Reviewer 1

The authors present a time series of observed surface meltwater features of Bach Ice Shelf in the Antarctic Peninsula, and use model data for the interpretation of those features. The central message is that the lateral flow of surface water off the ice shelf has resumed in 2022/23 after a pause of 9 years. The authors suggest that this lateral runoff is resumed after a 4-year period with a lower-than-average ratio of surface melt to SMB, temporally causing a thin firn layer to build up that prevents the formation of extensive surface meltwater features.

The carefully selected datasets in this study are a good foundation for a very interesting case study of firn hydrology and surface climate variability, but this manuscript fails to answer a number of important questions critical for understanding the link between climate, firn, and ice shelf stability.

Thank you for your review and your compliments on the foundations of our case study. We have found your comments to be really helpful in further enhancing this Brief Communication. We address specific comments and changes in turn below.

First, the manuscript misses the actual evidence of the lateral meltwater export itself. The intersection between surface melt features and the calving front or rifts is mentioned but not presented. It remains unclear what the (estimated) magnitude of the lateral transport off the ice shelf is. It looks as if the transport is small: only a small fraction of melt features in figure 1a are close to the rifts or the calving front. But the reader cannot judge this. The pattern of features closer to the grounding line in figure 1b suggests that most meltwater moves laterally to some extent, but most of it is arrested in the ice shelf firn. This raises some questions that the manuscript does not answer. How much of the surface melt area is likely contributing to runoff? How much runoff could there be? And if my feeling is right and the direct runoff is only a small fraction of the total surface melt area or volume, then what is the significance of a 9-year hiatus for the mass budget of the ice shelf?

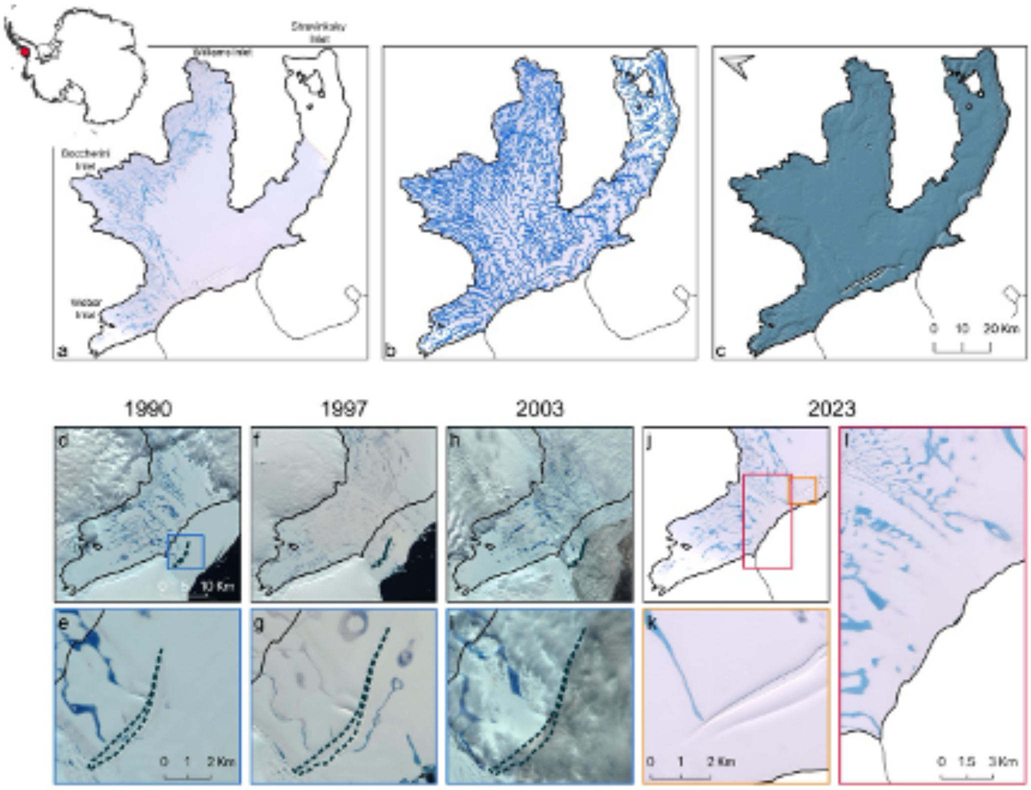
Evidence of lateral meltwater export

We have added a new Figure - Figure 1 (below), which provides clear evidence for the intersection of melt features with areas of structural damage and the calving front in 2023. Further, instead of showing these intersections for 2023 alone, we provide historical evidence of similar interactions prior to the observed nine-year hiatus. We hope this adds historical context to the study (also addressing major comment #2).

