The Cryosphere Discuss.,
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The Cryosphere Discussions

Interactive comment on "Subglacial permafrost dynamics and erosion inside subglacial channels driven by surface events in Svalbard" *by* Andreas Alexander et al.

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We would like to thank Yoram Terleth for reading our manuscript and providing feedback, as well as discussion input.

In the following we present our responses to the short comments and how we address these in the revision of the manuscript.

The short comments are presented in ***bold and italic***, our replies follow immediately thereafter.

Overall comments

This very interesting study provides time series of subglacial channel temperatures and erosion under two cold based valley glaciers on Svalbard. It indicates a link between meteorological events at the surface and the yet poorly understood soft bed subglacial processes affecting glacier hydrology and potentially basal slip under cold based ice. The highlighted importance of extreme events is especially relevant in the context of understanding the effects of climatic change on Svalbard.

We thank for this positive feedback of our study.

Detailed comments

1.The study uses sudden changes in sediment temperature to identify certain erosion events, such as the August 30thevent for the Tellbreen "subglacial 1" sensor (p.18l.35) and the late July unearthing of the 1.05 m sensor under Larsbreen (p.18 l.33). However, other variations in measured sediment temperature are not addressed much in the paper, while it seems they could contribute to the compelling case for the occurrence of episodes of strong erosion linked to surface events. For example, on Figure 6 the 0.45 sediment temperature follows the channel temperature very closely from the the late June / early July peak rainfall event onward. Could it be possible that this event eroded the channel bed down quite close to the buried sensor, in addition to coupling the subglacial conduits to the atmosphere? Similarly, both 'subglacial 2' sensors in Figure 7 register a step-wise temperature increase when surface melt starts to occur around June 24th and the 0.45 sensor shows more variation after the late June rainfall. Both the 0.45 and 0.9 sensors vary with channel air temperature after the second major rainfall event of August 30th, and are exposed upon recovery. Maybe it can be argued that these observations point towards distinct episodes of stream erosion occurring over the summer season?

Our main argument for the timing of the erosion events are not the absolute tem-

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peratures, but rather the change of temperatures. In the supplementary figure S3 of the submitted manuscript, we have prepared a figure showing the change of daily subglacial temperatures compared to the previous day. Looking at the plot for the 1.05 m sensor (Fig S3 b) a small temperature increase can be seen at the start of the melt season, followed by a long stagnant period with very low temperature change compared to the previous day. We argue that this first sudden temperature increase is caused by the first water flowing into the cave system, leading to a sudden and increased heat flow into the ground. Temperatures then slowly increase until end of June (almost no daily change), speaking for slow warming through heat-exchange. Between 18th and 22nd of June we can see a rapid temperature change, followed by more fluctuating temperatures afterwards. We argue that this rapid temperature change must have been caused by erosion of the sediment and that the sensor was exposed thereafter. Due to this rapid increase within short time and almost steady temperature changes preceding to this event, we argue that most of the erosion happened within the period 18th to 22nd of June.

We have prepared similar change figures for the two Tellbreen sites 'Subglacial 1' and 'Subglacial 2'. They can be found at the end of this report. In case of the 0.45 m sediment sensor at 'Subglacial 1', almost no daily change can be observed in the period preceding the 30th of August (Fig. 1 below). The increase of the absolute temperatures that can be observed in Figure 6 is therefore rather caused by slow heat-exchange between sediment and cave air/ water. We would argue for the erosion/ re-placement at 'Subglacial 1' to happen on the 30th of August.

We argue similarly for the case of the sediment sensors at 'Subglacial 2' (see Fig. 2 below). A small temperature change of the two sediment temperatures can be seen towards the end of June and attributed to water flowing into the cave system, making heat available for heat exchange. Looking at the 0.9 m sediment sensor no further

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temperature change can be seen before the 30th of August, indicating slow and steady heat-exchange, followed by fast erosion on the 30th of August. In case of the 0.45 m sensor a few episodes of temperature change can be seen in July. This could indeed be argued as a partial erosion of the sediment. It might as well also be linked to the increased heat input into the cave system as a result of the roof collapse in the lake area. As the 0.45 m sediment temperature is, however, not correlated to the surface air temperature in July (correlation coefficient -0.004, see Table 1), we argue, that the sensor itself was not exposed in July. An erosion event >0.45 m therefore occurred on the 30th of August, as both sediment sensors were exposed following this event.

