Comment on nhess-2022-175

Dear Editor and Reviewers,

we thank the guest editor Francesco Marra for handling our manuscript and the referees for their insightful comments, which surely helped us in improving our work. In the following we reply to point-to-point to anonymous Referee #1. As can be seen in the marked-up manuscript version, further minor revisions have been also applied throughout the manuscript to make it clearer.

Author's response to anonymous Referee #1
General Comments:

Referee #1: This is a mostly well-written preprint that I feel only needs minor revisions. The use of PCA to reduce the dimensionality of the hydrometeorological space is novel, and the thresholds produced are an improvement over other method. There are some missing details regarding the landslide inventory selection process, described below. These missing details constitute the bulk of my concerns and if addressed, I feel that the paper will tell a more complete story of the authors' methodology.
Author's Response: We acknowledge Referee#1 for globally appreciating our work, recognizing its novelty aspects. We revised the manuscript adding more details about the landslide inventory, in order to make clearer the description of the work done.

Specific Comments:

Referee #1: Regarding the landslide selection process described near the end of section 2.1.
The selection of ground truth is a critical decision for this type of analysis, especially if that ground truth is partially derived from other algorithms or datasets, such as what you are doing with CTRL-T. I believe this section needs two additions to help convince readers that what you're doing is scientifically sound.

Firstly, for the "adjustable parameters" of CTRL-T, I would like to see some description of how and why you chose the final parameter values. I believe you briefly mention the separating length of time for rainfall events in wet and dry periods later on in the paper. There is also this sentence in line 135: "Rainfall event parameters were calibrated adopting the monthly soil water balance model and evapotranspiration analysis." But I'm unclear on if this calibration process was done automatically by the program or manually by the authors. A final list of adjustable parameter values, with some brief defense of their selection, would help readers understand what parts of CTRL-T are automated and which are tuned by hand.

Author's Response: We thank the reviewer for pointing out that more details should be provided regarding these aspects, and the following lines have been added to the revised manuscript:

Lines 138-143: "[…] the instrumental sensitivity of the rain gauge and the minimum value exceeding which the isolated hourly measurements are considered relevant (E_R); and the radius of the buffer to assign each landslide to the closest rain gauge (R_B). Furthermore, in order to account for seasonality (i.e., different evapotranspiration rates in different periods of the year), additional rainfall parameters can be set by the user, namely: the dry interval separating isolated rainfall measurements (P_1); the time periods used to remove irrelevant amounts of rainfall, (P_2), and (P_3); and the minimum dry period separating two rainfall events, (P_4). The readers are referred to Melillo et al., (2018) for more detailed information on these parameters".

A summarizing table of adopted values for mentioned CTRL-T parameters has been also added as follow:

Lines 277-288: "For the calibration of these regional parameters required by CTRL-T, we referred to a previous application of the algorithm to the Sicily Island (Melillo et al., 2015). Specifically, according to this approach, the dry period (no rain) has been set equal to 48 hours ($P_{4,\text{ warm}}$) between April and October (warm season, C_w), while it has been set equal to 96 hours ($P_{4,\text{ cold}}$) from November to March (cold season, C_c). Indeed, in line with Köppen (1931) and Trewartha (1968), it is reasonable to assume that in Sicily, due to the Mediterranean climate, the warm period is longer than the cold one. The rain gauge sensitivity G_S has set equal to 0.2 mm, while the rain gauge search radius R_B has been established equal to 16 km. Table 2 summarizes adopted values for mentioned CTRL-T parameters".

Table 2: CTRL-T parameters for the reconstruction of the rainfall events used in the present study.

G_S [mm]	E_R [mm]	R_B [km]	P_1 [h]		P_2 [h]		P_3 [h]		P_4 [h]	
			C_w	C_c	C_w	C_c	C_w	C_c	C_w	C_c
0.2	0.2	16	3	6	6	12	1	1	48	96

Referee #1: Secondly, I would describe briefly in greater detail how you decided that landslides did not have identifiable or uncertain rainfall conditions. I presume some threshold on the weights was used. If so, what were those thresholds values and how did you decide them? Or if some other metric was used to quantify the landslide cause as being uncertain, briefly provide and defend those decisions.

