Consiglio Nazionale delle Ricerche

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To the Handling Editor
Dr. Ugur Öztürk

Perugia, Italy, 27 May 2026

Subj.: Re-Submission of a manuscript to ***Natural Hazards and Earth System Sciences***

Dear Editor,

this cover letter is to go with the re-submission of the manuscript entitled "***A century of landslide records in Calabria, southern Italy, looking for changes and trends through a dynamic analysis***", by Stefano Luigi Gariano and Olga Petrucci, for possible publication in the journal ***Natural Hazards and Earth System Sciences*** as a ***Brief Communication***.

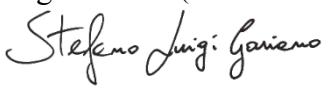
The manuscript was revised according to the valuable comments from the two reviewers. We sincerely thank them.

Below, we provide our point-by-point responses to the reviewers' comments, alongside the revised manuscript with all tracked changes. For ease of reading, our responses to **Reviewer #1** and the corresponding manuscript modifications are in **blue**. Replies and changes related to **Reviewer #2** are highlighted in **green**.

We added a new figure, following the advice from Reviewer #1 and some references according to the comments of both referees. Moreover, we added new text to address the reviewers' comments.

We look forward to hearing your decision soon.

Yours sincerely,
Stefano Luigi Gariano (on behalf of all authors)



Reply to Reviewer #1, Francisco Dourado

Below is our reply to the comments from the reviewer #1, Francisco Dourado. We report the comments from the reviewer in black and our replies in blue.
We sincerely thank the reviewer for his careful review of our paper and his insightful comments.

RC1: 'Comment on egusphere-2026-621', Francisco Dourado, 23 Feb 2026

The manuscript is an update of the data window (+10 years) of the paper presented by Gariano (2015). Gariano's (2015) work was an important milestone for understanding the spatial distribution of landslides and the relationship between rainfall intensity and landslides. This manuscript is an important update of this relationship between rainfall intensity and landslides.

The author points out his main doubts about the representativeness of the results (regarding the spatial and temporal distribution of the data).

R: We thank the reviewer for his positive comment on this work, and on our previous work too. As mentioned by the reviewer, we wanted to clearly highlight the pros and cons of the data used and the results obtained.

In addition to what was indicated by the author, the following doubts remained:

The Calabria region has a very large topographic variation, and I believe that the behavior of the rainfall distribution in the western (coastal) portion of the region is different from the distribution in the eastern (coastal) region. Thus, if there was a distribution of new gauges in a given region, the climatological analysis may present an artificially forced trend. It would be important for the author to present a map showing the distribution of the gauges, highlighting the new equipment added in this study, as well as a map of average annual rainfall recalculated with the new gauges. If possible, a comparative map showing the difference between the current map and the previous map (2015) should also be presented.

R: We thank the reviewer for this comment. Indeed, the rainfall distribution along the two sides of the region is different. Regarding the rain gauge number and distribution in the region, we have checked it and we haven't found any significant increase in the last 10-year period (2011-2020) compared to the preceding ones. Overall, only 13 new stations were installed in the region after 2011, out of a total number of 135 gauges currently operational. Of these, 8 gauges were operational only in 2016, 2017, and 2018.

We have prepared a new figure with a map showing the distribution of rain gauges used in the work, highlighting the ones currently operating. Moreover, the same map shows an updated map of average annual rainfall recalculated with the rainfall measurements in the period 1921-2020. Comparing this mean annual rainfall map with the one shown in our previous work (Figure 1b of Gariano et al. 2015), no significant changes can be found.
Another panel in the same figure shows the number of operating rain gauges per year in Calabria between 1920 and 2020 (updating Figure 1c from Gariano et al. 2015). It can be seen that overall the number of operating rain gauges in the region has not significantly changed after the year 2000, when the network was transferred from national to regional management and when automatic stations were installed and old stations were dismissed.

This new figure is added in the manuscript as new Figure 1.

