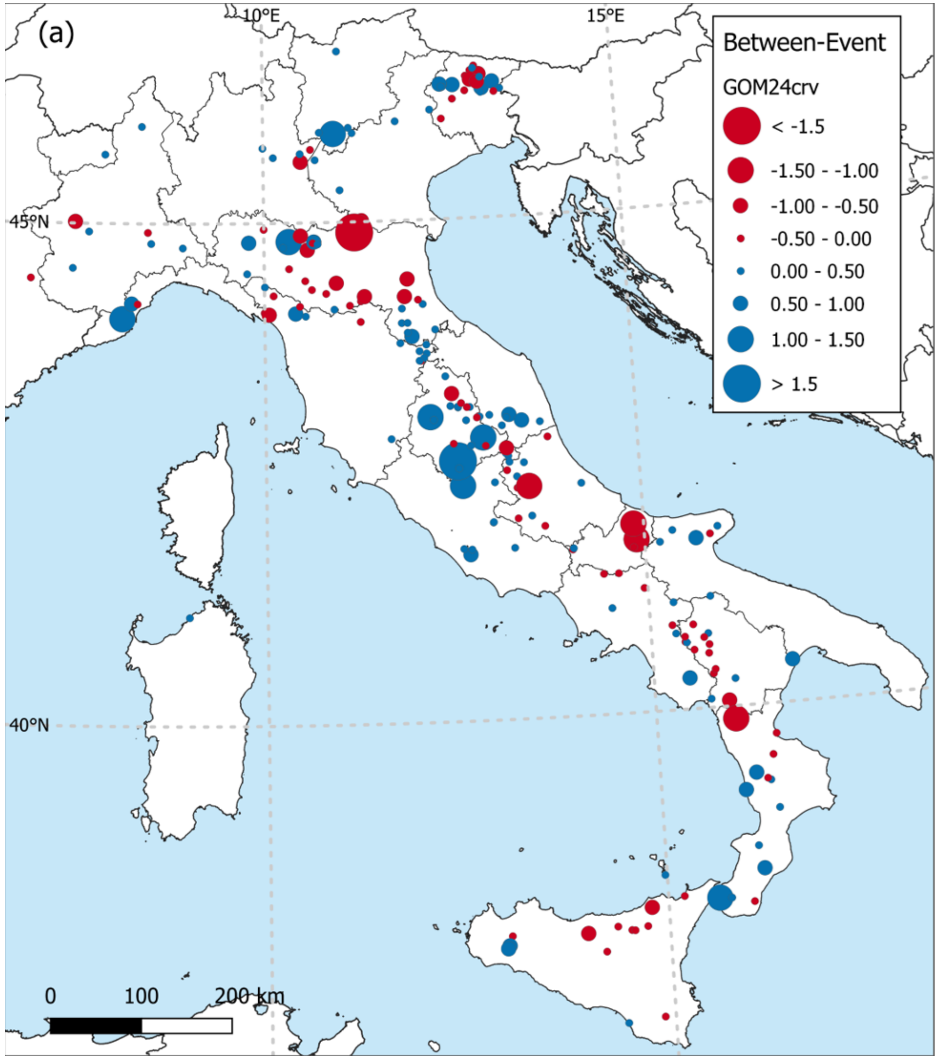
We assigned 5 points to the best-performing IPE (LLH or MAE values closest to zero) and 1 point to the worst

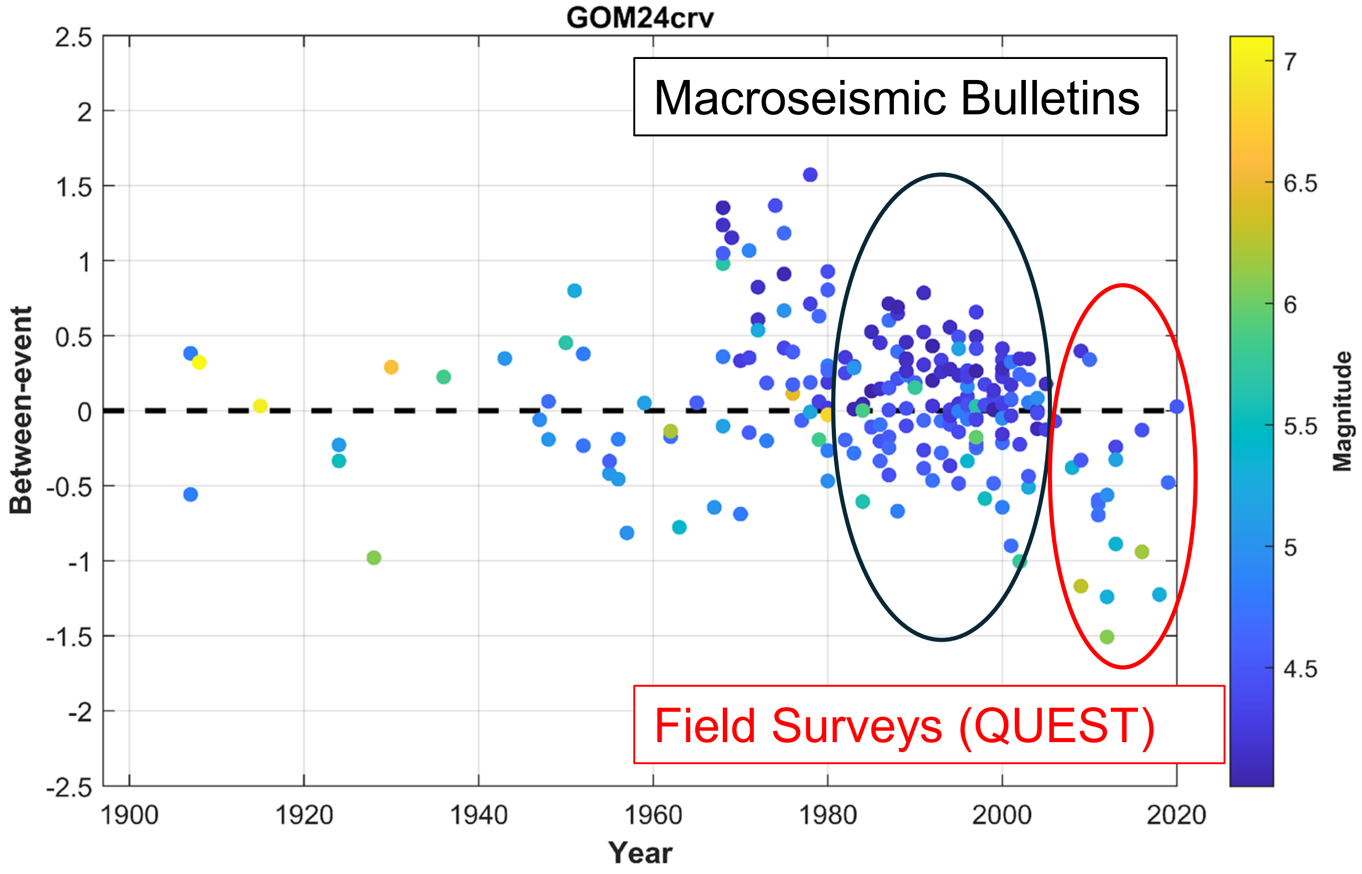
| Model | LLH scoring | | | | MAE scoring | | | | Total score |
|---|---|---|---|---|---|---|---|---|---|
| | D #1 | D #2 | D #1alt | D #2alt | D #1 | D #2 | D #1alt | D #2alt | |
| ROV20 | 3 | 2 | 5 | 4 | 3 | 3 | 5 | 3 | 28 |
| LOL24all | 1 | 3 | 3 | 5 | 1 | 2 | 4 | 5 | 24 |
| LOL24ins | 2 | 1 | 2 | 3 | 2 | 1 | 2 | 2 | 15 |
| GOM24 | 4 | 4 | 4 | 1 | 4 | 4 | 1 | 1 | 23 |
| GOM24crv | 5 | 5 | 1 | 2 | 5 | 5 | 3 | 4 | 30 |

# 4) Best-performing model

We estimated the **between-event** for each event as the mean of the residuals using GOM24crv

