

**Review:****EGU-2026-1396: Temporal evolution of the Petermann Ice Shelf estuary constrained by remote sensing observations****Overall Statement:**

The submitted manuscript outlines a creative study that looks at surface melting and the presence of an estuary at the edge of the Petermann Ice Shelf, Greenland. The manuscript is well-written and clearly present the necessary information for the reader to interpret their findings. However, there are some important gaps in the interpretation of the results that currently obscure the main takeaways of the text. I have no doubt that the information presented is of high value, but there needs to be some reinterpretation of the findings. I have included comments below on how the manuscript might to be altered to address these concerns - I believe that this will require a major revision. Ultimately, I think that with some more work this manuscript has high potential to be a significant contribution to the cryosphere discipline.

**Larger Comments:**

Seawater in theory flows underneath the freshwater in the estuary, resulting in a bidirectional flow that allow the freshwater still to flow out towards the top. Please demonstrate why you think this not to be the case for the Petermann estuary. See specific comments below.

I do not understand why measurements of the surface channel geometry before and after the melt season would not suffice to investigate incision rate. It does not snow much on Petermann.

Did you consider looking at 79N glacier also, just to comment on whether or not it has an estuary? It has an extensive supraglacial river network during the summer and is very thin at its front.

Discussion lacks a commentary on how important this surface estuary is to Petermann Ice Shelf's stability. At present, the estuary only occupies the very outer portion of the ice shelf, which has been shown to exert no buttressing (Rückamp et al., 2019).

<https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JF004775>. However, if ice-ocean interactions continue to thin the ice shelf, then it will lower the freeboard to allow for further seawater ingress that will exert more of an impact on its stability.

**Specific Revisions:**

“Ice shelf” and “ice-shelf” are used interchangeably through the text. Please pick one expression and stick with it.

Please use the phrase “seawater” instead of “ocean water” throughout the text and figures, as it is the more common expression. For example, compare “lake water” to “freshwater,” or “ocean ice” to “sea ice.”

“Bathymetry” typically is reserved for surfaces that are persistently covered in water, which is not the case for this ephemeral feature. I think that “channel geometry” or “channel topography” or “the channel base” is more accurate here.

**Title:**

**Abstract:**

The Abstract comes in a over 300 words, but online there is a word limit of 250 words ([https://www.the-cryosphere.net/about/manuscript\\_types.html#:~:text=Generally%2C%20these%20are%20expected%20to,abstract%20of%20150%E2%80%93250%20words](https://www.the-cryosphere.net/about/manuscript_types.html#:~:text=Generally%2C%20these%20are%20expected%20to,abstract%20of%20150%E2%80%93250%20words)). Please reduce the abstract length by 50 words. The coauthors should have addressed this before submission.

Li 29-30: Seawater will most likely have a higher heat content than the freshwater, due to a higher temperature and greater density. Furthermore, the geometry of less-dense ice below more dense seawater should encourage melting. Thirdly, it is current shear that increases turbulent-driven melting, which means that times of flow reversal should actually drive the highest melting. For all of these reasons, the text in Li 29 and 30 does not seem to be accurate at face value.

**Introduction:**

Li 37 – 38: The section of this sentence on the 25% of Greenland’s glaciers that currently or once formed ice shelves does not benefit the text, as currently written. Please rewrite this section to provide a timeline over which the glaciers that lost their ice did, because without providing temporal constraints one could argue that almost 100% of Greenland’s glaciers formed ice shelves at one time.

Li 40: Rewrite “and is projected to increase..” to “,which is projected to increase”

Li 36 – 47: I think it is important to link surface rivers to the basal channels that they often overlay (especially for Petermann). The following reference could be added to this paragraph and discussed some: Dow et al. (2018) <https://www.science.org/doi/full/10.1126/sciadv.aao7212>. This should be followed by a comment on the rift that shows up in Petermann’s central channel in 2018 to point out how the ice surface and base are linked, and just because there is a surface river doesn’t mean that the feature stabilizes the ice shelf.

Li 58: Please rewrite to “when a supraglacial river incises **the ice surface** below sea level”

Li 60 – 61: While I understand that this is not a paper dedicate to estuarine dynamics, if the estuary widens, then one could envision the fresher meltwater is still able to flow out at the surface while seawater flows in at depth, separated by a sharp pycnocline. Yes, there will be some mixing, but the seawater intrusion at Petermann may “partially slow down” more than “prevent” efficient meltwater export into the ocean. The amount of mixing and export in the estuary will also be influenced by the wind (and waves). I suggest adding several sentences to the end of this paragraph that discuss how estuarine dynamics may influence this setting.

Li 64: Please include a comment on this study, which revealed brine signatures on many Antarctic ice shelves with both radar and firn cores: Cook et al. (2018) <https://tc.copernicus.org/articles/12/3853/2018/>.

Li 65 – 66: Please add to this sentence the a qualifying statement that for Greenland this requires that the ice shelves do not break up, which is a major concern.

Li 72 – 72: What about ice penetrating radar for ice shelf thickness and basal channel depth.

Li 72: Change to “the measure of change in **surface channel** bottom elevation”

### **Data and methods:**

Li 98: this is picky, but Petemann Ice Shelf spans a range in latitudes and longitudes. If you are going to provide only one coordinate, then please add something information like “located at **approximately**” or “**centered** at...”