Author's Response: We thank Referee#1 for allowing us to clarify this aspect, and the following lines have been added/revised within the manuscript:

Lines 144-148: "Defined the maximum allowed distance between a landslide and a rain gauge as a circle of radius R_B specified by the user, if more than one rain gauge is located within the circle, the rainfall events from each rain gauge are weighted based on the rain gauge–landslide distance and the rainfall event characteristics (cumulated rainfall and duration). More specifically, given the multiple rainfall conditions (MRC) that are most likely responsible for the slope failures as pair of rainfall event duration (D_L) and cumulated event rainfall (E_L), or a set of two or more pairs, each MRC is assigned a weight to select the representative rain gauge and the rainfall conditions associated with the landslide. […]".

Technical Comments and Optional Suggestions:

Referee #1: See attached PDF for grammar corrections and other suggestions for additional figures or figure revisions that I do not feel are mandatory.
Author's Response: We also appreciate the additional grammar corrections and the other suggestions for figure revisions annotated in the supplementary pdf and that have been implemented within the revised manuscript.

In particular we applied all technical corrections annotated, and we introduced:

i. a more specific overview regarding some statistics related to the cost, damages, and number of casualties due to landslides on worldwide scale at lines 34-38:

Lines 40-45: “Landslides can cause serious damage to man-made structures and land, as well as loss of natural resources and lives. The role of landslide risk in human well-being, is highlighted by the fact that more than 4800 landslide occurrences have been documented from 2004 to 2016, with over 55000 reported fatalities at a global scale (Froude and Petley 2018). Furthermore, landslides triggered by rainfall have been identified as the cause of approximately 90% of fatalities globally (Haque et al. 2016; Sultana 2020) and, from an economic point of view, annual losses were estimated to total USD 20 billion (Sim et al., 2022)”.

ii. a grouped bar plot, as a subplot to Figure 4 (now Figure 5), graphing Eqs. 13, 14, 15, and 16 at lines 30-304:
Lines 317-319: “Fig. 5(b)) represents a grouped bar plot indicating the estimated loadings corresponding to each of four principal components as reported at Eqs. 13, 14, 15, and 16”.

