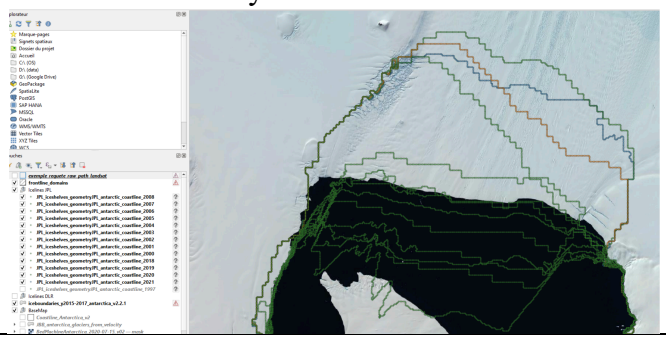
Response to review of "Change in Antarctic Ice Shelf Area from 2009 to 2019"

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 #2		
1	**Reviewer #2 (Remarks to the Author):** L51. I would not call ice shelf calving front position rare given the dense amount of paper that came out just in 2022. Maybe you can stress out that there is only one time series that goes far back in time (Green et al., 2022)?	Done. We have edited the text to reflect the reviewer's comment. While similar studies have recently been published, the data collected for this manuscript was completed prior to the publication of Greene et al. (2022). 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..."
2	L53. Another thing that could be stressed out is that recent studies are combining different sources of data (MOA, RAMP, MODIS, Sentinel-1a). Those datasets have different spatial resolution, with different related uncertainties. For example, the RAMP MOA and MODIS are composite mosaics, hence there is an uncertainties on seasonal front variations at these times right? What are these datasets most representative of? What are the uncertainties related to these datasets and the way they are combined? **One of the good points of this study is that the product is higher resolution and uses one single source of data, hence reducing sources of errors.**	Done. We thank the reviewer for these comments and agree that this study is unique in that it uses a consistent/single source of data to calculate ice shelf changes over an 11-year time span. The spatial resolution of the various satellites the reviewer highlights are different, and it would be interesting to sensitivity test the impact of this on the locations measured in future studies that take a multi-sensor approach. Certainly, the error estimate that we calculated in this study is directly related to the spatial resolution of the MODIS imagery, so a new error estimate should be calculated when measuring the calving front in different resolution satellite datasets.

	Also from the Greene et al paper, we can see that the delineation of the coastlines is really rough, and lots of the fronts looks like staircase, and does not follow smoothly the ice frontal position. I am wondering, overall, how these "wrong" or "low resolution" delineation are impacting the total change in area. These points of comparison should be stressed out in this paper, to try to assess the quality of product, and how the ones from Andreasen should be considered as a reference compared to other studies (see figure below from Pine Island glacier). A comparison with products from Baumhoer et al., 2018 should also be performed, as it was derived from deep learning vs manual in this study. 	We have updated the manuscript to provide a direct comparison of our measurements and the Greene et al (2022) result. Baumhoer et al. (2018) is also an extremely valuable dataset, and we are sure the community will make use of all of these in future studies. It was out of the scope of this paper to do a formal intercomparison of all calving front datasets. Edit: To address the differences between Greene et al.'s (2022) calving fronts and ours, we have created a direct comparison of areas in a Supplementary Table with reasoning as to why the datasets differ (see Supplementary Table #3).
3	L58. Why not doing all ice shelves? If you are missing 20% then you can't have a title saying "Change in Antarctic Ice shelf Area", this is misleading. How much work would be needed to add those missing ice shelves? I think that you should really consider having this comprehensive view of ice shelves here, which will contribute in imposing this dataset as a reference.	Comment. Depending on your definition, Antarctica has around 300 ice shelves in total, many of which are small and do not account for a large proportion of the ice shelf area change on the continent. In this manuscript, we focused on the largest ice shelves first, and prioritized measuring the calving front at annual resolution over a decade, rather than measuring more ice shelves less frequently.
4	L61. Does the choice of the month will impact the results compared to Green et al ? I think they have chosen March right?	Done. We selected images based on the availability of MODIS satellite data (accounting for cloud cover), as well as considering the presence of sea ice which makes it more challenging to identify the calving front boundary. There is definitely seasonal variability in the calving front location in some regions, so the temporal sampling does matter. Studies in the future that use all-season and all-weather instruments such as synthetic aperture radar data, will be well placed to measure this short-term variability. To minimize the impact of any seasonal variability we took care to select images primarily from January and February (occasionally March if absolutely necessary) to provide the best conditions for digitizing the front while avoiding any seasonal bias. This is discussed in the data and methods section of the paper.
5	Figure 1. If you use a classification on the type of retreat, I would recommend using different	Done. We really liked this suggestion and thank the reviewer for their comment. We

