Response to review of "Change in Antarctic Ice Shelf Area from 2009 to 2019"

Manuscript egusphere-2022-1087
Response to Reviewers

We thank the reviewers and the editor for their time and effort in reviewing our paper, "Change in Antarctic Ice Shelf Area from 2009 to 2019", submitted for publication in The Cryosphere. We welcome the positive feedback and insightful comments which we have endeavored to fully address in this resubmitted revision, and we hope you agree this improves the manuscript. We have incorporated the majority of the suggestions made by the reviewer, and in the limited cases where we have not, we have provided a detailed description of the justification for each decision. The changes are highlighted in the manuscript through the track changes function. Please see below a point-by-point response to the reviewers' comments, where all line numbers refer to the revised manuscript file with the tracked changes.

ID	Comment	Response
Reviewer #1		
1	**Reviewer #1 (Remarks to the Author):** **a.** My main concern is that this paper is similar to a number of studies that are already in the literature, and although some of the previous work is acknowledged in the present manuscript, it's unclear how the new findings build on previous efforts. If the present study is not intended to explore new ground, that may in fact be okay, as there is real value in independent analysis that replicates established findings. But if the purpose of this study is only to replicate previous studies, then I'd like to see more clarity about which previous results are reaffirmed here, and who might've gotten it wrong in previous studies. If the present work finds any notable disagreement with previous studies, then I'd like to see that clearly stated and I'd like to see some discussion about why different groups might be coming up with different numbers, and what the differences might mean in a broader context. **b.** A couple of Celia Baumhoer's papers are cited in this manuscript, but I'm afraid the most relevant one to the present study has been overlooked. In her 2021 paper, terminus positions were mapped for 1997, 2009, and 2018, and the paper investigated the environmental factors that led to terminus position changes during each epoch. The present manuscript presents effectively the second half of the time series from Baumhoer et al., 2021, but without looking into potential causes of terminus position change. Some other work worth mentioning in the manuscript includes a pan-Antarctic survey of	Done. **a.** The purpose of our study is to assess area change across all major ice shelves in Antarctica from 2009 to 2019. At the time this work was completed calving front datasets were not routinely produced across the continent, and most change analysis in the literature was limited to regional case studies which we have cited in our introduction. More recent work, primarily Greene et al., (2022), does provide a continent-wide assessment of ice shelf area change, so our work is complimentary to this manuscript. We provide a direct quantitative comparison between these two continent wide estimates in a new table in the supplementary material (Table S3), and we provide a reason for any differences on an ice shelf by ice shelf basis. We note that as the acquisition date of the underlying satellite images is different for both studies, and the spatial resolution of the calving front product is also different, there will always be some minor differences between the two results. We hope that both datasets will be complimentary and of use to the scientific community. We think there is considerable value in producing an independent dataset and analysis of ice shelf migration over this relatively long 11-year period. We focus on documenting regional patterns of calving front change and try to categorize ice shelves into different types of calving behavior which hasn't been done in previous studies. We discuss the change

	calving fronts by Miles et al., 2016, a recent regional study of calving fronts by Christie et al., 2022, and a 15-year annual pan-Antarctic calving dataset by Qi et al., 2021. Also, I'm not sure if it's citeable yet, but the authors may want to be aware of the high-resolution IceLines coastline dataset: https://download.geoservice.dlr.de/icelines/files/	observed in our study period with respect to other published literature, to provide wider context for why each ice shelf has changed. **b.** We agree that understanding the environmental forces driving change in calving front position is both interesting and important, and the Baumhoer et al., 2021 study does an excellent job of this. In this study we focused on the annual change of each individual ice shelf over a decade-long period, and we hope that in the future our new dataset will be used for studies of this type.
2	As far as I can tell, the analysis is sound, the main findings are accurate, and everything generally agrees with the results of previous studies. It's somewhat tricky, however, to frame the results in a way that won't be easily misunderstood, particularly in this case, where changes over 10 years are dominated by just a few ice shelves whose calving cycles repeat every few decades. I am slightly concerned that a cursory glance at the abstract and conclusions might give the impression that Antarctica is in an overall phase of growth, when the present analysis has only captured a small portion of the multi-decade calving cycles of the big ice shelves that dominate the continent-wide totals. My coauthors and I ran into this problem when we tried to describe a 24 year calving time series in a recent paper, and I'm not sure if we got the wording exactly right, but we did our best to put the results of our short time series into the context of the longer-term calving cycles of the big ice shelves. I'd like to see some more direct language or clauses in the abstract to make it clear that the authors are not implying that Antarctica is somehow already on track to recovery from climate change.	Comment. In addition to stating the overall Antarctic ice shelf area change number in the abstract we do also state in the abstract that there are clear regional differences, with retreat on the peninsula and WAIS, and advance in EAIS and on the large Ronne-Filchner and Ross ice shelves. We are also careful not to use language that might be misleading, like 'recovery'. There is clearly some nuance about how best to present these numbers within the length constraint of an abstract, but we do think that it's highly unlikely that a reader could conclude from our abstract that the results show recovery from climate change.
3	**a.** The Results section is lengthy and presents a long list of numbers, most of which are already presented in Table, 1, and at times it's unclear why certain numbers are worth mentioning or how they change our understanding of ice shelf calving. An attempt has been made to provide context in the Results section, for example by mentioning the sea level potential of the Aurora Subglacial Basin in the same paragraph as the calving-front position change estimates for Totten, but no conceptual bridge is provided to link calving processes to the	Done. **a.** We use the results section to present a comprehensive description of change on each ice shelf and highlight important numbers that encompass each shelf's trend of growth/retreat over the 2009-2019 decade. The inclusion of key values allows the reader to better interpret the many numbers included in Table 1. We have included a simplified and more legible version of Table 1 in the main text, while including the full table in the

