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Natural Hazards and Earth System Sciences
Discussions
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Interactive comment on "Changes in the occurrence of rainfall-induced landslides in Calabria, Southern Italy, in the 20th century" *by* S. L. Gariano et al.

S. L. Gariano et al.

gariano@irpi.cnr.it

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Replies to Referee #1 (R1)

R1: This study presented temporal and geographical variations of landslide occurrences in Calabria, Southern Italy. The authors analyzed the relation between 1466 rainfall events with landslides and the population from 1921 to 2010. This paper is interesting for the evaluation of spatiotemporal changes of landslide occurrences based on longterm landslide and rainfall datasets. However, I have questions regarding data quality and the method that would need to be verified by authors.

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Reply: We thank Anonymous Referee #1 (R1) for considering our work “interesting for the evaluation of spatiotemporal changes of landslide occurrences based on longterm landslide and rainfall datasets”. R1 has questions on the quality of the (landslide and rainfall) data, and on the methods of analysis. We respond to these questions below. Here we point out that the questions rose, although legitimate and meaningful, were already considered in our analyses and do not affect the interoperation of the results significantly. We now clarify the issue at several points in the text.

We further acknowledge that our analyses are preliminary, are not exhaustive or conclusive, and that more sophisticated analyses can be performed (e.g., doi:10.1002/esp.1858, doi:10.1002/esp.1998). This was not clear before, and – indeed – needed clarification. We have added language at the end of the Discussion (page 3600) to clarify the point. The new text reads, “We recognize that multiple factors have conditioned the results of our analyses and the discussion. These include (i) the completeness of the landslide catalogue, (ii) the reliability and homogeneity of the rainfall records, (iii) the length (90 years) of the catalogue, (iv) the number (3) and length (30 years) of the segmentation periods of the catalogue, (v) the modelling tools and parameters used to single out the RE and the REL, and (vi) to determine the rainfall thresholds. More sophisticated statistical techniques may also be used to analyse the catalogues of landslide events, of rainfall events, and of rainfall events with landslides (Rossi et al., 2010; Witt et al., 2010). For these reasons, we acknowledge that our results are preliminary”.

Major comments

R1: 1. I concerned qualities of the landslide catalog and rainfall data which were not verified by authors. For the time series analysis of rainfall data, validation of the homogeneity is necessary. In general, quality and accuracy of time series rainfall data have heterogeneities caused by improvements of the rain gauge system. For example, the minimum rainfall value observed by a rain gauge affect to the rainfall duration and cumulated event rainfall. It would be better to check the time series quality and accuracy

NHESSD
3, C1751–C1764, 2015

of daily rainfalls.

Reply: R1 poses questions concerning (a) the quality of the landslide and the rainfall information, and (b) the homogeneity (or lack of homogeneity) in the rainfall records. We respond to the two questions separately.

Concerning the quality of the landslide information, R1 argues that the landslide catalogue was not "verified" by us. It is rather difficult to respond to the criticism, because R1 was not clear in explaining what kind of verification we should have performed. The criticism is related to the second major point raised by R1 on the level of "incompleteness, bias and uncertainty" of our historical catalogue (see below). Overall, R1 is skeptical that historical information can be used to (a) construct reliable time series (historical records) of natural events and (b) the constructed time series can be used to perform sensible analyses, as these would be biased by incompleteness. We argue our case in more detail below, and here we point out that (i) we are aware of the problems related to the compilation of historical catalogues of landslide events from historical sources, but we maintain that this remains a fundamental – and in many cases the only – tool to construct time series of landslide events, (ii) it is virtually impossible to "validate" – as requested by R1 – and historical catalogue of landslide events, simply because independent information on the events is not available, (iii) we have addressed the issue of the completeness of the catalogue using the standard methods used in the literature to measure the (relative) completeness of a catalogue (i.e., constructing the cumulative chart shown in Figure 2b), (iv) it is not possible to determine an absolute value of completeness of an historical record, simply because lack of information on the record may be do to the fact that the historical events did not occur or were not reported, (v) the historical catalogue used in our work is the result of a long (multi-annual) compilation and review process, documented by a number of papers listed in the text (section 5.1, page 3586, lines 10-11), (vi) we acknowledge in the text (section 2, page 3583, lines 8-11) that "the completeness and quality of the landslide records varies with time (Petrucci and Pasqua, 2008; Petrucci and Gullà, 2010), depending on the abundance and type of the historical and recent sources, and the skill of the investigators (Lang et al., 1999; Guzzetti et al., 2005a)”, (vii) we acknowledge in the text (section 5.1, page 3587, lines 17-20) that the landslide catalogue is more complete in the period 1950-2010 than in the period 1910-1950, and (viii) for most of our analyses we separate the 90-year period covered by the catalogue in three 30-year sub-periods, and we show the results separately (e.g., in Figure 3, Figure 6, Figure 7, Figure 8).