Li 98: Rewrite to “, **which** has an area of...”

Li 100: Rewrite to “ice shelf’s large **central** ice shelf supraglacial...,” because there are in fact many streams and rivers on the ice shelf surface.

Li 114: Presumably the lakes also experience diurnal cycles in water level if they have streams running into and out of them, but not as pronounced because of their larger area. Can you comment on this in the text?

Li 155 – 169: How does this method compare to that used by Macdonald et al. (2018) <https://www.cambridge.org/core/journals/annals-of-glaciology/article/seasonal-evolution-of-supraglacial-lakes-on-a-floating-ice-tongue-petermann-glacier-greenland/3FB0176ABB47735A10DFB8F72E47534D?>

Li 195 – 211: This is really cool.

Li 234 – 242: This is excellent.

Li 243 – 256: Maybe I missed this, but shouldn’t ice advection be accounted for in this calculation? The river is incising on ice that is also flowing seaward.

### **Results:**

Li 280 – 310: This is really neat, but why does the time comparison stop in August before the end of the summer season, which should go until the beginning of September? Is it just because these are when there are available images around the same time? The near-surface air temperature from a weather station deployed on Petermann from 2015 to 2016 are published here: Washam et al. (2019) <https://www.cambridge.org/core/journals/journal-of-glaciology/article/summer-surface->

[melt-thins-petermann-gletscher-ice-shelf-by-enhancing-channelized-basal-melt/4F111AFFBE670992E7AAD21359561F1B](https://doi.org/10.1002/2019JGHC.00011).

Li 334 – 339: The surface melt rates obtained here are similar to what was measured in 2016 by Washam et al. (2019) with an ApRES, which was  $1.4 \pm 0.2$  m.

### **Discussion:**

Li 362 – 427: I think Section 4.1 lacks some critical elements of ice melting and estuarine hydrodynamics that result in a discussion of the formation mechanism of the Petermann estuary that is not completely accurate. The topics that need to be considered and integrated into the discussion are listed here below, please consider them and integrate them into this discussion.

1. The surface slopes more steeply in 2014 than 2016, which will drive a faster flow of water downstream. As melting is a function of current speed (by way of shear between fastest flow and the ice), this could lead to a deeper incision in that year than in 2016. Additionally, streams on steeper slope are generally narrower than on shallower slopes. This could contribute to the varying melt patterns between years.
2. The melting that occurs in this channel is a function of temperature relative to freezing and current shear, as stated in point 1. Seawater will likely have a higher temperature relative to freezing than freshwater, because of its salt content. Also, the current will be most sheared as two flows merge, because  $\Delta U$  will be greater than if one flow was simply sheared to zero at the ice surface. For both of these reasons, it seems that the seawater should drive higher melting than the freshwater in the channel, unless the freshwater is much warmer or is flowing much faster than the seawater.
3. Frictional heating is not really the right expression for what is happening in the channel. Review Holland & Jenkins (1999) and incorporate their results into the discussion of how the ice shelf channel melts. [https://journals.ametsoc.org/view/journals/phoc/29/8/1520-0485\\_1999\\_029\\_1787\\_mtioia\\_2.0.co\\_2.xml](https://journals.ametsoc.org/view/journals/phoc/29/8/1520-0485_1999_029_1787_mtioia_2.0.co_2.xml)
4. This discussion ignores the possibility that freshwater could be flowing above seawater in the estuary, as well as that seawater can continually flow into the channel once ice has formed on the surface after the melt season.

### **Conclusions:**

Li 65: here the authors point out that the seawater may be warm. Please consider the points raised above about how seawater will melt the ice, versus the fresh meltwater.

### **Figures and Tables:**

Figure 1c is too small to convey useful information. Please either increase the size of this image or trace the outline of the river so that the reader can better identify it. I also suggest to add the glacier's grounding line, so that the reader can appreciate the area of the Petermann ice shelf that buttresses the upstream glacier.

Figure 2 should have the glacier grounding line plotted on the main panel.

## **References:**

Dow, C. F., Lee, W. S., Greenbaum, J. S., Greene, C. A., Blankenship, D. D., Poinar, K., ... & Zappa, C. J. (2018). Basal channels drive active surface hydrology and transverse ice shelf fracture. *Science advances*, 4(6), eaao7212.

Cook, S., Galton-Fenzi, B. K., Ligtenberg, S. R., & Coleman, R. (2018). Brief communication: widespread potential for seawater infiltration on Antarctic ice shelves. *The Cryosphere*, 12(12), 3853-3859.

Macdonald, Grant J., Alison F. Banwell, and Douglas R. MacAyeal. "Seasonal evolution of supraglacial lakes on a floating ice tongue, Petermann Glacier, Greenland." *Annals of Glaciology* 59.76pt1 (2018): 56-65.

Washam, P., Nicholls, K. W., Münchow, A., & Padman, L. (2019). Summer surface melt thins Petermann Gletscher Ice Shelf by enhancing channelized basal melt. *Journal of Glaciology*, 65(252), 662-674.

Holland, D. M., & Jenkins, A. (1999). Modeling thermodynamic ice–ocean interactions at the base of an ice shelf. *Journal of physical oceanography*, 29(8), 1787-1800.