Review response

We would like to thank the Reviewer for the valuable input to our manuscript. In this document, we answer step by step to every comment. Reviewer's comments are depicted in black, the authors' answers are written in red. The line references in the authors' comments refer to the new revised manuscript.

Authors responded most of the comments during the first round. There is no doubt that the data of the manuscript is very comprehensive, and this work is strongly relevant for the journal of Natural Hazards and Earth System Sciences. However, there are still some issues that cause confusion in the article. Some suggestions can be addressed or clarified in revised manuscript:

(1) The author emphasizes in the introduction that the purpose of this manuscript is to discuss the influence of climate change on slope-type debris flow. However, in fact, it is only considered from the perspective of heavy rain, without considering the related indicators of extreme climate conditions including precipitation and temperature (for example, the number of continuous rainy days and extreme temperature, suggesting to refer to the extreme climate index), which could not fully reveal the control effect of climate change on debris flow. On the other hand, debris flow events are not only related to the single rainfall, but also related to the previous rainfall. Clarifications are welcomed here.

The main objective of the manuscript is to analyse and to discuss the development of frequencies and magnitudes of the debris flows in the study area since 1947.

One prominent explanation for possible changes in this development is that the climatic conditions are changing. Because the debris flows in our study area are known to be triggered by high-intensity precipitation events in the vast majority of the cases (Becht, 1995; Becht and Rieger, 1997), the most relevant climatic factor is the number of these events. This is what we refer to in our study by including heavy rainfall data to discuss the temporal development of debris flow frequencies. It is therefore not the main objective of the paper to include multiple climatic parameters.

We changed the respective passage in the Introduction (lines 64-67) to:

"Because high-intensity rainfall events are decisive for the initiation of debris flows in the study area, this paper aims to analyse the spatial and temporal differences in slope-type debris flow activity in the Horlachtal with the help of temporal high resolution precipitation data. Thus, we want to gain a better understanding of the process behavior throughout the past seven decades and link the results to changes in precipitation patterns due to the changing climate."

The surface runoff necessary to initiate debris flows in the study area are generated in the bedrock sections of the catchments. Here, it is not relevant whether there was antecedent rainfall or not, as all rainwater drains on the surface and the infiltration capacity does not change. This is why we did not consider antecedent rainfall as a main factor for debris flow initiation in the study area. We clarified that in lines 112-115:

"In contrast to other types of debris flow systems, the initiation of debris flows on the slopes of the study area is not affected by pre-event conditions like antecedent rainfall, as the necessary runoff is

formed in bedrock areas. The most important driving factors for debris flow initiation in Horlachtal are thus high rainfall intensities that generate high peaks of surface runoff."

(2) Loose material information is an important factor to discuss the formation of debris flow. It is recommended to add the estimation of potential source volume and its connectivity. Also, it is suggested to discuss the influence of earthquake and ice melt water, based on Seismic cataloguing and snow cover datasets.

We already described the type of debris flow material in our study area in lines 109-112:

"The debris flow material originates on the one hand from glacial morain material covered with rockfall debris on the talus slopes. On the other hand, it emerges from rockfall deposits temporarily stored in the bedrock catchments. The debris flows in Horlachtal occur in transport-limited hillslope systems and are triggered by high-intensity precipitation events of about 20 mm in 30 min (Becht, 1995; Becht & Rieger, 1997)."

There is no hint that earthquakes in Tyrol influence the debris flow activity. They cannot trigger debris flows as they do not provide the water content necessary to initiate such processes. As explained above, the debris flows on the slopes of the Horlachtal are triggered by high-intensity precipitation events. Antecedent rainfall or meltwater only play, if any, a minor role. In addition, snow melt alone cannot reach the intensities necessary to trigger a debris flow in the study area. So there is still a high-intensity precipitation event necessary for an initiation.

Specific comments:

Page 6, Table2: may need a figure to illustrate the image coverage.

In our opinion, a multitemporal coverage map of the single flight campaigns would be rather confusing to the readers. Therefore, we provided a link to a web service of the Province of Tyrol, which shows all coverages.

Lines 123-124: *"The coverage of the individual campaigns can be viewed in the "Laser- und Luftbildatlas Tirol" of the Province of Tyrol (lba.tirol.gv.at/public/karte.xhtml)."*

Page 8, Line 159: Suggest to add the full name of DoD.

We clarified the naming in the manuscript in line 165.

Page 9, Line 194: Suggest to add the full name of lm(), nls().

We clarified the naming in line 200.

Page 13, Line 280: What is the resolution of Lidar data? Suggest to check the debris flow with volume is not result of data error.

We added information about the spatial resolution of the 2019 LiDAR dataset in lines 156-158:

"The second LiDAR dataset was recorded during a field campaign of the University of Eichstätt-Ingolstadt in 2019 using a Riegl VUX 1LR integrated in a Riegl VP-1 HeliCopterPod (see riegl.com for details) with a spatial resolution of 13.1 points per m² on average."

Information about the errors in the debris flow volume measurements based on the DoD is provided in Table A1 (appendix). In all cases, the total error is well below the calculated volumes.

Page 17, Figure 9: Suggest use bar to indicate the number of extreme rainfall events.

The total numbers of days with heavy rainfall events (> 10 mm / 30 min) for both stations are already depicted in Figure 10 as cumulative sums over time. In our opinion, there is no need to add a bar showing similar information in Figure 9.

Page 17, Figure10: It is recommended to label years of rapid growth.
We labelled years with exceptionally many days with a high-intensity event in Figure 10. The new figure looks like:

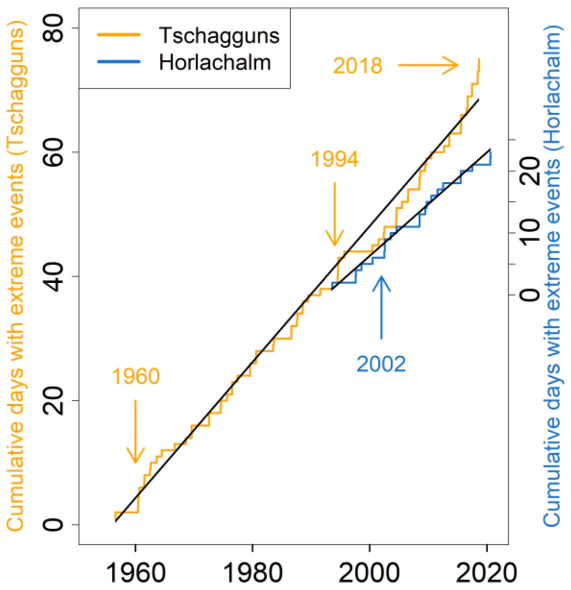

Figure 10: Cumulative sums of days with precipitation intensities exceeding 10 mm per 30 minutes for Tschagguns (orange) and Horlachalm (blue). Years with exceptionally many days with a high-intensity event (Tschagguns: four per year; Horlachalm: three per year) are marked.

Therefore, minor revision is suggested.