Reply to all reviewers:

We thank the reviewers for their considered and insightful review. We agree with the reviewers that the processes are interesting and highly relevant for the glaciological and volcanological community when it comes to further our understanding of hazardous flooding events but also the heat exchange between rock and ice.

Based on the feedback, we recognize that we did not draw sufficient attention to the new insights that this manuscript is focusing on in comparison to Eibl et al. 2020. To improve the manuscript and address the reviewer's concerns, we have improved clarity throughout in the old text and figures, to draw attention to the new findings and remove duplication.

We have also conducted new processing of the seismic data from the SIL network in combination with the seismic arrays at JO and IE. We have now processed (i) all three components of the arrays. (ii) We performed template matching and clustering of additional icequakes that indicate the collapse of the ice cap above the lake. (iii) We detected high frequency transient events in the array data that support our interpretation that Type 1 tremor is composed of repeated events. (iv) We investigated the 'local noise' in more detail and located the sources at rapids and a nearby waterfall.

In comparison to Eibl et al. 2020, we here show that we can differentiate 4 instead of 2 different tremor types. Our detailed seismological analysis yields 3 different subglacial tremor types (Type I to III), rapid-induced tremor (Type 4) from subaerial river flow, icequakes originating in the cauldron area, and high-frequency transient events propagating alongside Type I tremor with the flood front. This study hence provides much more detail of the detected seismological signals and their generation associated with the subglacial but also subaerial propagation of the flood.

As recognized by the reviewers we would like to help to classify tremors in less studied areas with this detailed and extensive study of a robust dataset. Further details of our modifications can be found in bullet points below:

Reviewer 1:

Review to "Seismic Characteristics of the Largest Measured Subglacial Flood from the Eastern Skaftá cauldron, Iceland" by Eibl and others, 2022

The authors of the manuscript present seismological observations from a subglacial flood that originated in 2015 from the Eastern Skaftá cauldron at the Vatnajökull ice cap in Iceland. Over the course of a few days, they detect various quakes and two types of tremors which they exploit to study the temporal evolution of the flood by means of quake locations, beamforming analysis, spectrograms and tremor amplitude. Guided by complementary measurements of the ice motion and hydrological parameters, Eibl et al. find that the quakes are related to the subsidence of the cauldron and the two tremor types to the subglacial hydrology: the longer lasting type 1 tremor is attributed to the flood wave propagation while the shorter but more impulsive type 2 tremor is attributed to geothermal processes including boiling in response to the flood. The study focuses on type 1 tremor and the authors suggest that this signal is caused by multiple brittle ice cracking as the flood wave propagates between ice and bedrock, lifting

the glacier by up to 1 m. This tremor type can be used to track the propagation of the flood and its speed via beamforming analysis (Eibl et al. 2020).

The investigated processes are interesting and highly relevant for the glaciological(/volcanological) community. Furthermore, the results appear robust and the conclusions convincing. However, in my opinion, the submitted manuscript does not provide significant new data and/or processing and thus not significant novel insights into the flood. Most of the eight figures show material, that is already presented in Eibl et al. (2020) (e.g. most of Figs. 1, 3, 4, 6) and the conclusion drawn are the same for both manuscripts. Doubtlessly, the present manuscript contains a more in-depth discussion on the involved processes compared to Eibl et al. (2020), but still concludes that type 1 tremor is caused by the propagating flood wave lifting the ice and type 2 tremor by hydrothermal explosions and subsequent geothermal boiling. Only the quake and water-chemical data are newly introduced but these solely play a side role and do not provide significant novel insights. Overall, the manuscript appears more like a supplementary material to Eibl et al. (2020). For this reason, I unfortunately cannot recommend to consider the article for publication in Earth Surface Dynamics.

