Review of egusphere-2023-1320

General comments:

The manuscript "Extreme melting at Greenland's largest floating ice tongue" by Zeising et al. investigates melting beneath 79° North Glacier by synthesizing pRES, ApRES, airborne radar, and satellite SAR (TanDEM-X) measurements. They find channelized melt features and, indeed, extremely high melt rates, although the largest estimated melt rates (150 m/a) seem to be spatially localized. I found that the manuscript was exceptionally well-written with excellent figures, a clear and concise narrative, accessible description of phase-sensitive radar, and high scientific merit. In sum, I think that this is a great paper that could benefit from some more context, discussion, and comparisons with alternative methods. Below, I provide some specific comments and suggestions for further improving the manuscript that should be addressed prior to publication in *The Cryosphere*.

Specific comments (major):

1. **Introduction:** The introduction section is a little short as written, and I think could benefit from adding descriptions of the physics of channelized melting, how channelized features have also been found in Antarctica, methods for estimating the basal melt rate (e.g., explain more why you are using ApRES in the first place?), and perhaps any other ideas that arise in light of my other comments below. A good paper to reference on the observational side would be Alley et al. (2016), for example. (I see the description of channelization in the discussion, but some more in the introduction would be good too.)
2. **Comparison with surface-based estimation methods:** Clearly pRES is great for estimating basal melt rates. I do think though that somewhere you should further acknowledge the prevailing method for estimating basal melt rates, i.e., using satellite altimetry and surface velocity measurements under the assumption of hydrostatic (flotation) ice thickness. Ideally, since you have the elevation change, ice thickness, and ice surface velocity, you should be able to compare the estimates for either the melt rate or the true ice thickness vs. the hydrostatic ice thickness estimate. In particular, I would guess that your ApRES estimates are likely higher than hydrostatic-based estimates if the ice thickness is not perfectly hydrostatic around the channels due to deviatoric (bridging) stresses. This would be interesting in the context of recent modelling (Wearing et al., 2021) and observational (Chartrand & Howat, 2020,2023) studies that investigated the role of hydrostatic imbalance in surface-based melt-rate estimation; moreover, this would (A) highlight an advantage of ApRES in capturing internal strain rates that the hydrostatic methods do not include and (B) perhaps more directly relate the elevation-change measurements (or pRES thinning) to the ApRES melt rates in a conceptual sense. I think anything along these lines would be valuable/interesting to include given that you are near the grounding line and, thus, as you state in the introduction, the ice is probably not in "free flotation".
3. **Surface melting:** You suggest surface melting and the resulting enhanced subglacial discharge could cause enhanced melting. I think this could be improved in two ways. First, I think it would be good to generally discuss how surface hydrology and subglacial hydrology have been found to be linked at several of Greenland's outlet glaciers (e.g., Helheim Glacier), and that a subglacial outflow source for many ice-shelf channels has been hypothesized in Antarctica (e.g., Alley et al., 2016). Second, if there are any

indications of surface hydrology in this region in previous studies or satellite imagery you have looked at (e.g., Figure 1b?), that could be useful for further testing this hypothesis.

4. **Appendix D:** This Appendix is really only mentioned in passing in the discussion section, but describes some numerical calculations of ocean currents that are able to support the high melt rates. Consider including this material directly in a new results section (and/or the discussion) along with an explanatory/results figure if you are going to include it in the paper, which you absolutely should in my opinion if it helps explain the ApRES melt rates.

Specific comments (minor):

1. Line 5: I think you should include something about how the highest melt rates are spatially localized (i.e., later you say 95% quantile) and short duration here.
2. Line 30: "Bentley et al. (2023) gives evidence that the AIW…": suggest saying that this evidence comes from an epishelf lake.
3. Line 35: describe how meltwater alters fjord circulation (Straneo et al., 2016 ref)?
4. Line 105: Please clarify what "ice base – ice surface – ice base multiple" means
5. Equation 4: Define the vertical coordinate system somewhere, i.e., z is in (0,R), but what exactly do 0 and R mean?
6. Figure 1: For a while, I thought that there was a red star near ApRES2, but I see now that it is a black star with a red dot in it. I think labelling the 2a and 2b endpoints on the map would help alleviate any confusion.
7. Line 185: "This can differ from the melt rate in the normal or vertical direction at the basal reflector." I got caught up on this statement, can you explain this in a little more detail? Related, in Appendix A you say "the resulting basal melting in the vicinity of the measurement is always underestimated, although the nadir melt rate might be lower", and I didn't completely understand that either.
8. Figure B1-B3: I think Including one of these in the main text would be good for understanding the ApRES data/method. I think plotting all of the components you use to calculate the melt rate (ΔR, ΔR_s, and ΔR_ε) in panel c would be good, along with the melt rate you already have in panel d.
9. Equation (7): I don't entirely understand how you are calculating this in practice but I think the previous comment would help clarify.
10. Figure 4: I would remove the word "sketch" from the caption as it makes it sound like you are drawing something rather than plotting data
11. Figure 5: It is hard to see the BedMachine profile in this panel b (is it absent?). Also should probably include BedMachine citation in the caption
12. Line 225: Which figure are you referring to in Appendix B2 regarding small strains?
13. Line 230: "marker shape of the off-nadir thinning rates" add "in Figure 1" here to clarify
14. Fig 6a: Is there a negative melt rate/freezing towards the right or just zero?
15. In the discussion, I think some of the results concerning basal ice slopes could potentially be connected to some recent studies on the relation between basal ice slope (e.g., "terracing"; Dutrieux et al., 2014) and melt rates (Schmidt et al., 2023; Watkins et al., 2021). For example, on Line 205 you say "With decreasing basal slopes inside the channel, the melt rate also decreases", which is related to these ideas.

