

**Manuskript:** Long-term monitoring (1953–2019) of geomorphologically active sections on LIA lateral moraines under changing meteorological conditions, Moritz Altmann, Madlene Pfeiffer, Florian Haas, Jakob Rom, Fabian Fleischer, Tobias Heckmann, Livia Piermattei, Michael Wimmer, Lukas Braun, Manuel Stark, Sarah Betz-Nutz, and Michael Becht  
Submitted on 27 Dec 2022

**Handling editor:** Giulia Sofia, [giulia.sofia@uconn.edu](mailto:giulia.sofia@uconn.edu)

**RC1:** ['Comment on egusphere-2022-1512'](#), Anonymous Referee #1, 23 May 2023

Reviewer: The preprint of an ESurf manuscript open for interactive discussion constitutes an interesting and important study and addresses one of the important research geomorphology currently focuses on. Among many aspects of modern and future 'Global Environmental Change', the development of recently deglaciated glacier forelands and connected morphodynamic processes in mountain regions is surely of considerable significance. Despite the related concept of the 'paraglacial period' is now well established for several decades, existing work often suffers from the lack of detailed long-term observations. Some conceptual facets and underlying assumptions would certainly highly benefit from such data.

Gully formation on the slopes of lateral moraines exposed by successive glacier retreat since the 'Little Ice Age' maximum extension is a prominent example of paraglacial processes and characteristic for many glacier forelands worldwide. The current study presents such detailed and accurate data from a total of twelve active gully systems on lateral moraines in five glacier forelands, all located within the Eastern European Alps. Several surveys over a rather long timeframe from 1953 to 2019 allow a detailed investigation of gully system development and sediment yield over a comparable long time and 3 separate time periods within this interval. The authors apply a highly developed methodology related to both the acquisition of aerial imagery, DEMs, LiDAR scenes etc. and their subsequent morphometric analysis. All results are well presented and all data are of high quality and accuracy. All individual methodological steps within the data analysis and well explained alongside all necessary information on the data base. It is, therefore, no surprise that the results of the truly long-term study are impressive and a valuable contribution to the topic.

In many aspects, the majority of the investigated sites confirm the validity of the established 'paraglacial period concept', for example with the highlighted decrease of sediment yield over time during the targeted time period (i.e. the 'sediment-exhaustion' model). On the other hand, an interesting result is that the gullies have still not been fully stabilised and some morphodynamic activity is still recorded during the final (youngest) time period. This is in disagreement to some existing studies, but also in agreement with other ones. Alongside a newly developed 'sediment activity concept' this finding and two sites that do, as exceptions among the total data set, not fully follow the expected conceptual decreasing sediment yield for 'paraglacial processes' are finally discussed. But here, a deeper discussion on basis of published work from other regions would likely improve the high quality of the manuscript. The new concept is introduced and discussed too briefly to convince that the observations justify the introduction of a new concept. An extension of the discussion chapter should serve to interpret the results of the study in more detail and highlight the differences from the established concept and assumption to underline its significance.

It seems only a minor points given the scientific value of the preprint, but an excessive use of acronyms and abbreviations for terms where they are neither necessary nor established negatively affects fluent reading, to an extent where it is annoying. It would be acceptable for a technical report, but for a journal article this should be avoided. Because it surely constitutes

no major effort to make related changes in the text alongside some final editorial and typographic changes, the authors are recommended to consider such changes (some examples are indicated in the technical comment section below).

Summarising, the long-term study and its well presented results constitute a valuable contribution to a wider audience within the targeted scientific community. The only scientific room for improvement is a recommended extension of the discussion section by adding some depths. In my specific comments below I will address this in more detail.

