

## Replies to Referee #2 (R2)

This study provides a detailed analysis of the spatiotemporal distribution of rainfall induced landslides in Calabria, Italy, from 1921 to 2010. The changes of the impact of landslides to the population are also covered in the Discussion session.

These are indeed two of the results of our work, namely: (i) determining geographical and temporal trends of rainfall induced landslides in Calabria for a long period (90 years from 1921 to 2010), and (ii) estimating variations in the impact on the population of the rainfall induced landslides in Calabria.

1. The first comment this reviewer has is: what is the significance of the study? At the end of the Introduction section, the authors state that “In this work, we exploit ... to study possible variations in the frequency, geographical distribution, and impact of rainfall induced landslides on the population of Calabria.” What is the research question? And, what does it contribute to the literature?

The question raised by R2 is legitimate, but we maintain that the answer to the question is given in the text, and specifically in the Conclusions [pages 3600-3601]. However, we articulate our response in more details below. We have added language to the text to clarify the significance of our work.

First, we stress that, to our knowledge, there are not many studies published in the literature that investigate the long term variation in the frequency of landslide occurrence in a (large) region for a long period (90 years), and that attempt to relate the long term variation(s) to rainfall records. We attribute the lack of similar studies primarily to the lack of sufficiently complete catalogues of landslide events for large regions. In many areas of the world, long records of rainfall measurements are also lacking, hampering this type of studies. Further, to our knowledge, there are not many studies that have attempted an analysis of the temporal trend of the impact of rainfall-induced landslides in an area. In Italy, a few works have analyzed the trend in the landslide societal and individual risk levels to the population (doi:10.1007/s00267-003-0257-1, doi:10.5194/nhess-10-465-2010). Thus, we consider relevant our investigation of the long-term variation in the frequency of rainfall-induced landslides and in the impact that the rainfall-induced landslides have on the population. To respond to R2, we have clarified the scope of our work at the end of the Introduction, adding an entire new paragraph that reads, “Only a few studies have investigated the geographical and temporal variations in the frequency and distribution of rainfall-induced landslides (e.g., Reichenbach et al., 1998; Mathie et al., 2007; Polemio and Petrucci, 2010; Chiang and Chang, 2011; Lollino et al., 2014; Stoffel et al., 2014), and the consequences of the variations on landslide risk (Guzzetti et al., 2005b; Salvati et al., 2010). Lack of information limits the possibility to evaluate the impact of the expected environmental and climate changes on landslide frequency, and the related risk. In an effort to fill this gap, we exploit detailed historical information on landslides and rainfall in Calabria, Southern Italy, in the 90-year period 1921 – 2010 to study the temporal and the geographical variations in the occurrence of rainfall-induced landslides and in their impact on the population, and we investigate some of the natural (i.e., rainfall) and human (i.e., population density) causes of the changes.”

Second, we acknowledge that our analyses are preliminary, are not exhaustive or conclusive, and that more sophisticated and in-depth analyses can be performed (e.g., 10.1002/esp.1858, 10.1002/esp.1998). However, we maintain that we cannot do everything in a single research, and

describe all the possible analysis in a single paper. We have added language at the end of the Discussion (page 3600, line 20) to clarify the limitation of the present work. The 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.

Third, we maintain that the research, and the paper, has methodological significance, and that the same experimented in this work can be tested in other areas, where similar landslide, rainfall, and population data are available. We have added language to the Conclusions to clarify the issue. The new text reads “We argue that there was nothing special or peculiar in the natural and societal landscapes in Calabria. We therefore hypothesize that the same complexity and variability exists in similar surrounding regions, in Italy and in the Mediterranean region. The hypothesis can be tested using the same methodology experimented in this paper for the joint analysis of historical landslide, rainfall and population information, anywhere adequate information is available”.

2. A similar question is about the implication of this study. In lines 398-400, the authors state that “... we found that the ratio between the number of REL in January (RELJan) and in November (RELNov) ... is the best indicator of the variation in the occurrence of REL in the studied period.” What is the implication of this finding? Is it related to climate change? Because many NHESS readers are unfamiliar with the study area, the authors must interpret their findings with that in mind and offer statements that make sense to the readers.

The second question posed by R2 has general and specific aspects. We have responded to the general implications above, where we have clarified the scope of our research. The new text added at the end of the Introduction and at the end of the Discussion also clarify the implications (and the limitations) of our study. We further clarify that a result of the work, now written in a new paragraph in the Conclusions, is that our analysis revealed a complex and diversified picture of the changes in the impact of rainfall-induced landslides in Calabria, in the investigated period. We think this is well exemplified by Figure 9 that does not reveal a clear trend in the increase / decreased impact of the rainfall induced landslides in Calabria, in the last 60 years. The new text in the Conclusions reads, “Overall, our research revealed a complex picture of the changes in the impact of rainfall-induced landslides in Calabria in the recent past, with areas where the impact and risk to the population have increased, and other areas where the impact and risk have decreased. The geographical pattern of the variations is diversified (Fig. 9), revealing the complexity of the interactions between the natural (climate) and the human induced (population, land cover) factors that control the frequency of the rainfall-induced landslides, and the intensity of the consequences. We argue that there was nothing special or peculiar in the natural and societal landscapes in Calabria. We therefore hypothesize that the same complexity and variability exists in similar surrounding regions, in Italy and in the Mediterranean region. The hypothesis can be tested using the same methodology experimented in this paper for the joint analysis of historical landslide, rainfall and population information, anywhere

adequate information is available. Finally, we stress that the complexity of the temporal and geographical pattern of the variations in the frequency and impact of rainfall-induced landslides observed for the recent past in Calabria suggests that it will be difficult and uncertain to predict the possible variations in the frequency and impact in response to future climatic and environmental changes”.

To respond to the specific question related to the variation of the  $REL_{Jan}/REL_{Nov}$  ratio, we cannot attribute it to climate change, necessarily. We notice that the ratio changed substantially from the first to the second, and the third 30-year period. On the contrary, the ratio between all the rainfall events in the same months ( $RE_{Jan}/RE_{Nov}$ ) remained constant or changed slightly in the three periods (as we state in page 3593, lines 26-28, and page 3594, lines 1-2). The finding is useful to understand that in Calabria the number of rainfall events (RE) per month did not change considerably in the three 30-year periods, while the number of rainfall events with landslides (REL) changed. We explain the issue in the text, where we now write (in page 3594, lines 8-9) “Despite the monthly number and ratios of RE did not change significantly in the three 30-year periods, the number of REL and their distribution through the year changed significantly, outlining a variation in the distribution of REL in the three 30-year periods.”

**3. Finally, this reviewer has a technical question. In lines 146-147, a rainfall event with landslides (REL) is defined as the occurrence of a LE during or immediately after a RE. If it occurs during a RE, is cumulative event rainfall calculated up to the date of LE? Rainfall after the date of LE should not matter in this case.**

This question is the same question posed by R1 (#4 of the major questions posed by R1). We acknowledge that our explanation was unclear and incomplete, and we repeat the response given above to R1. With “immediately after” and event we mean that to single out 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 new language in the revised version of our work to clarify the issue. The new text 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.”