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Interactive comment on "Current glacier recession causes significant rockfall increase: The immediate paraglacial response of deglaciating cirque walls" *by* Ingo Hartmeyer et al.

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Dear Jan Beutel,

thank you for your constructive and insightful comments which we feel helped to improve the manuscript.

We (i) uploaded a revised version of the manuscript (one version with markups showing revisions and responses to minor comments, the other with a clean layout), (ii) posted a new author's comment to inform on general amendments in the manuscript, and (iii) below provide a point-by-point response to your comments. Our response is structured

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Discussion paper

as follows: (1) referee comment, (2) author's response including direct references to manuscript changes.

(1) Specifically I am lacking a pertinent discussion as to the accuracy and validity of your quantitative analysis presented. In no way do I doubt your figures, but in the form they are presented it remains largely unclear how large or small your errors presented are w.r.t. the state of the art and what this errors depend on. I am especially worried since there is no apparent attempt to validate at least part of the figures presented. is it possible to manually cross check the volumes presented with photographs, site visits, deposits on the glacier surface such as seen in fig 4/KNW and KN?

(2) We expanded the description of the error calculation (Sect. 3.1.2) and provided additional information (Sect. 4.2) and figures (Fig. 7 and 8) to validate our observations/analyses.

(1) I am missing a detailed discussion of the exposition and the role of radiation/shading. can you add into figure 5 (polar plot) at which expositions you actually have rock walls in your portfolio and possibly also how much? You show altitude in great detail (fig 6) but little is shown w.r.t. south/north facing. Also your discussion of aggrading/degrading permafrost/active layer is weak and in parts not concise w.r.t. the influence of radiation and the stresses originating from it.

(2) Following your suggestions we added a new subchapter that elaborates on the pattern of rockfall with orientation (see Sect. 4.4 Sectoral Rockfall Distribution). We furthermore added a paragraph on the sectoral rockfall distribution to the beginning of the discussion (Sect. 5).

(1) In section 5 you discuss that groups of rockfall can be observed e.g. near structural weaknesses or in immediate proximity of the glacier surface. It would be very interesting to see this observation also in your evidence. Can you point out such weaknesses in the topography/photos? Can you point out such hot spots in there as well. Fig. 4 only shows the approximate distribution and size of the observations. But if you are really

able to bin these into classes and connect them with properties of the environment, you should really show evidence for that. Maybe only in the form of a spot check and not a total cumulative analysis but without further backing this claim is hard to make. A more detailed discussion and evidence of fracture/weaknesses existing in the Kitzsteinhorn rockwalls would be helpful.

(2) We expanded the study site description (Sect. 2) which now includes information on the dominant discontinuity directions. We furthermore added new content and new figures (Fig. 7 and 8) to Sect. 4.2 to demonstrate the rockfall concentration in weakness zones.

(1) I am not convinced of the discussion of the randkluft as you present it. To my understanding the key property of such deep reaching voids, typically found at the upper boundaries of glacier cirques (not just in the Alps) is that there is no continuous physical contact between ice and ground (rock). This means that there is no mass loading with ice or water pressure and the rock surface is largely exposed to air. So in effect the rock walls are "free standing" compared to vertical (or steep) rock parts that are completely encased in ice. Due to this missing mass loading and the missing water pressure the hydraulic regime changes (see e.g. Simon Loew et al Aletsch Glacier etc.). Due to the Randkluft reaching deep this is probably the case since a long time - a very long time. Concerning the air and the governing temperature regime I disagree that there is no active layer. It may not be very significant but your claim about ice cover in mid-October is not convincing, knowing that mid summer is in the end of June and that there is a lot of running water traversing these rock faces from spring (snowmelt) to fall bringing a lot of thermal energy deep into these rock faces below the glacier surface. I rather think that the active layer (and permafrost) regime is of very different properties (temporal, dimensional as well as thermal) as in free surfaces. So maybe you can add thermal data to back up your evidence. In a minimum this should be MAAT, MAGST etc. a discussion of north/south, shaded vs. unshaded etc.

(2) Following your suggestions we added a multi-year temperature dataset from the

Randkluft to describe its thermal regime in more detail. Data acquisition and measurement sites are described in Sect. 3.2, results are described in Sect. 4.7, and discussed in Sect. 5.1 and 5.2.

(1) Figure 2: Possibly this figure could be augmented by an even newer picture (end of the study period) to show explicitly the deglaciation that took place during the study period. Also, can you quantify this deglaciation somehow?

(2) We added a new subchapter (Sect. 2.1 Deglaciation) to discuss deglaciation during the study period more explicitly. We furthermore reconstructed the approximate level of the glacier surface from an aerial photo from 1953 (see Fig. 1 and new Fig. 3) and added a new table (Table S8) to the supplement.

(1) Table 2: Rather than repeating the sales brochure of Riegl please specify the settings used for obtaining your data. The general specs of this instruments are known/accessible through the manufacturer to everyone.

(2) Table 2 was removed and information was added to the text. Detailed information on data acquisition parameters are given in Table S2.

(1) Section 3.2: It would help if you give a short synopsis of the algorithms used (M3C2) and not only list benefits similar as how you briefly explain ICP above.

(2) Following your suggestion we provided a synopsis of the algorithm used (new Sect. 3.1.2).

(1) Availability of the data: Is the LIDAR (airborne and terrestrial) available? or can it be made available

(2) The terrestrial LiDAR data is available on request.

(1) Section 4.1: What is the detection limit mentioned? And how is this error determined? can you explain what influences this error (besides the size of the rockfall)? – You mention a theoretical discrepancy w.r.t. the detection. can you please detail here?

And besides theory, what does it mean in practice for your study?

(2) We renamed Sect. 4.1. and modified the paragraph. Please also refer to Sect. 3.1.2 where the error calculation is now described in more detail. The error calculation of the M3C2 does not discern between different error sources but instead gives a cumulative error (that factors in all error sources).

(1) Figure 3: What are the two lines? The correlations? Please explain this in detail.

(2) The lines represent the regression lines of the two distributions (all rockfalls; rockfalls > 0.1 m^3). We updated the caption.

(1) Section 4.2: Errors of +/- 1.5 mËĘ3 and 1.3mËĘ3 respectively. How sure are you? How did you validate this.

(2) Gaussian error propagation brought the error down to unrealistically low values and was therefore replaced. We updated the error calculation accordingly (which now yields an average relative error of 5.5 %), which is described in Sect. 3.1.2.

(1) Page 12, L 276: You discuss an event that took place before your campaign. If there is a direct context with the observations during your campaign, please explain and back this up with data and plots. If not leave this out. the discussion here is only of a qualitative nature.

(2) The mentioned past event seems to directly control current rockfall activity in the investigated rockwall. Despite the occurrence prior to the start of our monitoring campaign we believe it is justified to mention said event as it helps the reader interpret the observed patterns. We rephrased the relevant passages and hope it is clearer now (Sect. 4.2).

(1) Figure 8: Normally CDF functions are given normalized to 100% and not in absolute numbers. Maybe you can also add the thermal data you have to this plot, although clearly one borehole somewhere else is only of limited use in the discussion (you discuss this somewhere later).

(2) We modified the plot. The plot is now given normalized to 100 % and the seasonal maximum of the active layer is indicated.

(1) Page 14, L 320: I do not see what hinders debuttressing in this case.

(2) Due to the existence of a Randkluft (air-/snow-filled void) there is no direct contact between the glacier and its headwall (at least down to a certain depth), the glacier does not function as a buttress. Along the no-contact zone we therefore consider debuttressing as irrelevant.

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