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The ShakeMap Atlas of Historical Earthquakes in Italy: Configuration and Validation

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Workflow

This work aims at presenting how we have developed the **ShakeMap Atlas** of **historical earthquakes** in **Italy** through the following steps:

1. the collection of macroseismic data for a selected **dataset** of historical Italian earthquakes with magnitudes equal to or greater than 6.
2. the adoption of two different **ShakeMap configurations**.
3. the application of the iterative **leave-one-out cross-validation** procedure within ShakeMap to identify the most appropriate configuration.
4. the analysis of the **results**.

Dataset

- **79 earthquakes** that occurred **between 1117 and 1968** with **6 ≤ M < 7.5** according to the Italian Parametric Earthquake Catalog (CPTI15, Rovida et al., 2022).
- **12,632 Macroseismic Data Points** (MDPs) extracted from the Italian Macroseismic Database (DBMI15, Locati et al., 2022).

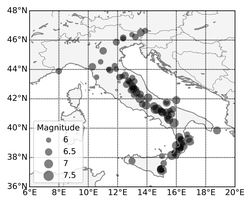

Fig 1: Spatial distribution of the selected seismic events.

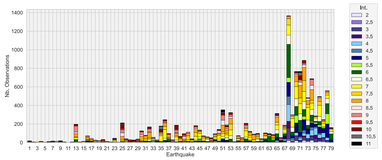

Fig 2: Number of MDPs per earthquake for different macroseismic intensities values.

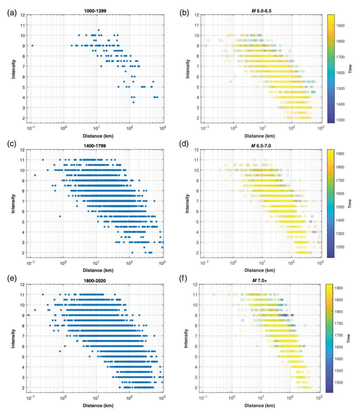

Fig 3: Earthquake distance coverage of the intensity dataset grouped by (a,c,e) year and (b,d,f) magnitude ranges.

ShakeMap Configurations

- We have computed the shakemap set using the following equations:

1. the ground motion model (GMM) proposed by Bindi et al. (2011).
2. the Ground Motion to Intensity Conversion Equation (GMICE) implemented by Oliveti et al. (2022).
3. two different Intensity Prediction Equations (IPEs), alternatively and separately as input:
   a) Pea08, the IPE proposed by Pasolini et al. (2008) and updated by Lolli et al. (2019).
   b) VIPE, the Virtual IPE adopted in ShakeMap when the operator does not specify an IPE.

1. GMM: $\log_{10} = e_1 + F_D(R, M) + F_M(M) + F_S + F_{sof}$

where e_1 *is the constant term,* $F_D(R, M), F_M(M), F_S$ *and* F_{sof} *represent the distance function, the magnitude scale, the site amplification and the style of faulting correction, respectively.*

2. GMICE: $I = a \pm b \log_{10} PGM \pm c \log_{10}{}^2 PGM$

where I *is the expected intensity at a site,* PGM *is the corresponding peak ground motion parameter and* a, b, c *are the regression coefficients.*

3a. IPE (Pea08): $I = I_E - a(D - h) - b[\ln(D) - \ln(h)]$

where I *is the expected intensity at a site located at epicentral distance R,* $I_E = -2.466 + 1.842\ M_w$ *is the average expected intensity at the epicenter,* M_w *is the moment magnitude, a is the coefficient of the linear distance term, b is the coefficient of the natural logarithm of distance,*
$D = \sqrt{R^2 + h^2}$ *and* $h = 4.27$ km.

3b. Virtual IPE (VIPE): combination of the GMM and the GMICE

Leave-one-out cross validation

- To test the godness of the **Pea08 and VIPE configurations**, we adopted an **iterative cross-validation procedure** that performs the following steps for each observed intensity and for all the selected earthquakes:

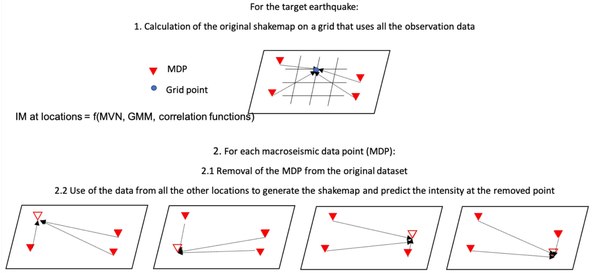

Fig 4: Schematic of the key processing steps of the Leave-One-Out (LOO) procedure adopted in ShakeMap.

