Answer to https://doi.org/10.5194/egusphere-2024-2509-RC1

Dear Reginald Hermanns,

Thank you for taking the time to review our article and the constructive feedback and input on the previous submission. We addressed all the issues raised and believe that the implemented changes have substantially improved the revised manuscript. We briefly outline the primary changes here and add a one-by-one reply to the reviews on the following pages.

- We updated the title to 'Mechanical modeling deciphering the massive permafrost rock slide under a warming polythermal glacier (Bliggspitze, Austria),' emphasizing the main methods used in the publication.
- Figure sizes and coordinates to maps were adjusted accordingly.
- Thank you for providing publications beyond ours to enhance a global perspective. We included various suggestions and added additional references, which extended and essentially improved the section introduction.

Please find all responses to each comment below, marked in blue.

With best regards,
Felix Pfluger
On behalf of all authors

Review of the manuscript: egusphere-2024-2509

Massive permafrost rock slide under warming polythermal glacier (Bliggspitze, Austria)

By: Felix Pfluger, Samuel Weber, Joseph Steinhauser, Christian Zangerl, Christine Fey,

Johannes Furst, and Michael Krautblatter

The manuscript is a back analyses of a multimillion cubic meter rock slide at Bliggspitze on 29 June 2007. It is based on a detailed geological/structural model of the failure zone, remote sensing data of the glacial extension of the Bliggferner glacier and its change, on-site temperature data from the failed mountain as well as metrological data from close by meteorological stations, data on springs from the slope, electric resistivity tomography on the slope from after failure as well as laboratory experiments on rock samples from the mountain and advanced 2D stability modelling using the software UDEC.

The topic is extremely timely as it relates slope stability to climate change. This case is particular interesting and unique as it investigates a rockslide that forms subglacial, and the study is unique in its depth in this environment adding to multiple studies in permafrost environment that are less related to glacial ice decay. The manuscript is very well written and balanced. Assumptions are well highlighted, and uncertainties based on the limited amount of data thoroughly discussed. Sensitivity tests were carried out and are well described. This manuscript puts light on changes that will occur in the high alpine but also artic environment with potential hazardous consequences for society.

I can only suggest minor revisions/technical corrections to this well written manuscript with a high quality and well-developed figures.

My suggestions are:

Add “slope stability analysis” into the title.
We updated the title to ‘Massive permafrost rock slide under a warming polythermal glacier deciphered through mechanical modeling (Bliggspitze, Austria),’ emphasizing the main methods used in the publication -> mechanical modeling.

Add coordinate system in all maps or block diagrams
We described the exact location in the text Bliggspitze summit (3453 m asl, 46°55'5''N, 10°47'10''E - WGS84). We added CRS to Fig. 1 and 16.

Add view position of all photos presented into the maps. Included in Fig. 1.

Add directions to the photos eg. NW-SE in upper right and left Included in Fig. 1.

Figure 16 is too small in size in the manuscript, it is difficult to read, consider enlarging
Corrected.

Add more references from outside the Alps to the reference list which will set a more global perspective. E.g. some suggestions:
The blue-marked references are now included in the manuscript.

Line: 33:

Geertsema, M., Menounos, B., Bullard, G., Carrivick, J. L., Clague, J., Dai, C., et al. (2022). The 28 November 2020 landslide, tsunami, and outburst flood–A hazard cascade associated with rapid deglaciation at Elliot Creek, British Columbia, Canada. *Geophysical research letters*, 49(6), e2021GL096716.

Svennevig, K., Hicks, S. P., Forbriger, T., Lecocq, T., Widmer-Schnidrig, R., Mangeney, A., et al. (2024). A rockslide-generated tsunami in a Greenland fjord rang Earth for 9 days. *Science*, 385(6714), 1196-1205.

Kuhn, D., Torizin, J., Fuchs, M., Hermanns, R., Redfield, T., & Balzer, D. (2021). Back analysis of a coastal cliff failure along the Forkastningsfjellet coastline, Svalbard: Implications for controlling and triggering factors. *Geomorphology*, 389, 107850.

Line 39:

Svennevig, K., Dahl-Jensen, T., Keiding, M., Merryman Boncori, J. P., Larsen, T. B., Salehi, S., et al. (2020). Evolution of events before and after the 17 June 2017 rock avalanche at Karrat Fjord, West Greenland – a multidisciplinary approach to detecting and locating unstable rock slopes in a remote Arctic area. *Earth Surf. Dynam.*, 8(4), 1021-1038. doi:10.5194/esurf-8-1021-2020.
Included: ‘Due to the complexity of large rock slope failures, their often remote alpine locations with challenging accessibility that result in limited available data, and the absence of a clear seasonal pattern, predicting such failures in permafrost regions is challenging \citep{Huggel.2008, Svennevig.2020}.’

Line 41: (Rewrite the paragraph before accordingly)

Ballantyne, C. K., Sandeman, G. F., Stone, J. O., & Wilson, P. (2014). Rock-slope failure following Late Pleistocene deglaciation on tectonically stable mountainous terrain. *Quaternary Science Reviews*, 86, 144-157.

