egusphere-2024-2316
Causes, consequences and implications of the 2023 landslide-induced Lake Rasac GLOF, Cordillera Huayhuasch, Peru

Emmer et al., 2024

General comments

The authors provide a description of a rock-avalanche induced GLOF from Lake Rasac in Peru and also discusses climate change attribution. The study provides some interesting information, but it somehow seems unfinished and I missed a clear take-away message. I have included a variety of specific comments below, but the main justification for me to investigate an event that had very little impact is to understand what attenuated the impact. This is currently done in passing, but without specific analysis. For example, it would be very interesting to know whether the second lake or a piece-wise fragmentation of the landslide was the key factor for the attenuation, a question that could be explored through some basic modeling. This would be an important takeaway for hazard assessments in other places.

The second question that the paper discusses is that of climate change attribution. This question is of utmost importance, and, as the authors discuss, is very hard (if not impossible) to answer for this setting. For me, the combination of the somewhat vague description and discussion of the actual event paired with the somewhat vague discussion of the climate change attribution leads to something that feels a bit like a collage. The attribution part would be more powerful if it included more locations/times (e.g., the dates of the other GLOFS), provided more context on absolute temperatures at different elevations etc. Understanding the return periods of temperature anomalies is interesting, but if the return period for a given warming event is nowadays ~1year, then there are many days/weeks during which no mass movements happen.

In addition to these two main points, the manuscript falls short on the discussion or presentation of many points. For example, statements like “significantly increased” often seem purely qualitative, when a quantification does not seem too hard. I have elaborated on these in the specific comments and a few technical corrections to the best of my abilities below.

Specific comments

L. 20: What do you mean by arête ridge? Seems redundant – would ridge not suffice?
L.20ff: The statement about the volume and origin from “zone with cold, deep permafrost” sounds like this information was pre-established. However, it sems that this information was in fact generated by this study. The abstract should reflect this, possibly saying a little bit more about how this information was procured.
L.28: Can you provide time scales for the “statistically significant” temperature rise and anomaly. It seems they could be very different?

L.30: can you be more specific about what made the geologic situation “already critical?”
L.41: Not hugely more insightful, but you could consider adding the reference to Bondesan, A., & Francese, R. G. (2023). The climate-driven disaster of the Marmolada Glacier (Italy). *Geomorphology*, *431*, 108687.
L.43: The term “piedmont areas” does not seem particularly well established (since you are not referring to the region in Italy). Consider simplifying.
L.66: Maybe add statement about why such “evidence-driven understanding” is important and who it can serve?
L.71: Maybe add elevation range?
L.83: Do you think the snow line elevation is still accurate for today’s conditions? Maybe add a statement to qualify this?
L.85: Interesting discrepancy between the two studies that is a bit confusing at first, but probably are consequence of the image resolution. Maybe reformulate to state that there is a relatively robust estimate of lake area, but not so much about lake number (which maybe does not matter since the small ones don’t really matter)? Could also compare to dataset from Shugar 2020?
L.88: Slightly confusing that a second lake is suddenly mentioned here.
L.90: what does it mean to characterize by “short longevity”? This whole paragraph seems a bit lost. Consider deleting/reformulating/refocusing. You don’t need to mention anymore at this point of the paper that lake Rasac is the focus of the study.
L.109: I was expecting the description of a second lake here… I don’t think it necessarily needs a separate section, but something about the distance between the lakes, the elevation difference etc. seems like it would be useful.
Section 2: I was maybe missing a little bit something about the general climate of the region (MAAT at the lake and the summit region, typical precipitation and weather patterns etc.)
L.132: Sentence spans 6 (!) rows of text… Consider merging the list of parameters that were derived from ERA-data to table 1?
L.145: I don’t think the “event as defined above” has been defined above, or at least I don’t understand what likelihood of occurrence has been assessed here.
L.147: What is temperature-GMST ?
P.3.2.2. I find the first paragraph very hard to follow. Can you provide a slightly more detailed description of what you did and maybe avoid the use of unnecessary acronyms (i.e., PR – it’s not thaaaat long ;-)).
S. 3.4: I am a bit surprised that the two most commonly used permafrost products by Gruber et al., or Obu et al., were not used for the permafrost assessment (Gruber, S. 2012: Derivation and analysis of a high-resolution estimate of global permafrost zonation, The Cryosphere, 6, 221-233. doi:10.5194/tc-6-221-2012; https://microsite.geo.uzh.ch/cryodata/pf_global/; Obu, J. (2021). How much of the earth's surface is underlain by permafrost?. *Journal of Geophysical Research: Earth Surface*, *126*(5), e2021JF006123; https://doi.pangaea.de/10.1594/PANGAEA.905512?format=html#download). Can you elaborate on why the global datasets were not used. If the omission was an oversight, I think it would be useful to include them in the analysis.
L.220: Not entirely clear what “under these conditions” refers to. The last sentence of the paragraph above? The entire last paragraph? It almost seems that this entire