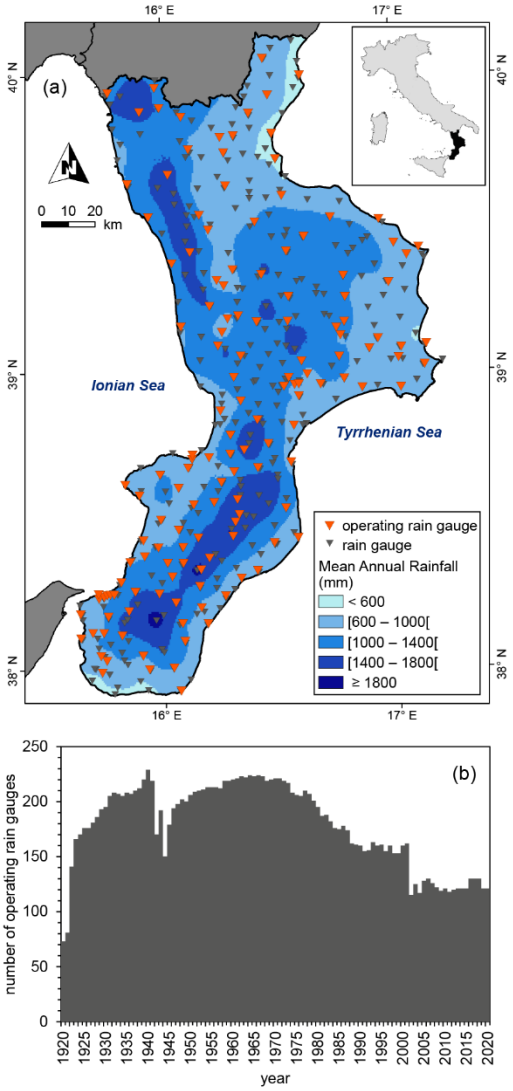


Figure 1. (a) Map of mean annual rainfall in Calabria region, in five classes, and distribution of rain gauges used in this work. (b) Number of operating rain gauges per year in Calabria between 1920 and 2020. Updated from Gariano et al. (2015).

Moreover, we added new text in the manuscript to describe and elaborate on this new figure. The new text, added in the Data and in the Conclusion sections, reads:

Lines 82-42. "*The study area is the Calabria region, located in southern Italy with an extension of 15080 km2 and characterized by elevations ranging from 0 to 2260 m a.s.l. and mean annual rainfall ranging from less than 600 mm in the coastal plains to more than 1800 mm in the inland mountains (Figure 1a).*"

Line 102-108. "*To calculate the REs, we used daily rainfall measurements captured by a network of overall 318 rain gauges across Calabria from 1 January 1921 to 31 December 2020, whose distribution is shown in Figure 1a. The number of operating rain gauges varied over time with a peak (more than 200 stations) in the 1930s, and between 1950 and 1975 (Figure 1b). Since 2000, the number of operating stations has settled at around 135. There have been no significant changes in the number and distribution of rain gauges over the recent 10 years (2011–2020) compared to the previous decade (2001–2010). In addition, Figure 1a shows the map of the mean annual rainfall in the region calculated using rainfall measurements from 1921*

to 2020. No relevant variations can be observed with respect to the map produced by Gariano et al. (2015) using data from 1921–2010."

Line 226-226. "*No significant variations in the number and distribution of rain gauges over the recent 10 years (2011–2020) compared to the previous decade (2001–2010) can be observed (Figure 1b)."*

We haven't added other discussion on this issue, given that the aim of this work is to analyze only temporal changes in landslides occurred in the region in the period 1921–2010, rather than investigate spatial variations.