We will add more explanation regarding these interpretations, and why we think a mechanism, as suggested in this comment, less likely, to the discussion part of our revised manuscript (see also response to referee 2) to make our interpretation more clear. We will further on add the two figures, provided in this response, to the supplementary material of the revised manuscript to allow the reader to better follow our interpretations.

2. page 19, last paragraph In the way I understand the proposed thermo-mechanical erosion mechanism (Figure10), it relies on high stream power to produce high rates of permafrost melting and erosion. The mechanism is especially effective after extreme rainfall and melt events, and applies to the channels of an efficient drainage system, which is where the measurements occurred. On lines 23 to 25, the paper mentions that a more inefficient drainage system would allow more widespread influence of extreme events on basal slip. It would be nice to clarify what is meant exactly, as it seems that in a fully inefficient distributed drainage system, water flow velocities would be too low to allow for turbulent heating and the thermo-mechanical erosion mechanism to occur. It could be interesting to consider Rippin et al. (2005), as they suggest that after mass build-

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up, pressurized and fast water flow through the cold based margin sediments could increase local ice velocities. This seems like it could be a situation where the mechanism presented in this study would be quite relevant.

While it is certainly correct, that in most cases an inefficient drainage system means low flow velocities and thus low erosional stream power, it does not exclude the possibility for high water flow velocities (as Yoram Terleth also mentions in regards to Rippin et al. (2005)) and turbulent flow. For more information see Flowers (2005) and the reference therein to Alley (1996), where turbulent flow is addressed for models of inefficient drainage. We will, however, remove this paragraph from the revised manuscript (P19, L21-34) as suggested by referee 1 and referee 2 (see RC1 and RC2, as well as author responses to both reviews).

References:

Alley RB. (1996) Toward a hydrologic model for computerized ice-sheet simulations. Hydrol. Proc. 10, 649–660.

Flowers Gwenn E. (2015). Modelling water flow under glaciers and ice sheets. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 471, 20140907.

3.A final short remark is that in a recent paper, Haga et al. (2020) mention the potential importance of an efficient drainage system in the partial freezing of the Negribreen glacier terminus to its bed surface. The rapid erosion in response to surface events in this study could indicate the capacity of a drainage system to adjust rapidly to changes, even in permafrost. Maybe such an adjustable system is necessary for the cold based conditions of many Svalbard glaciers termini to form, or at least facilitates formation?

The data presented in our study does indeed indicate a fast adjustment possibility for efficient drainage channels in permafrost, given enough available subglacial sediment.

A surge-type glacier such as Negribreen would certainly provide enough sediment for rapid channel adjustment, with the limitations outlined by referee 2 in his first detailed comment (see RC2). The cold based conditions of many Svalbard glacier termini are, however, more likely caused by a combination of thin ice and cold winter temperatures, leading to a cooling of ice and underlying sediment (if the ice is thin enough). This would especially be the case for Negribreen, which is located at the East coast of Svalbard, which is considerable colder than the west coast, due to ocean currents.