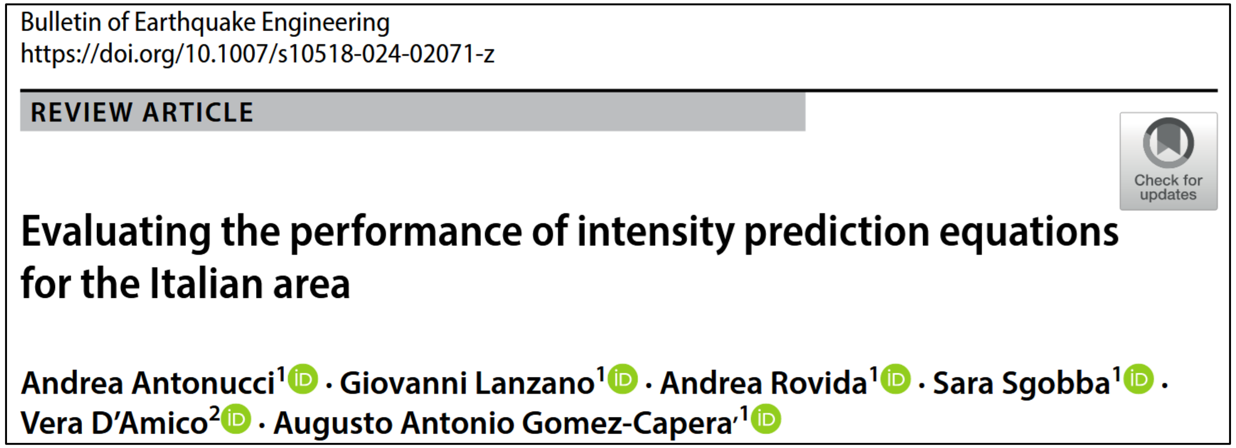
$$\delta B_e = \frac{1}{N_e}\sum_{i=1}^{N_e} R_{es}$$



# Results and perspectives

- The GOM24crv model is **the best-performing model**
- The statistical indexes showed small differences among all models, indicating the validity of all the tested IPEs. These differences can be attributed to the **different criteria adopted for the selection of the calibration dataset of each model**


Bulletin of Earthquake Engineering
https://doi.org/10.1007/s10518-024-02071-z

REVIEW ARTICLE

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**Evaluating the performance of intensity prediction equations for the Italian area**

Andrea Antonucci[1] · Giovanni Lanzano[1] · Andrea Rovida[1] · Sara Sgobba[1] · Vera D'Amico[2] · Augusto Antonio Gomez-Capera[1]

This study provided some hints:

(i) **Incorporation of different distance metrics** (e.g., Joyner–Boore) in the prediction models

(ii) **Investigating the within-event terms (δWes)** to highlight the influence of rupture-directivity effects on a model prediction

# Decomposition of residuals

We are reproducing the approach adopted in the GMMs to **decompose the residuals** into systematic effects to isolate of different sources of the model variability (Sgobba et al., 2021; Colavitti et al., 2022)

$$R_{es} = \delta_0 + \delta B_e \mid event + \delta S2S_l \mid locality + \delta W_0$$


- $\delta_0$ is the offset (approximately zero)
- $\delta B_e$ is the between-event term (mean error of each event *e*)
- $\delta S2S_l$ is the site-to-site term (mean error for each locality *l*)
- **$\delta W_0$ is the aleatory error that contains unmodeled effects, like directivity**

**We are investigating the azimuthal dependence of the residuals (δW0) to recognize potential directivity effects**

# Method

1. We used the event included in the **Dataset #1** (with instrumental location and magnitude)

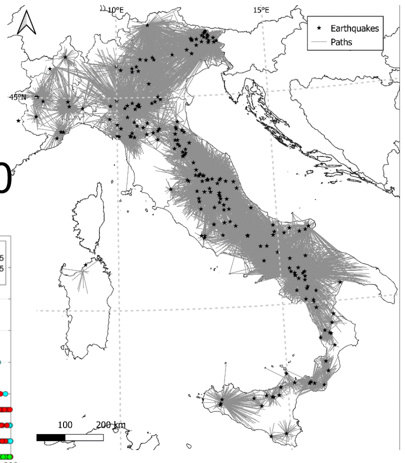
2. We removed the events with **incomplete azimuthal sampling** through spatial analyses of macroseismic data

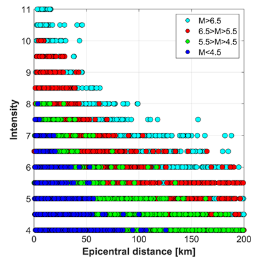
3. We **decomposed the residuals** at a single site for each event

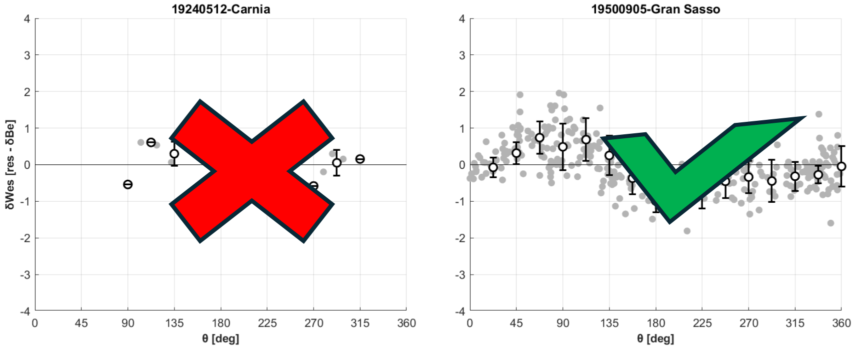
4. We **analyzed the results in terms of $\delta W_0$** as a function of the fault geometry