The question remains whether the increase in recorded landslide events is actually related to an increase in the frequency of extreme events, or whether this increase in recorded events is related to increased human occupation of the region and, consequently, an increase in the number of observers of these events

R: The reviewer points out a relevant issue in historic data collection from chronicle and technical sources over large areas, such as a whole administrative region as in our case. Indeed, our dataset is composed of landslides that have somehow caused some damage to the population, structures, and infrastructure, as to be reported in a chronicle or mentioned in technical reports. Thus, all landslides in our catalogue had some relations with (increased or decreased) human occupation of the region.
However, this limitation is widely acknowledged in literature and is intrinsic to documentary data sources, which nonetheless remain the only available source of information for reconstructing dated historical landslide events over long periods, in our case. On the other hand, geomorphological landslide inventories derived from aerial photographs or field mapping represent only a static snapshot of slope conditions at the time of the survey or image acquisition and generally do not provide an accurate date (year-month and day) for landslide initiation.
Historical documentary sources, despite their well-known limitations, make it possible to temporally constrain landslide occurrences and therefore to carry on temporal analyses and identify the potentially triggering rainfall events. This represents a key prerequisite for investigations such as the one presented in this paper, which aims to analyze the changes in rainfall conditions associated with landslide triggering.
This said, we collected the population data in the region available from national Censuses conducted by the Italian National Institute of Statistics (ISTAT – www.istat.it). In the 1920s and 1930s, the number of residents stood at around 1.7 million; since the 1951 census, however, the regional population has remained steady at around 2 million, with a slight downward trend beginning at the start of this century. Therefore, we could say that the increasing trend in the recorded landslide events is not related to the human occupation of the region. However, the higher number of landslides recorded in the main provincial capitals highlights on the one hand more comprehensive information in areas with more citizens (residents and workers), also linked to demographic trends in the analysed period, with a large proportion of the population that has moved to the main towns and, consequently, an increase in the number of people witnessing the landslides.

We added new text in the discussion to elaborate on this issue. The new text reads:

Lines 191-198. "*The general increase in the number of RELs during the years should not be linked to the overall human occupation of the region; indeed, an examination of the population data available from Censuses conducted by the Italian National Institute of Statistics shows that, between 1921 and 1951 the number of residents has raised from around 1.7 million to 2 million and then has remained steady over the decades, with a slight downward trend beginning at the start of the 21st century. The high number of RELs recorded in the main provincial capitals highlights on the one hand more comprehensive information in areas with more citizens (residents and workers), also linked to demographic trends in the analysed period,*

with a large proportion of the population that has moved to the main towns and, consequently, an increase in the number of people witnessing the landslides."

In conclusion, being aware of the pros and cons of documentary, historic data, and to avoid biased results, please note that our analyses and interpretations of changing landslide activity made in the work were mostly focused on the variations in triggering conditions rather than on the total number of landslides.

References:

Gariano, S. L., Petrucci, O., and Guzzetti, F.: Changes in the occurrence of rainfall-induced landslides in Calabria, southern Italy, in the 20th century, Nat. Hazards Earth Syst. Sci., 15, 2313–2330, https://doi.org/10.5194/nhess-15-2313-2015, 2015.

Reply to Reviewer #2, Bei Zhang

Below is our reply to the comments from the reviewer #2, Bei Zhang. We report the comments from the reviewer in black and our replies in green.

We sincerely thank the reviewer for careful review of our paper and insightful comments.

RC2: 'Comment on egusphere-2026-621', Bei Zhang, 29 Apr 2026

Taking the Calabria region in southern Italy as the study area, this paper systematically analyzes the spatiotemporal distribution patterns of rainfall-induced landslide events and the long-term evolutionary trends of their triggering conditions, based on a century-scale (1921–2020) landslide inventory and rainfall observation data. Overall, the study is supported by solid data, rigorous methodology, sound logic, and reliable conclusions. A few suggestions for revision are provided below for your reference:

R: We thank the reviewer for this positive comment and his review of our work.

Line 23: The opening sentence states that historical documentary data represent the principal source of information on landslide occurrences for implementing empirical models. As this is a broad statement, it would be helpful to support it with relevant references. Suitable examples include documentary/event catalogues such as FraneItalia and ITALICA e.g., Calvello and Pecoraro (2018), Peruccacci et al. (2023). In addition, recent studies that used documented landslide occurrences to define empirical rainfall thresholds for landslides in southern Italy may also be relevant, e.g., Zhang et al. (2025, 2026).