Concerning the possible heterogeneity in the rainfall records, we acknowledge that this problem was not addressed in the text, and should be addressed. However, we disagree with R1 that “validation of the homogeneity is necessary”, in this work. Instead, we analyze the causes of the homogeneity and the possible effects of the homogeneity on our analyses, and on the related discussion of the results. First, we clarify that we obtained the database of rainfall measurements from the “Centro Funzionale Multirischi” of the Environmental Protection Agency of Calabria (ARPACAL, http://www.cfd.calabria.it/). ARPACAL distributes the rainfall data following proper validation. We maintain that this reduces heterogeneity, and its negative consequences. Second, we consider the results of a study of climate variations in Calabria between 1916 and 2006 (doi:10.1002/joc.2233). The authors of the study have analysed 173 rain gauges pertaining to the same database of rainfall measurements used in our study, and found that the rainfall records were homogeneous for 50% of the gauges, and required some homogenization for 24% of the gauges. For 26% of the rain gauges homogenization was not possible, and the rain gauges were not used for the climatic analysis. The “gap filling” procedures used to homogenize the rainfall records for climatic research (Brunetti et al., 2012) may not be effective for short-duration, intense and localized rainfall events. Our work is based on daily measurements, or short sequences of daily measurements, and we therefore expect that the number of rain gauges characterized by homogeneous records is larger. We have added text to Section 5.2, Catalogue of rainfall events (page 3588, after line 6), to address the issue of the heterogeneity in the rainfall records. The new text reads, “We adopted strategies to consider and mitigate the effects of the heterogeneity inherent to the rainfall measurements. We obtained the database of rainfall measurements used in the study from the "Centro Funzionale Multirischi" of the Environmental Protection Agency of Calabria (http://www.cfd.calabria.it/) that distributes the data after validation. This contributes to reduce heterogeneity. In a study of climate variation in Calabria between 1916 and 2006, Brunetti et al. (2012) analysed 173 rain gauges from the same rainfall database, and found that the rainfall records were homogeneous for 87 rain gauges (50%) and required homogenization for 42 rain gauges (24%). The other 44 rain gauges (26%) were discarded for the climatic research. Our work is based on daily measurements or short sequences of daily measurements. We therefore expect that the number of rain gauges characterized by homogeneous records is larger. Also, the "gap filling" procedures used to homogenize the rainfall records for climatic research (Brunetti et al., 2012) may not work effectively for short-duration, intense and localized rainfall events. Different rain gauge stations may have different measurement accuracies, affecting the minimum measured rainfall, a possible cause of heterogeneity. We note that all the rain gauges used in our study have the same nominal accuracy (0.2 mm). This contributes to reduce heterogeneity. To mitigate further the effects of heterogeneity caused by the use of different measuring instruments at the same location, we excluded from the analyses the measurements obtained by the new automatic gauges. Where new gauges replaced old gauges the historical rainfall record was interrupted, and we used only the part of the record obtained by the old gauges."

R1: 2. As authors described, this kind of landslide catalog generally has incompleteness, bias and uncertainty. Additionally, the distribution and number of landslide reports may have a correlation of the distribution and number of population. I concerned that some of results and discussion, such as section 7.3, were affected by these incompleteness, bias and uncertainty of the landslide catalog. I would like see more information and validation of the landslide catalog.