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Interactive comment

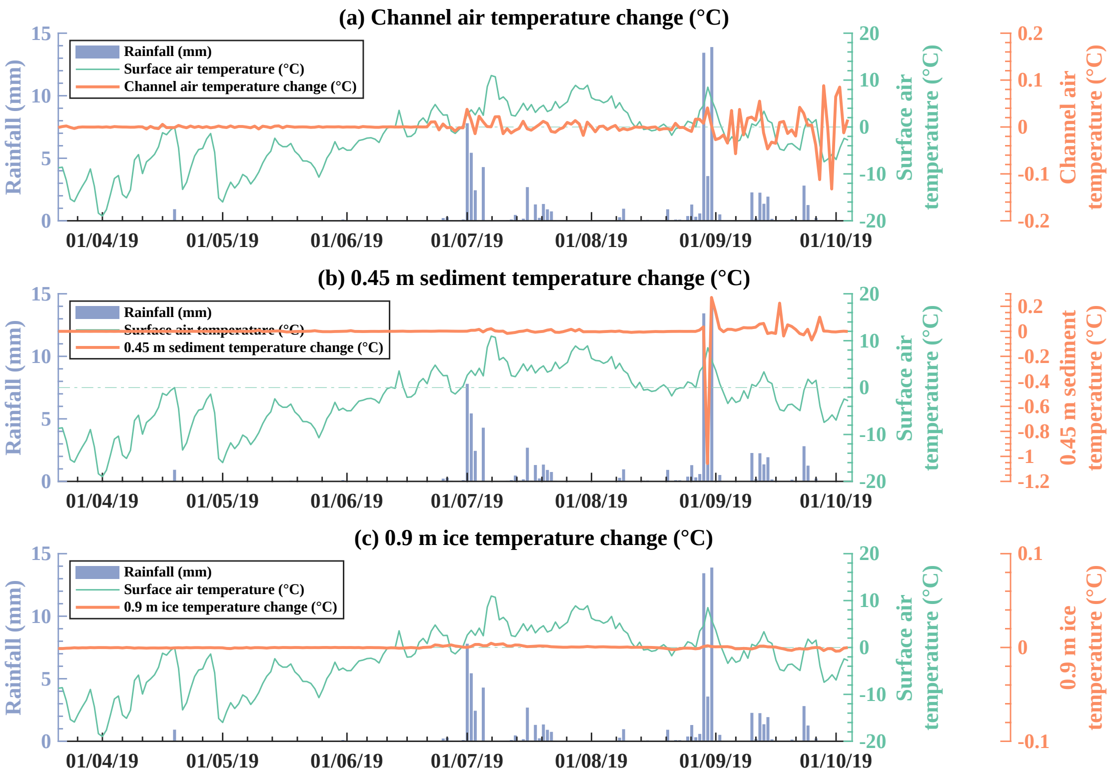

Fig. 1. Change of daily temperatures at logger 'Subglacial 1'.

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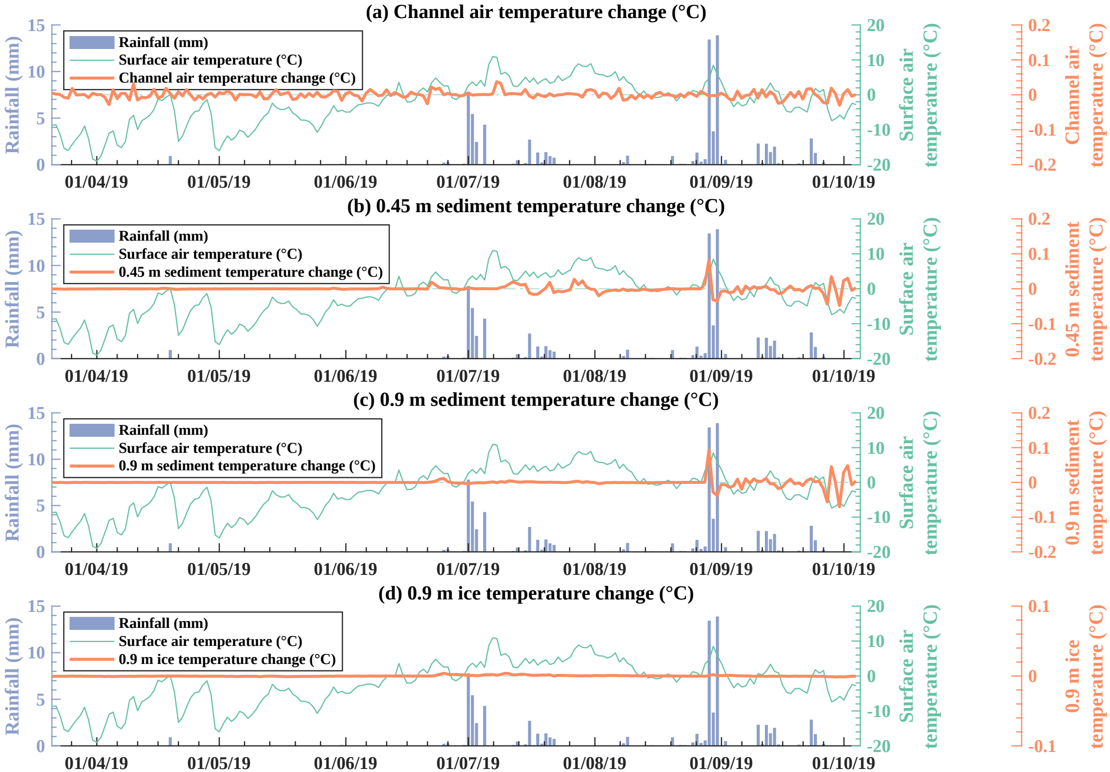

Fig. 2. Change of daily temperatures at logger 'Subglacial 2'.

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