

## Response to Reviewer

November 28, 2024

*Author responses are marked in blue*

This manuscript examines circulation and meltwater very near the terminal face of a Greenland glacier as it enters a fjord. To my mind the novelty in the manuscript centres around the near-ice helicopter CTD profiles and the balance of water mass and isotopic perspectives. The topic of drivers and response of glacier melt is clearly important – in fact perhaps existentially so for coastal communities around the globe. This manuscript then focuses on a central challenge – a global impact has critical details at the ice-ocean boundary layer scale – just a few metres.

There is a claim of uniqueness regarding proximity to the glacier front (line 30). Possibly this is true, but there are a reasonable number of Antarctic studies with oceanographic work very close by floating icewalls (Fer et al. 2012; Stevens et al. 2014 among others).

Thank you for your review; we greatly appreciate your input.

We recognize the importance of Antarctic studies and agree that they provide valuable insights into similar processes. However, our study focuses specifically on an Arctic glacier, which we believe has different boundary conditions that may not directly compare to those of Antarctic floating icewalls. To acknowledge this, we have added a brief note in the introduction (lines 24-27): ‘While studies have been conducted in the water column in close proximity to Antarctic floating ice shelves (Fer et al. (2012), Stevens et al. (2014)) comprehensive studies near the glacier terminus in East Greenland remain limited. Particularly, one of the main constrains for such studies derives from the life-threatening risk of sampling due to calving events (Holland et al., 2016)

The Introduction closes with a point that is pretty self-evident (lines 35-36). “This study highlights the importance of considering the complex vertical and horizontal movements and transformations of glacial meltwater in understanding the freshwater dynamics in glacial fjords.” Instead, I wonder if some more specific questions could be posed – perhaps around the horizontal extent of the boundary-layer zone, or something a more explicit in terms of the thermohaline budget?

We agree that the closing statement of the introduction could be more specific. In the revised manuscript, we will rephrase the closing statement to: ‘In addition, we identify and assess the mechanisms behind the observed temperature and salinity variations near the glacier terminus, assessing their implications for the thermohaline dynamics and meltwater distribution in Dickson Fjord.’ This way, we provide a more specific focus while still aligning with the overall research objectives.

Building on this – I would give the manuscript a new title to emphasize the aspects of the analysis that the paper does focus on rather than aspects it explicitly does not – i.e. the frazil formation. The manuscript actually says it could not be observed and will be examined in another manuscript – so why have it as the key point in the title? A very

strange choice. Furthermore, after the title “frazil” appears in the abstract and then not mentioned until section 3.4. Then the frazil section anticipates the heat budget section making for a very non-linear structure for the manuscript.

There’s plenty else here to highlight. “Meltwater circulation and thermohaline budgets in a Greenland fjord very close to the terminal face of a glacier” would be my starting suggestion.

Thank you for your helpful suggestion on the title. We have considered how to formulate a new title that more accurately reflects the full content of the paper. Building on your suggestion, we propose the following title: ‘Meltwater from the Greenland ice sheet and its water isotope distribution in Dickson Fjord, East Greenland’.

It also seems a lost opportunity to not examine more closely the connection between thermohaline and isotopic perspectives of water masses. No T-S diagram with isotope colours? And then how does the observed partitioning compare with other estimates from this or other systems?

A T-S diagram with isotope colors is a good suggestion and would allow for a direct comparison between temperature, salinity, and isotopic data. We will include this figure in the revised manuscript.

Although we unfortunately do not have isotope data from this system, we do have in-fjord oxygen isotope data from Kangerdlugssuaq Fjord in East Greenland, from a study by Azetsu-Scott et al. (1997). We will include a comparison to this study in the revised manuscript.

***Does the paper address relevant scientific questions within the scope of TC?*** The processes are all oceanic but driven by the ice-ocean interaction boundary condition. The title suggests there is an element of frazil formation which would make it clearly in-scope for TC however as noted below the actual content doesn’t reflect this so distinctly. I would say it is borderline but certainly of interest to many TC readers.

