Anonymous Referee #3 from 24 Oct 2025

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This study builds on years of meteorological, hydrological and turbidity/suspended sediment load (SSL) data collected by different institutions in and in the vicinity of a large partially glaciated catchment in the Austrian Central Alps for an event-based analysis of the contribution of different types of rainfall/precipitation/discharge events to suspended sediment yield. The study area Ötztal includes the smaller and more glaciated subcatchment Vent-Rofental. For the definition of precipitation events, the authors develop an interesting multi-scale approach, both spatially (catchment-scale vs. “grid” scale) and temporally (event duration). From the latter approach, they derive, for every duration class, a threshold at the respective 80% exceedance probability above which heavy precipitation events are delineated and characterized by a number of parameters. The authors then investigate trends in event number and characteristics, and the contribution of different types of events to the annual sediment yield. Major findings include an increase in the frequency of heavy precipitation and contrasting trends of annual suspended sediment yield that are attributed to different timing of ‘peak sediment’ and different reaction to heavy precipitation in the more glaciated part of the valley.

Regarding the study region and the focus on (changes in) suspended sediment load, the study connects with earlier publications by the same working group (Schmidt et al), but represents an original contribution. We appreciate the methodological development for the event-based analysis (and uncertainty assessment) of the INCA, discharge and SSC data that could be transferred to other study areas where comparative spatially distributed precipitation/rainfall data are available.

The manuscript is very well written and contains very rich figures, some of which might take readers some time to understand all the details contained in the diagrams. We think that the study is highly interesting for the geomorphological and hydrological scientific community and can be published pending moderate revisions being made.

General Comments

- (over)use of the term ‘extreme’. We suggest to replace this by “heavy precipitation event” whereever applicable (see e.g. L169 – the 10 mm/h judiciously mentioned there as “heavy” are for sure not extreme; L193: catalogue of heavy precipitation events instead of “precipitation extremes”). We acknowledge that extreme value statistics play a role in the analysis and that the results are used as a detection threshold for such events. However, not every single one of the events listed in the final catalogue are truly extreme in light of the whole dataset and the definition of extreme as very rare (an event with a return period of 1,25 years is for sure not to be termed extreme) and of the M sample as annual maxima that don't really need to be 'extreme' in a sense different from just being the highest in one year.

  Reply: *We agree that using the term “heavy precipitation event” makes more sense and will make adjustments.*

- “grid scale” vs. “catchment scale”: While ‘catchment scale’ can be understood intuitively, we suggest to rename “grid scale” (a grid can represent a whole catchment as well; it

consists of grid cells) in order to better represent the ‘grid cell’ or even more simply ‘local’ scale.

***Reply**: We see the point about “grid scale” not being an intuitive term. However, “local” can carry many meanings, and could be interpreted differently. We will adopt the term “grid-cell scale” instead.*

- Units seem to be formatted differently than normal text. If that is intentional and typesetting rules requires that => OK

  ***Reply:** Comes from the typesetting specific to the LaTex template.*

- Figure captions: We do appreciate the very rich figures, but in some cases we’d suggest to facilitate the readers’ orientation and intuitive understanding by including more direct relationships between axis title/label colour and diagram content, legend etc (see specific comments) instead of having lots of additional information in the figure captions.

Specific comments:

L 29: While this might be the finding of the cited studies, the reader might stumble across that statement because they’ve just read in the abstract that one major finding of this study is a decline in annual sediment load at Vent-Rofental! We suggest to tune that down to “some studies have found a measurable increase…”

***Reply:** The fact that the a measurable increase are not found everywhere is already clear in the phrasing: “measurably increased the amount of fluvial sediment exported **from some high-mountain areas**”*

L51f: The existence of high(er) amounts of unconsolidated sediments and sparse vegetation cover “downstream of glaciers” is only part of the paraglacial morphodynamics theory. According to the latter, it’s not only the existence and amount of sediments, but also the topographic and lithologic characteristics of hillslopes exposed by deglaciation. So, first, “downstream of glaciers” does not define well the proglacial areas (that include specifically important hillslopes) that are affected by paraglacial dynamics – we suggest to replace “downstream of glaciers” with “proglacial areas exposed by deglaciation”. Second, one characteristic of paraglacially enhanced erosion/reworking/transfer of sediments is that it is “system-internal”, not requiring increased external forcing. Hence, an increase in heavy precipitation would be anticipated to further enhance and maybe accelerate paraglacial dynamics.

