

The Cryosphere Discuss., author comment AC1
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Reply on RC1

Taryn E. Black and Ian Joughin

Author comment on "Multi-decadal retreat of marine-terminating outlet glaciers in northwest and central-west Greenland" by Taryn E. Black and Ian Joughin, The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-164-AC1>, 2021

Response to Reviewer #1 (Michael Wood) on "Multi-decadal retreat of marine-terminating outlet glaciers in northwest and central-west Greenland"

Thank you for these detailed comments, which have greatly improved the paper.

In this manuscript, Black and Joughin present a comprehensive record of glacier retreat in northwest and central-west Greenland, encompassing more than 80 glaciers across almost 5 decades. The results are compared with a variety of observations and models on the ice sheet and in the regional ocean to draw conclusions about the regional drivers of the observed glacier retreat. This study is timely and of scientific interest because terminus retreat in this region is linked with dynamics mass loss from the Greenland Ice Sheet – a substantial contributor to recent sea level rise.

The quantification of terminus retreat is a particularly robust component of this study. The record extends previous data of ice front position both forward and backward in time, and it supports previous findings about the magnitude and timing of overall glacier retreat in this region. Another particularly compelling component of this study is the authors' approach to investigate a wide variety of model and observational data for regional changes that have the potential to influence glacier retreat.

Summary comments, no action taken.

One major concern I had in reading this manuscript is that the main conclusion of this paper – "that a variety of processes ... contribute to, but do not conclusively dominate, the observed regional retreat" – is not sufficiently supported by the analysis of the data presented. In particular, two main points remain unclear: 1) the extent to which the sampled data and model results on the continental shelf reflect conditions within the fjords and near the glacier termini, and 2) a quantitative link between the documented regional parameters and glacier retreat.

These concerns are described in more detail below and we address them there.

For oceanographic data and model results, there are 8 sampling locations on the continental shelf, chosen to be representative of different "clusters" of glaciers along the coastline. The authors point toward a lack of reliable data in narrow fjords as justification for using offshore data as a proxy for fjord conditions; however, for ocean observations in particular, NASA's Ocean's Melting Greenland mission has been conducting conductivity-temperature-depth surveys of the fjords and continental shelf since 2015. This publicly-available dataset provides a means to quantify the extent to which oceanographic conditions on the continental shelf relate to conditions within the fjords, as well as assessing the ability of the 1/3 degree ECCO model to simulate ocean temperature on the continental shelf.

Because the paper focuses on annual trends over several decades, we chose to use longer-term oceanographic datasets that could provide annual averages, rather than the OMG data, which do not go back as far in time and provide only seasonal snapshots. With regards to the continental shelf vs. fjord conditions, in revising the paper we made several adjustments to our subsurface ocean temperatures. Emulating your Wood et al. (2021), we 1) calculated the depth-averaged ocean temperature over the bottom 60% of the water column, instead of using the 250m temperature, in order to better capture the ocean heat at depth; 2) we then calibrated those data to match the temperatures in comparable regions provided in the supplementary data of Wood et al. (2021), which performed a more detailed analysis of offshore and fjord ocean temperatures.

In a similar sense, it is unclear the extent to which changes in sea ice concentration and sea surface temperature outside of the fjords reflect changes in rigidity of ice mélange near the glaciers. Previous studies have used optical data and/or feature tracking of icebergs within fjords to get a sense of mélange rigidity, but it is unclear how these results compare with sea ice concentration and surface temperature outside of the fjords. Overall, an explicit quantitative link between conditions on the shelf and those in the fjords where they interact with glacier ice fronts would make the analysis in this study more robust.

We are using the sea ice concentration and sea surface temperature outside the fjords as a proxy – albeit, an imperfect one – for water in the fjords, which will in turn influence changes in mélange. The link between sea ice conditions and mélange rigidity has been previously shown (e.g., Joughin et al., 2008a; Amundson et al., 2010). We will also be looking at more detailed datasets of mélange rigidity inside the fjords as a subject of future work.

For the impact on glacier retreat, this study presents a suite of possible conditions which could theoretically induce changes in the glacier front positions through variations in the rates of iceberg calving and submarine melt. However, the analysis lacks a quantitative comparison with glacier retreat, either statistical or mechanical. Statistically, for example, how well do variations in glacier front positions correlate with any of the given parameters, either on a glacier-by-glacier, a glacier "cluster", or a regional level? While a visual comparison can be drawn by flipping through Figs 5-9, an explicit analysis, such as a multiple regression, would help more firmly establish this link and reveal which processes might be more prominent. From a mechanistic standpoint, how would the impact of the various regional changes compare quantitatively? For example, given the changes in regional oceanographic and atmospheric conditions, how would the magnitude of retreat from ocean melt (e.g. as a result of warmer ocean conditions and higher subglacial discharge) compare to the magnitude of retreat from enhanced calving as related to a decline in ice mélange rigidity (e.g. as a result of warmer surface temperature and lower sea ice concentration)? A quantitative comparison of all the potential processes

listed would help support the conclusion that any particular processes does not conclusively dominate retreat.

We performed a suite of multiple linear regressions to test the relationships between our various oceanographic and ice-sheet variables and terminus retreat and have incorporated the results into the discussion section, including a table of the resulting sensitivities to different climate variables. The regression results indicated that terminus retreat is most sensitive to runoff, and moderately sensitive to ocean temperatures, but only weakly corresponds to sea ice. We have revised the discussion accordingly. We feel that this has made the conclusions much more robust and we appreciate the suggestion.

Overall, this is an important study seeking to identify regional drivers of glacier retreat in Greenland, helping to shape our understanding of recent and future sea level rise contributions from the Greenland ice sheet. However, I would recommend a revision of the paper to provide a more robust, quantitative link between the regional conditions investigated in this study and the history of glacier retreat.

We believe that the revisions made in response to this review have addressed these quantitative concerns and greatly improved the paper.