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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Temporal evolution of landslide hazard for a road infrastructure in the Municipality of Nocera Inferiore, Italy, under the effect of climate change" *by* Marco Uzielli et al.

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The Authors wish to thank the Reviewer for his/her comments. Please see below the detailed responses by comment number.

Comment 1.1: Linkage between triggering probability and reach probability are expressed as equation (1) (p.4). However, the H (hazard probability?) are not calculated in this paper. Analyses of the triggering probability and the reach probability have been done separately, and never been linked together. Therefore, I felt that this paper is composed of two different studies.

Response: Triggering probability and reach probability are distinct parameters which depend from different factors and which are computed separately as shown in the paper. They are only linked in that they both appear in the hazard model. Triggering probability defines the likelihood of the triggering of at least one landslide in the study area as a consequence of the occurrence of given thresholds of cumulative rainfall. Reach probability describes the probability that any spatial location will be reached by a moving soil mass, assuming that landslides have been triggered. Additional text will be included in Section 3 "Method of analysis" providing more precise definitions of triggering probability and reach probability, and their conceptual significance in the overall hazard estimation approach. A fully worked computation of hazard for the case study will be conducted in the revised version according to the model proposed in Eq. (1).

Comment 1.2: Although relationship between the climate change and the triggering probability are presented in chapter 5, there is no analysis on influence of the climate change on the reach probability. Because one of the most important aspect of this study is estimation of landslide risk under the climate change (as noted in 1. Introduction), effect of the climate change to the reaching probability is needed in this paper. This problem occurs because of the poor linkage between analysis of triggering probability and reach probability as I pointed out in the comment 1).

Response: Reach probability is not related to climate change, as it parameterizes the probability of spatial occupation during landslide runout, assuming that triggering has occurred in one or more potential source areas. Reach probability only depends on terrain factors. Climate change is related to triggering probability through the probability of exceedance of the 1-day and 59-day cumulative rainfall thresholds. Additional text will be included in Section 3 "Method of analysis" providing more precise definitions of triggering probability and reach probability, and their conceptual significance in the overall hazard estimation approach.

Comment 1.3: Statements in discussion parts (latter half in chapter 5, section 6.2) and the concluding section (chapter 7) are mostly about case example in the study site. General findings applicable to other areas are limited.

Response: Following the Sarno event (1998), many investigations on landslides affecting pyroclastic covers on slopes of Campania Region have been carried out. These have stressed the important role played by local geomorphological conditions for landslide occurrence: cover depth and stratigraphy regulated by distance from eruptive centers and wind directions and magnitude during the eruptions, exposition, slope angle, bottom hydraulic conditions. These studies highlight the importance of avoiding generalizations regarding predictive models of Early Warning systems (e.g. I-D curves). Under such constraints, in this work, we prefer considering a unique geomorphological context as detected by Picarelli et al. (2008) . The macro zoning is intended mainly regulating the proxies. Nevertheless, the framework is totally replicable in other contexts where proxies implying the same stages are already known.

Comment 1.4: There are many assumptions in the analysis of this study. I agree that this kind of works need assumptions, because it is hard to obtain detailed data needed for the analysis. In addition, there are many uncertainties as authors discussed in the chapters 1 and 7. However, when the authors set important assumptions, explanations on reasonability of the assumption (or discussion on limitations in the assumption) are needed. See specific comments.

Response: Thank you for the suggestion. We will refer to the "Specific Comments" section in attempting to address the Reviewer's inputs.

Specific comments

Comment 1.5: Locations (or characteristics) of source area and runout area of previous landslides are not shown in this paper. Such information is important when we consider if the assumption in this paper is realistic or not. The landslide histories can be used to verify result of the prediction.

Response: Thank you for the suggestion. Please see below: Source areas: Source areas were identified by means of the official geo-morphological map of the "Campania Centrale" River Basin Authority (PSAI 2015) and coincide with the union of the 1) "zero order basin" (ZOB) and the 2) actual "niche/failure" areas. Figure 8 shows the perimeter that envelopes the two areas above mentioned. In the revised version, we will add a geo-morphological map with the two distinct components and specifications (and references) to clarify the assumptions. Runout areas: In the above-mentioned map, the traces of previous landslides obtained from the official landslides inventory of the "Campania Centrale" River Basin Authority (PSAI 2015) will be shown.

Comment 1.6: - pg.3, line 22 "(a) hyper-concentrated flows, which are. . .as debris avalanches" Is there any difference in rainfall threshold and runout distance amongst these three landslide types? Many previous studies have reported that travel distance (and slope angle) of landslides and debris flows are variable amongst different topography and different types of the mass movement. Gavan Hunter, Robin Fell (2003) Canadian Geotechnical Journal, 40, 1123-1141 R J Fannin, M P Wise (2001) Canadian Geotechnical Journal, 38, 982-994 C Scheidland, D Rickenmann (2010) Earth Surf. Process. Landforms, 2010, 35, 157–173 J Corominas (1996) Canadian Geotechnical Journal, 33, 260-271 In chapter 6, authors did not distinguish landslide types when they estimate the reach provability. Therefore, they assumed that the landslide type does not affect runout characteristics. Difference (and similarity) in the runout characteristics amongst landslide types is helpful for readers to consider reasonability of the assumption. Similar things can be said to the landslide triggering condition.