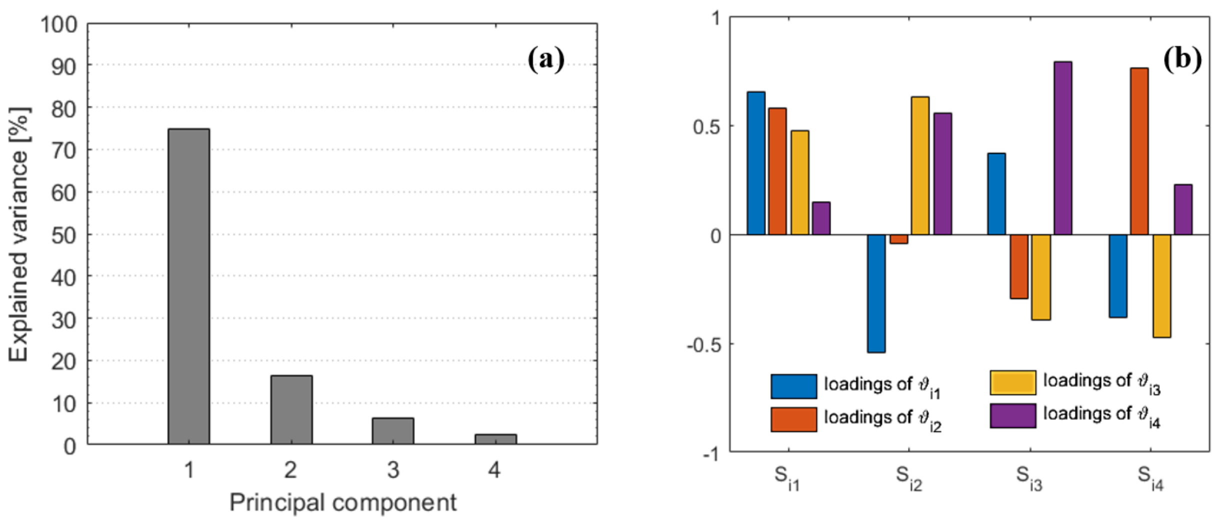

Figure 5: (a) Total variance explain ed by each principal component; (b) Estimated loadings for each principal component S_i

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Dear Editor and Reviewers,

we thank the guest editor Francesco Marra for handling our manuscript and the referees for their insightful comments, which surely helped us in improving our work. In the following, we reply point-to-point to anonymous Referee #2. As can be seen in the marked-up manuscript version, further minor revisions have been also applied throughout the manuscript to make it clearer.

Author's response to anonymous Referee #2
General Comments:

Referee#2: The authors compare classical intensity-duration power law thresholds with hydrometeorological thresholds that combine mean intensity with ERA5-Land reanalysis soil moisture. They consider both the soil moisture at 4 different depths and a combination of them obtained with principal component analysis. They find that adding soil moisture information improves the prediction of a rainfall-based threshold.

The manuscript is generally clear and well organized. I only have one major concern with the publication. In fact, the novelty in the work is the use of PCA for combining the soil moisture information at the different depths and keeping the problem 2D (rainfall intensity and soil moisture derived component). While I see the potential of such a methodology and agree with the advantage of keeping the dimensionality of the problem small, I believe some further analyses are required to demonstrate that it is indeed advantageous.

The TSS obtained using intensity and soil moisture at the first or second shallowest depth is pretty much identical to the one using the first component of the PCA. This means that the overall performances are not sufficient to demonstrate the advantage of PCA. The authors should find some alternative way of either demonstrating the advantages directly (with data/results) or demonstrating that the most influential soil layers changes depending on some properties. Can they observe any pattern in which one is more influential than the others? Those could be spatial patterns (e.g., in certain regions the shallower/deeper soil moisture is more important) or relative to landslide properties (e.g., for certain types of landslides the deeper/shallower soil moisture is more important) or relative to the time of the year (e.g., over certain times of the year deeper/shallower soil moisture is more important). Because the PCA piece is the novel piece in this manuscript, I believe it is important to show and demonstrate the advantage compared to just using the shallowest soil moisture.

Author's Response:
We thank the referee for the comment and, in light of the previous public discussion review, we revised the manuscript accordingly, in order to address the concern of Referee#2 and to better highlight the potential of the proposed methodology, as well as the novelty aspect that we introduced. In this regard, the following lines have been added and modified in the revised version of the manuscript:

Lines 24-34: "Overall, the results show that the soil moisture information allows an improvement of prediction performance, as the TSS increases from 0.50 to 0.71, passing from traditional to hydro-meteorological thresholds using soil moisture at the either the first or the second depth level. Using the first principal component, which combines in the most effective way soil moisture the four depth levels, similar performances are obtained. These improvements, gained in spite of the coarse spatial resolution and the limited accuracy of reanalysis data, provide further support to hydro-meteorological thresholds. At the same time, the study shows that the PCA can also be useful for the identification of hydro-meteorological thresholds, as it allows to easily combine multi-layer soil moisture information while keeping the thresholds two-dimensional and thus easy to be communicated to landslide risk managers."

Lines 379-386: "For the specific case study of Sicily Island, thus the use of PCA has no significant advantages in terms of prediction performance. Nevertheless, PCA still remains a valid approach to combining the information of the four available layers and can be applied to avoid the trial-and-error testing of the use of the various single layers, as the performances are at least as good. At the same time, this calls for further investigations about the possible increase in performances thanks to the combination of multi-layered information in a single variable through PCA. These investigations may involve other case study areas (different climates and quality of the landslide and rainfall datasets), as well as more specific analyses focused for instance on landslide type, seasonality, etc., which are out of the scope of the present work, given also the lack of the needed data".