**213 earthquakes**

- 18.714 IDPs
- Mw 4.0-7.1
- Time: 1907-2020



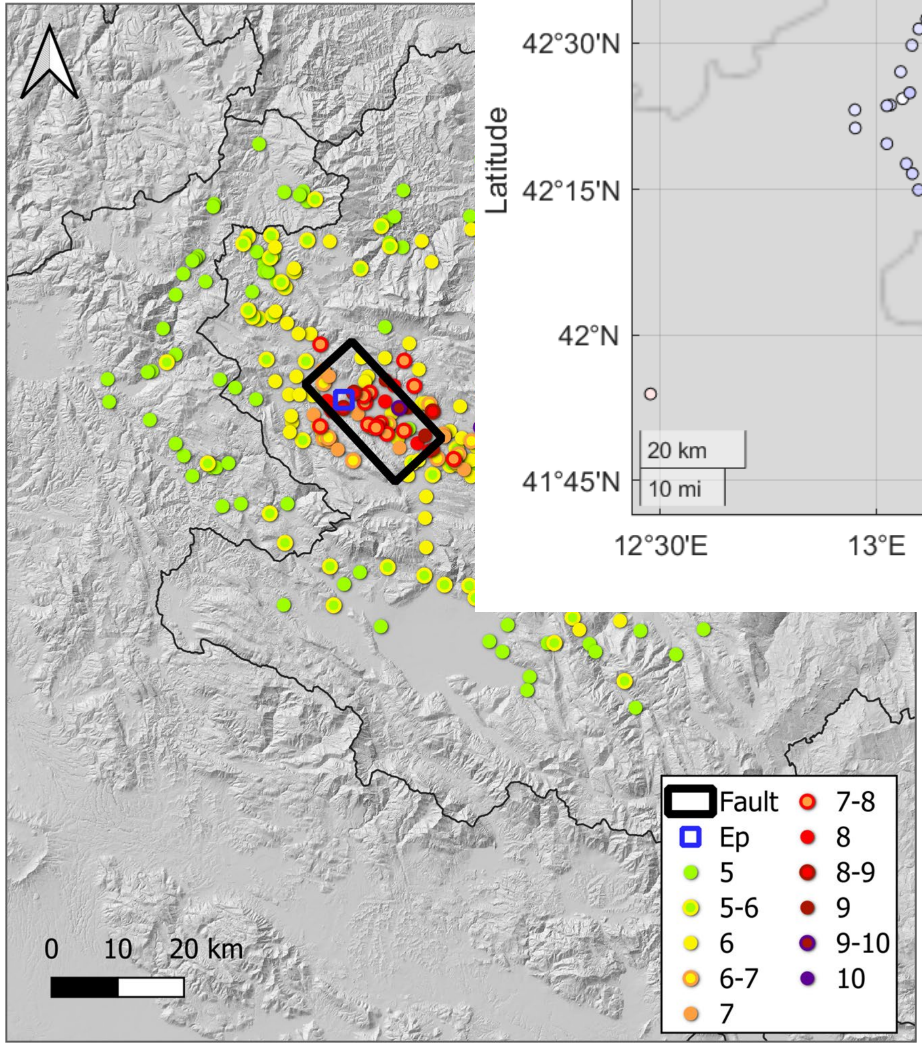



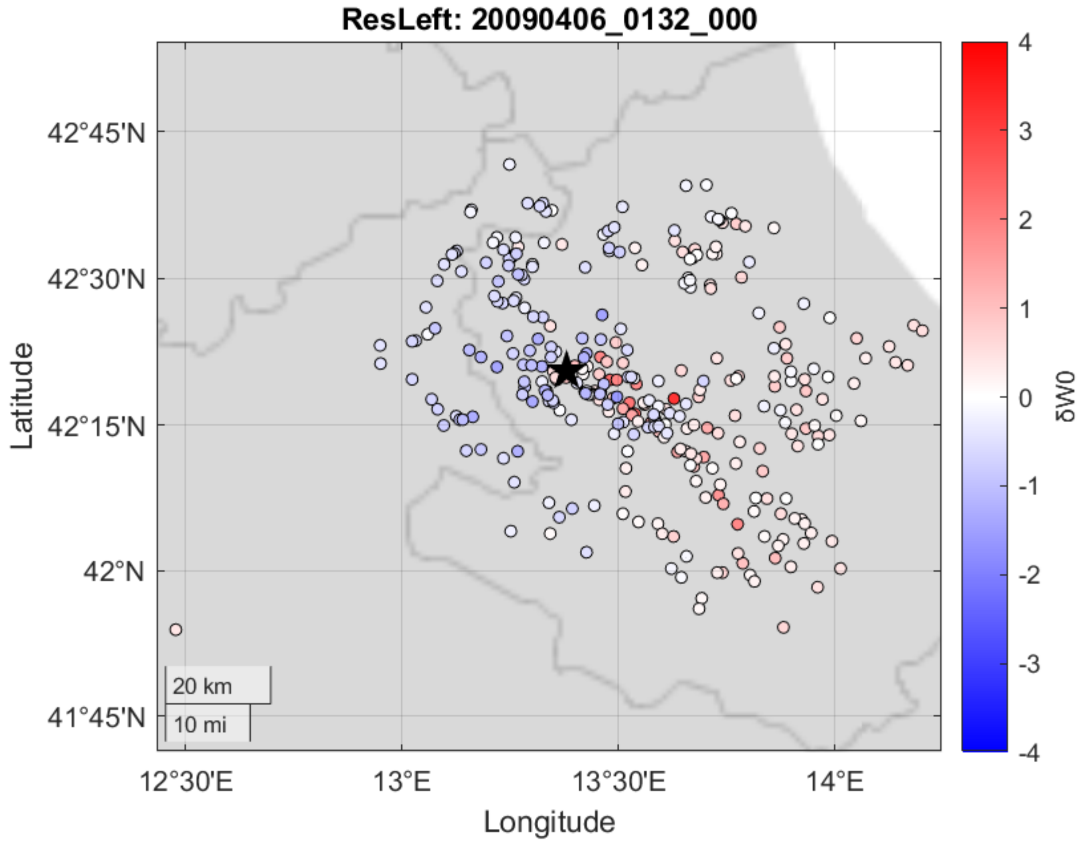



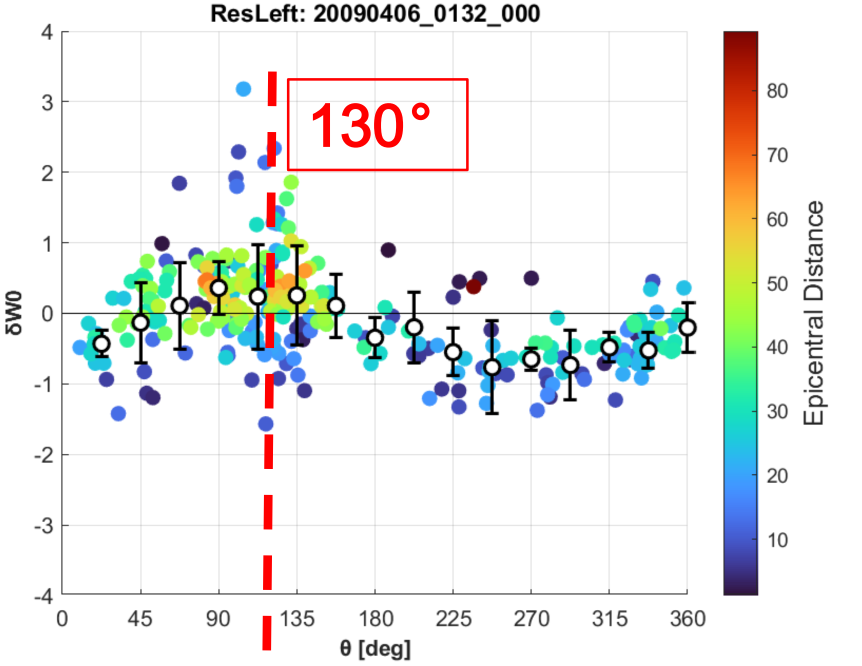

$$R_{es} = \delta_0 + \delta B_e \,|\, \text{event} + \delta S2S_l \,|\, \text{locality} + \delta W_0$$

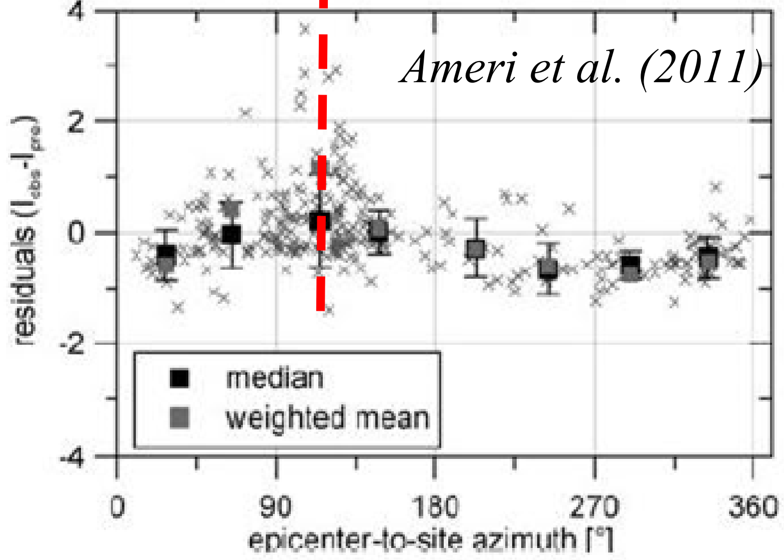
# 2009 - L’Aquila (Mw 6.3)