	doomsday value of sea level potential. As a consequence, the Results section feels somewhat incohesive at times, and it's unclear how all the facts and figures are related to each other or which findings might be most significant. I recommend significantly abbreviating the Results section, to put the main findings in clear focus. **b.** For anyone who wishes to know the exact amount of area change of a specific ice shelf between two arbitrary dates, I recommend sharing the data, so they can explore it as they see fit. **c.** Separately, the inclusion of a Discussion section may provide a better place to tell the "story" of a few key locations that may be of interest. Sticking with Totten as an example (but this is by no means a prod to focus on Totten in the revision), Sue Cook did some modeling work to understand the glaciological factors that can prime Totten for calving (Cook et al., 2018), Bertie Miles looked at environmental forcing and ice-front change there (Miles et al., 2016), and I've got a paper on Totten's dynamic sensitivity to calving (Greene et al., 2018). By following the thread of what causes calving to how calving impacts glacier dynamics, we gain a better understanding of how the present results are related to that 3.5 m sea level potential of the Aurora Subglacial Basin. Readers will appreciate this sort of "tying things together", as it will help us understand the importance of your results.	supplementary materials to improve readability (see Supplemental Table 2). We opt not to single out or highlight specific ice shelves over others because this is already done in regional case study papers. The patterns of retreat/growth within the 2009-2019 time period are of equal importance on all ice shelves, so it was interesting to describe many of the lesser studied ice shelves in this paper. We have used the results to categorize the 34 ice shelves into 6 different calving regimes, providing useful wider context into general patterns of behavior. We demonstrate the value of measuring the observed change in calving flux, as opposed to the steady state assumption. **b.** The data will of course be made freely available to the community. We are in the process of uploading the data to the opensource Pangea repository, and it will be freely available at the time of publication (see comment #4). **c.** See response 3a.
4	The real value of this paper is that it describes an independently derived calving-front dataset. The trouble is, the dataset apparently hasn't been placed in any public repository, it's not included as a supplement to the manuscript, and it's unclear if or how anyone will ever be able to access it, use it, build on this work, or directly evaluate the data. I do see a statement that the data will be made available upon request, but I think the field is trying to move beyond the old culture of sharing data via private handshake deals. (Sharing data "upon request" often fails when authors leave academia, and the social dynamic of needing to beg strangers for data tends to favor the well-connected and contribute to the Matthew Effect.) So that the data can be evaluated and we can feel	Done. See response 3b. The data will of course be made freely available to the community. All calving front shapefiles are currently in the process of being publicly available on PANGAEA after the paper is out of Pre-Print and has gone through full peer-review. Edit line 397: "The 2009-2019 MODIS calving front data that support the findings of this study will be available from PANGAEA."