R: Since both of us have been working for years on historical documentary data, mostly on landslides and floods (the first author is also co-author of ITALICA), we sincerely thank the reviewer for this comment.

We add the two references related to landslide catalogues – FraneItalia and ITALICA; i.e. Calvello and Pecoraro (2018), Peruccacci et al. (2023) – in the manuscript (Line 26). We thank the reviewer for suggesting the other studies that used documented landslide occurrences to define empirical rainfall thresholds for landslides in southern Italy. However, we prefer to do not add these two references given that they are out of the scope of the manuscript (the thresholds we are defining here are not to be used for operational landslide prediction) and, moreover, they pertain to a region in southern Italy (Campania) that is different from the one analyzed here (Calabria). If we had to mention all the articles that have used documented landslide occurrences in southern Italy (or even just in Calabria) to develop predictive tools such as rainfall thresholds, we would have to cite at least twenty articles. Therefore, we prefer not to cite these two studies, even though we consider them very interesting.

Line 110–112: The manuscript reports a considerable increase in the number of RELs starting in 2009 and notes that the last two 30-year moving windows contain more than twice as many events as the previous ones. However, the authors also acknowledge that the recent increase may be partly related to the greater availability of online information sources. I suggest discussing more explicitly how much of this increase may reflect improved reporting and data collection rather than a real increase in landslide occurrence. This distinction is important because the observed increase in RELs is later used to support broader interpretations of changing landslide activity.

R: We agree with the reviewer; indeed, we have explicitly mentioned in several places in the text that the increase in records in recent years is certainly also linked to the greater availability of information, particularly online. On the other hand, however, there can be no increase in information about landslides if

there are no landslides. Indeed, we would like to emphasize that in the decade from 2011 to 2020, the Calabria region was hit by numerous intense weather events that have caused widespread landslides in the regional territory, as we have mentioned by citing various studies (in this new version of the manuscript we add new references on events occurred in the region in the mentioned decade - Antronico et al., 2013; 2017). Therefore, it is certainly both factors that have contributed to the increase in records. Moreover, it should be remarked that this increase in documentation occurred despite a slight decrease in the regional population over the same period.
We added this new text in the discussion, at Lines 2024-205: "*Notably, this increase in documentation occurred despite a slight decrease in the regional population over the same period.*"

As regards the interpretations of changing landslide activity, we remark that we focused more on variations in triggering conditions than on the total number of landslides, to avoid such issues. Analyses of triggering conditions, using 30-year moving windows, have enabled us to obtain robust results even in the face of such variations in the amount of data.

Line 43–47 and Line 77–79: The use of 30-year moving windows with a 5-year step is an interesting methodological improvement compared with the previous static-period analysis. However, adjacent windows strongly overlap and therefore are not statistically independent. The authors should briefly acknowledge this dependence when interpreting temporal trends in threshold parameters and triggering rainfall conditions. This would help avoid overinterpreting small fluctuations between consecutive windows as independent temporal changes.

R: We thank the reviewer for this insightful and constructive comment. We agree that the presented approach introduces an overlap, with around 80% of shared data between consecutive windows. Our primary goal with this dynamic analysis was to capture the long-term changing trajectory of the triggering conditions over the century, rather than interpreting minor fluctuations between consecutive windows as distinct temporal changes. To address this concern and prevent any overinterpretation of minor variations, we have added a brief clarification in the revised manuscript (Section 4, Discussion) explicitly acknowledging this statistical dependence.