***Reply:** We will adopt the suggested phrasing.*

L58f: We feel that SSL/SSC peaks and especially hydrological events that are not driven by (heavy) precipitation (which you do address in the study!), need to be mentioned here already.

***Reply:** Will do.*

L68ff: Start with a sentence that makes it clear(er) that you have a nested catchment approach, i.e. that you investigate the whole catchment (with characteristics such as glaciated proportion) AND the Rofental subcatchment (with much more glaciated area). The two are easily defined as the contributing areas of the two gauging stations, so reference to the nested approach also introduces 2.1 well.

Reply: *We will make the nested approach clear from the first sentence of Section 2.*

L70-72: A bit confusing: (a) 10% of the (whole?) catchment are currently glaciated => need to give values for the whole vs. the sub-catchment. (b) “Glacier volume is projected to 4-20% by 2100”: 4-20% refers to what initial volume? Present-day? “pre-industrial”?

Reply: *Reviewer 1 also asked about the glacier coverage and its evolution. We will include a table which shows the glacier coverage for both basins for each of the available glacier inventories. We will also include a mention of the change since the Little Ice Age, and if Figure 1 allows, highlight the areas deglaciated since the LIA.*

L80-86 refers more to the catchment (and the subcatchment); consider moving this to the introductory “study area” paragraph, while 2.1 would then focus on the measurements conducted at the gauging stations.

Reply: *We will intregrate the descriptions of the two gauging stations and catchments to the opening paragraph of section 2.*

Fig1: The Rofental catchment boundary is hardly visible in the big map (c). Better visibility would support the ‘nested catchment’ approach that we ask to make explicit in the text. Using a different colour than gray in (b) and (c) would probably do the job in both maps.

Reply: *We will change the colour of the outline.*

Fig1 caption: “The topography of Ötztal is steep” => consider adding a table that gives e.g. average steepness and other characteristics (such as percent area glaciated see previous comment)

Reply: *We will include this in the aforementioned table with the glacier coverage.*

Fig2: We suggest to make the Fig as large as possible (text width); it is quite dense (which is fine, other figures are even more so) and therefore maximum size is needed to help the reader.

Reply: *We will increase the figure size.*

L92: Use “suspended sediment concentration” at the first mention of SSC (followed by a comma and SSCt). Add information on the ‘missing step’ from the originally measured turbitidy to SSC. The single “t” in line 93 can be removed, the unit is just “15min-1”).

Reply: *The first mention of “suspended sediment concentrations” is the paragraph before, where the acronym is defined. However, it might be clearer to not use the acronym here, so we will adopt the suggested change.*

We will add more details on the turbidity-derived SSC in L87-88.

We suggest to change to “tonnes per time step” instead.

L95 …are hourly precipitation grids” consider adding “at XX km resolution” (same: abstract, L9) and the number of weather stations to “from weather stations”

