Response to second round reviews for Hedetoft, Bang Brinck, Mottram et al.. Mélange or landfast ice: What controls seasonal calving at Greenland outlet glaciers?

We would first like to genuinely thank the editor and reviewers for their very clear and helpful comments all through this review process. It has substantially helped us to clarify our thinking and improved the manuscripts substantially.

Following the reviewer comments which were substantially similar we have updated the title, rewritten the abstract and restructured the introduction to better reflect the impact of other processes in controlling calving activity in Greenland. We have also cleaned up some typos and added a few additional references as suggested and ensured the manuscript conforms to the cryosphere submission guidelines with the appendix etc correctly formatted.

The new title is: “Mélange, landfast sea ice, ice velocities: What controls seasonal calving rates in North West Greenland?”

New abstract: “Calving glaciers in Greenland frequently exhibit seasonal cycles of terminus advance and retreat and changes in ice velocity and calving rate associated with changing air temperatures, surface melt rates and local sea ice conditions. Landfast sea ice that forms each winter in Greenland and glacier mélange (sikussaq) are part of a continuum of ice forms in front of marine-terminating outlet glaciers, posited to offer a buttressing effect on marine calving glaciers equivalent to floating ice shelves and potentially thereby helping to reduce the risk of marine ice sheet instability feedbacks. However, the role of mélange in controlling calving rates and front position is controversial, with previous studies showing mixed results and limited effects on terminus ice velocities. Here, we use a comprehensive range of different types of data including a novel in situ dataset of high time resolution GNSS position information, combined with satellite datasets of ice velocity and calving front position for three representative glaciers in north west Greenland. Our study at the Tracy, Melville, and Farquhar glaciers took place during the period from late winter (March) to peak melt season (July) in 2022 and 2023. Seasonal variations in outlet glacier velocity, calving activity and terminus position vary in-step with the seasonal cycle of air temperature and landfast sea ice formation and break-up. Our observations are consistent with previous granular material theoretical frameworks where fast ice acts to delay the removal of mélange. We also observe large calving events at the peak of the fast ice season suggesting that neither landfast ice nor mélange fully suppress calving activity. We find no evidence of tidally driven movements within the mélange zone during the fast ice season. Our observations show that the unbonded mélange at these outlet glaciers has very little influence on glacier velocity or calving rates and it is only when the separate ice blocks in the mélange zone are frozen into a matrix of landfast sea ice, losing the granular material properties that are characteristic of mélange but more associated with rigid multiyear sea ice, that they appear to exert any kind of (limited) influence on the calving rates. Our observations form a comprehensive and useful dataset for evaluating models of mélange interactions and developing insights into the material properties of fast ice and mélange. We conclude that at these representative small and medium-sized Greenland outlet glaciers, factors including surface melt and glacier velocity as well as the presence of landfast sea ice bonding mélange modulate seasonal calving behaviour.”

Report 1

Having reviewed an earlier version of this manuscript it is evident to see that the authors have revisited the study and made significant improvements to the paper. In particular, updates to some of the key figures have been made which has enabled further discussion points to be added relating to the multiple environmental factors which all play a role in the overall ice dynamics, including calving patterns, of the glacier systems.

My main comment now is perhaps more with how the manuscript is framed. Starting from the title, and throughout the introduction, it might be considered that only either fast ice or melange is important in the observed seasonal calving behaviours. From the results presented, I still struggle to see how robust conclusions about either fast ice or melange being a primary controller on these patterns of calving can be drawn. That is not to say they are not important factors as the authors suggest.

The authors discuss throughout the paper the importance of other factors, namely changes in surface melt and runoff, and their potential links to changes in glacier dynamics throughout the seasons. A minor reframing of the paper is therefore recommended prior to publication to better reflect the importance of these additional factors, as is already done in the conclusions.

The data collected throughout the field campaign appears extremely valuable in assessing the seasonal dynamics of these glaciers and it is nice to read that further data may be collected in the future, along with additional data being made available relating to UAV derived measurements of melange thicknesses, all of which will continue to be of great interest to the wider community.

Report 2

The authors have thoroughly addressed my major concerns. The paper and the reported data are very inspiring for understanding glacier-melange-ocean system. It's clear that in-situ measurements at the glacier-ocean interface are important and can complement remote observations. I recommend acceptance after the authors revise based on following specific comments [the following line number referred to the revised manuscript with tracked changes]:

1. The abstract needs some review to be more fluent. Some sentences can be reorganized, for instance, the "however, we also…." Might be better to be placed after "we therefore..".

"Seasonal variations in outlet glacier velocity, calving activity and terminus position vary in-step with the seasonal cycle of air temperature and landfast sea ice formation and break-up. Our observations are consistent with previous granular material theoretical frameworks where fast ice acts to delay the removal of mélange. We therefore suggest modelling landfast ice and glacier mélange as part of a glacier continuum that can modulate the response of glaciers to climate forcing on a seasonal cycle where landfast ice is seasonally present. However, we also observe large calving events at the peak of the fast ice season suggesting that neither landfast ice nor mélange fully suppress calving activity. …"

2. This sentence in the abstract is confusing: "however our observations show movements of the mélange away from the glacier fronts at a similar velocity, suggesting that landfast ice and mélange exert only a minor back stress on these calving termini." Why does similar velocity between melange and glacier equivalates to minor back stress? Minor back stress can only be inferred from active calving activities, right? Previous experimental paper [Nissanka2025] has shown that a steadily advancing thick melange with same velocity as terminus can still impose large buttressing force.

3. I like this response from the author very much, could be good to incorporate it into the abstract if possible (the current abstract reads a bit vague): “Our observations show that the unfrozen or unbonded mélange at these outlet glaciers has very little influence on glacier velocity or calving rates and it is only when the separate ice blocks in the mélange zone are frozen into a matrix of landfast sea ice, losing the granular material properties that are characteristic of mélange and have the material properties more associated with rigid multiyear sea ice, that they start to exert any kind of (limited) influence on the calving rates.”

4. This paper quantifies the size of melange zone (consistent with the IMZ defined by the author?) from satellite images and also showcases counterintuitive results that bring melange’s effect on buttressing into question. Might be a good reference to include, too: Lippert, E. Y. H., Morlighem, M., Cheng, G., Berg, D. L., Hassan, J., & Khan, S. A. (2025). Ice front and mélange dynamics at Kangerlussuaq Glacier, Eastern Greenland, since 1981, and future stability. Geophysical Research Letters, 52(13), e2024GL113982.

5. In the reference, delete Meng2024 preprint and only keep Meng2025 published version. Line295 can cite Meng2025 instead.