Reply: We are aware of the problems and difficulties related to the use of historical records of landslide events, and we understand the concerns of R1. In the text, (section 2, page 3583, lines 8-11), we acknowledge that "the completeness and quality of the landslide records varies with time (Petrucci and Pasqua, 2008; Petrucci and Gullà, 2010), depending on the abundance and type of the historical and recent sources, and the skill of the investigators (Lang et al., 1999; Guzzetti et al., 2005a)". We base our analyses of historical landslides in Calabria on what is now a consolidated literature on the collection and exploitation of historical information on natural hazards and their consequences, including landslides. In the modern literature on natural hazards historical sources are widely used to construct time series of events, including earthquakes [e.g., doi:10.1785/0120040007, doi:10.1007/s10950-013-9379-y, doi:10.6092/INGV.IT-CPTI11], landslides [e.g., doi:10.1007/bf02400865, doi:10.1007/978-3-642-31310-3_56, doi:10.1002/esp.1858], floods [e.g., doi:10.1023/b:nhaz.0000024895.48463.eb, doi:10.1016/j.jhydrol.2005.02.001, doi:10.1007/bf02400865, doi:10.1007/s10346-013-0448-7], and volcanic eruptions [e.g., doi:10.1016/j.jvolgeores.2008.09.020, doi:10.2307/504292]. Despite well-known problems, analysis of historical sources remains the foundation for the construction of historical records of hazardous events. In places, there are no other means (current or foreseeable) to obtain historical records of natural events, except probably for searching and interviewing eyewitnesses, but this is limited in space and time, necessarily.

For floods, even for the most recent years, historical / chronicle data represents a unique source of information for many ungauged basins. The importance and usefulness of historical information for flood frequency / risk analysis was recognized even by the European Parliament, that with the Directive 2007/60/EC has imposed to all member states and for each river basin district, to "prepare a description of the floods which have occurred in the past and which had significant adverse impacts on human health, the environment, cultural heritage and economic activity and for which the likelihood of similar future events is still relevant [. . .] and a description of the significant floods which have occurred in the past, where significant adverse consequences of similar future events might be envisaged". Similarly, historical data are widely used to investigate earthquakes occurred before modern seismic networks were available. It is recognized that many of these historical earthquakes would go undetected without the analysis of the available historical information. For landslides, the use of historical information is, if possible, more important than for floods and earthquakes, and this is because no systematic “measurement” of landslides and their activity exists over large areas (doi:10.1002/esp.1858). Thus, analysis of recent and old chronicles remains the only “tool” to construct records of landslide events in a region.

Certainly, problems exist with the collection, organization and use of information obtained from historical sources. Some of the most common problems depend on issues that cannot typically be modify or controlled by the investigators, including:

- The search for historical information can never be considered complete, because accidental factors (e.g., natural and human induced events, fires, inundations, robberies) can result in loss of documents and related valuable information. Information sources in inaccessible archives may result in gaps in the time series.

- Landslides that have occurred in unmanned areas may have gone undetected, because no one noticed them or claimed the damage. In the geomorphological community there is a general consensus on the fact that there is little hope to construct a fully complete record of landslides that have occurred in the distant past. In Italy, and elsewhere in Europe, landslide inventories have become common since the 1970/80s, and were uncommon before. In the past, scientific papers were rare, and focused on single landslides. In the scientific papers, the timing of the landslides was rarely given, hampering the construction of historical records [doi:10.1007/BF02400865, doi:10.1002/esp.1858].

- It is also rather difficult to estimate the degree of completeness of an historical record of natural events (e.g., landslides). This is because lack of information in the historical record may depend on the lack of occurrence of the event or the lack of information. The two are virtually indistinguishable in a catalogue. Simple techniques have been proposed to compare the relative completeness of different parts of an historical records based on the construction of cumulative curves [doi:10.1016/s0013-7952(00)00047-8, doi:10.1007/s00267-003-0257-1]. For our analyses we adopted these techniques, and we constructed curves showing the cumulative number of landslide events (LE), Figure 2b.

- One could obtain information on landslides in unmanned areas through the systematic interpretation of aerial photos. However, this approach does not provide information on the date of the landslides, and it is applicable only since about 1950 i.e., from the systematic availability of aerial photography.