### **Specific comments:**

I feel that the authors should extend the discussion chapter by exploring some of their most interesting findings, for example that their investigated active gully systems still are active and show, despite a decrease of sediment yield in most cases, no stabilisation. As correctly stated, this finding is different to previously published work from other regions, for example Western Norway. Perhaps the authors should present a hypothesis or some possible reasons for this, simply because it is to some extent contradictors to the established sediment-exhaustion concept for the development of gullies. Regional different conditions of gully development need, however, to be taken into account with the discussion of this apparent discrepancy. Among those are the different geomorphological setting (typical Alpine-type lateral moraines vs. debris-covered slopes of different origin in Norway) and the sedimentological properties of the lateral moraines related to their genetic origin etc. Factor other than the morphometric properties have to be taken into account.

**Authors:** Hypotheses or possible reasons are required as to why geomorphic active areas on LIA lateral moraines stabilise over several decades in some regions and not in others. This is difficult to determine and cannot be finally investigated or clarified. It is assumed that this is due to local conditions. This could be due to the changing triggering events caused by changing heavy rainfall events, also to the different sedimentological properties of the lateral moraines in relation to the genetic origin or the different geomorphological settings. Furthermore, it could be due to the different characteristics of the lateral moraine sections, such as slope gradient, slope length, time of ice exposure and the different development of vegetation. It would be possible to include this in the discussion, but ultimately only assumptions can be made.

**Reviewer:** The 'sediment activity concept' developed by the authors is only comparatively briefly introduced. With a limited number of study sites and - as least this is my (potentially wrong) assumption - mainly based of two exemptions from the trend the basis for developing such an innovative concept is rather small. And with the 'ice release' not included and a limited temporal validity (see lines 556 ff.) the authors need to properly elaborate is this constitutes a significant new and valuable concept - in other words justify that their observations support such a step instead of accept that exceptions from other established concepts always may exist. Perhaps it would strengthen the value and depths of the discussion chapter if the authors focus more on the investigation of potential reasons for the deviating date of these two gully systems instead of developing a new and obviously limited concept.

**Authors:** We would like to keep the development of the sediment activity concept to the number of study areas in this study. However, what we can include in the discussion are the results of this study and the developed concept with the description of the development of the lateral moraines of other studies. Thus, there is a broader discussion with already existing results. The concept is indeed well compatible with already existing studies (e.g. Betz-Nutz et

al. (2023)), as geomorphologically active areas could also be identified there, which on the one hand show a decreasing trend, have activity at similar levels or show an increase. Reasons for this different development can also be brought into the discussion, which are based on the fact that each slope has very individual conditions that can also lead to an increase in geomorphological activity over several decades.

(Betz-Nutz, S., Heckmann, T., Haas, F., and Becht, M.: Development of the morphodynamics on Little Ice Age lateral moraines in 10 glacier forefields of the Eastern Alps since the 1950s, *Earth Surf. Dynam.*, 11, 203–226, <https://doi.org/10.5194/esurf-11-203-2023>, 2023.).

Reviewer: In their discussion section 5.4 'meteorological drivers' the authors present an interesting review on potential meteorological drivers for the current morphodynamic activity of the gully systems investigated. In contrast to what some readers may have expected based on frequently emphasised (popular)scientific statements, there seems to be major increase in the frequency or magnitude of heavy-precipitation events in the study areas. They accurately describe the differences of simulated vs. observed meteorological data what is good and provides good insights. But as this aspect of the study is even included in the title, it seems that some summarising conclusion (or assumptions) regarding the potential influence on climate change need to be provided. These could be along the lines 'paraglacial period'/'sediment exhaustion' concept vs. development of geomorphological activity and morphodynamics in times of Global Change. And to throw in just a provocative hypothesis: Could future climate change lead to increased morphodynamic activity (erosion) and disturb the 'normal' decrease of sediment yield as predicted by the established paraglacial period concept?

Authors: No increase in the frequency and magnitude of heavy precipitation events could be demonstrated. The hypothesis proposed by the reviewer seems too strong to us. Finally, assumptions are made as to why the warming of the air temperature could have had a positive effect on erosion (increase in the number of warm-air inflows). Ultimately, however, the exact influence cannot be proven. The general decrease is best explained by the generally effecting paraglacial adjustment processes. Special cases always show special characteristics. We would therefore rather suggest changing the title to: Long-term monitoring (1953-2019) of geomorphologically active sections on LIA lateral moraines in the context of changing meteorological conditions.

