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Camerino, Italy
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Dear Dr. Seda Yolsal-Çevikbilen,

Please find below our detailed responses to your comments on the manuscript entitled "***A workflow for the identification of earthquake sources from macroseismic data***" by Veronica Gironelli and co-authors.

Before addressing your comments, we would like to apologize for the inconvenience that occurred during the previous revision. During the submission of our detailed response to the Reviewers, the revised manuscript could not be uploaded because the "**Review File Upload**" option was not active in the system at that time. As a result, the version available for your evaluation was the original manuscript rather than the revised version in which the reviewers' comments had already been addressed.

The current submission includes the revised manuscript together with all the required files. In this revised version, we have carefully addressed both the reviewers' comments and your comments.

Thank you for your time and consideration.

Kind regards,

Veronica Gironelli
Corresponding Author

RESPONSE TO THE EDITOR

The authors are grateful to the Editor for the time dedicated to reviewing this manuscript and for the highly constructive comments, which have significantly helped to improve the clarity, visual quality, and overall impact of our work. All suggestions have been carefully addressed, and the manuscript has been revised accordingly.

General Comments

Comment 1: The manuscript is generally well prepared; however, some revisions are necessary, particularly concerning the contents of the sections (e.g. Introduction, Discussion, References) and the presentation of the results. First of all, I think that the quality of the figures needs substantial improvement. The text displayed on the maps is too small, making it difficult to read and interpret. In addition, the color scales, legends, symbols, active faults, and map layouts should be redesigned and standardized to enhance clarity and visual quality.

Reply: We thank the Editor for this comment. We would like to note that the revision of the figures had already been initiated in response to similar comments raised by Reviewer #1. Following both the Reviewers' and the Editor's suggestions, all figures (Figures 1 to 8) have been revised. Specifically, the font sizes of text labels and map legends have been significantly increased to improve readability. Furthermore, geographic coordinates (latitude and longitude) have been added to all the figures.

Comment 2: Another issue concerns the use of abbreviations throughout the manuscript. Throughout the manuscript, abbreviations are repeatedly written together with their full explanations, resulting in unnecessary repetition. Once an abbreviation has been defined, it should be used consistently throughout the text.

Reply: The entire manuscript has been thoroughly checked. All abbreviations (such as GMICE, BE, RMSE, and DISS) are defined only upon their first occurrence in the text. Thereafter, the acronyms are used consistently without further repetition.

Comment 3: I suggest that the manuscript would benefit from a broader review of the relevant scientific literature as the literature review in the manuscript appears to be rather weak. Including additional recent studies representing different datasets and methodological approaches would strengthen the scientific background of the study and provide a broader context for evaluating the proposed methodology. Besides, a more comprehensive discussion of these studies would enrich the discussion section and help to better emphasize the motivation, necessity, and scientific contribution of the present work.

Reply: We thank the Editor for this recommendation; we have expanded the literature review in the Introduction to better highlight the limitations of existing approaches and establish the necessity of our work (see lines 42-58). Furthermore, the Discussion section has been enriched

with a broader comparison against recent scientific literature, emphasizing the novelty, motivation, and scientific contribution of our proposed comprehensive workflow (see lines 548-580).

1. **Figure 1:** It would be better to write the geographical coordinates of the map (e.g. latitude and longitude). The 24 earthquakes (starred) are not seen clearly on the map. Please write “N” on the North symbol.

Reply: Following the Editor’s suggestions, Figure 1 has been thoroughly revised. A clear geographical coordinate grid (latitude and longitude) has been added along the map borders, and the letter "N" has been explicitly added to the North arrow. To improve the visibility, the symbols representing the 24 earthquakes with instrumental solutions have been changed with green stars. Additionally, following a related suggestion, we have split Figure 1 into two panels: Figure 1a displays the dataset, and a newly added Figure 1b provides the regional morphotectonic and administrative framework of Italy.

2. **Figure 2:** Please explain the black square plotted on the map. It would be better to write the date and location of the earthquake on the map (a).

Reply: We correct Figure 2 by clarifying that the black square indicates the specific boundaries of the zoom area depicted in panel (c). We added the location and the date of the earthquake as a reference. Furthermore, the geographic location ("Amatrice") and the date of the earthquake ("24 August 2016") have been explicitly labeled on panel (a) for immediate reference.