**316 MDPs** (Galli and C
**Ix = 9-10**



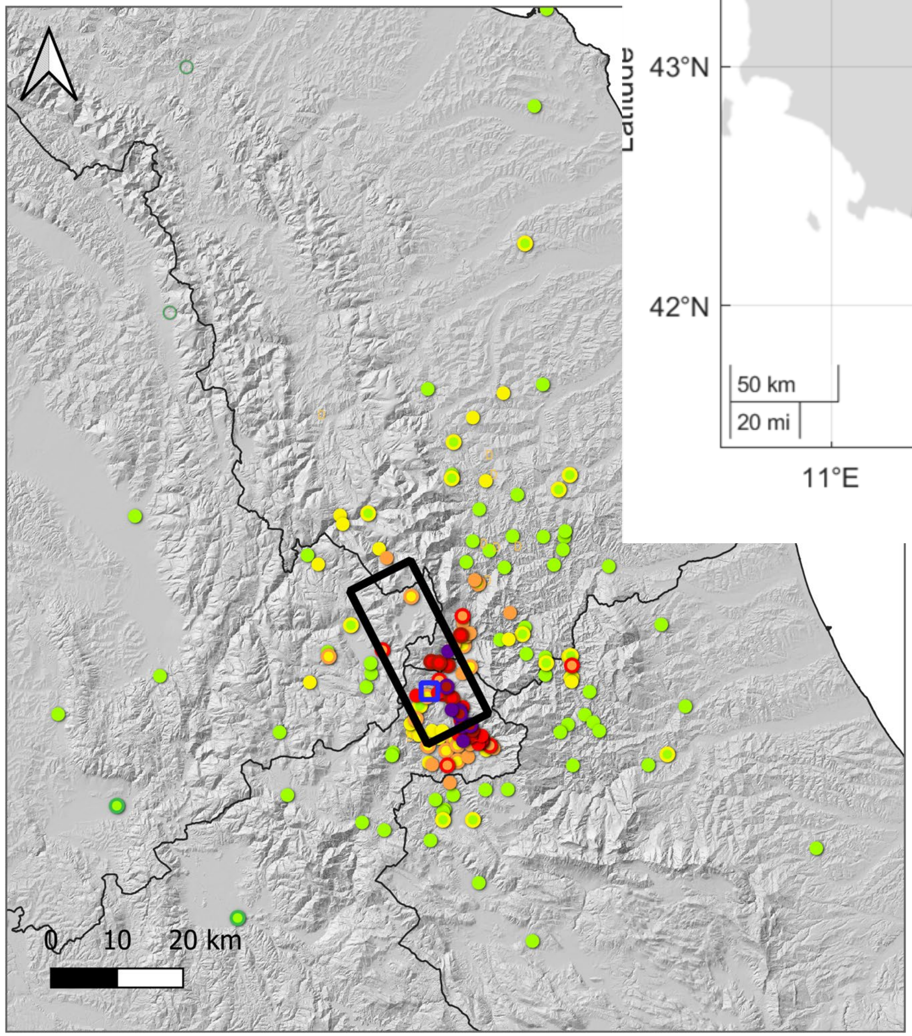



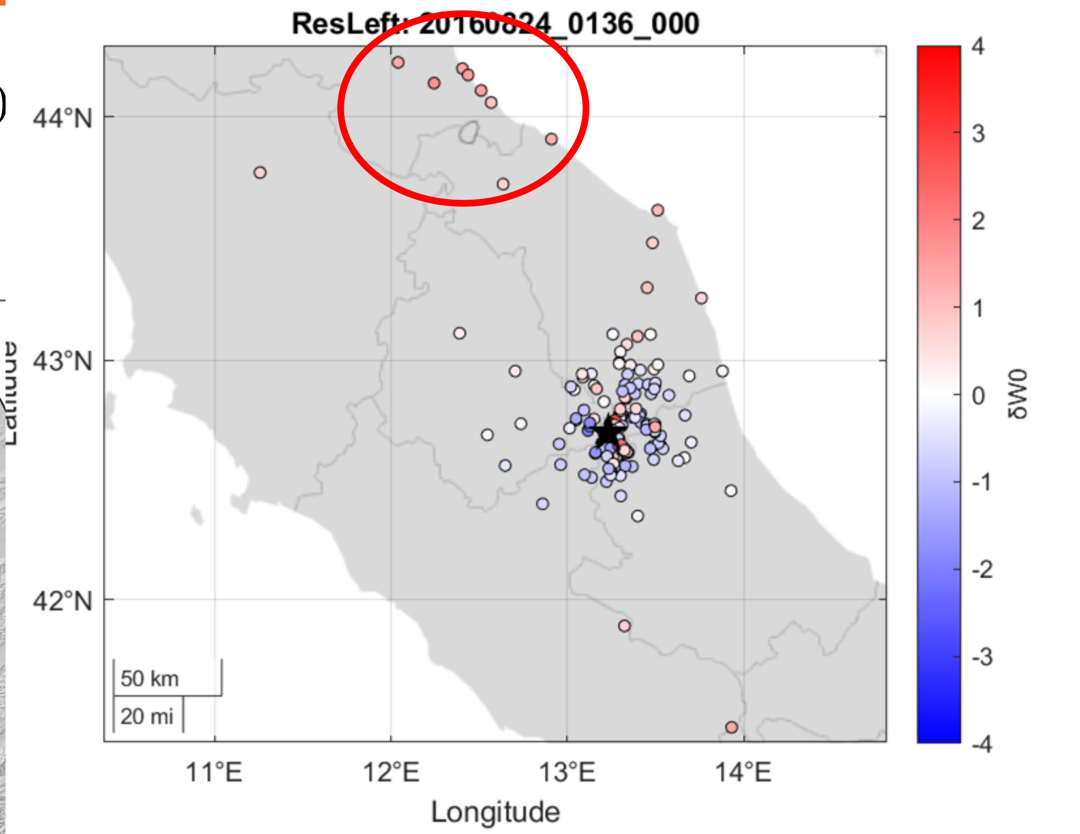



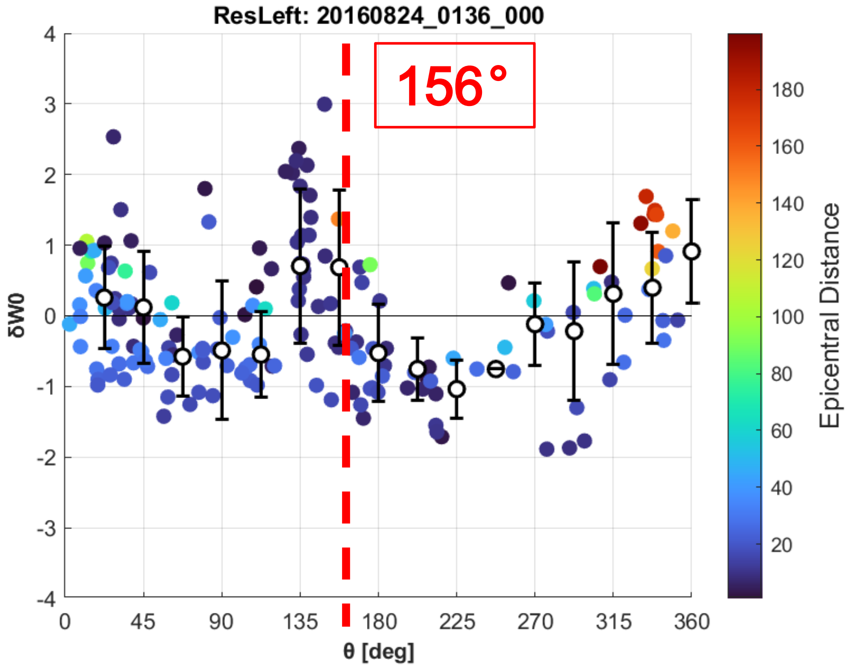

**Ameri (2009)**
Strike140.0
Dip 50.0
Rake -90.0

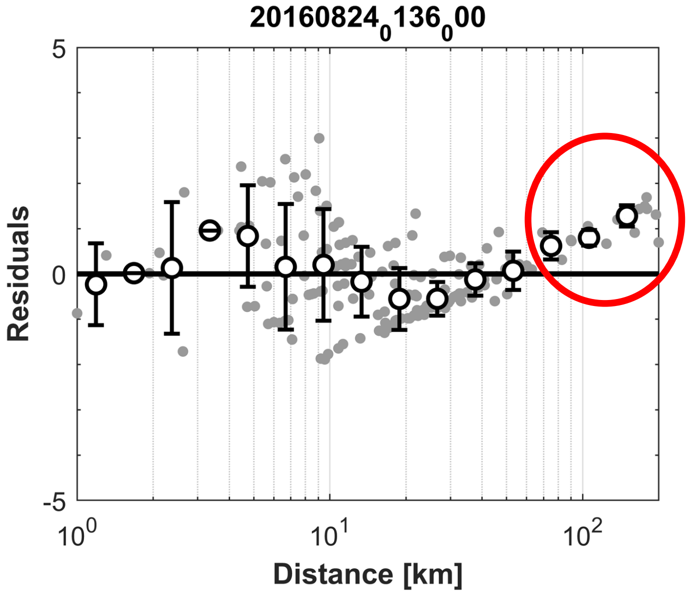
# 2016 - Amatrice (Mw 6.1)

