

Reviewer 1

General comment

This manuscript provides a comprehensive analysis of a complex event that resulted in an extreme debris flood in a small catchment of the French Alps in June 2024.

The results point out that the severity of the event stems from its compound nature, i.e. the co-occurrence of different drivers. Such a result is undoubtedly relevant for the interpretation of cascading events in alpine catchments under current climate changes. **The conclusions could stress the wider interest of these findings beyond the interpretation of this study case.**

This work could become a valuable contribution to NHESS after moderate revision aimed at improving the structure and organization of the manuscript.

I would like to invite the authors to perform a thorough revision of paper structure and organization aimed at making it smoother and easier to follow. The present manuscript, because of its structure, looks like a research report instead of a journal paper. Moreover, although an important part of the work is presented in Appendices, the text is very long, and it has some redundancies. For instance, the Introduction includes a rather long text and some figures that would be more appropriate in the description of the study site. I would recommend checking the entire manuscript for repetitions and redundant text.

Thank you for your valuable and constructive feedback. Implementing the suggestions on restructuring the manuscript and revising the conclusion of the paper will, we agree, strengthen the message beyond a pure description. We will rework the entire structure by removing redundancies and inconsistencies across the entire paper. The method section will be elaborated and focused on each key method used to raise our points. The conclusion will be re-written in accordance with the questions raised in the introduction about the findings we could draw from analyzing the event with the paradigm of compound events. So, thanks to your suggestions, the manuscript will gain clarity, and intent.

We propose to restructure the manuscript as follow:

1. Intro
2. Study site
3. Methods and Data
 - 3.1. Data

- 3.1.1. Monitoring networks
- 3.1.2. Reanalysis datasets
- 3.1.3. Geospatial data

3.2. Methods

- 3.2.1. Spatial analysis
- 3.2.2. Snowpack modeling
- 3.2.3. Hydraulic reconstruction
- 3.2.4. Hydrological modeling
- 3.2.5. Seismic analysis
- 3.2.6. Statistical analysis
- 3.2.7. Debris flow analysis

4. Results

4.1. Preconditions to the event:

- 4.1.1. Geomorphological context
- 4.1.2. Glacier
- 4.1.3. Snowpack

4.2. Triggers of the 19-21 June 2024 Event

- 4.2.1. Synoptic and meteorology
- 4.2.2. Snowmelt
- 4.2.3. Glacial lake drainage

4.3. River's response

- 4.3.1. Hydrometric observation
- 4.3.2. Hydrological modeling
- 4.3.3. Seismic analysis
- 4.3.4. Reconstructing the event's chronology

4.4. Impact of the event

- 4.4.1. Human and infrastructure impacts
- 4.4.2. Geomorphological changes

4.5. Qualifying the rarity of the event (a transferer dnas la discussion?)

- 4.5.1. Historical events
- 4.5.2. Event probability
- 4.5.3. Comparative sediment production

5. Discussion

- 5.1. Role of the GLOF
- 5.2. Paraglacial adjustment
- 5.3. Spatial connectivity
- 5.4. Compound nature of the event
- 5.5. Climate change

6. Conclusion

Specific comments

Figure 2 does not provide significant information: it could be expunged or moved to the Appendix.

Figure 2 is a 19th century, impressionist painting of the village of La Bérarde that was affected by the debris flood on June 21, 2024. This painting depicts the village, the surrounding landscape, with the Etancons stream in the forefront of the image. The water is rushing, threatening houses by its location on canals. This figure brings more than data on a graph or a contextual map. It depicts in one image, not only the village of La Bérarde itself, but the grandeur of the nature surrounding the village, and how little, vulnerable human infrastructures are in this landscape. The mood chosen by the artist to paint is gloomy, dark, echoing the danger to be in this place. The choice to bring forward the painting in the paper is to ground the reader, not only to an intellectual demonstration, but also in the context of the place itself, depicted in a monumental and historical art piece (2.8 x 1.2 m at the Musée de Grenoble).