R1 asked about the validation of the historical landslide catalogue. From a strict point of view, validation of an historical catalogue of landslides cannot be performed. Validation requires independent information, and the available historical information is commonly barely sufficient to compile the catalogue. To consider the possibility to use independent information for full validation of an historical record is unrealistic. More realistically, the construction of an historical catalogue of landslide events is a craftsmanship work, where all the existing information is considered and crosschecked. When new information becomes available, it is crosschecked with the previous information, and the catalogue confirmed, updated, or modified accordingly. We also note that to "validate" an historical record one should have information on the level of completeness / incompleteness of the same record. As explained before, this information is not available because lack of information in the historical record may depend on the lack of occurrence of the event or the lack of information; and the two are indistinguishable in the record. The catalogue of landslide events for Calabria used in this study is the result of a long work, and was discussed in different papers. This is explained in the text at the beginning of Section 5.1, Catalogue of landslide events (page 3586, lines 8-11), where we write "To compile the catalogue of landslide events (LE) we used different sources of information, including local and national newspapers, web sites, reports from national and regional agencies and public offices, and post-event field surveys (Petrucci and Versace, 2005; 2007; Petrucci et al., 2009; Palmieri et al., 2011)". More detailed information on the methods used and the problems encountered in compiling the landslide catalogue in Calabria is available in the listed references.

R1: 3. Throughout the sections 6 and 7, the authors described the spatiotemporal changes in the REL and the thresholds. While they described detailed results, I would like to see a more in-depth discussion on the directions of climatic conditions, land use changes, geological and geomorphological conditions in the study area, and uncertainty of the landslide catalog.

Reply: This comment of R1 mixes different issues. First, in the time span of our analysis (90 years from 1921 to 2010) the general and specific geological and geomorphological conditions (e.g., seismicity, uplift rate, lithological types, fracturing, degree of weathering) have not changed to the extent to be detectable at the regional scale and potentially significant for our analyses. Frankly, we would not expect the geological and geomorphological conditions to change significantly in such a short geological/geomorphological period [doi:10.1016/j.geomorph.2005.06.002]. The same applies to the "directions" (i.e., "trend") of changes for the geological and geomorphological conditions. Second, we have analyzed – in broad terms – the changes in climatic conditions occurred in our study area when we have analyzed and discussed the available rainfall records. This is discussed in section 7.1, where we discuss changes in the distribution of REL during the year, and in section 7.2, where we discuss changes in the minimum ED rainfall thresholds needed to trigger landslides for different periods. Third, we have not considered variations in land use and/or land cover because this information is not available to us. Land cover maps for Calabria are available only for the recent period analyzed in the study, and not for the intermediate and old period. Thus, a systematic analysis of the effects of land use change on landslide frequency and abundance is not possible at this time. We also note that this analysis, although potentially very interesting, would be extremely difficult (and costly) to perform. The older source of land cover information with the adequate resolution / accuracy covering the entire study area are aerial photographs taken in 1954-1955. Production of a complete land cover / land use map from the visual interpretation of hundreds of aerial photographs would be a very long work, and would provide a “single” point in the record, greatly limiting any possible temporal analysis.

R1: 4. This study defined a rainfall event as a continuous sequence of rainfall days with cumulated daily rainfall > 0. Then, a rainfall event with landslides (REL) was defined as the occurrence of landslides during and immediately after a rainfall event. What did you mean by “immediately”? It would be better to define the end date of REL, because rainfall amounts after landslide occurrences make little sense for the analysis. The landslide catalog has date of landslide occurrences.

Reply: We acknowledge that our explanation was unclear and incomplete, and we thank R1 for pointing this out. With “immediately after” an event we mean that to identify the individual RELs we used information of RE and LE, adopting the following criterion (discussed in page 3584, lines 23-24): “the date of the LE must be between the start and the end dates of the RE, or no more than one day after the end of the RE”. Consequently, the end date of the REL is defined as: (i) the day in which the rainfall-induced landslide occurred, if the latter occurred between the start and the end dates of the RE; or (ii) the end date of the RE, if the landslide occurred the day after the end of the RE. We have added language in the revised version of our work to clarify the issue. The new text (added at page 3584, after line 24) reads, “The starting date of the REL corresponds to the start date of the RE. The end date of REL is (i) the day when the rainfall-induced landslide occurred, if the landslide occurred between the start and the end dates of the RE, or (ii) the end date of the RE, if the landslide occurred in the day following the end day of the RE.”

Minor comments

R1: 1. Section 4: It would be better to show a map of the mean annual precipitations.

Reply: To respond to the request of R1, we have prepared a new map showing the mean annual rainfall (MAR) in Calabria in the 90-year investigated period, and we have

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added the map to Figure 1, as Figure 1b. We added the new map to Figure 1 in an attempt to give general information on the rainfall regime typical of the study area. The new figure also contributes to give climatic information on the study area. However, the geographical distribution of the mean annual rainfall shown in the new Figure 1b does not add to the analysis or the discussion. This is mainly because our work focuses on short duration events characterized by prolonged and/or large cumulated rainfall. These events do not affect significantly the long-term geographical trend of the mean annual rainfall shown in Figure 1b.