	symbol for the retreat types (circle, triangle, square…). Or some kind of symbology that would give an idea on the behavior of each ice shelf ?	wanted to retain the circle symbol on the current figure one as the diameter corresponds to the area change, so we felt that using different symbols might make interpretation of that information more challenging. We tried changing the outline of the circle to a color that corresponded to the calving regime, but this didn't look satisfactory. We have therefore added a new figure to the supplementary information file (Supplementary Figure #1) highlighting the calving regime of the ice shelves with a symbol as suggested. Edit Lines 259, 294: Additionally, the creation of this figure inspired a reorganization of the sections in this paper, with the new format placing the "Rapid Calving Front Advance" section (3.5) before the "Steady Calving Front Advance" section (3.6). As well changing the order of sub-images in figures 2 and 3 (switching the placement of Figures 3e. and 3f. as well as Figures 4e. and 4f).
6	L78. How does the sampling distance influences the accuracy of the ice front position and the overall derived ice shelf area ? Can you provide a figure in supplementary maybe, that shows how the ice shelf area change with the sampling ? That would be a good point of comparison with Green et al., who seem to have used a rather coarce sampling method.	Comment. The sampling resolution will impact ice shelves that have complex ice fronts most, as well as smaller ice shelves. Ice shelves with long relatively straight ice fronts (e.g. Ronne-Filchner or Ross) will be much less affected by sampling density as their calving front is simple and well represented by a line. We chose the sampling distance (points plotted every 1,000 meters) based on the resolution of the MODIS satellite images used (which have a pixel size of 250 x 250 meters). Although it is possible to down sample the spatial resolution of our calving fronts to the underlying MODIS imagery, we didn't sensitivity test the impact of this within this study. As suggested in response to reviewer comment 2, this will be a much more important consideration in multi-sensor studies when the underlying datasets are not all a consistent spatial resolution.
7	L93. Why not using the continent wide grounding line mapping made by Rignot et al to have the most accurate delineation ? In the Antarctic peninsula, updated grounding line position where also made using Sentinel-1, and could also be used to update grounding line with the yearly front position (Christie et al., 2022).	Done. We used the MEaSUREs grounding line dataset (Rignot et al., 2016), and we have clarified this in the text. Edit Lines 94-95: "...MEaSUREs Antarctic Grounding Line from Differential Satellite Radar Interferometry, Version 2 (Rignot et al., 2016)..."
8	L100. Why using BEDMAP-2? How is the ice shelf thickness determined in there ? Why not using BedMachine that used REMA as a DEM ?	Comment. 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.
9	L106. Where does this 1 km2 comes from ? How was it calculated ?	Done. We round our areas to 1 km^2 precision based on methodology found in Cook and Vaughan's 2010 publication and accounting for errors within the calving front delineation (of 254 m). 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)."
10	Table 1. I am thinking that this Table should be given as a supplementary file. Here it is not realy readable.	Done. We have edited Table 1 to contain less information, and we have moved the full detailed table into the supplementary data (Supplementary Table 2) for those who wish to explore the data in more detail. Edit Table 1: remove columns "Most Inland Calving Front (yr)", "Mean Ice Thickness (km yr^{-1})", "Mean Ice Speed (km yr^{-1})", and "Inland CFL Length (km)"
11	L124. This is over a short period I guess ? I think you need to include here a time variable for the definition of major calving events	Done. Edit Line 126: "...over a short time-period (calving events that occurred in less than a month)."
12	L159-160. I don't understand why this is not resolved in this study ? For those specific cases, can you investigate that using Sentinel-2 if MODIS is not sufficient ?	Done. This study focused on providing annual evaluations for each ice shelf extent due to MODIS being a passive sensor and therefore wouldn't collect sufficient data quality outside of the Austral Summer due to sea ice, increased cloud cover and lack of solar radiation. For specific large calving events, we provide information on the timing of each event because it is of particular interest to the community in Section 3.1. Additionally, we emphasize the importance of annual analysis as a baseline for future seasonal studies. Edit Lines 160: "This analysis of calving events on an annual scale provides robust data for future studies..."
13	L163-164. General comment for all the classification part: you need to give the reader some insights on how you determined those %	Done. We defined the percentage change based on the area change for each ice shelf during the study period. The grouping of ice

	area loss or increase used for the classification. Now it seems a bit random.	shelves within each percentage threshold category helps us understand the wide range of behaviors in all regions of Antarctica. For some behavior types, such as the large calving events, the classification is dependent on the time period, i.e., when the calving event took place. Studies over longer multi-decadal time periods would help better define each ice shelf's ice cycles and patterns of change; however, this dataset is a useful starting point for better understanding ice shelf area change in Antarctica. We have included references to the time periods for each calving regime in the first sentence of each section (3.1-3.6). Edit Line 126: "...over a short time-period (calving events that occurred in less than a month)." Edit Line 166: "...significant ice loss throughout the 11-year study period (2009-2019), loosing at least 15 % of their total area" Edit Line 191: "... lost less than 4 % of their total area over the 11-year study period (2009-2019)" Edit Line 235: "...but also have individual years of retreat within the last decade (2009-2019)" Edit Lines 261: "...by over 5 % during the 11-year study period (2009-2019)" Edit Line 295: "... ice shelves that have gradually grown in area from 2009-2019"
14	Section 3.7. Please compare your values with Green et al over the same time period	Done. We agree that a comparison in values would provide helpful insight on how the datasets compare. Please see comment #21 and Supplementary Table 3.
15	L366. Why do you use the most inland observed calving front position and not the latest 2019 position ? Why not the average ice front position over the time period ?	Done. Edit Lines 371-373: "We used the most inland calving front position when calculating ice thickness and velocity to ensure that the fronts were within the spatial coverage of the thickness and velocity datasets."
16	L366. which ice speed do you use? did you make sure it was representative of the ice front date?	Done. We used MEaSUREs InSAR-based Antarctica Ice Velocity Map, version 2., with a 450 m resolution. This dataset is assembled from multiple satellite interferometric synthetic-aperture radar systems and was largely acquired during the International Polar Year 2007 to 2009, as well as between 2013 and 2016. This range represents a similar timeframe to that of the ice front dates. Edit Lines 369: "...where the mean ice speed, MEaSUREs ice velocity at 450m resolution..."

17	L368. Split this sentence in two.	Done. Edit Lines 373-374: “To compare the different methods, we calculated the difference between the two numbers on all ice shelves within the study. We observed mass loss on 18 ice shelves and mass gain on 16.”
18	L370. Could you consider calculating a yearly calving flux? Would it make sense to compare it with the yearly mass losses from your changes in ice shelf area?	Comment. This is a good suggestion, and we hope our dataset will be used for this in future studies.