	confident that it will be made available to all, I'd like to see the data placed in a long-term data repository or uploaded as a supplement to this manuscript.	
5	Throughout: Area change estimates are presented to 0.1 km2 precision. That's probably a tad too precise, particularly given that uncertainty is stated as being 1 km2.	Done. We agree with this suggestion and have removed the decimal point precision to ensure that we are not misrepresenting uncertainties.
6	L7: "50-years" hyphen is unnecessary.	Done. Edit line 7: "50 years"
7	L15,16, and a few other places: Only the word "Antarctic" needs to be capitalized in the phrase "Antarctic ice shelf" or "Antarctic ice shelves". I think we only capitalize "Ice Shelf" when it's part of the official name of a specific ice shelf.	Done. Edit lines 6, 14, 16, 25, 386: "Antarctic ice shelf..." or "Antarctic ice shelves..."
8	L51: "there are only five examples of regional assessments that have been updated since 2011" The wording here might make some folks feel left out. I'm thinking of Antarctic ice-shelf advance driven by anomalous atmospheric and sea-ice circulation by Christie et al., 2022, Environmental drivers of circum-Antarctic glacier and ice shelf front retreat over the last two decades by Baumhoer et al., 2021, Pan–ice-sheet glacier terminus change in East Antarctica reveals sensitivity of Wilkes Land to sea-ice changes by Miles et al., 2016, and a handful of other studies that have looked at the histories of single ice shelves or neighboring ice shelves. Consider rewording the sentence to focus on the positive—Talk about the work that has been done, rather than the focusing on what hasn't been done.	Done. Several of the studies mentioned were only just published while this manuscript was in its final stages of preparation. We have made the following edits following the reviewers' useful suggestions. Edit Line 49-50: "Due to the importance of this glaciological parameter, there are several recent publications that measure change in Antarctic ice shelf calving front location, from regional assessments to full continent-wide evaluations..." Edit Line 54-55: "In this study, we expand on this previous work and provide a Circum-Antarctic survey by mapping the annual calving..." Edit Lines 57-58: "The results provide a comprehensive assessment of ice front migration across Antarctica over the last decade, expanding on historic patterns of ice movement and enabling areas of growth and..."
9	L53: "In this study we address this gap..." It's not entirely clear what gap is being addressed. Consider wording more along the lines of, "In this study, we build on previous work to answer such-and-such remaining question" or "We build on previous work to gain a better understanding of such-and-such." (The "yes, and" rule of improv is often a good starting point for motivating scientific studies, and it always feels better than "yes, but".)	Done. See comment 8 response. Text edited to reflect comment.
10	L62: Hyphenate "cloud-free".	Done. Edit Line 64: "Cloud-free"
11	L83: The method of quantifying uncertainty in terminus pick position sounds sensible to me. How does picking uncertainty propagate into uncertainty in final estimates of area and mass change?	Comment. Please see additional details in response to comment #14.
12	L97 and elsewhere: "We computed the mean annual rate of calving by dividing the total area	Done. Calculating the mean annual rate provides helpful context for ice shelves that

	change by the number of years observed...” The pedant in me is reacting to this framing. Ice shelves may grow at a linear rate, and they may retreat at an ~linear rate when successive small calving events occur over many years, but in the case of a single calving event over the course of the observation period, it feels somewhat inappropriate to describe this as a rate of change. It’s more appropriate, in my opinion, to talk about the cumulative change over the observation period, without dividing by time.	are steadily retreating and advancing (sections 3.3 and 3.6); however, the reviewer is correct that this metric is less representative for ice shelves that have undergone major calving events where the overall ice loss is not indicative of a steady rate of change. We placed the mean annual rate of calving for ice shelves that experienced major calving events in brackets in Table 1, to highlight this point to the reader. Edit Table 1 and Table caption: “Table 1: Summary table with data on each ice shelf including: area change from 2009 to 2019, the absolute difference, percentage difference, and rate of change between the first and last recorded dates (ice shelves that have experienced major calving events are indicated with brackets)...”
13	L102: How are uncertainties in ice thickness handled when estimating ice mass changes? Keeping in mind that Bedmap2 ice shelf thickness is estimated by subtracting modeled firn air content (order of 20 or 30 m) from surface elevation measurements and applying hydrostatic inversion (multiply by 9.3), the firn correction alone can influence ice thickness by hundreds of meters, and firn is rather poorly constrained in Antarctica. I realize there’s no good way to validate ice shelf thickness where it has not been directly measured (and even radar has its uncertainties), but it would be good to have some approximate bounds on the mass change estimates that are presented in this study. I recommend making some reasonable guess at thickness uncertainty, and propagate it into the mass change estimates.	Comment. As the reviewer points out, ice thickness estimates may carry large uncertainties which vary spatially. In this study, we use the Bedmap2 ice thickness to calculate both the steady state and observed calving flux, so any difference can be attributed to the change in calving measurement alone. We don’t account for the uncertainty in the thickness data in our results. As we are making the calving front dataset freely available to the community, all results will be directly reproducible from the same datasets, and colleagues can use their preferred ice thickness when doing any further analysis.
14	L106: I’m not entirely sure I follow the logic of the ice shelf area uncertainty estimates. Above, the uncertainty in picking position is estimated at 254 m, and that sounds very reasonable to me. I interpret line 106 to mean that the 254 m value is not considered in the area uncertainty. Line 106 says accuracy is rounded to 1 km2, but it’s unclear whether the 1 km2 uncertainty applies to each ice shelf separately, or Antarctica as a whole. My intuition says 1 km2 may be a reasonable estimate of area uncertainty for a small ice shelf, but those 254 m position errors are likely highly correlated along the edge of the bigger ice shelves like the Ronne. The Ronne front is some ~2000 MODIS pixels wide, so a fully correlated 250 m picking error should result in something like 125 km2 uncertainty for the Ronne, if I’ve done the math correctly. Perhaps errors are not	Done. It was important to characterize the uncertainty on the calving front location measurement, and we chose to do this by testing how accurate the manual delineation was on Dotson Ice shelf. This provides us with the 254 m number, which we do think is a good indication of the uncertainty on our core measurement. It wasn’t feasible to repeat this analysis on all ice shelves due to the time-consuming nature of the method used, even though we fully acknowledge that there is inevitably regional variability on the quality of the measurements. For example, Dotson and Ronne have clear, cloudless MODIS imagery as well as relatively straight and easy-to-navigate fronts, reducing potential delineation error. However, more complex shelves, such as Shackleton, have intricate calving fronts

