Responses to second set of reviewer comments for the article "The effect of landfast sea ice buttressing in the Larsen-B Embayment, Antarctica"

We want to thank again the reviewers and editor for the time they have spent evaluating this article and for providing such valuable feedback.

Please find my responses to the final comments of reviewers #1 and #3 below. As before, my responses to general comments are in teal, while specific comments are tabulated afterwards.

Changes are confined largely to small edits in the wording of the abstract, and changes to section 4 "Environmental drivers". There are no significant edits to the figures.

Responses to comments from anonymous Reviewer #1

Reviewer 1: I think this paper is really great and the authors have exhaustively answered all my questions. One exception to that is section 3.3 - Environmental drivers.

We thank the reviewer very much for their praise of the revised manuscript. We agree that the work invested during this review process has improved the article - and thank them for their significant part in that.

As the authors admit 3.3 is more of a detour, but unlike the rest of the paper, which is really clear, well-reasoned and to the point, this section is highly speculative and doesn't do justice to the rest of the paper. I think it would be best to leave it out.

While the reviewer is still not a fan of section 4 (which was section 3.3 prior to my edits following the first set of reviewer comments) on environmental drivers, my co authors and I have decided to keep it in the paper, with various small changes, for the reasons I set out below. Firstly, though section 4 contains some conjecture, I don't think it's fair to call the whole section 'highly speculative', rather it presents a set of quantitative observations and reanalysis data that are used to evaluate the wider environmental change at the time of the sea ice breakup. Reanalysis data on temperatures and wind speeds are complemented by satellite observations of basal melt rates on the one remaining section of ice shelf (Scar Inlet) which is large and intact enough for this dataset to be produced. This information has not been included in other publications discussing the Larsen-B sea ice breakup, so we feel it is an interesting contribution to the literature. We would have liked to also include some ocean temperature observations as the reviewer suggests (see their comment below), as this may have strengthened our suggestion that higher ocean temperatures caused the larger basal melt. We had conversations with our oceanography colleagues about sourcing this, however, as the timing of the sea ice breakup coincided with the COVID19 pandemic there is simply no in situ temperature data from this time

as ocean cruises were not able to take place.
In terms of edits, I have removed a couple of sentences that speculate on the contribution of warm water to mélange disaggregation and increased calving rate. Additionally, I have made statements regarding the timing of changes in basal melt rates over Scar Inlet less precise to reflect the large uncertainties in the estimates.
Ultimately, though some of the results in the section could be given more attention in a separate piece of work, I don't think leaving the section with these edits does any harm to the article, and doing so allows us to present data that some readers will find interesting.

Reviewer 2		
ID	Reviewer Comment	Response
1	There no details about how these melt rates were inferred and how they were validated. The uncertainties are so high, that a straight line could be fit through the data over almost entire duration of the record. The time series is from the grounding line region where bending effects are typically present - was this glacier dynamics taken into account or is hydrostatic approximation used in that region as typically done?	We provided the citation to Gourmelen et al. (2017) which explains in detail how the basal melt rate data is produced and validates this method over an ice shelf in the Amundsen Sea Embayment. We have added the a to Davison et al. (2023) which presents the same basal melt rate data (along with other parameters) across the whole of Antarctica. I disagree slightly with the reviewer that it is meaningful that that a straight line could almost be drawn through the basal melt data presented in Figure 5d. If one were to analyse how the data shown here were evidence for different timeseries models, even given the error, the likelihood associated with a linear model would surely be small, especially when you consider that we are looking at a large number of densely spaced datapoints. Regardless, I have changed the wording of the sentence describing the timeseries to reflect that, due to the large uncertainties, the timings of specific changes in melt-rate should not be stated too precisely. The reviewer is right to say that the hydrostatic condition is used to infer basal melt rates, but the timeseries is not taken from the region around the grounding line, where this condition might not hold.
2	What is the ocean structure here and is it plausible increased ocean temperatures (in presumably the lower part of the water column) actually reach the melange which is much thinner than the grounding line location?	I have removed sentences referring to the interaction of warm water with the mélange or calving fronts. (Also, see comment above regarding the lack of in-situ measurements of ocean structure.)