While the paper is written for a scientific journal, we believe it important to highlight the importance of this place beyond the purely materialistic consequences of the event. Moreover we intend this manuscript to become a historical reference for the locality, describing the event that will shape the future of this place for decades to come. In that sense contextualizing in a broad and historical way, to the extent we can, what this event means for the place and the people relating to it, does justify, to our eye, showing the depiction of La Bérarde by Abbot Laurent Guetel from 1882 as part of the introduction.

For these reasons we would like to maintain the painting in the manuscript. To reduce its size, we incorporated it with Figure 1 (before and after event photos). We move the paragraph introducing La Bérarde prior to the paragraph describing the event, so that the reader understands why La Bérarde has an importance reaching further than an average village.

The methods applied to the study of this event would deserve to be described in a separate section, instead of being part of Section 2, which also discusses site and data (Section 2.5 is very short and does not present all methods applied in the study). All relevant methods should be described or referred to by indicating the Appendices where they are described.

We will expand the method sections to introduce with better clarity and depth each method used. See outline proposed above. Each sub section introduces the key methodological elements with reference to the Appendices if more details are needed.

Section 2.1

The Melton ruggedness number of the Étançon at La Berarde could be computed: its value, together with the fan slope, would provide some clues about long-term flow processes (debris flow, debris flood, mixed processes?) in the distal part of the torrent (see Bertrand et al., 2013 for thresholds between debris flows and fluvial processes). Of course, no ultimate answers on the type of flow processes that occurred during a specific event can be expected from these simple morphometric indices, but they could be of some interest in site description.

Reference: *Bertrand, M., Liébault, F., & Piégay, H. (2013). Debris-flow susceptibility of upland catchments. Natural Hazards, 67(2), 497-511.*

Thank you for this suggestion. We will add in the site description some morphometric metrics and use the classification of Bertrand et al. (2013).

Could Sections from 3 to 6 be pooled under the general heading “Results”? This would imply a three-levels heading, but it would result in a better-defined structure of the work. Will be done

Section 3.1. Some details on the warning procedures, which permitted rescuing people and avoiding loss of lives, should be reported.

A couple of sentences will be added. Indeed, risk of intense precipitation and flooding were reported in the Department of Isère. The level chosen was orange, preparing rescue teams to intervene. Also, mountain professionals (mountain guides, mountain rescuers) were also present in the village.

“Drivers of the event” (now Section 4) should be described before “Impact of the event” (now Section 3).

See the proposed structure. We will do so.

The reconstruction of event chronology, now in section 5.4 and part of the section on river response, should be one of the first reported results. Moreover, event chronology should not be limited to fluvial processes, and it should cover the entire spectrum of the processes involved in the studied event.

The chronology section is a reconstruction bringing together all elements either directly observed or deduced/interpreted from our analysis. Bringing this section earlier to other results would be difficult, as it pulls many elements from our work. Figure 9

(hydrograph) is the piece tying this timeline together. Consequently, we would like to keep this section after all other results.

Lines 41-43. “The detached... mobile debris flow”. This sentence is redundant: the references to the Himalayan event are sufficient.

The sentence will be removed

Line 72. Baud-Bovy, 1907 is not on the references list.

Thank you for catching the mistake. Corrected

Lines 103-106. I wish to suggest reporting the areas of upper Étançons and Bonne Pierre catchments. The current sentence “Its [*upper Étançons*] catchment is about 2.5 larger than Bonne Pierre Torrent” does not clarify the extent of these two subcatchments.

This is a great suggestion. We will change the sentence to be more specific, mentioning the catchment areas. With the restructuring, this number is now less repeated. We caught a typo in Event’s Chronology concerning these numbers. This will be withdrawn for preventing repetition, thanks to the new structure.

Line 130 “alluvion fan” should be corrected to “alluvial fan”.

Will be done.

Lines 130-138. Some rephrasing and more details are necessary. What is the alluvial fan area? Reporting it would permit appreciation that the fan is small in comparison to the catchment size (line 130). The truncation of the fan toe by the Vénéon river should be reported immediately after the second sentence, which mentions the evacuation of sediment by the Vénéon river.

Thank you for the suggestion. The fan area will be added and the sentence reformulated to mention how the Veneon truncates the alluvial fan at its base. We will also add the area of the Veneon above La Berarde.