The contextual historical satellite images in Figure 1 (1990, 1997, 2003) show lateral surface meltwater transfer across Bach Ice Shelf, both off the ice shelf and/ or into areas of structural damage, where it contributes to a calving event (Fig.1d-i). Presented next to a set of detailed images for 2023, with zoomed panels documenting lateral surface meltwater transfer into the present day nascent rift system and off the ice-shelf edge (Fig.1g-l), these images highlight the potential for meltwater to contribute to rift propagation, calving events, and (a small amount of) ice-shelf mass loss on Bach Ice Shelf under present day, high melt conditions.

N.B. Figure 1 also includes calculated flow routing pathways and a hillshade of the REMA DEM (Howatt et al., 2022), to provide additional context on the distribution of surface meltwater across the ice shelf.

Major elements of the manuscript have been re-written to support the addition of Figure 1.



"Figure 1: Surface meltwater distribution and the surface topography of Bach Ice Shelf *shown using (a) a Sentinel-2 image mosaic (08/02/2023), (b) the same Sentinel-2 image overlain with meltwater routing pathways , calculated at 8 m resolution (calculated using REMA V2 at 8 m resolution; Howat et al., 2022), and (c) a hillshade visualisation of the 2 m REMA mosaic using a northwest illumination azimuth (315°) and altitude of 60°; a z-factor of 25 was applied to enhance the subtle surface topography of the ice shelf for visual interpretation. Panels d-l provide contextual observations of surface hydrology near Weber Inlet from optical satellite imagery in 1990 (panels a–b; Landsat 4; 1990-01-29), 1997 (panels c–d; Landsat 5; 1997-02-09), 2003 (panels e–f; Landsat 7; 2003-01-17), and 2023 (panels g–i; Sentinel-2; 2023-02-08). Dashed lines in panels a–f delineate the rift extent in 1990 (a–b) and 1997 (c–f), showing that by 2003 the ice shelf had calved along the 1997 rift position. Ice-shelf shapefile data from the SCAR Antarctic Digital Database, 2024 (Gerrish et al., 2024). Inset map (top left) marks Bach Ice Shelf's location within Antarctica."*

<u>Quantifying Runoff</u>

Whilst we acknowledge that the quantity of meltwater being exported is small, we would like to emphasise that our focus has never been on calculating the impact this has on the current mass budget of the ice shelf, instead we are highlighting the ways in which this may impact current ice-shelf (in)stability. We have strengthened our text to make this clearer (lines 62-74 - below) and re-instate several of these points in the conclusion.

"Ice-shelf hydrofracture is increasingly studied through field-based (Banwell et al., 2024) and remotely sensed observations (Dunmire et al., 2020; Sommer et al., 2025; Trusel et al., 2022), yet evidence for lateral surface meltwater transport (Dell et al., 2020) and export remains scarce (e.g. Bell et al., 2017). However, these processes are linked: where surface meltwater is routed towards the ice-shelf edge it may intersect areas of pre-existing structural weakness and drive hydrofracture events (Kingslake et al., 2017; Dow et al., 2018). Conversely, it can also facilitate meltwater export, which reduces firn-air depletion and may in turn lessen the likelihood of future hydrofracture and instability (Bell et al., 2017; Trusel et al., 2022). Given these complexities it remains crucial to monitor changes in the distribution of surface meltwater systems, even though the absolute magnitude of surface meltwater runoff from Antarctic ice shelves is low (van Dalum et al., 2025). This is particularly important when meltwater is routed towards the ice-shelf edge, where it may be exported or contribute to rift propagation and calving events."

Further, we believe it is beyond the scope of this brief communication to quantify run-off, although this is considered an opportunity for future research. Recent work by van Dalum et al. (2025) investigates this, and states that "*Modeled runoff remains negligible around the AIS, as nearly all melt water refreezes locally, except for a few grid points at the Amery and George VI ice shelves and the tip of the AP"* (van Dalum et al., 2025, p.4074), we have cited this work on line 72.

Second, judging from figure 2, the absence of surface melt lakes seems to be the exception rather than the rule. In almost all the years between 1980 and 2014, the snowmelt-to-SMB ratio seems high enough for the ice shelf to support surface lakes, and thereby lateral runoff. What, then, does this mean for the hiatus? Is lateral runoff the rule and the hiatus the exception? If so, how can it be reconciled that the ice shelf has been there for a very long time, despite ongoing lateral runoff? How destabilizing is the observed lateral runoff for the ice shelf really?