3	If melt rates have been increasing for some time already, was there any noticeable variability in the glacier motion that could be attributed to changing melt rates?	This is a very good question! The timeseries data at the grounded locations we analysed do not show significant dynamic changes before 2022 compared to the dramatic changes we see afterwards. However, further work is required to establish whether there is a signal detectable anywhere in either dynamics or grounding line location. I have added the following line stating this point in the article: "Further work is required to establish whether the deeply grounded glaciers of the Larsen-B Embayment, and perhaps beyond, exhibit a dynamic signal before the landfast sea ice evacuation that could point to the influence of enhanced ablation due to ocean warming.".
4	If anything, what seems more plausible is that enhanced subglacial runoff would be responsible for such increase in melting than sudden increase in ocean temperature (within the values that are realistic).	This is a good thought and one we have considered, as subglacial melt and associated ocean plumes can enhance turbulent mixing and melt at the grounding line/ice shelf base. However we don't have any evidence to show that this was occurring in the study region at the time of the change. Future studies could investigate the runoff parameter in regional climate models to assess whether the runoff is likely to be higher than the usual seasonally driven surface melt that occurs in this region. The increase in basal melt rates we measure appears to extend over a longer multi-year period with only subtle seasonality, so this might suggest that another process such as ocean warming has more of an effect.
5	What is the biyearly variability in the melt rates - is that a filtering artifact or is there any explanation for melt rates varying on a 2-yearly timescale? 2 years is a bit odd yet there seems to be a signal of that period in the inferred melt rate.	We are not sure what is behind this ∼biennial variation in the data as, like the reviewer suggests, the 2-3 year period is not immediately indicative of any processes that come to mind. It might well be an artefact of the data. However, the signals of interest occur on a different timescale with larger amplitude, so these do not influence the statements made in the section.
6	How does increased melt in the grounding zone cause rapid calving?	On Crane glacier, after the initial disaggregation of ice mélange and the most seaward part of the calving front, the calving front was likely to be close to the grounding zone - a configuration in which warm water could, for example, induce a calving multiplier effect. However, I have removed mention of the impact of warmer water on calving as the mechanism is different for the two ice shelves of interest and dependent on factors we do not consider in the data.

Responses to comments from Reviewer #3

Reviewer 2		
ID	Reviewer Comment	Response
1	L9-12: This is a little confusing. Are you saying that the loss of sea ice buttressing caused the ice shelves in front of these four glaciers to speed up but not the grounded ice? Or some glaciers but not others? I think part of the confusion stems from the fact that the paper talks about all of the glaciers in the Larsen-B Embayment but the abstract specifically discusses just four of them.	I have changed the abstract in a couple of places to help disambiguate whether the statements refer to the four glaciers the study is concerned with or all the glaciers in the region. I have changed the particular sentence in question to: "The results show that direct landfast sea ice buttressing had a negligible impact on the dynamics of the grounded ice streams. Furthermore, we suggest that the loss of landfast sea ice buttressing could have impacted the dynamics of the rheologically weak ice shelves, in turn diminishing their stability over time, however, the accompanying shifts in the distributions of resistive stress within the ice shelves would have been minor. This indicates that this loss of buttressing by landfast sea ice is likely to have been a secondary process in the ice shelf disaggregation compared to, for example, increased ocean swell or the drivers of the initial landfast sea ice disintegration."
2	L53: This is somewhat ambiguous. Were there no calving events from 2001–2022? Was it just in 2022 that it was difficult to define the calving fronts?	I have changed this to read: "For much of the period prior to the first calving events of 2022 the transition between consolidated ice shelf to landfast sea ice appeared smooth in satellite images, encompassing a region of ice mélange, making the calving fronts difficult to define precisely." .
3	L81: I'm not convinced from Fig. 1b that Crane Glacier started to accelerate in February 2022, especially when you consider the uncertainty shown in the plot.	I have changed this to 'early-to-mid 2022'.
4	Fig. 1a: The color (white) for the 2021 sea ice extent is not visible in the legend because of the white background. Perhaps consider adjusting the color scale so that the last line isn't white?	I have changed the background of the legend to grey so each line is visible. Thank you for pointing this out.
5	L96: Cite Fig. S3b?	I have added this reference to figure S3 b (alongside a reference to figure 1 f).

6	L228–230: I agree that the landfast sea ice removal did not cause a large, instantaneous change in speed at/above the grounding line, but I'm not sure if you can say it wasn't the primary cause. Would the glaciers have sped up if the sea ice had remained intact?	I have changed this line to read: "This is an indication in its own right that the buttressing effect of landfast sea ice was not its primary control on the dynamics of the glaciers of the Larsen B Embayment." The reviewer is quite right, the wording here is not correct and I think the glaciers would not have sped up had the sea ice remained intact.
7	L347: But it does seem to have a buttressing effect on the ice shelves, which are part of the glaciers.	I have changed "landfast sea ice does not have the ability to buttress glaciers" to "landfast sea ice has limited ability to buttress glaciers". Thank you for pointing out this inconsistency.
8	L441–442: Maybe I missed it, but I don't see how the results from this study support this claim.	We show it is likely that the perturbation to the viscous stress in the ice shelves with the removal of the landfast sea ice buttressing was small compared to the spread of viscous stress within the ice shelves. Hence, a widespread disintegration of the ice shelves is not likely to have been caused by this change.

References

Davison, B. J., Hogg, A. E., Gourmelen, N., Jakob, L., Wuite, J., Nagler, T., Greene, C. A., Andreasen, J., and Engdahl, M. E.: Annual mass budget of Antarctic ice shelves from 1997 to 2021, Science Advances, 9, eadi0186, https://doi.org/10.1126/sciadv.adi0186, 2023.

Gourmelen, N., Goldberg, D. N., Snow, K., Henley, S. F., Bingham, R. G., Kimura, S., Hogg, A. E., Shepherd, A., Mouginot, J., Lenaerts, J. T. M., Ligtenberg, S. R. M., and van de Berg, W. J.: Channelized Melting Drives Thinning Under a Rapidly Melting Antarctic Ice Shelf, Geophysical Research Letters, 44, 9796–9804, https://doi.org/10.1002/2017GL074929, 2017.