The new text reads:
Lines 169-173. "*However, it must be acknowledged that the use of 30-year windows with a 5-year step results in adjacent periods that share 25 years of overlapping data and therefore are not statistically independent. Consequently, minor fluctuations between consecutive windows should not be overinterpreted as independent temporal changes; rather, the focus of this analysis is strictly on the broad, long-term evolutionary trends observed across the entire century.*"

Line 59–62 and Line 182–193: The manuscript clearly explains that daily rainfall data were used because this is the only temporal resolution available over the full century. However, the use of daily rather than hourly rainfall data may strongly affect threshold estimation (Gariano, 2020). Although this limitation is discussed later, I suggest mentioning it earlier in the Methods or briefly in the Abstract/Conclusions. This would make clearer from the beginning that the thresholds are mainly intended for long-term comparative analysis rather than operational early warning.

R: We accept this suggestion and modify the text by adding in the Method and in the Conclusions section the following sentences:
Lines 79-80 (in the Method). "The threshold calculation is made in this work with the sole purpose of long-term comparative analysis and without aiming to operational landslide prediction."

Lines 241-243 (in the Conclusions). “However, rainfall thresholds derived from low-resolution rainfall data (i.e., daily measurements) can be used for long-term comparative analysis but suffer from uncertainty and underestimation, which hinders their practical application in operational landslide prediction.”

Line 138–140 and Line 210–212: The conclusion that less rainfall was progressively needed to initiate landslides, and that the territory has become more prone to landslides, is interesting but should be expressed with caution. Because the landslide catalogue is based on documentary sources, changes in reporting practices, urban exposure, information availability, and source completeness may also influence the apparent triggering conditions. I suggest slightly qualifying this statement, for example by stating that the results “may indicate” or “are consistent with” an increased territorial propensity, rather than presenting it as a definitive outcome.

R: We thank the reviewer for this comment and agree with him on the caution needed in this statement. We revised the sentences accordingly.

The new text reads:

Lines 152-154. “A finding that **may indicate** that less rainfall was progressively needed to initiate landslides in the region, i.e. the regional territory has **likely** become more prone to landslides, over the decades.”

Lines 235-237. “These general findings on the one hand suggest a change in rainfall patterns triggering landslides in the region and on the other hand **may indicate** an increased propensity of the territory to generate landslides, even with less severe triggering rainfall events, likely driven by a combination of climate change and anthropogenic factors”

Figure 2 caption and Line 137–150: Please check the consistency between the text and the caption of Figure 2. The main text discusses threshold values for durations of two and four days, and Table 1 reports E at 2 days and E at 4 days. However, the caption of Figure 2 refers to “durations of one and two days.” This appears to be an inconsistency and should be corrected.

R: Thank you for pointing out this issue. There was an error in the caption of former Figure 2 (now Figure 3) – the correct durations are two and four days, as indicated in the main text and in Table 1. We have now corrected the error in the caption.

References:

Antronico, L., Borrelli, L., and Coscarelli, R.: Recent damaging events on alluvial fans along a stretch of the Tyrrhenian coast of Calabria (southern Italy). Bull. Eng. Geol. Environ. 76, 1399–1416, https://doi.org/10.1007/s10064-016-0922-2, 2017

Antronico, L., Borrelli, L., Coscarelli, R., Pasqua, A.A., Petrucci, O., and Gullà, G.: Slope movements induced by rainfalls damaging an urban area: The Catanzaro case study (Calabria, southern Italy), Landslides, 10, 801–814, https://doi.org/10.1007/s10346-013-0431-3, 2013

Calvello, M., and Pecoraro, G.: FraneItalia: a catalog of recent Italian landslides. Geoenviron. Disasters 5, 13, https://doi.org/10.1186/s40677-018-0105-5, 2018.

Peruccacci, S., Gariano, S. L., Melillo, M., Solimano, M., Guzzetti, F., and Brunetti, M. T.: The ITAlian rainfall-induced LandslIdes CAtalogue, an extensive and accurate spatio-temporal catalogue of rainfall-induced landslides in Italy, Earth Syst. Sci. Data, 15, 2863–2877, https://doi.org/10.5194/essd-15-2863-2023, 2023.