Lines 413-417: "Future developments of the work will consider other regions in order to investigate more in depth the potentialities of PCA in improving landslide prediction performance, also by taking into account further information on landslides - e.g., spatial patterns, landslides properties, seasonality - not easily available for the region considered in this study".

Minor Comments:

Referee#2: I think the method for the definition of rainfall events should be better explained. The definitions of parameters P1-P2-P3-P4 are unclear and so is the sentence in line 148. What does it mean that rainfall conditions were not identified? What are the uncertainties? In rainfall? In landslide properties. Does this mean they were incorrectly identified as "rainfall triggered" in the database ()? Also, what are the values of the parameters chosen (e.g., the maximum radius Rb)? Only information about the interarrival times was provided.

Author's Response: We thank the reviewer for pointing out that more details should be provided regarding the definition of rainfall events. In consideration of this, the following lines have been added to the revised manuscript:

Lines 138-143: "[…] the instrumental sensitivity of the rain gauge and the minimum value exceeding which the isolated hourly measurements are considered relevant (E_R); and the radius of the buffer to assign each landslide to the closest rain gauge (R_B). Furthermore, in order to account for seasonality (i.e., different evapotranspiration rates in different periods of the year), additional rainfall parameters can be set by the user, namely: the dry interval separating isolated rainfall measurements (P_1); the time periods used to remove irrelevant amounts of rainfall, (P_2), and (P_3); and the minimum dry period separating two rainfall events, (P_4). The readers are referred to Melillo et al., (2018) for more detailed information on these parameters".

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Lines 277-288: "For the calibration of these regional parameters required by CTRL-T, we referred to a previous application of the algorithm to the Sicily Island (Melillo et al., 2015). Specifically, according to this approach, the dry period (no rain) has been set equal to 48 hours ($P_{4,\ \mathrm{warm}}$) between April and October (warm season, C_w), while it has been set equal to 96 hours ($P_{4,\ \mathrm{cold}}$) from November to March (cold season,

C_c). Indeed, in line with Köppen (1931) and Trewartha (1968), it is reasonable to assume that in Sicily, due to the Mediterranean climate, the warm period is longer than the cold one. The rain gauge sensitivity G_S has set equal to 0.2 mm, while the rain gauge search radius R_B has been established equal to 16 km. Table 2 summarizes adopted values for mentioned CTRL-T parameters".

Table 2: CTRL-T parameters for the reconstruction of the rainfall events used in the present study.

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			C_w	C_c	C_w	C_c	C_w	C_c	C_w	C_c
0.2	0.2	16	3	6	6	12	1	1	48	96

Referee#2: On soil moisture: could you provide more information about soil moisture? The only information I could find is "association of SM data to the beginning of each rainfall event", but what does this mean? The first hour of the rainfall event? The hour before its beginning?
Author's Response: We thank Referee#2 for allowing us to clarify this aspect. The following lines have been revised in the manuscript:

Lines 175-177: "The ERA5-Land soil moisture data are provided at the hourly scale, as grid data with a horizontal resolution of 0.1° x 0.1°. Thus, being at the same temporal resolution of rainfall time series, the soil moisture values representative of the closest cell to the rain gauge that recorded the rainfall event are associated, without delay, to the considered event".

Referee#2: Do rainfall events end when the hour of landslide occurrence or whenever they ended (which could be N hours before or even after the landslide)?
Author's Response: We agree with Referee#2 that more details should be added to explain how rainfall duration is defined in relation with the landslide timing. In reason of that, the following lines have been added within the revised manuscript, as well Figure 2.

Lines 166-171: "Lastly, Fig. 2, depicts how the duration of a triggering rainfall event is defined. Specifically, when a landslide occurs during a dry period the whole event that preceded it is considered as triggering rainfall event; otherwise, just the rainfall that occurred before the landslide occurrence is taken into account".