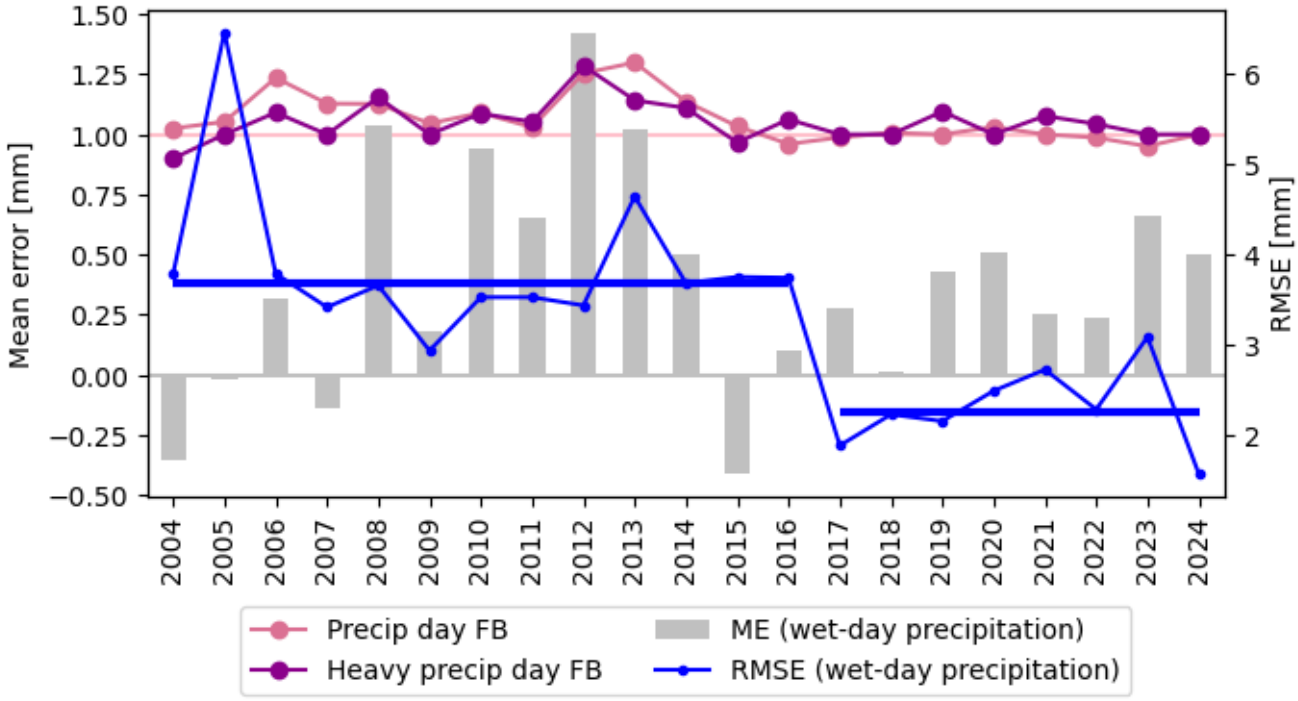
Reply: *We will add these clarifications.*

2.1: We appreciate the detailed explanation of INCA and the own validation approach of this paper. Consider moving the “quality check” (L112ff) to the methods chapter (3.1) uncertainty analysis

Reply: *We prefer to keep the mention of the “quality check” here as it related to the merging of the two INCA sets with different resolution, and not to the uncertainty analysis.*

L145ff: Does the computation of deviations between INCA and OBS include “0 precipitation” hours? Further down a threshold is introduced to distinguish wet from dry days, which is good - but that does not refer to the amount of rain in INCA vs Station data. We suppose ME and RMSE are likely biased by including a large number of dry hours where the deviation between INCA and station are 0. This is either a point to discuss in the discussion section or preferably to change (use only hours with nonzero precipitation in the station record)

> ***Reply:*** *Yes, the computation of RMSE and ME shown in Fig. A3. We also checked the RMSE and ME for wet-days. The results are not substantially different as can be seen by comparing the figure below to Fig. 5.*
>
> *We suggest to include this figure in the supplementary materials, and make mention of the key results in the results section.*



L177: Consider referring to Fig in Appendix

> ***Reply:*** *Will do.*

L181f: Consider adding one more sentence so that the reader does not have to look up Ulrich et al. The GEV distribution family has three parameters (location, scale, shape), - how many (which) parameters are being fit in the dGEV and why can the number of parameters be reduced?