3. **Figure 3a,b:** a) The font of the text is too small. b) Please write a few locations on the map that will help readers identify the study area more easily. Furthermore, I recommend adding an inset map showing the position of the study area within Italy (see Figs. 5, 6)

Reply: Figure 3 has been modified as requested. The font size of all labels and legends has been significantly increased. Key localities reference names have been added directly to the map. Finally, a small locator inset map showing the exact position of the study area within the Italian peninsula has been integrated, ensuring visual consistency with Figures 5 and 6.

4. **Line 39:** Please provide the reference of “Bakun and Wentworth, 1997” in the references section.

Reply: We have added this citation to the reference list (lines 662-663).

5. **Line 40:** Please write “,” instead of “;” between 2019 and 2023 in the citation of Sbarra et al.

Reply: Corrected as recommended.

6. **Line 139:** There is no reference of “Dziewonski, 1981” in the References section.

Reply: We have added this citation to the reference list (lines 694-695).

7. **Line 766:** Please check the date of the citation/reference (1923 or 1932?)

Reply: The reference date has been verified and corrected (lines 857-858).

8. **The locations mentioned in the manuscript should be indicated on the maps to help readers identify and better understand the study area (e.g., Amatrice, Irpinia, Abruzzi,**

Molise, Calabria, Schio, southern Alps, the Po and Veneto plains, Posina, Besenello, Marche as such).

Reply: Following the Editor's suggestion, in the revised manuscript we introduced a new multi-panel layout for Figure 1: Figure 1b now illustrates the main physiographic structures (e.g., Southern Alps, Northern, Central, and Southern Apennines, Po Plain), tectonic lineaments, and the Italian administrative regions (with an explicit legend for the names). Localities associated with specific case studies, such as Amatrice, have been indicated in Figure 2, while Schio, Posina, and Besenello are now clearly labeled in Figures 6a and 6b.

9. Lines 215: The abbreviation of GMICE has already been explained in the text (see Line 31). Please check throughout the text.

Reply: Corrected. The redundant explanation has been removed from the text.

10. Line 285: "Between Event-BE" and "RMSE" have already been explained in the text (see Line 225, 226).

Reply: Corrected. The redundant explanation has been removed from the text.

11. Line 399: The abbreviation of DISS has already been explained in the text (see Line 208). Please check throughout the text.

Reply: Corrected. The redundant explanation has been removed from the text.

12. Line 400: It should be "reverse faulting".

Reply: Corrected.

13. Line 401: It should be "focal mechanism solution".

Reply: Corrected.

14. Line 186, 466, 471, 479, 497: Please indicate locations of Mt. Vettore fault system, Apennine fold-and-thrust belt, the Umbria-Marche ridge, Montiego thrust, Sassorotto and Col Lungo faults, Mt. Nerone fault system on the map.

Reply:

- **Mt. Vettore fault system:** The specific mention of this fault system has been removed from the text, as it represents a detail that is not useful and critical to the illustration of Figure 2.
- **Apennine fold-and-thrust belt:** This term refers to the macro-structural definition of the Northern-Central Apennine chain rather than a place name. To clarify this for the reader, an explicit reference to the newly added Figure 1b has been added to the text.
- **Umbria-Marche ridge:** To maintain consistency with the standardized regional nomenclature used in Figure 1b, this localized term has been replaced in the revised text with the definition of "Central Apennines".
- **Montiego thrust:** In Figure 8, we have updated the layout to explicitly trace the major frontal thrust lineaments of the Apennines. This includes the major regional thrust front (associated with the Monte Montiego anticline), which corresponds structure interpreted by the DISS database as the location of the source of the 1781 Cagli earthquake.
- **Sassorotto, Col Lungo, and Mt. Nerone fault systems:** Given the small-scale nature of these shallow normal faults, and to avoid introducing geological details that cannot be

properly represented at the map scale, all references to the Sassorotto and Col Lungo faults have been removed in the revised manuscript. Nevertheless, to preserve spatial context, we have included topographic peak symbols and labels for Mt. Nerone, which serve as reference points for these fault systems.