Reference

Eibl, E. P. S., Bean, C. J., Einarsson, B., Pàlsson, F., & Vogfjörd, K. S. Seismic ground vibrations give advanced early-warning of subglacial floods. Nature Communications **11**, 2504 (2020). https://doi.org/10.1038/s41467-020-15744-5

Reply:

- *We performed a new array processing at higher frequencies and detected transient events that follow the flood front. This supports our conclusion that tremor Type 1 is composed of icequakes.*
- *We ran a STA/LTA detector and correlated the waveforms to detect more events. Our final catalog was clustered based on the station HAM, which was the closest 3-component seismometer to the sources based on our back azimuth estimate. Based on station HAM, the waveforms were clustered into 20 different families. These all originate in the cauldron area indicating a gradual collapse of the ice-shelf on different faults.*
- *We analyzed, located, and discussed the other detected seismic sources which are caused by the flood once it reaches the subaerial river (previously just referred to as "local noise" in Eibl et al 2020)*
- *We realized that we had not made it clear enough that we are discussing three different tremor types here (while Eibl et al. 2020 only discuss two)*
- *We modified all figures to highlight the above-mentioned new points (and deleted former Fig. 2 as this was merely doubling most information).*
- *We clarified that the role of the geochemistry is crucial when it comes to discussing the source of Type 2 and 3 tremor in the context of volcanic eruptions or hydrothermal explosions.*
- *We modified the discussion to add our new insights about the drainage processes.*
- *Based on our additional analysis we modified our abstract and conclusion.*

Reviewer 2:

This preprint describes the largest measured subglacial flood from the Eastern Skafta cauldron in Iceland in 2015. The Authors aim to improve the current understanding of processes behind seismic signal generation during subglacial floods. Thanks to the analysis of seismic, GPS, and hydrological observations, the Authors propose two source mechanisms from tremor signal generation: geothermal boiling of water in crustal rocks and repeating icequakes caused be glacier lift.

Yet, most of these observations and the same event have been already published in the paper by Eibl et al., 2020. Moreover, the Authors used the same methods to analyze seismic data. I believe that for this paper to be published, more new information or novel processing approaches should be explored. Some of the claims seem speculative now; for example, the authors propose that tremor 1 is associated with repeating icequakes. This can be very easily verified with clustering methods (e.g., RedPy, Hotovec-Ellis et al., 2019) or template matching (Beaucé et al., 2018). For now, I do not see much value added and novelty compared to Eibl et al. 2020 paper, which, unfortunately, does not allow me to accept this preprint.

References:

Beaucé, E., Frank, W. B., and Romanenko, A.: Fast Matched Filter (FMF): An Efficient Seismic Matched-Filter Search for Both CPU and GPU Architectures, Seismological Research Letters, 89, 165–172, https://doi.org/10.1785/0220170181, 2018

Eibl, E.P.S., Bean, C.J., Einarsson, B. et al. Seismic ground vibrations give advanced early-warning of subglacial floods. Nat Commun **11**, 2504 (2020). https://doi.org/10.1038/s41467-020-15744-5

Hotovec-Ellis, A. and Jeffries, C.: Near Real-time Detection, Clustering, and Analysis of Repeating Earthquakes: Application to Mount St. Helens and Redoubt Volcanoes, in: Presented at Seismological Society of America Annual Meeting, 2016

Reply:

- *We performed a new array processing at higher frequencies and detected transient events that follow the flood front. This supports our conclusion that tremor Type 1 is composed of icequakes.*
- *We tested RedPy, but the clustering based on a predefined transient list did not yield any families. We hence ran a STA/LTA detector and correlated the waveforms ourselves to detect more events. Our final catalog was clustered based on the 3-component station HAM, which was closest to the sources based on our back azimuth estimate. Based on station HAM, the waveforms were clustered into 20 different families. These all originate in the cauldron area indicating a gradual collapse of the ice-shelf on different faults.*
- *We analyzed, located, and discussed the other detected seismic sources which are caused by the flood once it reaches the subaerial river (previously just referred to as "local noise" in Eibl et al 2020)*
- *We realized that we had not made it clear enough that we are discussing three different tremor types here (while Eibl et al. 2020 only discuss two)*
- *We modified all figures to highlight the above-mentioned new points (and deleted former Fig 2 as this was merely doubling most information).*
- *We modified the text severely to reflect the additional processing we have done.*