> ***Reply:*** *The number of parameters are reduced, since if a duration-dependent GEV is not used, you have to fit a GEV to each duration separately each with 3 parameters, which for 8 different durations are 8 * 3 = 24 parameters, whereas using a duration-dependent GEV with an additional multiscaling parameter as we used can fit a single 6-parameter distribution for all duration simultaneously.*
>
> *We will add more clarification on the duration dependent GEV to the text.*

L190: Here, you name the “0.8 exceedance probability quantile”, while in the caption of Fig A2, you write “0.2 non-exceedance probability”. Pls homogenise.

Reply: *We will update to use the term "0.2 non-exceedance probability" throughout.*

L187ff: This makes one think immediately of runoff/discharge events triggered by snow (and glacier) melt without precipitation. Yes, snowfall in winter is not relevant to your study, but snowmelt in spring is.

Reply: *True, however, this portion of the text concerns itself with precipitation and it's phase. Reviewer 2 requested more consideration and discussion of melt-driven processes and this will be incorporated more into the manuscript.*

L194f: The whole "peak detection" approach is explained in the caption of Fig. 3: While that enhances the immediate understanding of Fig3, it's sort of missing in the text. If you like to keep it as is, consider writing "…tpeak (Fig. 3, explained in detail in figure caption)"

Reply: *We will add the reference to the caption.*

Eq5/6, L198ff: We appreciate your approach (starting from peak, searching for first and last threshold exceedance before and after the peak, respectively) as an alternative to the "peak over threshold" declustering approach (that starts from a threshold exceedance) used in the corresponding extreme value statistics. However, what happens if the threshold is not exceeded for just one 15 min data point before exceeding it again? In some declustering approaches, a user-specified parameter would prevent two events from being separated by just one (especially that short) 'break' in a time period otherwise exceeding the threshold. We feel this could be explored and, also if not implemented, at least discussed later.

Reply: *When detecting the extreme peaks over a threshold, we used the pyextremes.get_extremes function which includes declustering of peak over threshold (POT) extremes. We used a minimum time distance (window duration) between adjacent clusters of 24 hours. Note that the minimum time distance parameter will only have a limited influence, since we then (1) subsequently searched forward and backward in time to isolate the whole precipitation event, and (2) merged overlapping events. We tested minimum time distance parameters, e.g. the same as the threshold duration, 12 hours, 6 hours, etc. The number of events detected varied minimally (one or two events more or less) or not at all. This suggests that the isolation of the whole precipitation event and merging overlapping events has much greater effect than the minimum time distance parameter for the de-clustering of peaks.*

L215: Consider giving an example of what kind of pattern would be judged as a data artefact/mistaken detection

Reply: *We will add an example.*

Headline 3.3: Would "Classification and characterisation of heavy precipitation events" be better? We felt yes because you do not only characterise the events but also categorise/classify them

Reply: *We will update the heading.*

L235: Not clear to what the "search window" refers, pls specify. It is not possible to imagine what constitutes a hydrological event (as opposed to the precipitation event whose delineation is described in detail). This has implications for the following, specifically for the hydrological events that are not triggered by (heavy) precipitation.

Reply: *The "search window" refers to a parameter for the local minima algorithm. A 21 hour window means each local maximum is at least 10.5 hours apart. A hydrological event is the slice of the streamflow timeseries between two local minima. As such a hydrological event is a streamflow pulse. We will update the text to make this clearer.*

Eq 7,8,9: add units for SSF and SSC

Reply: *Will do.*

L255f: The section heading specifies "precipitation-driven events", but how does the approach detailed here deal with hydrological events that are not triggered by precipitation but by snow and/or glacier melt? Fig 2 clearly shows that spring snow-melt is relevant specifically at Tumpen. Pls address this in more depth in the methods and/or discussion section.