The modified caption of Figure 1 reads. Figure 1. (a) Map of Calabria, Southern Italy, showing terrain elevation (shades of green to brown), main cities (yellow squares), and location of rain gauges used in the study (triangles). Shades of blue show number of years with measurements for each rain gauge, in five classes. (b) Map of Mean Annual Rainfall (MAR) in Calabria, in five classes. (c) Number of operating rain gauges per year in Calabria between 1920 and 2010.

R1: 2. Section 5.1: I would like to see a more information of landslide catalogue list. 77 % of landslide events had the geographical locations. How did authors analyze other 23 % of landslide events?

Reply: In Section 5.1, page 3586, lines 19 to 23, we wrote: "Information on the geographical location of the landslide(s) consists in the geographical coordinates of the site(s) where the landslide(s) has (have) occurred (available for 23% of the LE), or in the geographical coordinates of the centroid of the municipality where the landslide(s) was (were) reported (available for 77% of the LE)." Thus, we know the precise geographical location (i.e., the exact place of occurrence and the geographical coordinates) of 23% of the LE. For the remaining 77% of the LE, we know the name of the municipality where the landslide(s) was (were) reported. For these landslides, we used the coordinates of the centroid of the municipalities to locate the landslide(s) geographically.

R1: 3. Section 6: Considering the incompleteness of landslide reports during a rainfall event, the classification of “single” and “multiple” makes little sense.

Reply: Definition of a REL as “single” or “multiple” depends on the quality of the available information, which we have acknowledged before may be incomplete. We therefore acknowledge that the classification of the REL in “single” or “multiple” is uncertain, but we disagree with R1 that the classification “makes little sense”. This is because if a REL was classified as “single” it could indeed have been “multiple”. But if a REL was defined as “multiple” (two or more landslides) it is certain that the LE was not “single”, given our definition of a “single” REL. Thus, we maintain that the classification contains valuable information. This is a case when partial information is better than no information. Also partial information (being certain of “multiple” events only) does not mean wrong (incorrect) information. We have added language to the text in Section 6 (page 3590, after line 25) to clarify the issue. The new text reads, “We acknowledge uncertainty in the classification of a REL as having triggered a “single” landslide. Indeed, a “single” landslide REL may have triggered multiple landslides, and the information may not be available to us. However, REL with “multiple” landslides are certain, because they have triggered two or more landslides”.

We note that the same reasoning can be applied to the classification of LE as “small” or “large”, which is discussed in the same section of the text (Section 6).

In Section 6 we further wrote, “REL with “single” landslides have average and maximum cumulated event rainfall E lower than REL with “multiple” landslides (Table 1)”. This was expected, and it is due to the fact that some of the REL with “multiple” landslides have triggered several landslides as a result of severe rainfall conditions. We have added language to the text in Section 6 to clarify the issue. The new text reads, “Even considering the uncertainty in the classification of REL associated to “single” landslides, the finding was expected because some of the REL with “multiple” landslides have triggered several or many landslides, as a result of severe rainfall conditions”.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/3/C1751/2015/nhessd-3-C1751-2015-supplement.pdf

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3, C1751–C1764, 2015

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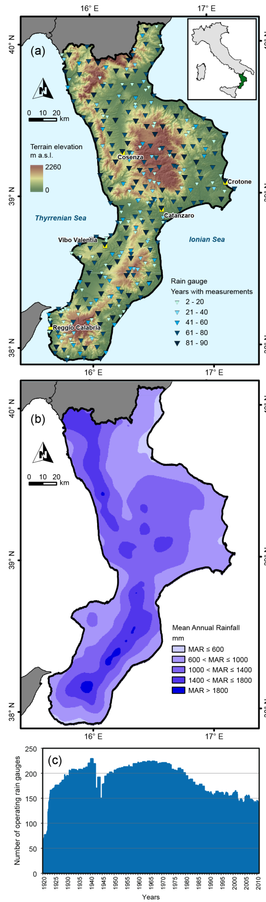

Fig. 1.

NHESSD
3, C1751–C1764, 2015