Reviewer 3:

The manuscript “Seismic Characteristics of the Largest Measured Subglacial Flood from the Eastern Skaftá cauldron, Iceland" presents seismic, GPS and hydrological data, collected during a subglacial flood event in Iceland. The authors found two different types of glacial tremors. Both are related to the flood event. Type 1 tremor originates due to the glacier uplift, leading to icequakes. In the manuscript, the authors show the propagation of the tremor towards the glacier terminus by calculating the back azimuth and comparing these results with GPS and hydrological measurements. Additionally, to the tremor caused by icequakes (type 1), a second tremor type caused by boiling water, called type 2, is presented. After emptying the subglacial lake, the pressure at the glacier bed decreases and allows the water in the volcanic hydrothermal system to boil. Seismometers can see the exploding water bubbles, which show up as type 2 tremor. The authors also present the typical frequency band of both tremor types.

The study of interactions between solid, fluid and gaseous water is unique. In my opinion, the topic of this manuscript is important to understand the hazardous flooding events but also the heat exchange between rock and ice better. Nevertheless, to me the manuscript does not include enough new findings, compared to Eibl et al., 2020, to be presented as a self-standing paper. The manuscript seems to me more like supplementary information to Eibl et al., 2020 because most of the figures and the results are already presented in Eibl et al., 2020. Based on my findings, I do not recommend this manuscript for publication in the current state.

Adding new methods to the same dataset would help to make this manuscript a self-standing paper. For example, Eibl et al., 2020 proposed an early-warning approach using tremor type 1, which could be tested in this manuscript. Increasing the warning time and reaching as few false alarms as possible would be a beneficial application of the findings shown. Another further application would be to train machine learning algorithms to cluster the tremor types automatically by analyzing different tremor features in the time and frequency domain. The seismic dataset seems robust and can help to classify tremors in less studied areas. Also trying to reproduce the measured seismic data with a physical model would improve the manuscript and make it a self-standing paper. A physical model would help to understand the complicated processes at the glacier ice, glacier bed, and englacial lake interface, including the volcanic heat fluxes. However, based on the above-mentioned reasons I can not recommend accepting this manuscript for publication in Earth Surface Dynamics.

Reference:

Eibl, E. P. S., Bean, C. J., Einarsson, B., Pàlsson, F., & Vogfjörd, K. S. Seismic ground vibrations give advanced early-warning of subglacial floods. Nature Communications 11, 2504 (2020). https://doi.org/10.1038/s41467-020-15744-5

Reply:

- *We think that testing the early-warning approach would bring this manuscript closer to Eibl et al. 2020 and hence did not implement this.*
- *We also think that a sample size of 4 is too small to implement a systematic early warning approach or machine learning.*
- *However, we performed a new array processing at higher frequencies and detected transient events that follow the flood front. This supports our conclusion that tremor Type 1 is composed of icequakes.*
- *We ran a STA/LTA detector and correlated the waveforms to detect more events. Our final catalog was clustered based on the station HAM, which was the closest 3-component seismometer to the sources based on our back azimuth estimate. Based on station HAM, the waveforms were clustered into 20 different families. These all originate in the cauldron area indicating a gradual collapse of the ice-shelf on different faults.*

- *We analyzed, located, and discussed the other detected seismic sources which are caused by the flood once it reaches the subaerial river (previously just referred to as "local noise" in Eibl et al 2020)*
- *We realized that we had not made it clear enough that we are discussing three different tremor types here (while Eibl et al. 2020 only discuss two)*
- *We modified all figures to highlight the above-mentioned new points (and deleted former Fig 2 as this was merely doubling most information).*
- *We modified the text throughout to reflect these additions.*