Reply: *As mentioned above we will include more discussion of melt-driven processes.*

L260: typo: Theil-Sen slope

6, L 262ff: This is about "sediment discharge events". How are these detected? Do they always coincide with hydrological events? That is, are "sediment discharge events with high SSC / SSC spikes" exclusively a subset of hydrological events? We can't know, but couldn't it be that, for some reason, a sediment spike takes place in a minor hydrological event that does not belong to the sample/catalogue of hydrological events? E.g. a very localised rainfall event that does not lead to highly increased discharge but to a substantial input of suspended sediment? Or the sudden mobilisation of subglacial sediment without a very conspicuous hydrological event recorded at a gauge kilometres away? Is it possible that a "peak SSC event" is longer than the hydrological event(s) it is attributed to?

Reply: *Yes, it is assumed that a sediment discharge event is a spike in SSC contained within a hydrological event, or explained differently: a hydrological event where the peak SSC is above the 90th SSC percentile.*

Since the hydrological event catalogue covers the entire period with streamflow and SSC data (given that it splits the streamflow time series at local minima), there is no part of the study period that is not covered by a hydrological event. Therefore, we will never miss a SSC spike outside of a hydrological event, because every SSC spike will be contained within a hydrological event.

There is a possibility of the streamflow pulse (i.e. hydrological event) not being closely linked with the suspended sediment pulse recorded at the same time. However, given the strong influence of streamflow on SSC in Ötztal, and especially the pronounced diurnal cycle in streamflow, it is unlikely that this type of event actually occurs within the catchments.

1, L269ff: See comment @ methods: Precipitation=0 included in uncertainty assessment?

Reply: *See reply above.*

L277: INCA under-predicts => suggest to use "underestimates" instead of "predicts"

Reply: *Will do.*

L285: This is an example of "extreme" that we'd like you to reconsider

Fig 4 caption/legend:

- Dot size indicates the duration of events, but there's no legend item. Or is dot size meant to be only a qualitative / ordinal measure of duration?

  Reply: *Yes, it is meant to be qualitative.*

- in addition to the event with the highes Ptot and Imax. Event 2020-k…: These three events are not shown in the figure – which is a bit confusing. Information on single events not shown should be in the text.

  Reply: *All events mentioned are shown in panel b which is what this part of the caption in explaining.*

- Average precipitation area: Is a relative measure (related to the total catchment size)? Shouldn't it be called "relative precipitation area" instead? The same applies to section 3.3 L220f.

  Reply: *Yes, it is a relative measure. But calling it the "average relative precipitation area" is confusing. Furthermore, the measure is explained in section 3.3.*

- Especially in (c), the Vent/ROfental catchment boundary is barely visible (see earlier comment), consider choosing a different colour.

Fig5a

- FB is hard to see (dark purple on dark grey), consider choosing a different colour
- Add a pink left y axis label for RMSE
- Consider making the precipitation y axis labels blue in order to ease relation to the blue line (like RMSE and also for number of events).
- We suggest to specifiy "Precipitation" axis title instead of just explaining in caption => "May-Oct precipitation [mm]"

  Reply: *We will adopt the suggested changes.*

Fig5b

- Dot size should have a legend item
- Include grey dots/circles in the legend (otherwise, in order to understand the figure, the reader would have to read the whole caption first)

  Reply: *We will expand the legend to make it clear what the dot size and colour refer to, although, we do not think it unreasonable for the reader to read the caption in order to understand details from the figure. That is, after all, what the caption is for.*

Tab 2: add number of events (n) and type of events (all?). Moreover: Does r refer to Pearson's r? If so: Pearson's r only quantifies linear correlations, Spearman's r would quantify all kinds of (monotonous) correlations.