RESPONSE TO REVIEWER #1

1. **Abstract:** This study presents a methodology to constrain the sources of large earthquakes..." Additionally, please mention the novelty of integrating residual analysis with outlier detection in the abstract.

Reply: We thank the Reviewer for his/her suggestion. We have corrected the typo to the plural form ("large earthquakes") in the second sentence. Furthermore, as suggested, we have explicitly highlighted the novelty of our workflow by adding a dedicated sentence explaining the detection of intensity outliers through residual analysis based on an intensity prediction equation (IPE), (see lines 7-12).

2. **The literature review is extensive;** however, it may benefit from a short paragraph emphasizing the limitations of existing approaches and how the proposed workflow addresses them.

Reply: Following the Reviewer's suggestion, we briefly specified the request in the Introduction of the revised manuscript (see lines 51-58) and in the Discussion section (see lines 548-580).

3. **Some long sentences could be simplified for better readability,** particularly lines 50–65.

Reply: Following the Reviewer's comment, we revised the text by breaking long sentences and simplifying the sentence structure where appropriate (see lines 59-80 in the revised manuscript).

4. **The explanation of the pre-processing stage and outlier removal using the Gomez-Capera et al. (2024) IPE is scientifically sound.**

Reply: Thank you for the comment.

5. **The authors may consider discussing the sensitivity of the results to the selected 3σ threshold for outlier identification**

Reply: We specified in the text (see lines 121-125) the choice of the 3σ criterion (2.25 intensity units) for the identification of intensity outliers. This value ensures the removal of extremely large outliers, without reducing the data set excessively.

6. **The methodology would benefit from a small flowchart legend explaining abbreviations such as BE, RMSE, GOM20, and OLI22 for readers unfamiliar with the terminology**

Reply: In the revised version of the methodological workflow (Figure 4), we have fully expanded the acronyms and explicitly defined the meaning of the abbreviations (GMM, GMICE, BE, RMSE, GOM20, and OLI22) directly within the figure text boxes and their captions to ensure maximum readability.

7. **The choice of Wells and Coppersmith (1994) scaling relations is appropriate, but the limitations of applying these empirical relations to historical earthquakes could be briefly discussed.**

Reply: We specified in the revised manuscript the limitations of applying these empirical relations to historical earthquakes (see lines 226–228).

8. **The discussion of the 1990 Potenza earthquake clearly illustrates how outliers can bias epicentral estimation.**

Reply: Thank you for the comment.

9. In Tables 3 and 5, it may help readers if the best-performing source configurations are highlighted using bold formatting in addition to the asterisk

Reply: Following the Reviewer's suggestion, we have highlighted in bold the best-performing source configurations in Tables 3, 5, and 7 to improve readability.

10. Some figure captions are very long and may be shortened for improved readability.

Reply: Following the Reviewer's comment, we have revised and shortened all the figure captions (Figures 2 to 8) as much as possible to improve readability. In addition, table captions were also edited to reduce redundancy and ensure a more concise and consistent presentation throughout the manuscript.

11. Increase font size in several figures (especially residual maps and legends), as some labels are difficult to read

Reply: We agree with the reviewer's comment, and we have revised all the figures to ensure better readability. Specifically, the font sizes of the labels, text, and map legends have been increased in Figures 2 to 8.

12. Table formatting could be improved slightly for better alignment of columns and readability

Reply: The table formatting has been revised by standardising the decimal precision of numerical values to improve visual consistency.

RESPONSE TO REVIEWER #2

1. Title: I'm in doubt... Maybe the title should be "A methodology for...". Then, in the article body, on presenting the methodology, there is a workflow to be followed. Maybe the editor has a better view about what to use.

Reply: Thank you for this suggestion. To better reflect the methodological nature of the study, we have revised the title to: "A methodological workflow for the..."

2. Lines 38/39.- Citations (Gasperini and Ferrari, 1995, 2000) are not in the reference list.

Reply: We have added this citation to the reference list (see lines 724-726 and 729-731).

3. Lines 75 and 86.- At line 75 you mention the IPE of Sibol (1987). It is used in Boxer. In line 86 you are referring the IPE of Gomez-Caper at al. (2024). I assume you are using the last one to generate the synthetic IDP; but not in Boxer. Am I right?? Using one IPE for earthquake parameters and another for synthetics does not look very nice (or coherent). I agree it is the easiest way. Other way, you should recompile Boxer.