Results

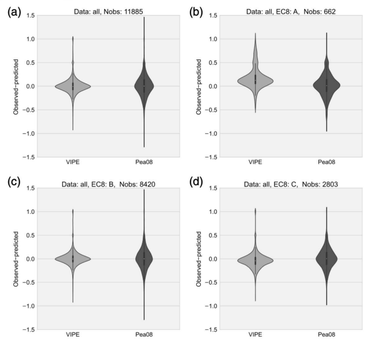

Fig 5: Violin plot diagram of the differences between observed and ShakeMap predicted intensity values for the entire validation data set (79 earthquakes) and for the Eurocode 8 (EC8) A– C classes disaggregated subsets, using the VIPE and Pea08 configurations.

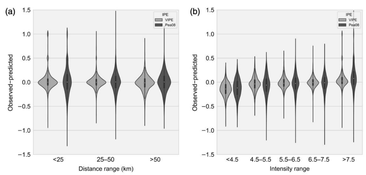

Fig 6: Violin plot diagram of the differences between observed and ShakeMap predicted intensity values for the entire validation data set (79 earthquakes) using the VIPE and Pea08 configurations, classified into: (a) earthquake distance and (b) intensity categories.

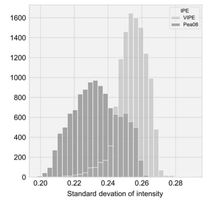

Fig 7: Histograms of the standard deviation distribution of the predicted intensity values at the macroseismic data points for the VIPE (light gray) and Pea08 (gray) configurations.

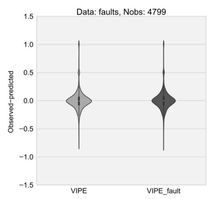

Fig 8: Violin plot diagram of the differences between observed and ShakeMap predicted intensity values for a subset of the validation data set (16 of 79 earthquakes) resulting from the leave-one-out cross-validation test, using the VIPE configuration with and without the fault geometry.

ShakeMap Atlas

- The shakemaps are available on the **INGV ShakeMap (**Oliveti et al., 2023a) and on the Italian Archive of Historical Earthquake Data (**ASMI**, Rovida et al., 2017) **platforms**.

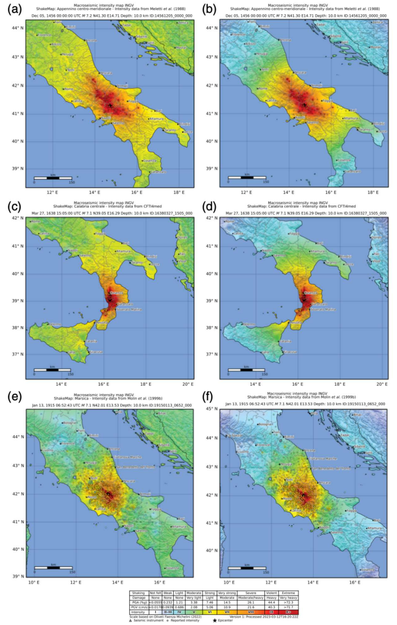

Fig 9: Intensity maps for the 5 December 1456 M 7.2, 27 March 1638 M 7.1, and 13 January 1915 M 7.1 earthquakes for the (a,c,e) VIPE and (b,d,f) Pea08 configurations.

Conclusions

- The ShakeMap configuration adopting the **Virtual IPE predicts accurately the intensity**: the median value of the residuals for both IPEs is around zero, whereas the standard deviation calculated using the Virtual IPE is lower than that achieved adopting the Pea08.
- Since the Virtual IPE is computed in ShakeMap by combining the **GMM** by Bindi et al. (2011) and the **GMICE** by Oliveti et al. (2022), we also cross-verified the **consistency** of these relationships.
- Overall, we implemented a strategy to provide a **consistent and quantitative description** of the distribution **of shaking intensity for historical earthquakes in Italy**.
- These rigorous and accurate estimates of ground-shaking field of past historical earthquakes are of foremost importance in **assessing earthquake effects** and for the **evaluation of seismic hazards**.
- **Future approaches** will consider a larger sample of other representative and smaller earthquakes occurred in Italy. The final scope is to provide **shaking maps for all the historical earthquakes collected in CPTI-DBMI**.
- This work is published as an original article in Seismological Research Letters (Oliveti et al., 2023b). The **reference list** is available here.

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