sentence could just be omitted. If some condition is important, it would be helpful to clarify.
S.4: Somewhere, either in the introduction, integrated into section 2 or latest at the beginning of section 4 (though that feels a bit late), a brief overview of the event would be very helpful. As a first time-reader, all I know at the point of starting on 4.1.1. is that there was a rock-failure triggered GLOF and I'm immediately presented with detailed facts about the ice aprons and hanging glaciers and the development of rockfall areas. I think some context about the general chain of events would be very useful up-front, maybe including a map of the runout zone and impacted area (which doesn't seem to appear anywhere else in the paper).
L.227: Can you provide some information about the bedding planes and their dip and strike and how these relate to the terrain slope? This would be more informative than "tilted layers". Also, rather than saying "right bank" maybe use cardinal directions?
L.239: How do you know the timing?
L.241: Is there truly no way to get a post-event DEM to better constrain the volume?
L.265: can you express the "substantial increase" in a quantitative way?
L.270: can you express the "rising significantly" in a quantitative way?
L.304: Maybe specify which Alps you mean? Based on the reference I take it that this is the European Alps? Maybe include some newer references for the statement on the aspect differences (e.g., Kenner et al., 2019 https://tc.copernicus.org/articles/13/1925/2019/ and Böckli et al., 2012 https://tc.copernicus.org/articles/6/807/2012/)
L.317: I think I miss a statement about why these horizontal gradients matter? What do they do? You state that "such thermal asymmetries are not uncommon in detachment zones with permafrost rock avalanches", but it's not clear why they matter. Ridges will frequently have strong heat-flux gradients and they are prone to mass movements (that's why they are ridges). Can you elaborate on the causal relationship?
S.4.2.2. Generally feels very discussion-y
S.4.2.3. This seems like an unreasonably short paragraph with very little information that I learn no conclusion from. Showing only 2 months of data to argue that the temperatures "started to become anomalously warm" is rather unsatisfactory, especially when a similar looking peak in January is obscured by the legend. I would be nicer to see these data in the longer term context (how "anomalous" is this?) and also learn what the absolute temperatures were. How much warmer than usual were things? Fig. 8 also includes precipitation, but this is not discussed at all. If it doesn't show anything (which it appears not to, just don't show it).
S.4.3 I think I would move this section up before the met-analysis. It provides more context for what happened.
L.361: can you quantify the "pronounced steepness"?
L.363: it would be very nice to see some of the photos taken of the site post-event!
L.360: was there any change in the height of the moraine dam? This seems like it would be a very important insight for future hazards, since may limit the possible lake level.
L.385: "this may explain the two dam overtopping locations" → I think this is the first I read of this, but it should probably be described somewhere in the results.
L.392: This Salkantaycocha GLOF is mentioned twice here in the discussion, but has not been introduced. Given its similarity but different outcome, I think introducing the reader to it in the introduction would be warranted.

L.395: I am a bit confused by the deposition of the frontal part vs. clear water apparently having been seen in the fontal part of the lake after the GLOF. I think (similar to comment above on S.4), some simple mapping would be nice to clarify the different areas.
S. 5.3: For me, the results of the attribution analysis belong in the results section, not in the discussion.
L.430: "A promising way forward…" This statement is interesting but it is not at all backed up or provided in context. Has this been done? (→ references)? If not, why not? (→context).
L.433: "overall trend is clear" → references?
F.11: I do not get the reference to "global mean sea level temperature". Is this supposed to be in the caption?
S.5.4: Feels unfinished and not very insightful.
L.470: These are very few events to be reporting averages and increases. Is there a chance that certain events could have been missed or do you exclude that? You could include a statement about this. I also wondered whether the size classification is the right way by which to select events. If a smaller triggering event led to a destructive (or not – since that does not seem to be the criteria) GLOF, then it seems like it would also qualify?

Technical corrections
Personally, I find that things that were done by the authors should be described in the past tense. E.g., we analyzed, we evaluated etc.

L. 61: wording makes it sound like there were numerous GLOFs from Lake Rasac and the authors are only examining the most recent one. I don't understand this to be the case, so the wording should be adjusted (if this is wrong, then background information on prior events should be provided.)
L.70: north *of* Lima
L.82: *the* (total?) glacier extent
L.83: Suggest to move reference (McFadden) to the end of the sentence.
Fig. 1: I'm really perplexed by the pink glaciers ;-) Can you just make them white? In (C) can you point out the important lakes, it took a bit of staring to find it. Generally, I think the colors could be improved (white ocean, yellow mountains, missing coastline etc.)
Fig. 2: Recurring rockfall release zone is very hard to read. What does images AE mean? Please provide image dates. (C) these are all oblique views, so there is no need to specify this for the last image. I'm still confused what an "arête ridge" is. If this is important, please define it.
L.106: insert space lakeand
L.115: "analyzed" instead of "integrated the analysis of"
L.116: "characterize" or "describe" rather than "estimate spatial characteristics of"
L.149: superfluous - after climate
L.266: "solid rainfall, i.e. snowfall" → just write snowfall ;-)
L.360: "a moraine dam" → is there more than one?

L.421: “human-induced increased energy content of the climate system” seems a very roundabout way of saying CO2 increase. Could be stated in more simple terms.
L.429: …attribution of event is challenging: This feels fairly repetitive at this point in the section.
L.455: “evet”
L.465: There is a discrepancy in the year of McColl & Cook between in text reference (2024) and the bibliography (2023)