Response: The landslide catalogue used for retrieving triggering probability primarily refer to debris flow in channelized or open slopes (see De Vita and Piscopo, 20022). The landslide types considered in that study are: (1) "channelized debris flows, which can be generated by slope failure in ZOB areas (Dietrich et al. 1986; Cascini et al. 2008)" and (2) un-channelized debris flows, which are locally triggered on open-slopes areas propagating as debris avalanches. We will specify it in the revised version. Just only one un-channelized event (March 2005) occurred in Nocera (Pagano et al. 2010; Rianna et al. 2014). The "niche/failure" areas of this specific event are considered as source areas in the runout analysis. The event/runout characteristics of the above-mentioned two landslide types can be significantly different; nevertheless, the same calibration parameter set (reach angle, velocity) seems to satisfy enough both event conditions.

Comment 1.7: pg.4, line 4 "resolution of 15x15 m" - This resolution is larger than that recommended by Horton et al. (2013) NHESS. Why do you think this grid size is sufficient for estimation of the reach probability? It is hard to understand from the statements in chapter 6.

Response: Horton et al. (2013) stated the following: "a 10m DEM resolution as a good compromise between processing time and quality of results. However, valuable results have still been obtained on the basis of lower quality DEMs with 25m resolution". A variety of DTM resolutions were tested for the case study. We opine that the adopted resolution adequately represents the surface morphology (simply comparing – numerically and by expert judgment – the DTM with the real current morphological shape of the areas – the resolution represents with a good accuracy the channelized shape and the fan areas). This assessment will be described in greater detail in the revised version.

Comment 1.8: pg. 4 line 8 Equation (1) - H in the equation (1) can be given by the triggering probability multiplied by the reach probability. In my understanding, triggering probability indicates the probability of occurrence of one landslide in the entire analysis area (if only one landslide occurred during each rainfall event in table 2). However, if the reach probability was multiplied by the triggering probability, it means that landslides simultaneously occur at all of source areas during one rainfall event. Maybe I am misunderstanding the method, but detailed explanation is needed to prevent misunderstanding.

Response: This study replicates the hypotheses and glossary introduced by Berti et al. (2012) regarding the implications and possible limitations of the Bayesian approach to quantifying landslide triggering probability empirically. Regarding the specific aspect discussed by the reviewer, this study adopts the modelling hypothesis by Berti et al. (2012) by which multiple landslides are counted as one single event. Hence, the Bayesian method presented in the paper quantifies the probability of occurrence of the event (defined as "at least one landslide in the proximity area"). Reach probability as defined and calculated in the study is consistent with this definition, as the results obtained are calculated as the superposition of all possible runout paths from all landslides potentially occurring from all source areas. Hazard as calculated using the above hypotheses is a conservative, upper-bound estimate related to a specific rainfall scenario involving specific values of 1-day and 59-day cumulative rainfall. These hypotheses, along with additional insights into conceptual background of the Bayesian approach to landslide triggering estimation, will be presented more explicitly in the revised version.

Comment 1.9: pg. 5, line 6 "The inventory of landslide events was. . .the Regional Civil Protection" - What kind of data do the reports include? Landslide timing? Locations of source area and runout area?

Response: As reported in the paper, multiple sources are used for reconstructing the inventory. De Vita and Piscopo (2002)2, for example, report for events in the same geomorphological context the cumulative rainfall values inducing the events on time spans up to 60 days. Vallario (2000) provides brief descriptions about the events (also for the other natural hazards affecting the Region) including also the number of fatalities and injured. "Event Reports", drafted by the Regional Civil Protection, report exhaustive descriptions about the weather patterns inducing the triggering event and the main consequences for the affected communities.

Comment 1.10: pg.6, line 1 "In the present study, climate simulations included in EURO-CORDEX multi-model ensemble at 0.11' (approximately 12 km) are considered under the RCP4.5 and RCP8.5 scenarios as described in Table 3." Differences in the triggering probability between RCP4.5 and RCP8.5 (Fig. 7) are based on the difference in the rainfall characteristics between the two scenarios. However, rainfall characteristics of the two scenarios are not explained in this paper. I suggest to explain difference in the rainfall characteristics between the two scenarios.

Response: The trends of maximum daily precipitation and 59 days cumulative values under the two RCPs will be reported in the revised version of the paper in terms of ensemble mean value and related spread. This will allow a clear insight into future evolution of weather forcing parameters which are of interest for landslide occurrence.