> ***Reply:*** *We will consider to use the Spearman's correlation coefficient and update the legend to make it more clear that the numbers refer to the correlation across all events and not by class.*

L300ff: We accept that your MK test was significant, and that RMSE does not greatly vary between the two major parts of your data characterised by different (INCA vs. pre-INCA) data available. However, can you exclude that the MK trend rather represents a difference between the two parts that is (partially) not due to climate change but to a change in how the data were acquired?

> ***Reply:*** *No, we cannot exclude this possibility. This is already part of the discussion. At the prompting of another reviewer, we have also looked at the event numbers at stations within the catchment, and found that there is an increasing trend at all of them, although not significant for all. This will also be added to the discussion.*

L324: The difference is particularly pronounced for RFmax and SSY: We think RFmax has been confused with RFtot – here, the difference in r between SSY and SSF is 0.51 vs. 0.27, while it is much more similar for RFMax and SSY/SSF…

> ***Reply:*** *The difference referred to here is the difference between sub-daily and long-duration extremes and it refers to Figure 6, not Table 2. This is quite clear from the reference to Figure 6 in parenthesis at the end of the sentence.*

Fig6: Consider adding a legend for point/circle sizes, and add "n" to the boxplots (has been done with other boxplots, should be the same here). Fig6 caption: "Labelled events" Only three out of five labelled events are mentioned in the text (2019g, 2020k, 2022d), and events are mentioned in the text that are not contained neither in Fig4 nor here (2020j,2020n, see page 24).

> ***Reply:*** *We will add the number of events in each class to the top of the box plots. The labelled events are meant to be consistent with the ones shown in Fig. 4. We will consider adding more labelled events, but we also want to be cautious of cluttering an already detailed figure with too much.*

Fig7: Try to separate column a/c better from column b/d

L348: Remove duplicate "only about 10%"

> ***Reply:*** *Will do. Thanks for spotting it.*

Fig8: We suggest to position the two plots horizontally (would make the figure fit better with page)

> ***Reply:*** *This will be a single column figure, which will appear different in the final typesetting.*

L375: Pls specify what "geomorphological variables are sensitive to small-scale changes in rainfall spatial structure" means

> ***Reply:*** *We will add some clarification.*

Lines 376ff somewhat repeat lines 370ff

L417ff: We suggest to include the findings of a study that conducted sprinkling experiments on steep moraines; these could be more representative of (parts of) your study area: Maier, F., Lustenberger, F., & van Meerveld, I. (2023). Assessment of plot-scale sediment transport on young

moraines in the Swiss Alps using a fluorescent sand tracer. Hydrology and Earth System Sciences, 27(24), 4609–4635. https://doi.org/10.5194/hess-27-4609-2023

Reply: *Thank you for the suggestion.*

L432: add where the debris flows reported by the two papers took place (Horlach valley, tributary to Oetztal)

Reply: *Will do.*

L468: See comment regarding the MK test results (L300) in light of the higher RMSE in the first years. In light of this, the "robust" in L525 of the conclusion needs to be reconsidered.

Reply: *We will remove the word "robust" from the conclusions.*

Fig A2: Title of (b) should read "Local-scale (a placeholder for an alternative to "grid scale") maximum precipitation It, just like in the caption. Moreover, the blue threshold line (and others) use the "20% non-exceedance probability" unlike the "80% exceedance probability" terminology used elsewhere. Pls homogenise.

Reply: *Already addressed in replies above.*

Fig A3 – Legend for "Station in Ötztal": Change fill colour to white, because the Ötztal stations have different colours and a thick black outline. Moreover, grey dots have been used elsewhere. Moreover, consider adding a legend for circle sizes

Reply: *We think on the whole the figure legend is clear. However, we will add some more details to the caption to avoid misunderstandings.*

Fig A4: Legend for point/circle sizes missing; add n to the boxplots. Similiarly to Fig6, you could add number of events and time period.

Reply: *We will adopt the figure to conform with suggested changes made to Figure 6.*