Summary: the authors present new hydrographic observations in two of Greenland's fjords that quantify the substantial impact of a 4-day period of ice mélange melt on water column properties. The observations are compared to output from standalone plume and iceberg-melt models to demonstrate that the observed changes in water column properties can be explained by ice mélange melt during the period of mélange presence, in addition to contributions from a subglacial discharge-driven plume.

Overall, the paper is very well-written, clear and convincing. It provides much needed observational evidence that support and add more detail to several modelling studies of iceberg-ocean interaction, which I think will be a great interest to the community.

I have just a few minor suggestions, questions and comments listed below, but otherwise I think the study is ready for publication:

The authors thank Dr. Davison for reading our manuscript and providing a thorough and positive review, the suggestions in which will be beneficial to our paper. We have provided responses to Dr. Davison's comments and will modify our manuscript accordingly in the next submission.

Minor comments

Line 25: can you go any further with this statement? Do your observations support the notion that ice mélange meltwater needs to be included (or its effects parameterised) in ocean circulation models or in ocean boundary conditions used to force glacier models? As written, this is implied but it's not clear the absence of a direct statement is deliberate.

Our observations do support the fact that ice melange meltwater needs to be included in both ocean circulation models and as forcing for tidewater glacier models for glaciers with deep grounding lines and high ice fluxes. To make this more clear, this sentence will be rewritten as "These observations provide critical constraints for and agreement with recent modeling studies that have suggested ice melange meltwater needs to be included in ocean circulation models for glaciers with deep grounding lines and high ice fluxes, which are precisely the glaciers exhibiting the largest magnitude terminus retreats at present".

Line 29: I'm not sure that "ice tongues" is the correct terminology here? I think ice tongues strictly refers to small, ice shelf-like features, which there are a few of in Greenland, but I don't think they existed at the majority of its now marine-terminating glaciers as the second part of the sentence implies.

While the breakup of ice tongues and replacement with ice melange has been documented at large glaciers like Sermeq Kujalleq, we agree that this is not the best terminology for our focus on marine-terminating glaciers that did not historically have ice tongues. Therefore, we

will remove the focus on ice tongues from this opening sentence and will combine it with the next to read “Ongoing observations have documented the rapid retreat and dynamic thinning of Greenland’s marine-terminating outlet glaciers (e.g., Greene et al., 2024; King et al., 2020), which has been attributed to environmental forcings occurring at the ice-ocean boundary (Carnahan et al., 2022; Murray et al., 2010; Nick et al., 2009).”

Line 34: consider “days to years”, since this study focuses on a 4-day period of mélange.

This will be changed in the manuscript.

Line 36: “the influence of ice mélange meltwater and its temporal variability” seems a bit ambiguous to me and somewhat contradictory to the first part of the sentence that cites several modelling studies that examined the influence of ice mélange meltwater on fjord water properties and circulation. Can you rephrase to make your meaning clearer, which I think is that the cited studies focused on long-lived mélange rather than ephemeral mélange?

This statement was intended to highlight that we lack observational data to confirm the modeling studies cited. We will rephrase this statement to “Although several numerical modelling studies have suggested that meltwater from ice melange can alter the ocean forcing near tidewater glaciers (Davison et al., 2020, 2022; Kajanto et al., 2023; Hager et al., 2023), this process is yet to be confirmed by observations”.

Lines 46/47: Can you be clearer about the directionality of the impact of changes in freshwater flux on fjord-shelf exchange? i.e. does an increase in freshwater flux enhance or reduce exchange? As written, it states that any change in freshwater flux corresponds to an increase in exchange, which doesn’t seem right to me.

This statement will be reworded from “Changes in the freshwater flux exiting these glacial fjords can enhance exchange…” to “Increases in the freshwater flux exiting these glacial fjords can enhance exchange” in order to improve clarity when describing this feedback.

Equation 6: Shouldn’t *Aice* be the total iceberg-ocean contact area, not the area of the fjord surface covered by ice mélange?