Comment 1.11: pg. 6, line 7 "Landslide triggering probability was estimated. . .and the 59-day rainfall." - Why one-day rainfall and 59-day rainfall were used in the analysis? Rainfall intensity and duration are generally used in this kind of analysis (e.g., Berti et al., 2012). Berti et al., Journal of Geophysical Research, 117, F04006, 2012.

Response: Thank you for the suggestion. In the revised version, we will clarify the rationale behind this choice. Several works (De Vita and Piscopo, 2002 ; Fiorillo & Wilson, 2004 ; Pagano et al., 2010 ; Napolitano et al., 2016 ; Comegna et al., 2017 ;Reder et al., 2018) stressed the prominent role of antecedent precipitations for landslide occurrence in pyroclastic covers. However, the effective length of such window is highly dependent from local conditions. In this perspective, for the same geomorphological context, De Vita and Piscopo (2002) use again 59 days. Preliminary analyses were conducted using a number of proxies in the calibration of the Bayesian approach developed in the paper. Such analyses showed that 1-day and 59-day rainfall could be confidently used. The results of preliminary analyses involving other proxies will be briefly mentioned in the revised version.

Comment 1.12: pg. 7, line 10 "More specifically, Fig. 7a shows. . . variation for both scenarios" - This sentence is repetition of the Figure caption. I suggest to remove this sentence.

Response: Thank you for the suggestion. This will be done in the revised version.

Comment 1.13: pg. 9, line 3-5 "In this work, source areas were identified. . ." - In this study, zero order basin and current failure areas are considered as source areas. Does this assumption agree with location of previous landslides in this area? Although this hypothesis are briefly explained in the next sentence, detailed explanations are needed, because setting of the source area is one of the most important factor controlling runout areas.

Response: Thank you for the suggestion. This will be done in the revised version.

Comment 1.14: pg. 9, line 12 "An angle of reach of 4_ was calibrated based on the geomorphological information (i.e., the extension of the slope fan deposition)..." - "Extension of the slope fan deposition" is the maximum travel distance of the landslide. Do you mean all landslides possibly reach the end of fan deposition if there is no limitation by the flow velocity? As many papers have reported, landslide runout distance is variable depending on the landslide volume and landslide type (e.g., Corominas, 1996, CGJ). I afraid that the "angle of reach" in this study overestimates the reach probability.

Response: Yes, runout distance is variable depending on the landslide volume and landslide type and all landslides cannot reach the end of fan deposition. In this work, reach probability was evaluated considering a "paroxysmal" event, based on the official geomorphological characteristics and the official "high" and "extremely high" hazard areas. The assessment by process-based modelling at a large scale (no single event/flow or slope) is generally difficult due to the complex nature of the phenomenon, the variability of local controlling factors, and the uncertainty in modelling parameters. We used a simplified approach that is not highly parameter-dependent. Maps and specification will be added in the revised version to clarify these aspects.

Comment 1.15: pg. 9, section 6.2 - Results and discussion are mostly about spatial distribution of the runout area. However, the runout area is mainly controlled by "angle of reach" and "maximum velocity", which are arbitrary set by authors. Therefore, results and discussion of probability is more important than the runout area. I suggest that authors add results and discussion on the probability.

Response: Thank you for the suggestion. This will be done in the revised version.
Comment 1.16: Table 1 - Coordinate of weather station at Castellammare di Stabia should be expressed by degree-minute-second.

Response: Thank you for the suggestion. This will be done in the revised version.

Comment 1.17: Table 2 - Please note the date of March 2005 event in Gragnano.

Response: Thank you for the suggestion. This will be done in the revised version.

Comment 1.18: Table 2 - How many landslides occurred during each event?

Response: For the three towns, the date reported in Table 2 refers to single main event; in this perspective, when, for a same weather patterns, landslide events have been observed in two towns (for example, 10-11 January 1997), they are reported as different occurrences.

Comment 1.19: Fig. 1 - A scale and a north arrow are needed.

Response: Thank you for the suggestion. This will be done in the revised version.

Comment 1.20: Fig. 2 - does the area named M. Albino correspond to the area of Fig. 8? Please clarify.

Response: Thank you for the input. We will introduce in the caption of Figure 8 the indication of the area shown in Figure 2

Comment 1.21: Fig. 3 - I think the area surrounded by the red line is the highway. Please note that in the figure caption.

Response: Thank you. We will add this significant detail in the Figure's caption

Comment 1.22: Fig. 4 - "Estimation of landslide triggering probability for RCP 4.5 and RCP8.5 scenarios" and "Estimation and mapping of reach probability" have been done

in this study. However, three items at the bottom of the flow chart have not been done. Therefore, it is hard for me to image procedure in the last part of this flowchart.

Response: The terminal phases of the procedure will be addressed more explicitly through the completion of the case study example. This will be achieved through additional text, figures and tables.

Comment 1.23: Fig. 10 - In the x-axis, the value "0" may indicate location of the point A. Please clarify.

Response: Thank you. We will add this significant detail in the Figure's caption

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