**221 MDPs** (Rossi et al, 2019)
**Ix = 10**



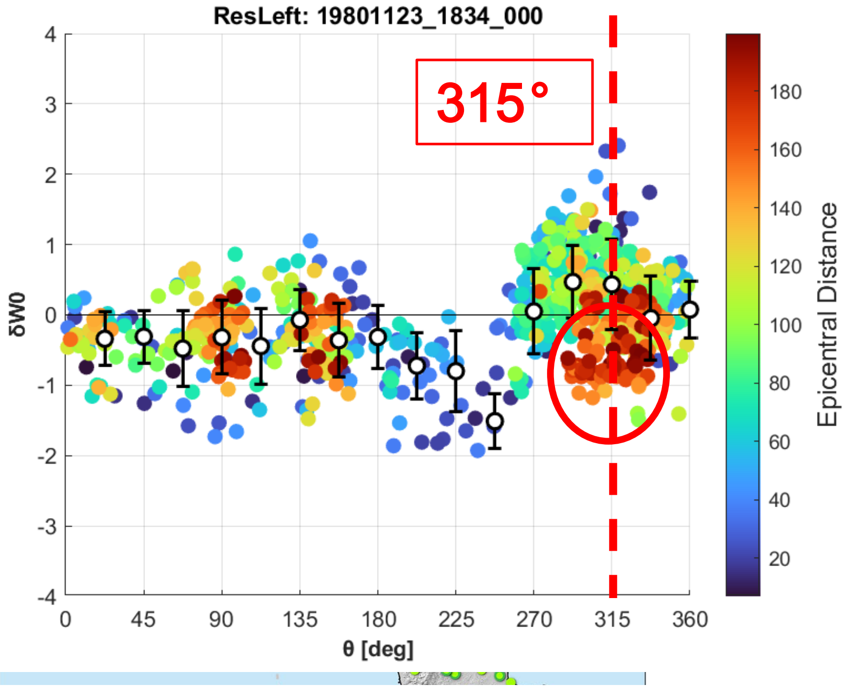




**Complex azimuthal distribution**

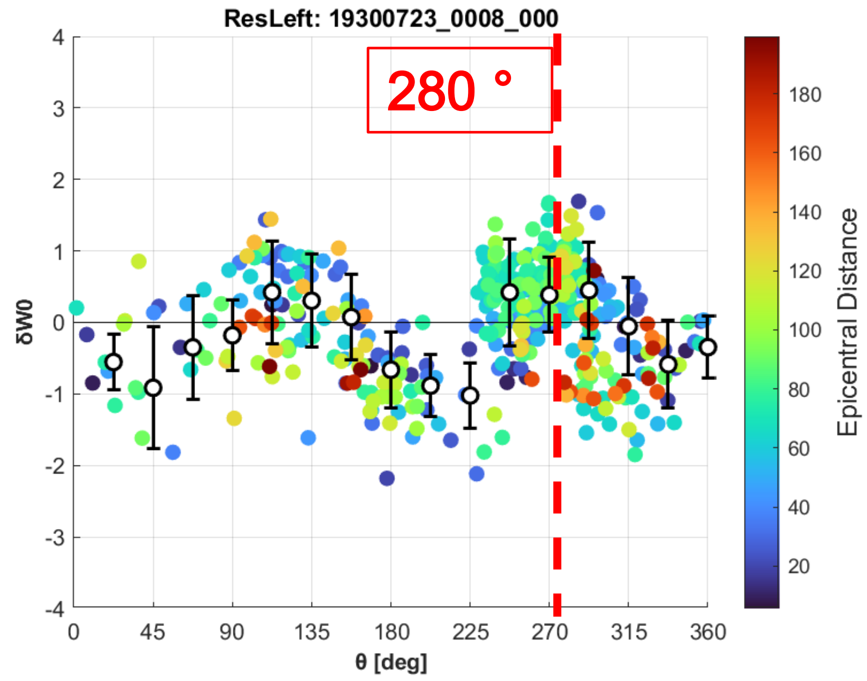
**Tinti (2016)**
*Strike 156.0*
*Dip 50.0*
*Rake -85.0*

Positive Bias for long distance data (R> 80km)

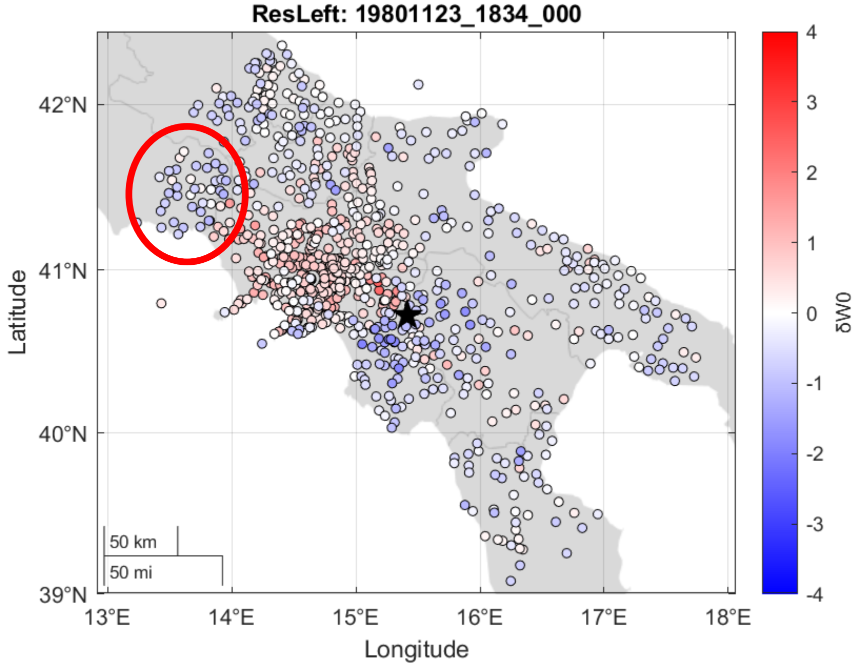



Mw 6.8 (CPTI15)
Ix 10

Ameri et al. (2011)
*Strike* 315
*Dip* 60
*Rake* -90

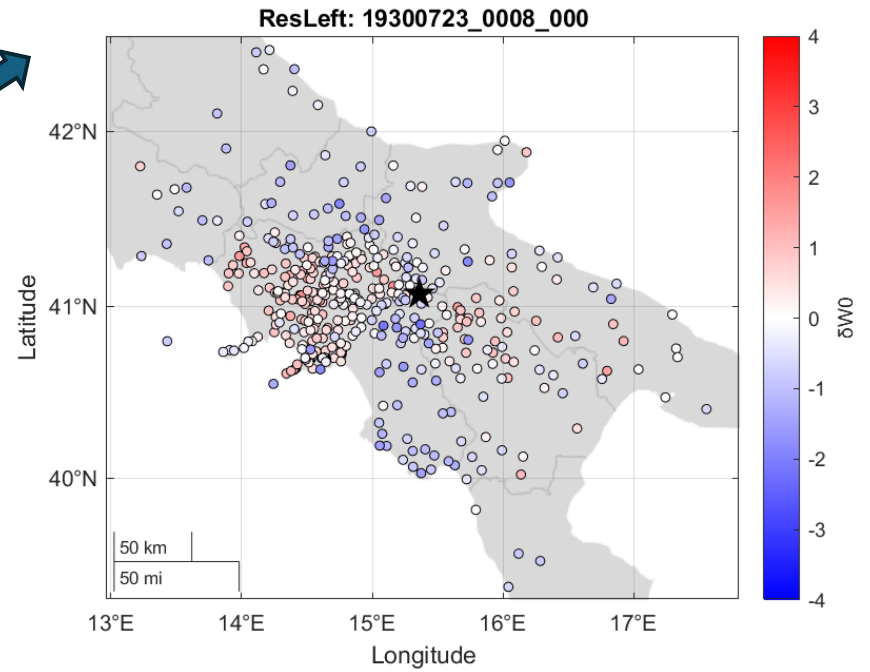


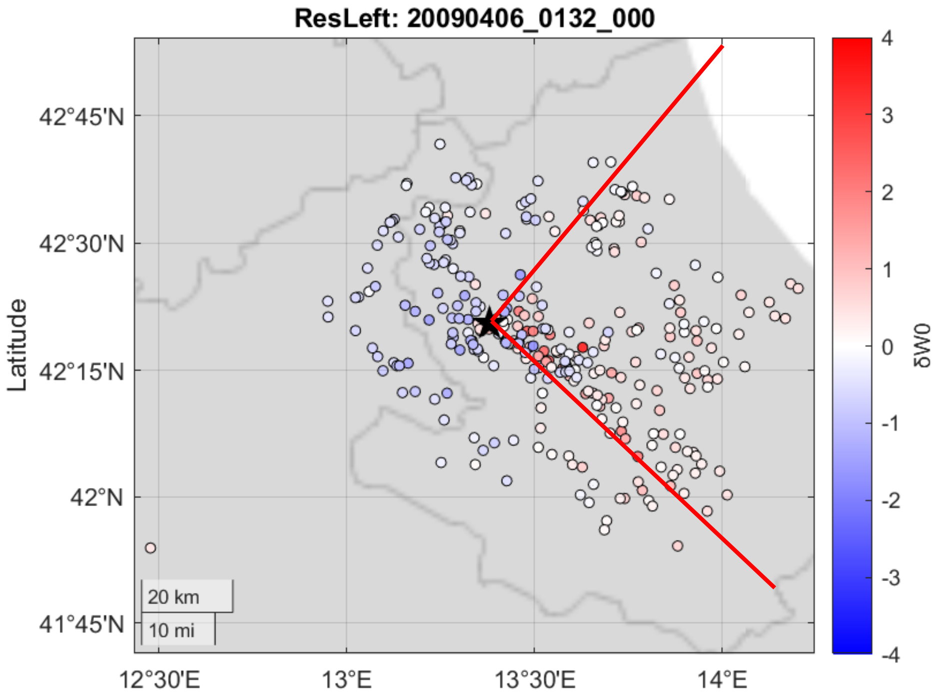

**Negative residuals at long distances (>120 km)**




Mw 6.6 (CPTI15)
Ix 10

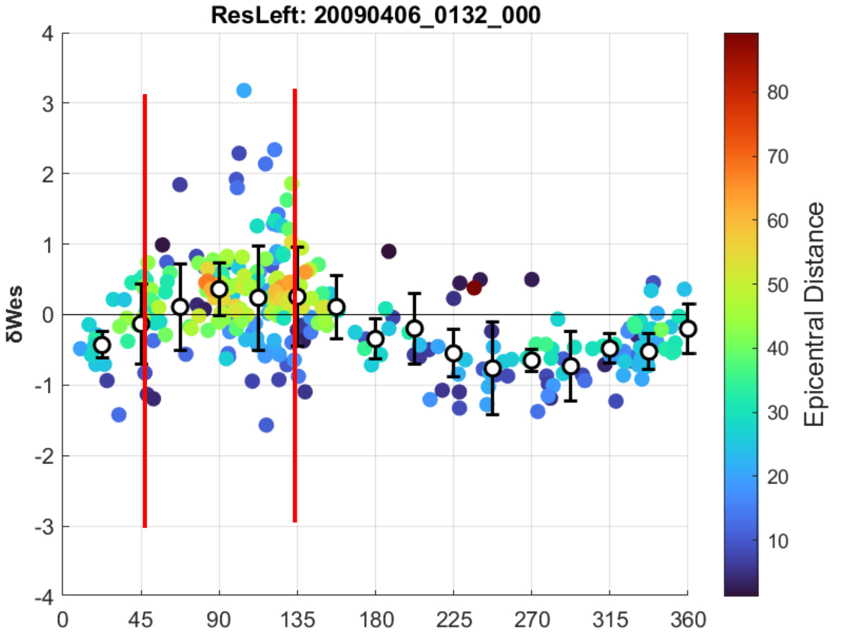
DISS - ITIS088
*Strike* 280
*Dip* 64
*Rake* 237