Hermanns, R. L., Schleier, M., Böhme, M., Blikra, L. H., Gosse, J., Ivy-Ochs, S., et al. (2017) 'Rock-Avalanche Activity in W and S Norway Peaks After the Retreat of the Scandinavian Ice Sheet' *Workshop on World Landslide Forum*. Springer, pp. 331-338.

We added: Investigating the timing of rock slope failures in Scotland and northwest Ireland in relation to deglaciation, \cite{Ballantyne.2014} found that 95\% of the analyzed failures occurred within approximately 5400 years after deglaciation, with peak activity occurring between 1600 and 1700 years post-deglaciation. They suggests that glacier unloading and seismic activity were the primary triggers. Similarly, \cite{Hermanns.2017} identified a time cluster of rock avalanche deposits in Norway originating from the first millennium after deglaciation, as well as a second cluster during the Holocene climatic optimum. Studying rock slope failures in the European Alps, \cite{Prager.2008} noted a time cluster of events several thousand years after ice withdrawal. These failures, occurring several thousand years after deglaciation, are hypothesized to have been prepared by glacial cycles and finally triggered with a time lag relative to the Last Glacial Maximum (LGM), accounting for the loss of permafrost \citep{McColl.2012, Krautblatter.2013}.

Line 504:

Geertsema, M., Menounos, B., Bullard, G., Carrivick, J. L., Clague, J., Dai, C., et al. (2022). The 28 November 2020 landslide, tsunami, and outburst flood–A hazard cascade associated with rapid deglaciation at Elliot Creek, British Columbia, Canada. *Geophysical research letters*, 49(6), e2021GL096716.

Line 618: (here there are references missing at all) Some suggestions:

Willenberg, H., Evans, K. F., Eberhardt, E., Spillmann, T., & Loew, S. (2008). Internal structure and deformation of an unstable crystalline rock mass above Randa (Switzerland): Part II - Three-dimensional deformation patterns. *Engineering Geology*, 101(1-2), 15-32. doi:http://dx.doi.org/10.1016/j.enggeo.2008.01.016.

We assumed it was state-of-the-art in rock slope mechanics and there is no need to references. Due to the broad readership it does definitely make sense! And I adopted the references and added Eberhardt et al. (2004)

Brideau, M.-A., Yan, M., & Stead, D. (2009). The role of tectonic damage and brittle rock fracture in the development of large rock slope failures. *Geomorphology*, 103(1), 30-49. doi:http://dx.doi.org/10.1016/j.geomorph.2008.04.010.

Welkner, D., Eberhardt, E., & Hermanns, R. L. (2010). Hazard investigation of the Portillo Rock Avalanche site, central Andes, Chile, using an integrated field mapping and numerical modeling approach. *Engineering Geology*, 114(3-4), 278-297. doi:http://dx.doi.org/10.1016/j.enggeo.2010.05.007.

Added Eberhardt et al. (2004):
Eberhardt, E., Stead, D., and Coggan, J.: Numerical analysis of initiation and progressive failure in natural rock slopes—the 1991 Randa885
rockslide, International Journal of Rock Mechanics and Mining Sciences, 41, 69–87, 2004.

Brideau, M.-A., & Stead, D. (2012). Evaluating kinematic controls on planar translational slope failure mechanisms using three-dimensional distinct element modelling. *Geotechnical and Geological Engineering*, 30, 991-1011.

Lines 775-785:

I would also suggest discussing against:

Geertsema, M., Menounos, B., Bullard, G., Carrivick, J. L., Clague, J., Dai, C., et al. (2022). The 28 November 2020 landslide, tsunami, and outburst flood–A hazard cascade associated with rapid deglaciation at Elliot Creek, British Columbia, Canada. *Geophysical research letters*, 49(6), e2021GL096716.
This case is an example of a valley glacier in contact with the toe of the rock slope. The glacier for the case of Elliot Creek was only covering marginal parts of the lower part of the rock slope. Its thermal impact on the rock slope is not of central interest as it is the case for Marmolata glacier (Chiarle et al. 2023), Mt. Steller (Huggel et al. 2008), or here at Bliggspitze.

Svennevig, K., Hicks, S. P., Forbriger, T., Lecocq, T., Widmer-Schnidrig, R., Mangeney, A., et al. (2024). A rockslide-generated tsunami in a Greenland fjord rang Earth for 9 days. *Science*, 385(6714), 1196-1205.

-> See comment before.

Some minor typos:
Thank you, we corrected all the typos!

Line 307: there seems to be one or more words missing

Line 317: a space missing after “glacier,”

Line 319: consider “up-glacier” and “fracture band”

Line 330: is rather a repetition of the method section

Line 386: May be rewrite “The picture …”

Line 412: Figure number is missing.

Line 451 and 454: consider writing in the same wording: “ice-free stage” and “glacier-free conditions” reads as if different aspects are meant. If indeed different aspects are meant make clearer the difference in both sentences.

Line 459 a space is missing after the bracket

Line 804 the “,” should be positioned prior to the line break

---