Lines 139-143. Why has a 48-hours duration been considered? Does it correspond to the duration of the rainstorm and snowmelt that triggered the 2024 event (see lines 59 and 211-213)? Please specify. The authors could consider moving here the text at lines 211-213.

Thank you for suggesting this change. We will edit as suggested, bringing the rationale for the 48h window choice in the Site Description section. In short, 48h is approximately the event duration, and also happens to be the time window for which the event is statistically of high probability. Shorter and longer time windows minimize the event’s

intensity. We will add a short table in the appendix showing the reason why 48h is the time window chosen.

Lines 163-164. A reference to the Glacioclim program is necessary.

We will add the reference Vincent et al. (2007). The URL to the webpage is already included as a hyperlink.

Vincent, C., Le Meur, E., Six, D., & Thibert, E. (2007). Un service d'observation des glaciers des alpes françaises « glacioclim-alpes », pour quoi faire ? La Houille Blanche, 93(3), 86–95. <https://doi-org.insu.bib.cnrs.fr/10.1051/lhb:2007040>

Line 242. “leading to many damages in the Bérarde village”: damage to the village has already been mentioned. No need to say it again.

It will be removed.

Lines 639-641. Two possible references to papers that propose different interpretations on the formation of a cluster of megafans in the eastern Alps:

Jarman, D., Agliardi, F., & Crosta, G. B. (2011). Megafans and outsize fans from catastrophic slope failures in Alpine glacial troughs: the Malser Haide and the Val Venosta cluster, Italy.

Brardinoni, F., Picotti, V., Maraio, S., Bruno, P. P., Cucato, M., Morelli, C., & Mair, V. (2018). Postglacial evolution of a formerly glaciated valley: Reconstructing sediment supply, fan building, and confluence effects at the millennial time scale. Bulletin, 130(9-10), 1457-1473.

Thank you for the suggestions. We have read the two references. The paper by Jarman et al. describes megafans of much larger dimensions and their formation by huge catastrophic rock slope failures. These have no similarity with neither the 2024 event, nor the formation of the Bonne Pierre proglacial fan, which is interpreted as a fluvio-glacial fan. There is no similarity either regarding the total fan volume. The Bonne Pierre proglacial fan has a relatively small total volume, since its upper part covers a bedrock slope (several outcrops over the whole area), only the lower half filling the margin of a U-shaped valley. We therefore decided to discard this reference.

The paper by Brardinoni et al. describes situations that could be analogous to the Etançons catchment although at a larger spatial scale. The Bonne Pierre proglacial fan may effectively have partially dammed the main Etançons valley, and induced a sediment trap upstream of the fan. However, we lack data to confirm this hypothesis.

More generally the mentioned low gradient sections of the upper Etançons are all induced by lateral fans. This is however a very common feature in Alpine valleys. The existence of a major paraglacial adjustment phase during the Early Holocene, followed by several shorter, more limited accretion phases on torrential cones during the second half of the Holocene, were already evidenced in the French Alps by work done by the team of Maurice Jorda from Aix in the 1990's. We chose the work of Ballandras 1997 as reference (the most recent and most complete). The Brardinonni et al. 2018 reference will be added in the text as well as further to cite the duration of the torrential crisis they highlighted (5 k. years).

Lines 609-620 and A12: The authors note that the observed flow depth at La Bérarde is much smaller than would have been assuming 200,000 m³ debris flow triggered by the sudden drainage of the superglacial lake. Could we argue that the also the type of flow processes observed in the distal part of the channel (i.e. a debris flood instead of a debris flow at La Berarde) indicate that a sudden lake drainage is highly unlikely?

Thank you for this suggestion. It is true that observations made during the night showed processes on the fan resembling debris floods, in particular flows with two clearly distinct phases. The deposits on the fan did not show clear evidence of debris-flow processes, but the event lasted quite a long time, so such evidence may have been removed by subsequent flows. We will thus add sentences specifying these aspects in the revised version.

Line 1327 (Torricelli law): If the authors wish to cite the original work of E. Torricelli, which is probably not strictly necessary, the year of publication (1644) should be reported.

Will be done. Thank you for providing us with the correct reference.

The reference would be *Torricelli, E. Opera geometrica, typis A. Masse et L. de Landis, Florentiæ, 1644.*