Reply: We agree with the reviewer's comment. We adopted Boxer for consistency and comparison with the CPTI catalogue, which is based on it. The recompilation of Boxer is out of the scope of this paper. In addition, Boxer algorithm is specifically designed to use Sibol's functional form, which explicitly takes epicentral intensity into account and separately considers the attenuation of each intensity degree as a function of each isoseismal area.

4. Line 137.- Citation (Tinti et al, 2016) is not in the reference list.

Reply: We have added this citation to the reference list (see lines 871-873).

5. Line 174.- I think citation (Pondrelli, 2002) is wrong.

Reply: We would like to clarify that the citation "Pondrelli, 2002" refers to the reference of the RCMT catalogue, a dynamic dataset from which the Mw value was retrieved and not to the determination of the moment magnitude of the 2016 Amatrice earthquake. The adopted citation follows the reference provided by the authors of the dataset on the official webpage <https://data.ingv.it/dataset/197#additional-metadata>.

6. Line 176.- Maybe on citing Rossi et al, (2019) it should be indicated these data will be called ROSAL019 here. Otherwise, ROSAL019 is found for the first time in figure 3 caption.

Reply: We agree with the reviewer's suggestion. We have added in the text of the revised manuscript (see line 197), the acronym "ROSAL019" alongside the citation of Rossi et al. (2019).

7. Lines 221/223.- It will be good to give a reference for the problem of saturation exhibited by OLI22.

Reply: We agree with the Reviewer' suggestion. We revised the statement in the manuscript by clarifying that the observed saturation behaviour of OLI22 equation refers to the quadratic

formulations of the GMICEs proposed by Oliveti et al. (2022), whose regression curves tend to flatten at high PGA and PGV values (see lines 241-244).

8. Lines 230/231.- Are you fixing thresholds for BE and RMSE arbitrarily or have you some previous experience on this topic.

Reply: The thresholds for BE and RMSE errors were chosen to maintain an acceptable comparison between observed and predicted intensity values. This choice specifically considers the intrinsic uncertainty of macroseismic intensity data, which is of ± 1 degree. A Between-Event error of ± 0.5 represents a conservative criterion, corresponding to a maximum discrepancy of only half an intensity degree compared to the observed value. We specified this in the revised text (see lines 251-256)

9. Line 281.- Citation (Westaway et al, 1989) is not found in the reference list.

Reply: We have added this citation to the reference list (lines 888-890).

10. Lines 310/314.- Thus, your choice is META_04 because META_007 does not fit properly with the geological setting, isn't it??

Reply: Yes, that is correct. The selection process of the best-fitting seismogenic source is based on both statistical performance and geological consistency. Although META_007 shows a good fit with macroseismic observations, providing the lowest BE_i and RMSE_i values among the sources derived from macroseismic parameters, its fault trace is not consistent with the active fault structures mapped in the study area. Conversely, META_004 satisfies the adopted thresholds and shows the best agreement with the Barrea–Castelnuovo fault system.

11. Lines 328 and 344.- See note about Pondrelli in the reference list.

12. Lines 683/685.- For coherence with the body text (line 327), this reference should start as OGS-RSFVG, Istituto...

Reply: The reference has been modified in the bibliography of the revised manuscript (see lines 802-804).

13. Line 688.- Again, for coherence with the body text (line 140), this reference should start as ISC, International...

Reply: The reference has been modified in the bibliography of the revised manuscript (see lines 758-759).

14. Lines 745/749.- It should be clarified which article is “Pondrelli et al, 2006a and 2006b”. Check also in the body text.

Reply: We have checked and resolved the ambiguity regarding the citations “Pondrelli et al., 2006a” and “Pondrelli et al., 2006b” both in the body text and in the bibliography. In the revised manuscript, the citations have been revised accordingly by referring to the Italian CMT Dataset. The official reference for the dataset (<https://doi.org/10.13127/rcmt/italy>) has been adopted in the reference list.

15. Lines 798/802.- Please, check alphabetical order.

Reply: We have checked the bibliography and corrected the alphabetical order of the references in this section.