This is a good point, which we have also addressed through updates to Figure 1 and edits to the text. As mentioned above, Figure 1 now provides historical context to our observations, as we present high quality images showing evidence of lateral meltwater export prior to the nine-year hiatus. Whilst the ice shelf has persisted throughout time, we show evidence for meltwater likely contributing to calving events, as it is delivered to a crevasse along which a calving event later occurs (1d-i). Again, we strengthen our commentary on this (lines 216-239). Unfortunately, we are unable to systematically extend our maximum summer surface meltwater extents back before 2012/13, due to both the lack of image availability and quality often experienced prior to the launch of Landsat 8.

Third, the interpretation of the hiatus remains superficial. It is linked qualitatively to the firn air that temporarily provides some storage for meltwater, so that it is hidden from the surface. But a mass budget estimate of what happened between 2010 and 2014 in terms of firn would have been instructive. Apparently, sufficient snow fell in those years to postpone the reactivation of surface melt features for four or five more years. It is interesting that is has been observed on Bach Ice Shelf, but the link with climate and firn has been drawn before, e.g. for the Larsen C Ice Shelf in Hubbard et al. (2017). Without some firn model, the role of firn and hydrology within the firn remains elusive. And without such an analysis, more specific conclusions for the future of the ice shelf cannot be drawn.

Adding a firn modelling component to the study is beyond the scope of this brief communication (https://www.the-cryosphere.net/about/manuscript_types.html), particularly a 3D firn model that can produce lateral transport of meltwater. Any firn modelling focused on the hydrology of Bach Ice Shelf would require extensive validation with field observations of firn density as recent as the 2022/2023 season, which we don't have, and this research in itself could amount to a dedicated study of the ability of 3D firn models to recreate the observed spatiotemporal patterns of meltwater transport on Bach. Our brief communication assesses the recent and present-state of remotely sensed surface meltwater transport on Bach, and we absolutely agree with the reviewer that our results motivate future studies investigating the specific firn hydrology of the ice shelf and how it may change under anthropogenic warming. Indeed - it is our hope that this brief communication will inspire such work!

Fourth, the paper is contradictory about the effect of lateral runoff. Bell et al. (2017) suggest that lateral runoff could stabilize an ice shelf, because the exported meltwater is no longer able to engage in a positive meltwater-albedo feedback. This is not compatible with the suggested increase in ice-shelf weakening and instability in lines 224-25, and the consequences of surface meltwater export presented in lines 236-244.

We appreciate that we have not mentioned the potential stabilising effects of lateral run-off (as in Bell et al., 2017), and we have added comments to both sections (now lines 67-69 and 289-292) to correct for this. However, we note that the stabilizing effect outlined by Bell et al. (2017) is linked to the reduced potential for ice-shelf loading and hydrofracture rather than the positive meltwater-albedo feedback, as the reviewer suggests.

Whilst lateral runoff may stabilize an ice shelf, it may also drive instabilities through the delivery of meltwater to pre-existing flaws in the ice shelf structure (e.g. fractures), as we now demonstrate in Figure 1. Further, if meltwater run-off increases as expected under climate warming, then instabilities may also arise from ice-shelf thinning. Whilst these ideas may seem contradictory to the work of Bell et al. (2017), they in fact demonstrate the complex nature of the system we are dealing with.

I have been somewhat in doubt about my recommendation for this manuscript. I understand that a brief communication may contain a smaller amount of information than a full paper. The assessment that lateral runoff is happening here in the first place is interesting. Also, I like the interpretation that a few snowy years prevent surface meltwater features to appear for many more years. But all in all I think that this observation only is not sufficiently novel, and it lacks a context of magnitude and importance.

We thank Reviewer 1 for their comments, which have ensured that this manuscript is now certainly both (i) novel, and (ii) important. We outline the evidence for this below. With regards to magnitude, we refer back to our response to major comment one, as it was never the intention of this work to quantify the magnitude of run-off, which is known to be very small across Antarctic ice shelves at present (van Dalum et al., 2025).