***Does the paper present novel concepts, ideas, tools, or data?*** As noted above – there is clear novelty in the near-ice helicopter CTD profiles and the balance of water mass and isotopic perspectives. Given the challenges of collecting a helicopter CTD profile I would have built on this to explore questions around what this brings us – does it sample within the boundary-layer structure? i.e. where are the profiles in relation to the generally nice schematic of Fig 7? Has all that effort brought some new insight? The zoom in of the CTD data (Fig 2) seems to suggest those inner profiles are indeed different.

In the manuscript, we discuss the volatility of the temperature and salinity measurements near the glacier terminus, which suggests that our CTD profiles capture conditions within or very close to the boundary layer. Due to the dynamic nature of this environment, it is challenging to precisely determine the boundary layer's extent.

To provide further clarity, we will link these observations more directly with the schematic in Fig. 7, showing where the profiles are located relative to the glacier terminus.

**Are substantial conclusions reached?** Somewhat - the authors provide clear estimates of the transfers in the heat and energy budgets.

**Are the scientific methods and assumptions valid and clearly outlined?** Yes, mostly.

- Were the two CTD units cross-compared?

The vertical 1-m binned temperature and salinity measurements between the two instruments were tested, No significant differences were observed for temperature (paired t-test,  $p = 1.00$ ,  $\alpha = 0.05$ ) and salinity (paired t-test,  $p = 0.98$ ,  $\alpha = 0.05$ ) between the two instruments (data not shown).

- The description of the mooring data is very superficial – and are the data even used?

Thank you for pointing this out. Indeed, the mooring data were not directly used in the study, only the weather station data from the on-land observatory at Ella Island. We will remove all references to the mooring.

- Why use  $S_p$  and not  $S_A$ ?

We used  $S_p$  to make it easier to compare with previous data from East Greenland fjords that all use the same unit.

**Are the results sufficient to support the interpretations and conclusions?** For the heat content material yes but clearly not in the case of the mention of “frazil” in the title.

**Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?** Mostly

**Do the authors give proper credit to related work and clearly indicate their own new/original contribution?** Yes – maybe some additional references especially to Antarctic comparisons and an earlier reference for mixing line analysis.

Additional references to Antarctic studies will be added to the introduction, as described. A reference was already made to Mortensen et. al. (2020) for the mixing line analysis (line 155).

**Does the title clearly reflect the contents of the paper?** No – it is not clear why the frazil aspect is included in the title as it is misleading.

We will change the title as suggested.

***Is the overall presentation well structured and clear?***

Somewhat:

- Fig 1 – panel b fonts too small, where were the profiles?  
Panel a fonts too small, bathymetry indistinct – possible to mask the land? Possible to expand b so we can see the full width of fjord?

We agree that the visibility of the labels in both panels should be improved. We will make figure (a) larger (extending to the width of the page) and switch the location of panel (b) and the Greenland map. We will also make the fonts bigger in panel (b). We fear that the expansion of b to the full fjord width will make it hard to distinguish the different flight measurement locations, as these were deployed within relatively close to one another (about 100 metres).

- The profiles in Fig 2 are challenging to plot due to the wide range near the surface but the importance of small differences elsewhere... I suggest having a single panel that has the full T and S profile but just show the average or far field. Then I would have an additional figure with the zoomed in sections which, along with the isotope data, are the primary novel results – so make them big!

We will enlarge the insets and put the flight measurement profiles on top to make the temperature and salinity profiles in Fig. 2 clearer.

- Fig 3 – can the panels have an a and b? And the right hand panel seems hardly worth the zoom... instead I'd make the inset the 2<sup>nd</sup>

We will label the panels as (a) and (b). However, we believe that the zoomed-in section in the right-hand panel is important, as it highlights the transition from the polar water layer to the surface water layer. Additionally, having the separate figure with the individual plots allows us to show the profiles from individual station locations.