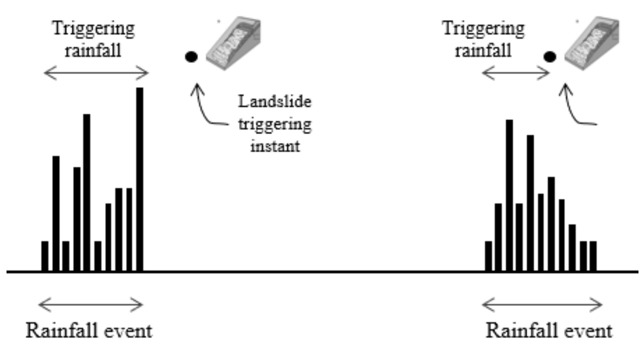

Figure 2: Sketch illustrating how the duration of a triggering rainfall event is defined (adapted from Peres et al., 2018)

Referee#2: Would be good to report in Figure 5 also the timing of each landslide (maybe as a vertical black line)

Author's Response: We thank the Referee#2 for this suggestion ad Figure 5 (now Figure 6) has been revised as follow:

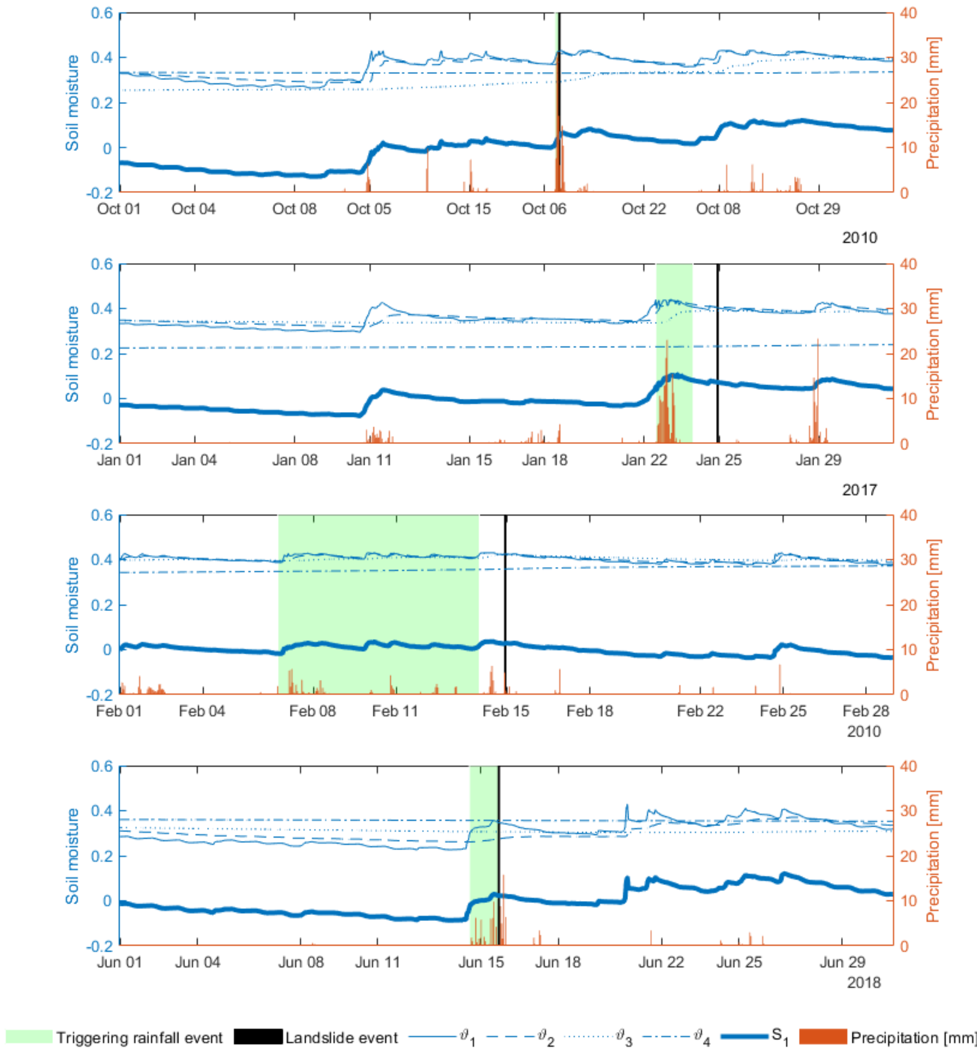

Figure 6: Panel showing four different triggering rainfall events. For each of them the precipitation time series together with the soil moisture time series (ϑ_1, ϑ_2, ϑ_3, ϑ_4) are reported, as well as the first principal component of soil moisture S_1 and the timing of each landslide.

Referee#2: In Figure 6 you could consider using different plotting techniques to make the figure more readable. In fact, it is impossible from a scatter plot to understand where/how many points there are in the different parts of the plot. You should consider plotting the 2D histogram instead (e.g., see Leonarduzzi et al., 2017). This would allow the reader to better see where most of the events are and which groups of events are "driving" the thresholds. Based on more visible (because it's less events) distribution of the triggering events, it looks like the not triggering