Novelty

- To the authors knowledge, this is the first single study to present a detailed analysis of observed surface meltwater patterns on Bach Ice Shelf. In doing so, it draws attention to a lesser studied ice shelf on the Antarctic Peninsula - a region that is likely to see a lot of melt in coming decades!
- This paper also adds to (a very limited set) of observations of lateral surface meltwater export from Antarctic Ice Shelves. Again, to our knowledge, this has only been reported in detail once before for Nansen Ice Shelf (Bell et al., 2017). These observations have been further strengthened by our revisions, which also show the influence the ice-shelf surface topography (Figure 1) has on surface meltwater distribution and routing.
- Finally, the nine-year hiatus of lateral meltwater export from Bach Ice Shelf has not yet been reported.

Importance

The importance of our findings are best outlined in sections of both the updated discussion and conclusion of the manuscript. Provided below for ease:

Discussion (lines 283-292): *"Given projected warming on the Antarctic Peninsula under a range of 21st-century climate scenarios, it is increasingly pertinent to consider how Bach's surface meltwater network will respond. In this context, our cumulative surface meltwater extents (Fig. 2) partially intersect regions that are vulnerable to hydrofracture and, in some cases, provide active buttressing (Lai et al., 2020). Further, lateral surface run-off into a nascent rift system during high melt years (as evidenced in Figure 1) has the potential to facilitate further rifting and ice-shelf calving events. Conversely, increased lateral surface meltwater export from the ice-shelf edge and along topographic gradients may act to increase ice-shelf stability, as generated surface meltwater may be removed from the ice-shelf surface rather than being locally stored, where it has the potential to drive hydrofracture (Bell et al., 2017).*"

Conclusion (lines 311-328): "*The volume of surface meltwater stored and routed across Bach Ice Shelf is heavily influenced by the balance between snowmelt and snowfall (and therefore on future variations in T_{2m}), as this balance is a determinant of both firn air content and depth (e.g. Amory et al., 2024). The end of the nine-year hiatus in lateral surface meltwater export from Bach Ice Shelf may indicate a transition toward climatic conditions in which the ratio of snow accumulation to melt no longer provides an effective buffer against widespread meltwater ponding, flow, and export (Veldhuijsen et al., 2024). However, the ice shelf's meltwater regime is not determined by climate alone, and the distribution of melt towards both the ice-shelf-ocean edge and areas of structural damage is also heavily influenced by ice-shelf surface topography.*

The consequences of increased ponding and/or lateral surface meltwater export on Bach Ice Shelf are several-fold: meltwater ponds promote ice-shelf flexure and fracture and may drive ice-shelf collapse in extreme cases. Further, any continuation and increase of the observed lateral surface meltwater export (i) off the ice-shelf edge, and (ii) into the nascent rift system has the potential to drive ice-shelf thinning and promote ice-shelf calving events respectively. Given the anticipated climate warming across Antarctica, the reactivation of lateral surface meltwater export on Bach Ice Shelf may signal a shift toward conditions in which the buffering of meltwater by accumulated snow is progressively overwhelmed, increasing the likelihood of sustained meltwater export and reduced ice-shelf stability."

Further, I have a number of specific comments listed below:

line 25: negative surface mass balance - decrease of surface mass balance

Amended - thank you (now line 29)

line 58: a statement of its magnitude here is relevant. Also, Bell et al. suggest a negative feedback, where meltwater export from an ice shelf no longer engages in a meltwater-albedo feedback.

We have added a paragraph here to provide more commentary on the various ways meltwater may impact ice-shelf (in)stability (Lines 62-74), further detail on our response to this comment can also be found in our responses to major comments #1 and #4.

line 70: why is "adapted from" in italics? And, perhaps cite in chronological order?

Amended - thank you (now lines 87-88)

line 82: no more technical description on the expert judgment is needed, but it would be good to provide a statement on how much data is removed or modified by this step.

We have added this detail (lines 108-110): *"To ensure data quality, each water mask for 2012/13 was manually cleaned by a subject expert, resulting in a 3% difference in observed water area."*

figure 1: the inset rectangle in panel b, indicating the location of Bach Ice Shelf on the AP, is too difficult to see at this size.

Figure 1 has now been changed substantially (see above). The inset for this figure now shows Bach Ice Shelf's position within Antarctica, marked by an exaggerated red dot. We believe this is now clearer.

line 183: 8.36 -> 8.4 deg C

Amended - thank you.

line 240: this statement is vague and possibly contradicting. Meltwater export from the ice shelf is in itself not destabilizing. Probably it is stabilizing, as discussed by Bell et al.

Please see our response to your Major Comment 4, above - where we address this.

line 231: the Veldhuijsen reference is not from 1983.

Amended - thank you (line 317)

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