Ideally, Aice should be the total iceberg-ocean contact area rather than the surface area of the fjord covered by ice melange. As we do not have direct measurements of this underwater surface area, we use the surface area of the fjord as a lower bound for this calculation. The actual iceberg-ocean contact area will be larger than the surface area of ice melange cover, which would lead to a reduction in the total length of time needed to melt the volume of ice melange predicted. For example, Sulak et al. (2017, *Annals of Glaciology*) used remote sensing to investigate icebergs in the proglacial fjord of Kangilliup Sermia

during a similar time examined here (summers of 2013-2015). They found the average cross-sectional areas of icebergs in the fjord and calculated what their keel depths would be if the iceberg maintained its shape throughout its depth (i.e., was a block shape). They found that the average submerged surface area of icebergs in this fjord was 41.34 km2. The surface area that we calculate for Aice by outlining satellite imagery of the ephemeral ice melange was 29.56 km2. Therefore, using the estimate from Sulak et al. (2017) we can infer that the actual iceberg-ocean contact area in our ice melange is roughly ~1.4x higher than the value for Aice that we have used in this manuscript. This would reduce the duration of time required to produce enough ice melange meltwater to realistically cause the observed changes in salinity observed, and would further strengthen our findings. To clarify this, we will add a statement to this effect in the new version of the manuscript.

Lines 191-194: can you clarify what the errors on the T and S measurements represent? As presented, they seem large relative to the observed changes in T and S, which might or might not be important for the interpretation depending on how the errors are defined.

The reported numbers for T and S are the transect-averaged measurement +/- one standard deviation from this average. To obtain these, we take the average of all CTD casts in the pre- and post-ice melange transects respectively. We then average these casts over the depth range in question (full water column and 200 m). The reported ranges are obtained by taking the standard deviation over the same depth range which the casts are averaged over, so they show the spread of the data within that depth region and not an error. We will specify this in the new version of the manuscript.

Line 203: erroneous “then”?

This will be removed from the manuscript.

Line 229-232: are these melt rates from icebergs with a particular keel depth? Or averaged across icebergs with a range of keel depths? I think this should be specified in the text.

These melt rates are averaged over all modeled iceberg keel depths. This will be specified in the text by changing “Modeled iceberg melt rates vary between 0.08-1.40 m/d (Fig. S3)...” to “The total range of iceberg melt rates is between 0.08-1.40 m/d for all modeled keel depths…”

Line 242: “these time spans for complete melting of the ice mélange” – I found this a bit confusing. Wasn’t the preceding paragraph providing time-spans for melting of 14% of the ice mélange? So it is expected that 86% of the mélange must have been exported as solid ice? (plus or minus the uncertainties relating to the initial ice volume, but the main thing here is that there was more than enough ice available). I recommend providing a figure to illustrate the time-spans required to produce Vmelt under the range of estimated melt rates.

We will clarify this in the new version of the manuscript. We agree that the wording currently used makes it sound like the time estimates stated are for 100% of the ice melange to melt, when instead it should read that these time estimates are for the 14% of icebergs that needed to melt to explain the observed changes in salinity. We will add a figure to the supplementary information showing how the time-span to produce Vmelt varies with the different melt rate estimations.

Line 252: erroneous “surface”?

This will be removed from the manuscript.

Line 300 and surrounding text: I’m not sure that evidence has been presented to support this statement. Hydrographic observations are only available before and after the icebergs were present in the fjord, so there is no information about how the water properties changed during that period of 4 days – the modification may have happened steadily over the 4-days or it may have mostly happened in the first day. We do know that the icebergs were only held in place for ~12 hours before becoming mobile, which either suggests that rigid mélange caused all of the modification in the first 12 hours, or that modification continued despite the mélange become mobile.

This statement was intended to highlight the difference between the impact of ice melange on water column properties as opposed to free floating icebergs from a typical calving event. We recognize that we do not have evidence identifying the exact time span over which the water column modification occurred over the course of the 4 days, but we believe that the formation of a briefly rigid ice melange increased the residence time over which the calved icebergs were able to inject meltwater into the glacier-adjacent water column.

To make this more clear, we will address the limitations of this data by rephrasing the statement to “While iceberg melt itself is responsible for the freshening and cooling signal observed here, the sea ice matrix holding the icebergs in place in the proglacial fjord supports this meltwater injection into the fjord by increasing the residence time of icebergs in the glacier-adjacent water column. In this regard, it is the presence of ephemeral ice mélange, rather than free floating icebergs, that facilitates the observed water column stratification changes.”

Line 358/9: “progressively cooling the upper layer of the fjord over the course of the summer” – I think it would be clearer if this statement came after the explanation given the following paragraph. I also think it would be relevant here to state whether any ephemeral mélange events occurred before the one described here, and if so give the dates of that occurrence and describe how that might or might not have affected the pre-event water properties.

We believe that this statement helps introduce the calculation done in the next paragraph and connect the results in the current paragraph to numerical modeling results done in prior studies. Therefore, we would like to leave this sentence at its current location.