- Fig 4 – because of the dominance of salinity are the density panels required? And the scales are a mess. I would have complete panels for T & S and then an additional figure doing the same for the upper 20 m – and this separate Figure could have different colour scale. As it is there are different depth and ranges for each. And for all that not much actually happens in most of the panels.

We agree that the density panels are not necessary, given the dominance of salinity, and will remove them in the revised figure. However, we believe that maintaining the separation in scaling for the Polar Water layer is crucial, as it effectively shows the temperature increase and the absence of salinity changes.

- Actually for Fig 4 – probably the other dimension worth highlighting in multiscale form is the horizontal – the helicopter

profiles have great novelty so why not have some structure for the inner 100m?

The main focus of this study was the changes in hydrographic conditions along the fjord, and we feel that including a horizontal cross-section in Fig. 4 would not provide significant new insights at this stage. A comprehensive analysis of the ice-ocean boundary layer would require more detailed data, which we plan to collect in future field campaigns during Fleur's (first author) PhD work. This study will offer better data and allow for a more thorough exploration of the ice-ocean boundary layer.

- Fig 7 – why two panels? It would seem straightforward to merge. “Liquidus” is not mentioned anywhere else and presumably relates to the unfounded frazil conjecture. Why would the latent heat radiate as suggested in (a)?

We considered merging the two panels into one; however, we found that this made the figure chaotic and less clear. We believe it is more effective to present them separately. We will replace "liquidus" with "0°C isotherm" to be consistent with Fig. 5. As noted in the caption, the orange panel represents the estimate for excess heat observed in the polar water layer near the terminus, rather than latent heat radiation.

***Is the language fluent and precise?*** Sufficient for clarity. A few minor suggestions:

- Lines 123-125 “distinct” and “distinguishable” needed in the same sentence?

Thank you for pointing out this redundancy. The revised sentence now reads: "These transects show the three distinct water layers typical for East Greenland glacial fjords: the surface water layer (0-20 m depth), the underlying Polar Water layer (20-120 m depth), and the Atlantic Water layer below (Straneo et al. 2015, Rysgaard et al. 2024)."

- There are a couple of single sentence paragraphs that really should be either expanded or combined or removed. E.g. line 138 – I don't think it is good practice to have a sentence that serves to identify a figure... how about... “ The temperature-salinity ( $\theta$ -S) structure (Fig 3) reveals the key water types whereby XXXX”. (although see my point about Fig 3 made above).

We will revise the sentence using your proposed structure. It will now read: "The temperature-salinity ( $\theta$ -S) structure (Fig. 3) reveals the key water types in Dickson Fjord, illustrating the presence and mixing of surface water, Polar Water, and Atlantic Water layers."

- Line 140 – where is the “clustering” shown? Is it Fig 3? Isn't this just a scatter plot?

To improve clarity, we will replace "clustering" with "grouping" in the manuscript. This change should make it clear that the data points in Fig. 3 are grouped based on

measuring locations relative to the glacier terminus, such as drone-deployed measurements, deeper measurements near the terminus, in-fjord measurements, and out-fjord measurements.

- Line 208 – another 1 sentence paragraph.

We will expand the sentence on line 208 to provide more context and integrate it with the figure information: "Figure 6 presents the meltwater partition profiles based on water type salinity, temperature, and  $\delta^{18}\text{O}$ . The profiles reveal a significant discrepancy between the temperature-based and salinity-based partition values, with the temperature-based values being significantly larger. This discrepancy confirms that the excess heat in the Polar Water body does not originate from liquid warmer glacial meltwater."

- Are fractioning and partitioning different?

"Fractioning" and "partitioning" refer to the same concept in our study. We will make sure that only "partitioning" is used consistently throughout the manuscript for clarity.

## References

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