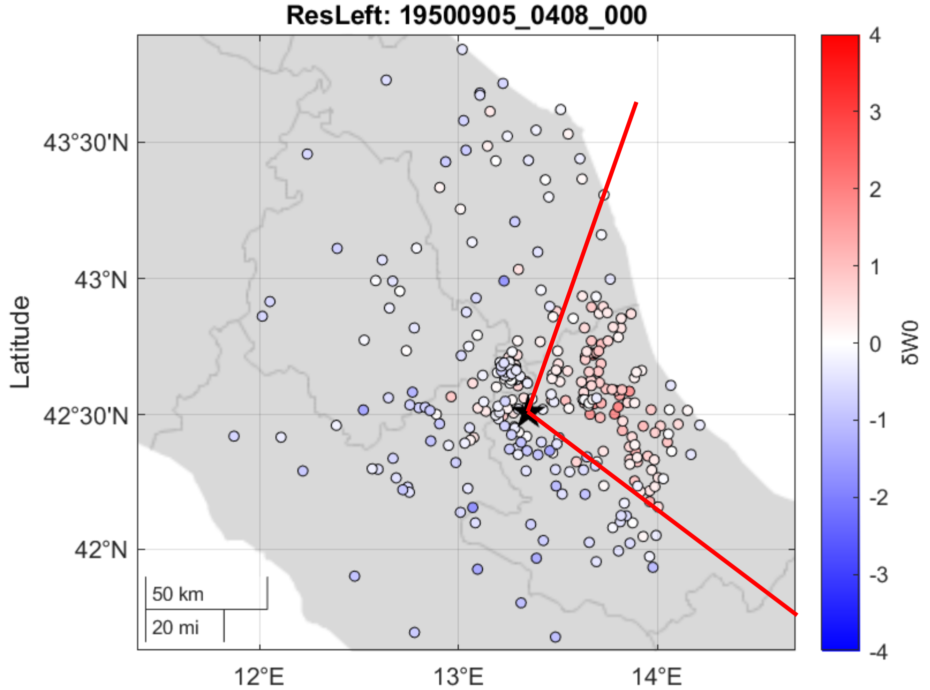





**2009-04-06**
**Mw 6.3 (CPTI15)**

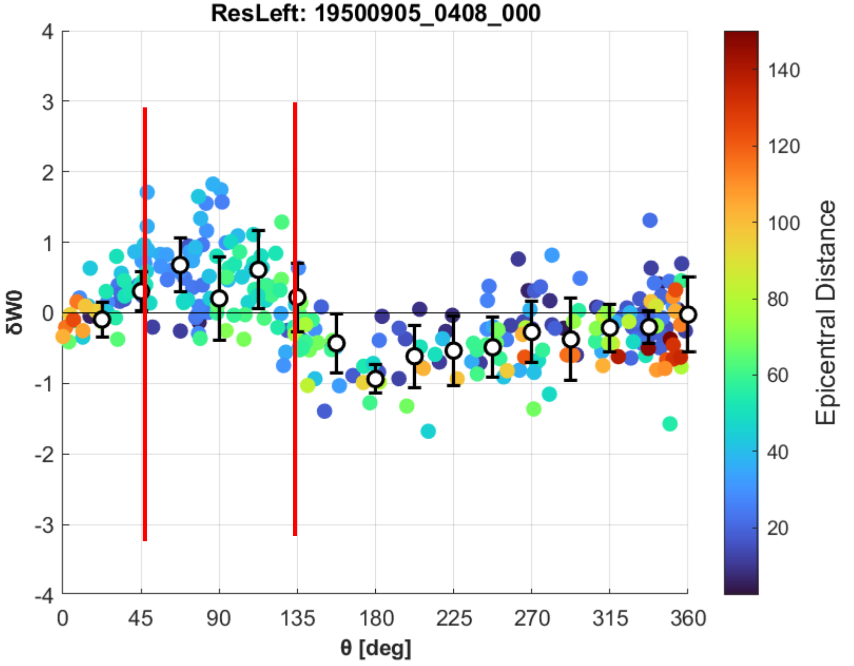
**18 km of distance from 2009 – L'Aquila**




**1950-09-05**
**Mw 5.7 (CPTI15)**

**Directivity effects at sites located between 45° and 135°**



# Preliminary results and next steps

- We are carrying out an exploratory **systematic analysis to detect directivity effects in the macroseismic data through the approach based on the residuals,** originally developed for ground motion parameters obtained from the recordings

- We preliminary observed **positive residuals** ($I_{obs} > I_{pred}$) in a given direction **corresponding to strike of the fault**