	fully correlated along the entire Ronne ice front, but I suspect the measurements are not accurate to 1 km2 for the big ice shelves.	with crevassing, sea ice, and the presence of cloud cover, making the margin for error much higher. More automated methods of generating calving front datasets will be much better placed to provide a spatially and temporally variable error estimate. Lastly, we round our areas to 1 km^2 precision based on methodology found in Cook and Vaughan's 2010 publication. This correction can be found in Table 1 and Sup. Table 2. Edit Lines 108-109: "...in line with the methodology of previous studies (Cook and Vaughan, 2010) as well as to account for errors within the calving front delineation (254 m)."
15	L219: I think "tsunami" can be uncapitalized.	Done. Edit line 221: "tsunami"
16	L291: Units appear on this line as m/a, whereas in the rest of the manuscript it's m/yr. According to the style guide (https://www.the-cryosphere.net/submission.html) they should all be written exponentially (m yr-1).	Done. Edit lines 14, 149, 151, 182, 184, 201, 212, 223, 226, 231, 250, 275, 281, 304, 316, 323: "m yr^{-1}", "km^2 yr^{-1}", and "km yr^{-1}"
17	L306: The heading "Rapid Area Growth" strikes me as a little funny, given that it's occurring at a glacial pace. Perhaps "Steady Area Growth" would be a better descriptor? Feel free to disagree.	Done. "Rapid Area Growth" has been renamed to be "Rapid Area Advance" to match other usage of the term "advance" and is an appropriate descriptor when comparing the growth of these glaciers to the speed at which the other glaciers are growing/receding. This is because the area is rapidly advancing but not at a steady annual pace (see Fig. 3e). This is a stark contrast from the "Steady Calving Front Advance" category, which describes calving fronts that are growing at a slower but steady annual rate (see Fig. 3f). Edit Lines 120-121, 187, 257, 260, 275: "rapid calving front advance"
18	L357: Liu et al., 2015 is incorrectly cited as an example of a study that estimates steady-state calving flux. Similar to Qi et al., 2021, they actually just counted the icebergs that were bigger than 1 km2 (and the uncounted icebergs smaller than that might be why their calving estimates are so much lower than Rignot's). If you'd like to cite another highly relevant paper that used steady-state analysis, check out Depoorter et al., 2013.	Done. We agree that Liu et al., 2015 does not utilize steady-state calving flux calculations. We cited this paper in this location because it explicitly discusses the importance of avoiding using this assumption. We have clarified this in the text to avoid confusion, and we also cite Depoorter et al., (2013) as the reviewer suggests. Edit line 361: "Depoorter et al., 2013" Edit line 380-381: "These comparisons are in agreement with past studies that compare observed data to steady state (Liu et al., 2015) and show..."

19	Results: Cook Ice Shelf drains a major marine-based subglacial basin, and the ice flow has been shown to be sensitive to changes in the terminus position (Jordan et al., 2022). Is there a reason Cook was excluded from this study?	Comment. Cook is a really interesting ice shelf and there are lots of papers documenting its importance. As you might imagine it was a significant task to manually delineate the ice shelf calving fronts on the 34 ice shelves we did include in our study, so it was simply a function of time that prevented us from extending the scope further.