16. Line 337: I wasn't sure what you meant by "because they exceed such melt rates, which are necessary for a steady-state ice thickness"—I found this sentence confusing.
17. Line 338: "off the center"… center of the glacier? Suggest rewording
18. Appendix B1: On Line 370, what is β?
19. Equation B2: Are the shear terms neglected in the z integral in equation B1 to derive equation B2?
20. Appendix E: If you need to shorten the paper, I did not think this was strictly necessary.
21. Figure 7/Discussion: The surface temperature seems to drop slightly between 2005-2009 period and later years. Could this somehow be related to the decrease in melt rates? In general, more discussion of why the melt rates might be decreasing would be good. I know you say something about the "inflow of colder water", but could a diminishing subglacial outflow due to less surface melt also contribute?
22. Related to previous, you suggest a "recent inflow of colder water", just wondering if there are there any other observations available that might support this idea?
23. Table A1: In Case D, I was not sure what "simple measurements" meant
24. In the introduction, you talk about how basal melting may be related to ice shelf stability or disintegration. I think you should at least mention something about the stability of this system, and the uncertainties in that in the discussion. For example, do you think the channel is going to eventually break through the ice shelf thickness or otherwise destabilize the system somehow? Or, is it all very uncertain given the temporal dynamics of the melt-rate decreasing and possibly complex interactions with ice flow, ocean currents, and atmospheric changes?

Technical corrections:

a. Line 40: In the last sentence of the paragraph, I suggest reversing the order of clauses (i.e., "Other methods must be used to monitor…")
b. Line 165: Suggest changing "which results in an underestimated melt rate" to "underestimates the melt rate by X m/yr…" or similar. As written, I thought you meant that 2.7 m/yr was the absolute melt rate, not the underestimation amount.
c. Line 180: Change (Vaňková et al., 2021) to Vaňková et al. (2021)

References:

- Alley, K. E., Scambos, T. A., Siegfried, M. R., & Fricker, H. A. (2016). Impacts of warm water on Antarctic ice shelf stability through basal channel formation. *Nature Geoscience*, *9*(4), 290-293.
- Chartrand, A. M., & Howat, I. M. (2020). Basal channel evolution on the Getz Ice Shelf, West Antarctica. *Journal of Geophysical Research: Earth Surface*, *125*(9), e2019JF005293.
- Chartrand, A. M., & Howat, I. M. (2023). A comparison of contemporaneous airborne altimetry and ice-thickness measurements of Antarctic ice shelves. *Journal of Glaciology*, 1-14.
- Dutrieux, P., C. Stewart, A. Jenkins, K. W. Nicholls, H. F. J. Corr, E. Rignot, and K. Steffen (2014), Basal terraces on melting ice shelves, Geophys. Res. Lett., 41, 5506–5513, doi:10.1002/ 2014GL060618.
- Schmidt, B. E., Washam, P., Davis, P. E., Nicholls, K. W., Holland, D. M., Lawrence, J. D., ... & Makinson, K. (2023). Heterogeneous melting near the Thwaites Glacier grounding line. Nature, 614(7948), 471-478.
- Watkins, R. H., Bassis, J. N., & Thouless, M. D. (2021). Roughness of ice shelves is correlated with basal melt rates. Geophysical Research Letters, 48(21), e2021GL094743.
- Wearing, M. G., Stevens, L. A., Dutrieux, P., & Kingslake, J. (2021). Ice-shelf basal melt channels stabilized by secondary flow. *Geophysical Research Letters*, *48*(21), e2021GL094872.