**Extending the dataset to past events with macroseismic magnitudes and locations**

# Thank you

**Andrea Antonucci**

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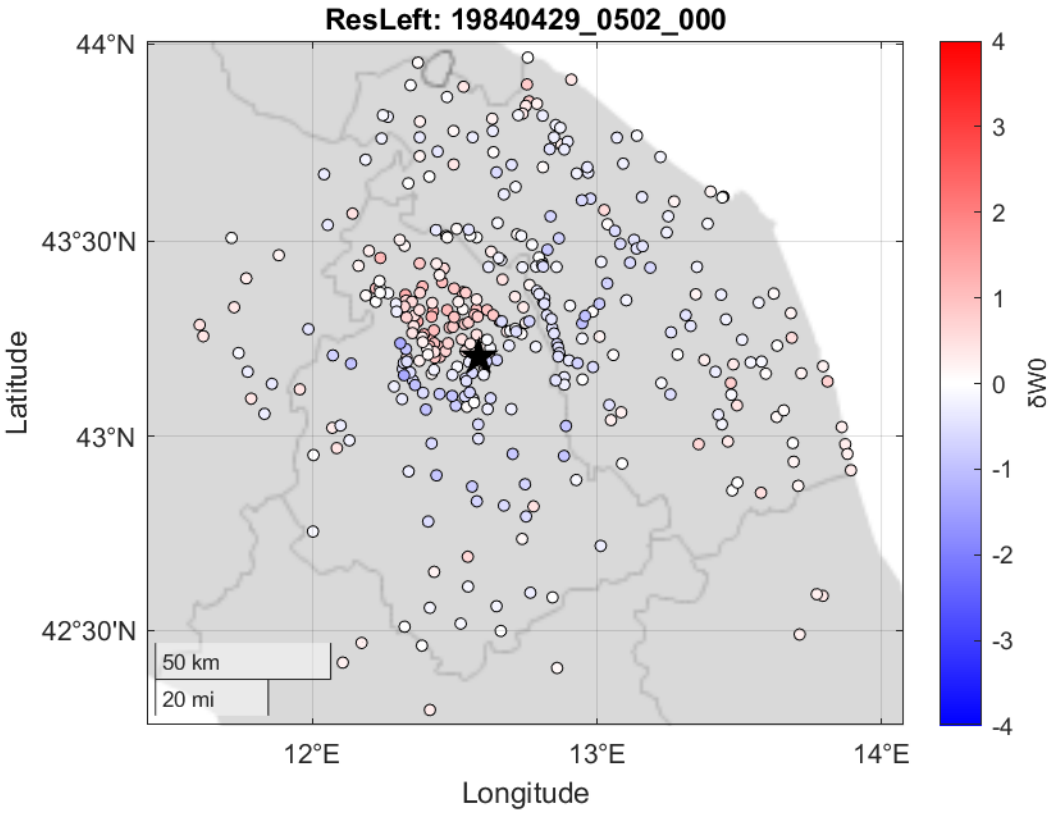
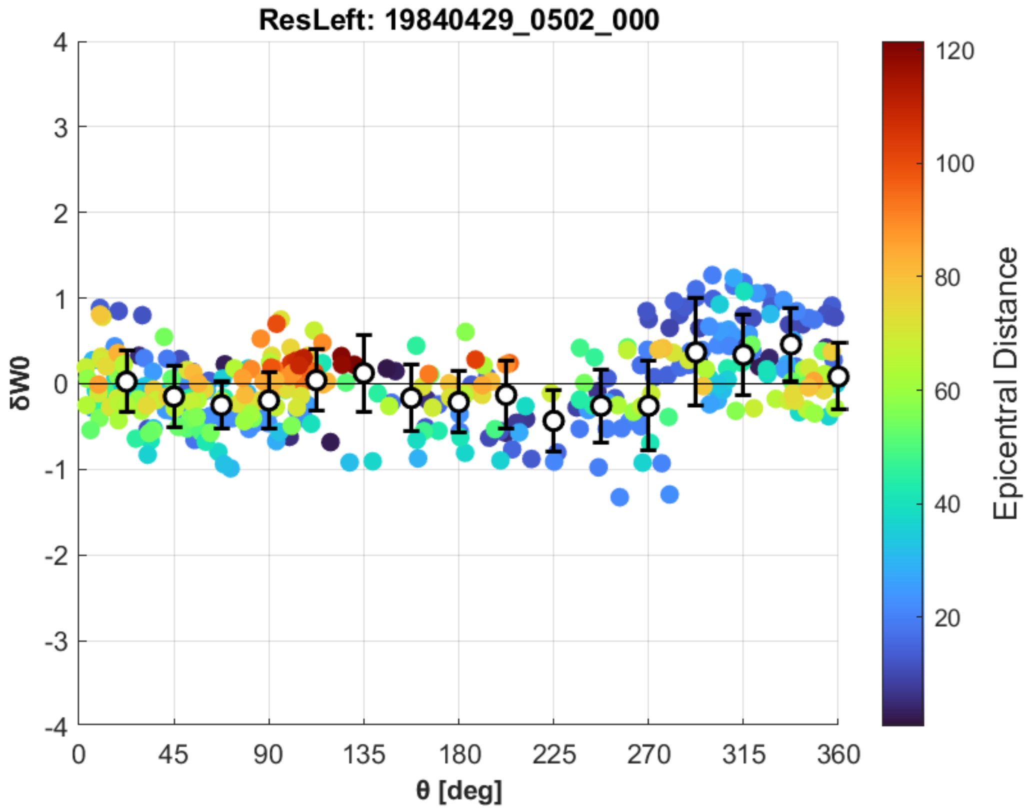
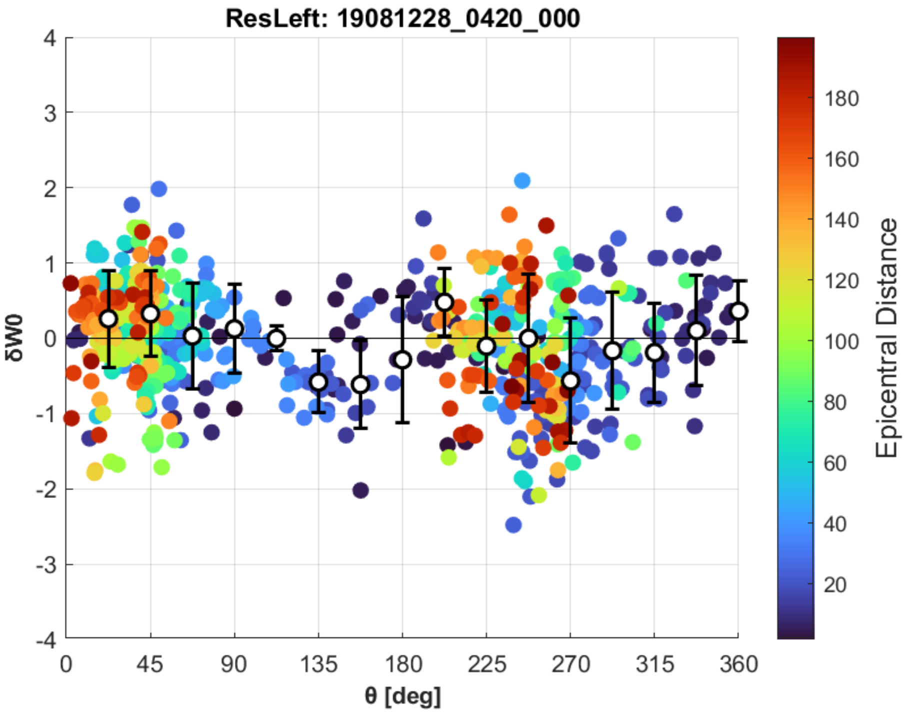
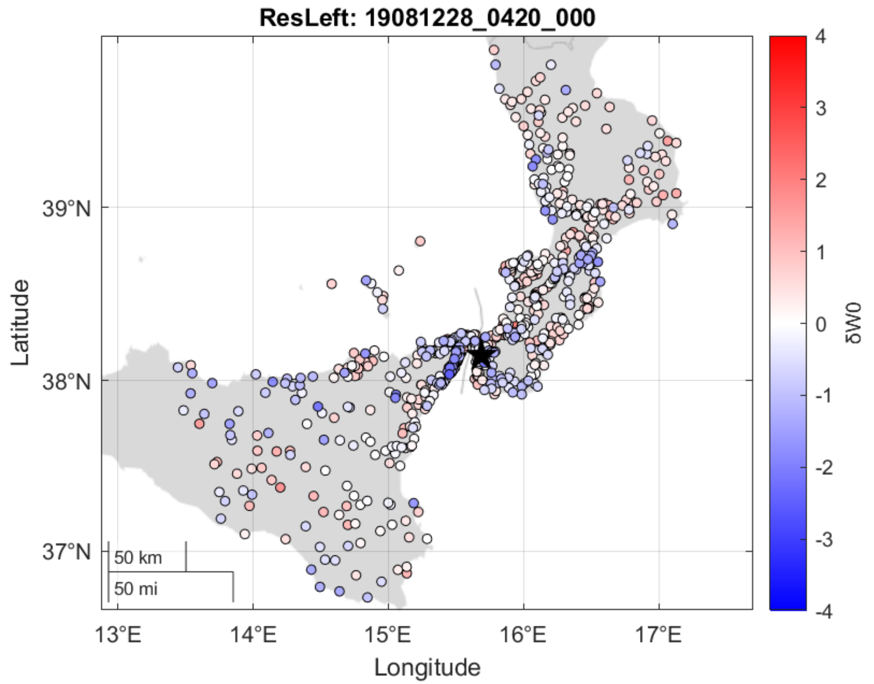


