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## **Reply on RC1**

Paola Sbarra et al.

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Author comment on "Inferring the depth and magnitude of pre-instrumental earthquakes from intensity attenuation curves" by Paola Sbarra et al., Nat. Hazards Earth Syst. Sci. Discuss., <https://doi.org/10.5194/nhess-2022-30-AC1>, 2022

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First of all, we wish to thank this anonymous Reviewer #1 for his/her comments, which we found very pertinent and stimulating. We will consider his/her detailed suggestions in the revised version of the manuscript, which will undoubtedly be improved in terms of clarity and readability.

Below we respond to the Reviewer's #1 main comments.

### **The article should be self-explanatory by itself**

This work extends the work by Sbarra et al. 2019 and includes a new experimental method to calculate the earthquake magnitude. We will make the work self-explanatory, avoiding to make reference to our previous work too often, and adding the necessary details.

### **Sections reorganization**

We will try to organize the manuscript following the suggestion of Reviewer #1.

### **Description of the catalogues**

We will add a brief description of all the catalogues used and cited in the text.

### **Qualitative nature of macroseismic intensity and use of average intensities and rational intensity values instead of integer values**

We will add a comment on the qualitative nature of macroseismic intensity.

In general, macroseismic intensity is far from being normally distributed, and we know that the different issues involved in treating the intensity as an integer or as a real number.

Macroseismic intensities are assigned after evaluating the effects of an earthquake at any

given location. The resulting estimate is an integer, although the half-degree is often used even in direct field surveys in case of uncertainty between two contiguous degrees. This latter approach implies that intensity values must be processed as real numbers and that an uncertain assessment is either approximated to a half-integer, as proposed by Gasperini (2001), or simply discarded from the data set, as proposed by Albarello and D'Amico (2004). Nevertheless, assigning macroseismic intensities using web-based questionnaires entails greater precision, because it involves using decimal intensities rather than simply integer values (Wald et al., 2006). It has been demonstrated that this procedure leads to lesser scatter than if the calculated intensities were truncated to integers (e.g., Dengler and Dewey, 1998; Dewey et al., 2002).

Thus, if on the one hand the macroseismic scales were designed as formed by a set of integer numbers, on the other hand, using decimal intensities allows for greater precision and lesser scatter. At any rate, both types of values must be dealt within our work.

**Both steepness and slope are used indistinguishably, but formally the meaning is different.**

We acknowledge the potential misunderstanding. We will always stick to 'steepness'.

**About the need to include some figures since both instrumental and macroseismic epicentres seem to be used in the catalogues**

We will add new figures and/or links to the openly accessible repositories that make available the macroseismic fields and source parameters for all the earthquakes analysed in this study.

We understand that we were not clear enough in explaining the different use of the "preferred" epicentral location as supplied by the CPTI15 catalogue for our analysed set. While the catalogue reports both an instrumental and a macroseismic epicentre, the choice of which of the two is the "preferred" is made on a case-by-case basis by the catalogue compilers. Nevertheless, to minimise the ambiguities that may arise from these circumstances we analysed only pre-1984 events, for the vast majority of which the compilers 5 selected the intensity-based magnitude as preferred (Rovida et al., 2021). While this may influence the results, we preferred to stick to the choice made by the compilers for a more direct comparison with our results, also on the grounds that CPTI15 is an official 'reference database' for Italy.

**Improve formal statistical validation of procedures and formal estimation of uncertainties.**

We already formally validated our procedure, at least partially, but we will add more checks and examples of our applications along with the associated errors.

**The possible distortion introduced by the instrumental epicentre/hypocentre in the computed distances and linear fits considering that the point where the**

## **fracture originates is not necessarily the point from which seismic wave energy radiates (Ground motion, macroseismic intensity).**

A change in the location of the epicentre indeed affects the estimation of depth and magnitude, to an extent that strictly depends on how big the change is. If the distance is in the order of 1-2 km, the resulting differences are negligible. This distance, however, may be larger for significantly bigger events, but our dataset does not include earthquakes larger than  $M > 6.5$ . We will add examples that clarify how the source parameters may influence our results.

## **Choice of crossover distance of 50 km even for such seismotectonic complex.**

In most cases, the trend of the attenuation curves for the 42 learning set earthquakes shows a substantial decrease in attenuation beyond an epicentral distance of about 50 km. This experimental result is confirmed by the work of Gasperini (2001) based on intensity data, and by Fah and Panza (1994), who used a numerical simulation of PGA attenuation, and was verified by Sbarra et al. (2019a), also based on macroseismic evidence. As shown by the attenuation curves given by the Intensity Prediction Equations (Fig. 7), 50 km is still a reasonable limit for a linear regression.

## **Learning set macroseismic data: How much does mixing HSIT and dedicated traditional studies affect the results of the learning set?**

The use of web-based data was fundamental to accomplishing our goals because these data were almost always the only available observations, especially for deeper earthquakes ( $> 30$  km). Furthermore, the use of macroseismic data obtained from direct surveys of earthquakes damage was fundamental for the correct analysis of the attenuation curves, especially in the epicentral area.

Intensity maps drawn for historical earthquakes exhibit more widespread damage patterns than those revealed by spatially-rich, web-based intensity data for similarly large events (Hough, 2013, 2014). This problem affects specifically those earthquakes whose effects are estimated through written sources. The same happens if only written sources (e.g., newspapers) are used to estimate intensities for recent earthquakes; they will inevitably be overestimated (Sbarra et al., 2010; Hough, 2014). The earthquakes included in our *learning set* are all relatively recent and the macroseismic field was estimated through a direct field survey, but, the problem delineated above does affect the *analysed set*. At any rate, assessing the quality of the macroseismic surveys available for historical earthquakes is beyond the scopes of this paper and will similarly affect the outcomes of any type of methodology designed to infer source parameters.

## **Uncertainties in location (epicentre/depth) in the learning set. Depth uncertainty is critical in the analysis.**

We determined the depth of the 42 events of our *learning set* based on an expert evaluation, after having discarded all the events whose depth had been fixed a priori. For each event of the *learning set* Table 1 of the first version of our manuscript reports the bibliographic source of its depth and magnitude. Whenever a specific study about a given earthquake exists, we used the relocated depth (if available). We ensured that our *learning set* contains only well-located instrumental earthquakes, i.e. events whose

location uncertainties are small (uncertainty of catalogue depth estimates is +/- 1 km in most cases).

**Fitting of the slope-depth function. The curve is not constrained for depths above around 35 with only few data. Also, while uncertainty in slopes is taken in account, depths are assumed not to be affected by uncertainty**

Yes, indeed. For distances larger than 35 km the uncertainty is inevitably greater. As a consequence, the confidence interval of EQ.3 in Figure 5 exhibits wider bounds, but it still provides valuable information on depth estimation, albeit within a larger error range. We will add a discussion to clarify this issue. We have neglected the uncertainty on instrumental depth because in most cases it is in the order of 1 km or less. See also the previous answer.

**Residual plots (Obs-Calc), not included in the manuscript, will greatly help to check for unbiased estimates of the empirical parameters.**

Although we are not sure which particular estimate the comment refers to, we will consider adding a figure in the supplementary material; at any rate, the instrumental parameters and those estimated by our method (for *learning set* events) are listed in Table S2.

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