ones are "driving" the threshold. In other words, just by looking at the triggering events, a steeper threshold would improve the performances, which seems to suggest there are a lot of not triggering events in the 20-300h 0.1-1 mm/h region. Would be nice if that could be looked at! What I am suggesting is something similar to what Leonarduzzi et al., (2017) did in Figure 3.

Author's Response: We thank Referee#2 for suggesting a better plotting technique to make the figures more readable. The revised Figures are reported in the follow, and the manuscript has been accordingly revised.

Lines 343-345: "In particular, the plot shows the triggering events as red points, while the non-triggering, since there are in a very large number, are better represented by a colormap indicating the relative frequency of non-triggering rainfall events, following a plotting technique inspired to Leonarduzzi et al. (2017)".

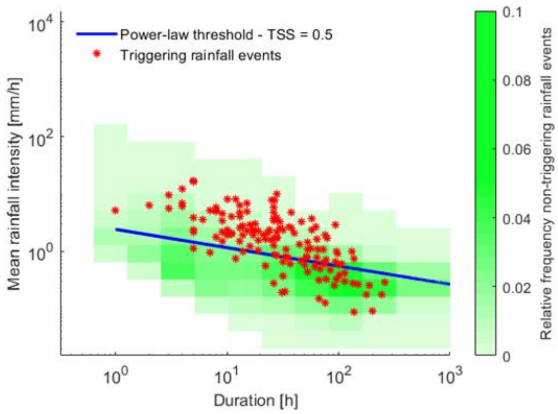

Figure 7: Traditional power-law threshold on the log-log plane between observed mean rainfall intensity (I) and duration (D).

Lines 354-356: "Furthermore, at all depths taken into consideration, there is a noticeable clustering of the highest relative frequency values of non-triggering rainfall events below the related parametric threshold".