It is difficult to quantify the exact number of ephemeral ice melange events that occur in the proglacial fjord of Kangilliup Sermia due to the temporal resolution of satellite imagery and the fact that ice melange can remain frozen in place as short as 12 hours like the example discussed here. We state on line 368 that ephemeral ice melange occurs at least 4 times during the summer of 2014, but we agree that adding the estimated dates of these events would be helpful for interpretation and they will be added to the next version of the manuscript.

The prior ephemeral ice melange events that occurred in the fjord during the summer of 2014 would have progressively cooled and freshened the upper layers of the water column. We can see the effect of this in our pre-ephemeral ice melange CTD cast on August 4 in Figures 2 and 4, where the surface waters in the fjord of Kangilliup Sermia are cooler and fresher than the water column at the 'Outside' mooring. The change in our hydrographic observations between August 4 and August 11 help isolate the influence of a single one of these ephemeral ice melange events, and it is likely that other events in the fjord would create similar water column changes (with the exact magnitude dependent on the size and duration of the ice melange in question). We will add a statement explicitly acknowledging this in the next version of the manuscript.

Paragraph starting line 361: I think this analysis assumes that the mélange events have no impact on 'offshore' water properties. The offshore properties used here are from a co-located CTD-cast and mooring outside of the sill where the two fjords branch, some 60 km from the glacier terminus. If the authors agree, I think this assumption should be acknowledged and the direction of impact on this analysis should be given.

The authors agree and will include this assumption in the new version of the manuscript as:

"As the offshore water properties are taken from a mooring located ~60 km from the glacier terminus, this calculation assumes that meltwater from ice mélange has not altered the offshore water properties. If ice mélange meltwater did in fact modify the offshore water properties, a smaller meltwater volume would be needed to explain the difference in salinity between the two locations, indicating that fewer ephemeral ice mélange events would be needed to match the observed differences in S."

I think it would be worth adding a paragraph to the discussion examining why ephemeral mélange events occur at some fjords but not others (some combination of mid-depth plume outflow and large calving events, but not so much calving that you get near-permanent mélange?), or at least to give some indication as to how widespread they are or might be

around Greenland. As written, some readers could conclude that most fjords are either like Kangerlussuup Sermia without ephemeral mélange events, or they are like Sermilik Fjord where there is near-permanent mélange, and only a few have these ephemeral events.

There currently are no published Greenland-wide inventories of the fjords in which ephemeral ice melange forms. A master's thesis by Emma Swanninger (2020, University of Idaho) looked at a set of 24 glaciers around the margin of Greenland between 2000-2019 and found that 11 of those experienced ephemeral ice melange in the summertime. We believe that investigating what causes ephemeral ice melange events is beyond the scope of this study, as the hydrographic changes indicated here for ephemeral events are also likely observed at systems with permanent ice melange. However, we will add a reference to Swanninger's thesis to show that ephemeral ice melange occurs at quite a few fjords around Greendland's margins.

Figure 3a: I think it would help if labels I, II and III were briefly summarised in the figure caption, as well as in the main text, just to save the reader scrolling around the manuscript.

This will be added to the new version of the manuscript.

Figure 3a: I found the square markers a bit confusing. The caption states they are at intervals of 50 m, but I count 9 black square markers before (above?) the panel (b) inset, which includes data from 50-100 m. Does that just mean the water column properties don't change smoothly in T-S space with depth? If so, then I'm not sure that the square markers aid the interpretation of panel (a). Or should I just be comparing the position of a black square with a position of a blue square in T-S space? If so, then is there some way you can make it clear which squares correspond to the same depth on the black and blue curves?

The square markers are intended to allow the reader to determine relative position in the water column along the data profile. Deep in the water column, the temperature and salinity are largely uniform and so many of the markers in the deepest section of the profile (top right) are stacked on top of eachother. While we present data for the entire water column in this manuscript, the changes induced by the ice melange and subglacial discharge plume occur in the upper ~400 m of the water column, which have markers visible in the plot. To aid in interpretation, we will add labels to the plot every 100 m in black and blue text.

Figure 4: what do the grey dots represent? I can't see a description of them in the caption. Please can you also specify the dates of the presented CTD casts? It's not clear if the RNK data is from before or after the mélange event.

Each panel of the figure shows all data from 'Outside', 'RNK', and 'KAS'. To facilitate comparison between the region being emphasized and the other regions' water properties, we highlight the region of focus in each panel with the blue-green colorbar and leave the

other regions' properties as grey dots. We will specify this in the figure caption in the updated version of the manuscript.

The hydrographic data presented in this figure comes from all CTD casts collected during the field campaign in the summer of 2014, which took place between July 29 and August 12. We will add a table to the supplemental information stating the dates of the CTD casts presented in this figure.

Benjamin Davison