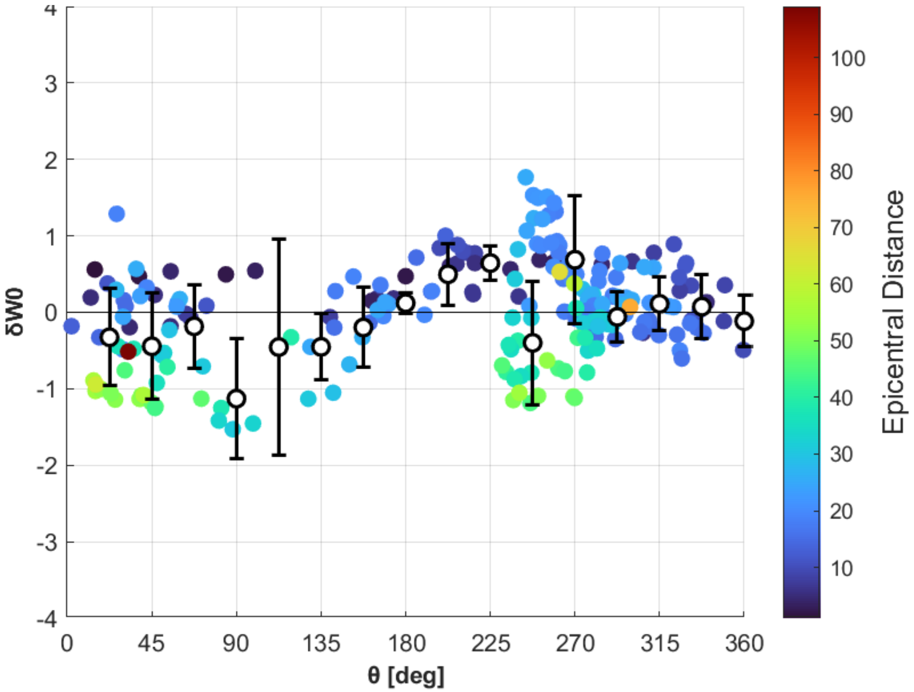



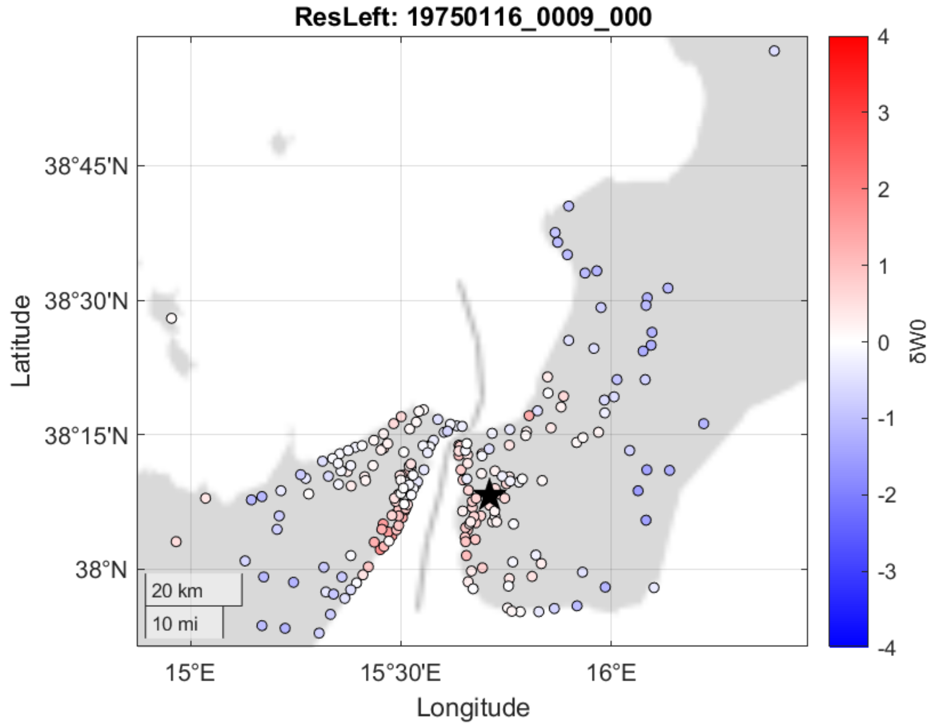

Ameri et al (2009)
Strike 130 °
Dip 20°
Rake -90°



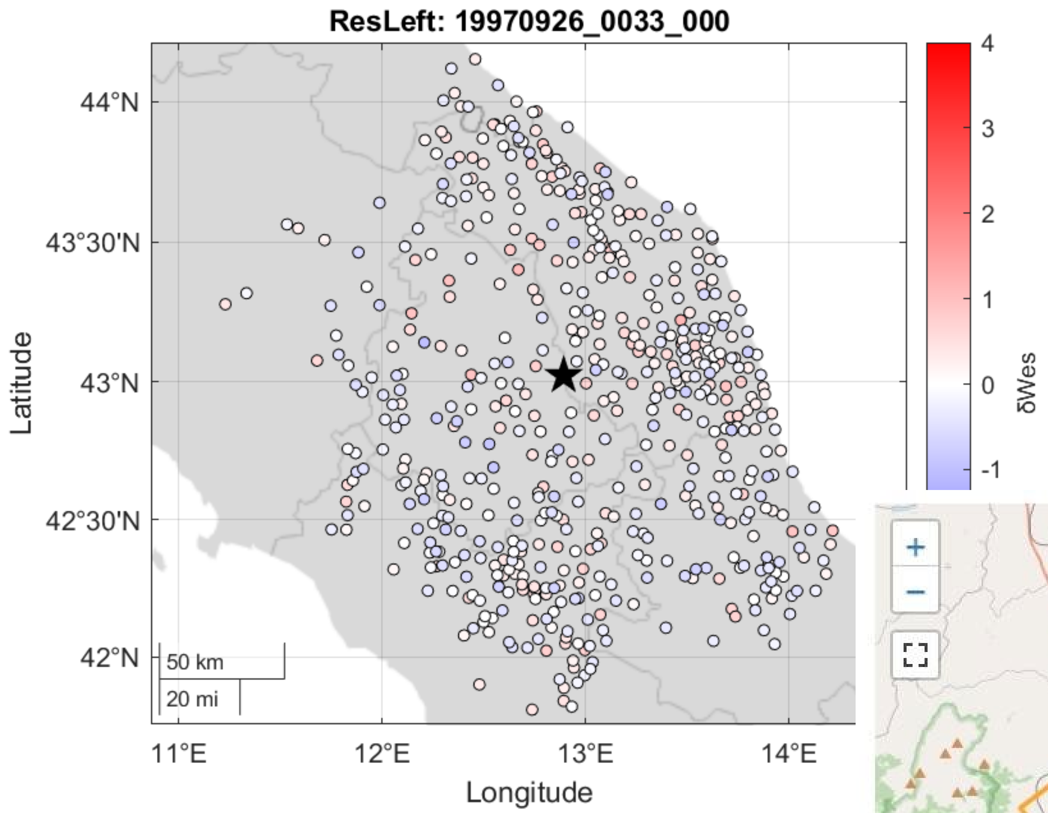




Faglia del 1908 Secondo Natale and Pingue (1991) ha provocato evento 1975

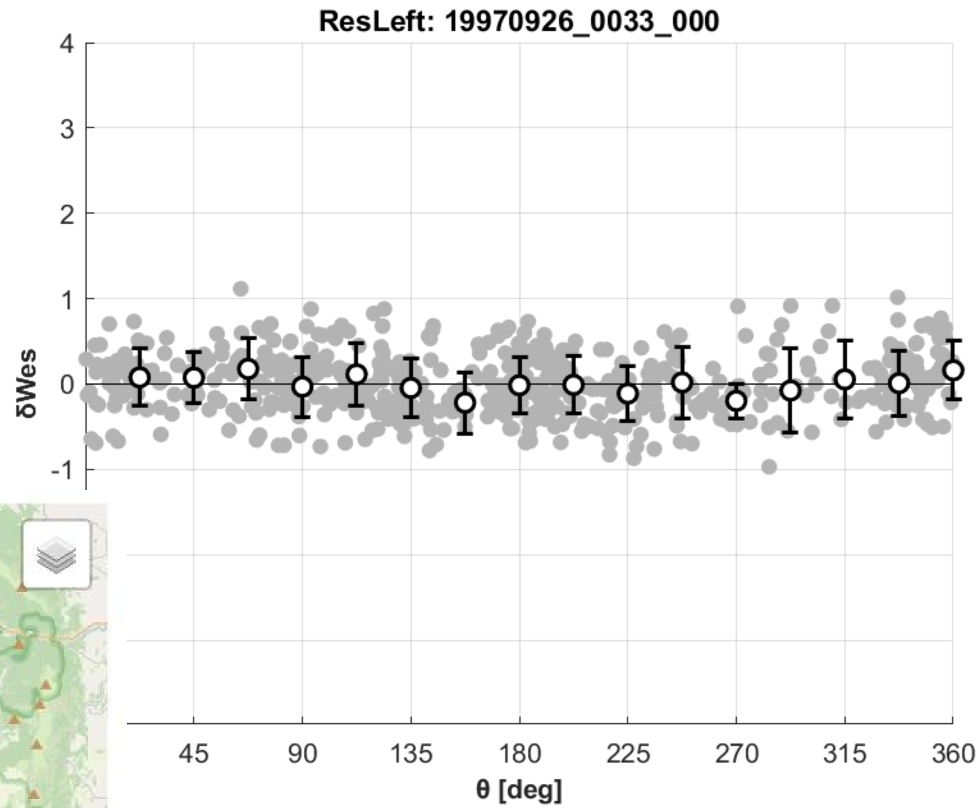


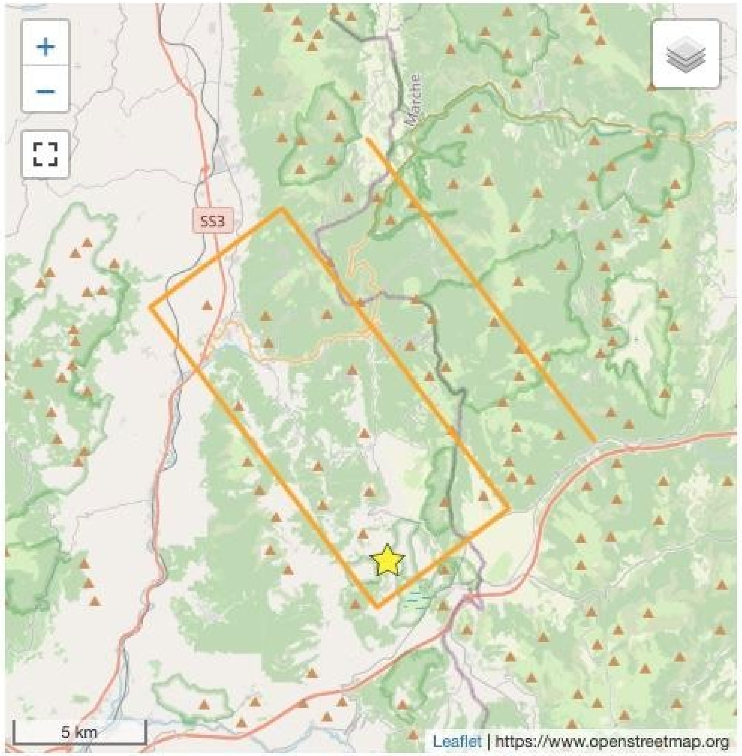
# Results examples: Umbria-Marche (1997) Mw 6.0




No signature of source directivity




No residual bias with distance




DISS
Strike143.0
Dip40.0
Rake-85.0