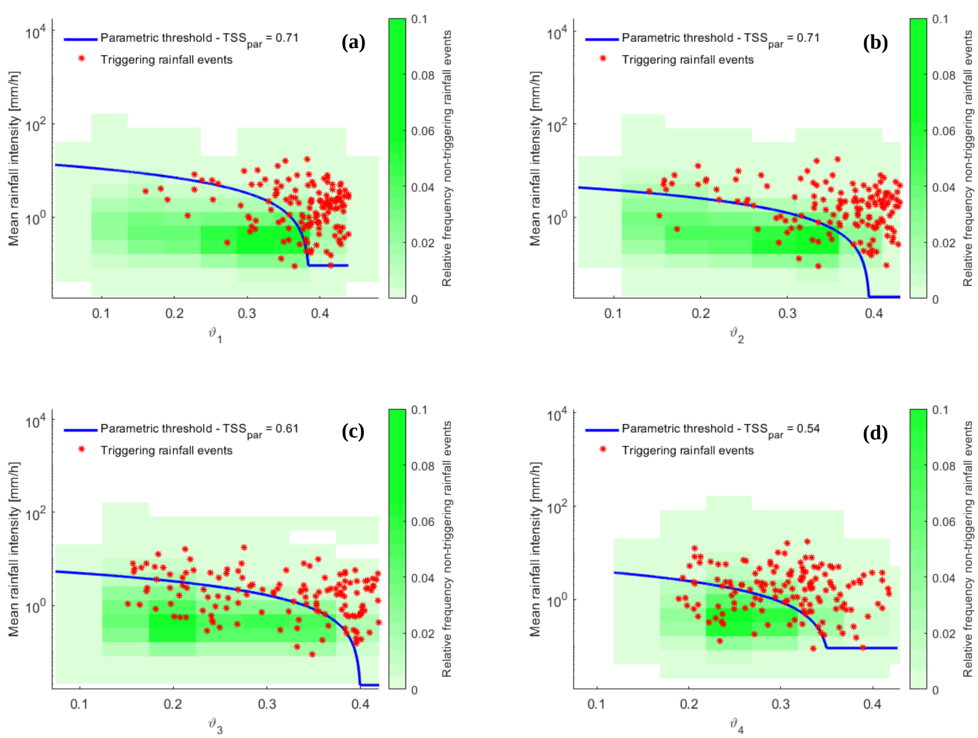

Figure 8: Parametric thresholds on the semi-log plane between mean rainfall intensity and soil moisture at the four distinct depths: (a) ϑ_1 0-7 cm; (b) ϑ_2 7-28 cm; (c) ϑ_3 28-100 cm; (d) ϑ_4 100-289 cm.

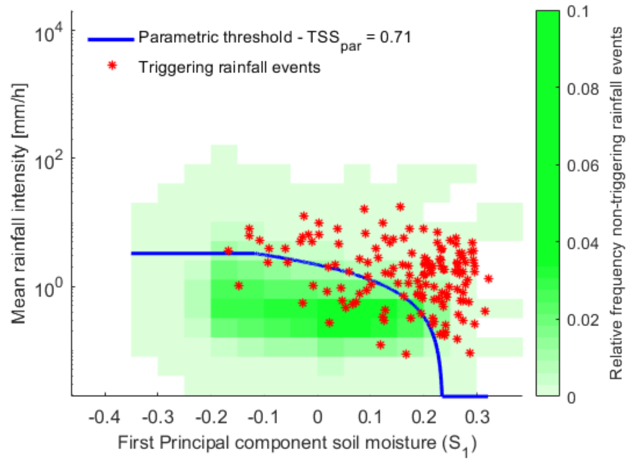

Figure 9: Parametric threshold on the semi-log plane between observed mean rainfall intensity (I) and first principal component of soil moisture (*S*₁).

<u>**Referee#2**</u>: Would be nice to have information also about TPR and FPR also for the ID threshold (maybe as an additional entry in Table 2)
Author's Response: This additional information about TPR and FPR for the ID threshold has been added at line 349 of the revised manuscript:

Line 349: "For this threshold a $TSS_{pl} = 0.50$, corresponding to a $TPR_{pl} = 0.76$ and $FPR_{pl} = 0.26$, is obtained […]".

<u>**Referee#2**</u>: I have a similar suggestion for Figure 8 as for Figure 6, allowing the reader to see the distribution of the no-triggering events (the triggering sample is small enough that they are visible without much overlapping)
<u>**Author's Response**</u>: We appreciate this suggestion that certainly improved the readability of the mentioned Figures, and as previously stated, we revised all the Figures representing the landslides thresholds as previously shown.

<u>**Referee#2**</u>: Finally, in the supplementary pdf, some grammar/rewording suggestions are provided.
<u>**Author's Response**</u>: We thank Referee#2 to have carefully reviewed the manuscript also from a grammar/rewording point of view. All provided suggestions noted in the supplementary pdf have been implemented within the manuscript.