Reviewer: I am confident that by investing some effort to extend and strengthen some sections of the discussion chapter will substantially increase the overall scientific value of the comprehensive and important research presented by the authors. The overall goal should be to place the significant long-term approach and its results better in a general context, also beyond the Eastern European Alps.

#### **Technical corrections:**

The manuscript is mostly well structured and written, with the important exception of excessive use of (to a considerable extent) unnecessary acronyms/abbreviations that can make reading a pain. A few typographic/editorial changes should, however, be addressed during the revision:

Authors: All acronyms and abbreviations are checked. The established ones are to be kept, the less established abbreviations or those developed specifically for this study are removed and not abbreviated but written out in full.

- Reviewer: I feel that in the title the acronym 'LIA', despite well established, should be written in full. Also, I think it should be '...sections of ...' and, given the time period investigated, perhaps better 'climatic conditions'.
- Authors: The proposed changes can be incorporated and the title can be changed accordingly: Long-term monitoring (1953-2019) of geomorphologically active sections of Little Ice Age lateral moraines in the context of changing climatic conditions.
- Reviewer: Line 13: Add 'European' to Alps (only once in abstract and general text).
- Authors: The proposed amendment is adopted.
- Reviewer: Line 19/20: I recommend to consider different expressions for 'areas of interests' and 'entire areas of interest'. As I understand it, this refers to the active gully system and the entire lateral moraine. Why making it unnecessarily complicated with an excessive use of the term 'area of interest'? 'Sites' or gully systems allow the reader to read the abstract more fluently
- Authors: The proposed amendment is adopted.
- Reviewer: Line 21: 'Can be shown'
- Authors: The proposed amendment is adopted.
- Reviewer: Line 21: 'Epochs' is a wrong term in the context.
- Authors: The proposed amendment is adopted. The sentence is amended accordingly: Subsequently, both the areas of interest and the different time periods of both approaches are compared.
- Reviewer: Line 21: This sentence should be re-written as it is a bit unclear.
- Authors: The sentence is amended accordingly: Based on the slopes of the calculated regression lines, it could be shown that the highest variability of sediment yield in the areas of interest occurs in the first epoch (mainly 1950s to 1970s). This can be attributed to the fact that in some areas of interest the sediment yield per square metre increases clearly more strongly (regression lines with slopes up to 1.5). In contrast, in the later epochs (1970s to mid-2000s and mid-2000s to 2017/2019), there is generally a decrease in 10 out of 12 cases (regression lines with slopes around 1).
- Reviewer: Line 34: Better: 'with influence of dead ice over decades'
- Authors: The sentence is amended accordingly.
- Reviewer: Keywords: A quite high number, are all necessary? Paraglacial process system should be added
- Authors: The keyword Modelling is removed. The keyword "paraglacial process system" is added as suggested.
- Reviewer: Line 42: There is no defined or general 'end' of the Little Ice Age. The authors could well be more specific and relate it to the Eastern European Alps (if they wish).
- Authors: The end of the Little Ice Age is also underpinned with literature (Matthews, J. A., & Briffa, K. R. (2005). The 'little ice age': Re-evaluation of an evolving concept. *Geografiska Annaler. Series A. Physical Geography*, 87(1), 17–36. <https://doi.org/10.1111/j.0435-3676.2005.00242.x> and Ivy-Ochs, S., Kerschner, H., Maisch, M., Christl, M., Kubik, P. W., & Schlüchter, C. (2009). Latest Pleistocene and Holocene glacier variations in the European Alps. *Quaternary Science Reviews*, 28(21-22), 2137–2149. <https://doi.org/10.1016/j.quascirev.2009.03.009>
- Reviewer: Line 44: Better: 'extending'
- Authors: The proposal can be accepted and amended accordingly.
- Reviewer: Line 61: Better: 'and subsequently'
- Authors: The proposal can be accepted and amended accordingly.
- Reviewer: Line 97: A recent comparative study could be worth being cited in this context: Eichel, J., Draebing, D., Winkler, S. & Meyer, N. (2023): Similar vegetation-

geomorphic disturbance feedbacks shape unstable glacier forelands across mountain regions. *Ecosphere* 14(2), e4404.

- **Authors: The proposal can be accepted and amended accordingly.**
- Reviewer: Lines 104, 111: The inflationary use of acronyms/abbreviations in this chapter (and subsequent ones) makes it a bit hard to read the text fluently. Whereas for very established and complex term (DEM, SfM, LiDAR) it is all fine, abbreviating 'historical aerial imagery' and in particular 'sediment yield' goes over the top. The space saved does not compensate for poor readability with so many acronyms.
- **Authors: The suggestion can be accepted and amended accordingly.**
- Reviewer: Line 124: Explain the acronym AOI the first time it is used in the general text - or much better avoid this term at all.
- **Authors: The suggestion can be accepted and amended accordingly.**
- Reviewer: Line 124: See comment to 'epoch' above, why not 'period' or 'time period'?
- **Authors: For better understanding, the term epoch is changed to time period.**
- Reviewer: Line 128: Add 'European'
- **Authors: Will be added.**
- Reviewer: Line 138: Capital letters for 'Main Alpine Divide'
- **Authors: Will be added.**
- Reviewer: Line 153: 'Sparse' for 'low'
- **Authors: Will be changed.**
- Reviewer: Figure 1: Although the term is 'Gletschervorfeld' in German, the appropriate term is 'foreland' not 'forefield'. It would be good to (a) mention 'glacier outline' or 'glacier margin' in the legends as well. Please use the same colour for the same glacier extent (e.g. not green for the 1953 margin at Gepatschferner and blue for the same margin at Weißseeferner). Better to only use one colour for one data on all
- **Authors: The suggestions will be changed. The terms foreland and glacier outline are amended. Furthermore, the same colour of the glacier stands should be chosen, which can be assumed.**
- Reviewer: Line 180: Is it necessary to give such a detailed information? The same applies for the full project titles on Table 3.
- **Authors: This section can be shortened, but we would like to have some information about the ALS recordings and previous projects.**
- Reviewer: Line 245 ff.: This sentence could be made clearer by re-wording it.
- **Authors: The sentence will be rewritten accordingly: No threshold has been set for the level of detection of the DoDs, as Anderson (2019) clearly recommends not using this for volumetric calculations as it leads to bias in the results (Anderson, S. W.: Uncertainty in quantitative analyses of topographic change: error propagation and the role of thresholding, *Earth Surf. Process. Landforms*, 44, 1015–1033, <https://doi.org/10.1002/esp.4551>, 2019.).**
- Reviewer: Line 365/366: Find a different solution for the two subsequent brackets and re-word the sentence
- **Authors: The sentence will be rewritten accordingly: With regard to section 3.3, a decreasing intercept together with an almost constant, although slightly decreasing, slope close to one can be seen over the different epochs in the log-log model, indicating that the relation between SCA and SY remains almost constant.**
- Reviewer: Line 368/369: This sentence is a good example what I highlighted as excessive use of acronyms. Apart from those for the different active gully sections in the sentence above, no other acronym is necessary here, neither AOI nor SCA or SY.
- **Authors: This will be amended as suggested.**
- Reviewer: Line 501/502: If the authors would like to find a citation for this assumption, they could use [Jäger, D. & Winkler, S. (2012): Paraglacial processes on

the glacier foreland of Vernagtferner (Ötztal Alps, Austria). *Zeitschrift für Geomorphologie N.F. Supplement Bd. 56 (4): 95 – 113.*] where this influence is described from another glacial foreland in the region.

- **Authors: The reference suggestion has been read and will be added.**