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The Cryosphere Discussions

Interactive comment on "Satellite altimetry detection of ice shelf-influenced fast ice" *by* Gemma M. Brett et al.

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Author Response to Anonymous Referee #3

Authors: We thank the referee for taking the time to review our manuscript and for providing valuable feedback. We have considered your comments and modified the manuscript according to suggested changes where we agree and provided a justification where we do not. We hope that the responses given below and modifications made have addressed the reviewer's comments.

General Comments.

Referee 3: The paper examines the ability of CryoSAT 2 to detect the existence of a sub-ice platelet layer found under McMurdo Sound fast ice and previously determined

to result from the upwelling of supercooled Ice Shelf Water. The study provided good comparisons with the freeboard rise from satellite altimetry with a detailed ground truth campaign conducted over four years of measured sea ice freeboard, snow depth, sea ice thickness and sub-ice platelet layer thickness distributions. Proof of the utility of satellite altimetry to effectively determine the distribution of these sub-ice platelet layers even in a selected region like McMurdo Sound is worthy of publication given that the lack of ground truth in other sea ice studies is a continuous impediment to progress in maximizing the potential of satellite remote sensing to effective monitoring of sea ice processes from space. There are some needed revisions to fully realize the paper's potential.

Specific Comments.

Referee 3: Proof of the utility of satellite altimetry to determine the distribution of these sub-ice platelet layers will provide an effective means of monitoring them from space and help in monitoring the interannual variability of the flux of Ice Shelf Water from underneath the Ross and McMurdo Ice Shelves in future.

That said, there are some difficulties in the presentation of the results. For example, in Figure 5, the use of the same color bars for quite different scales, CS2 freeboard in 5a (up to 0.6m), CS2 ice thickness in 5b (up to 5.8m) and drill hole MET in fig 5c (up to 3.5m) is difficult to interpret correctly. (note also in Technical Comments about the need for intermediate values).

Author Response: We thank the reviewer for this comment. We will use different colour bars for the three parameters.

Referee 3: In the abstract the sentence "We demonstrate the capability of CryoSat-2 to detect higher Ice Shelf Water influenced fast ice freeboard in McMurdo Sound and the wider application of this method as a potential tool to identify regions of ice shelf-influenced fast ice elsewhere on the Antarctic coastline." Is a reach too far, given the unique condition of McMurdo with its generally very thin snow cover which may not be

generally found in other coastal regions. There is also no attempt in the paper itself to apply the technique to other regions. Suggest limiting the statement to only: "We demonstrate the capability of CryoSat-2 to detect higher Ice Shelf Water influenced fast ice freeboard in McMurdo Sound." In the discussion of the paper, the concepts can be best given as to applicability to other regions, with sufficient caveats given as to the role of thicker snow than found in McMurdo Sound for example, and how this may affect the interpretations elsewhere.

Author Response: We thank the reviewer for this comment and agree that McMurdo sound presents favourable conditions. We meant to say in this statement that it could work elsewhere and have now clarified this as below:

"We demonstrate the capability of CryoSat-2 to detect higher Ice Shelf Water influenced fast ice freeboard in McMurdo Sound. Further development of this method could provide a tool to identify regions of ice shelf-influenced fast ice elsewhere on the Antarctic coastline with adequate information on the snow layer."

Technical Comments.

Referee 3: Abstract: "We attribute this overestimate in satellite altimeter obtained ice thickness to the additional buoyant forcing of the sub-ice platelet layer. " Comment: Need to know if the measurement of the sub-ice platelet layer distribution verified this.

Author Response: Yes, this was obtained from the central region of McMurdo Sound where the SPL is consistently thicker every year. We have added the following statement to the abstract and L426:

'The regional mean interpolated drill hole SPL thicknesses in the centre of McMurdo Sound was 3.90 m.'

Referee 3: Line 124: What were the equivalent freeboard rises in cm to the 12% and 19% freeboard increases at those locations? Were there also thickness measurements of the SPL at that time?

Author Response: The 12 % is the mean deviation in calculated sea ice thickness for the fast ice in McMurdo Sound and 19 % the maximum deviation. Price et al., 2014 do not state the equivalent rises in freeboard or for these overestimated sea ice thickness values and do not indicate the location where the maximum deviation of 19 % was observed. Price et al 2014 did assess in situ SPL measurements in their analysis.

Referee 3: Line 139 (Grammar error)."Refer to Brett et al. (2020) for a detailed description of the thickness distributions of ice shelf-influenced fast ice, the SPL and snow in McMurdo Sound in November of 2011, 2013 and 2017." Change to: Brett et al. (2020) provide a detailed description of the thickness distributions of ice shelf-influenced fast ice, the SPL and snow in McMurdo Sound in November of 2011, 2013 and 2017.

Author Response: Thank you, we will change the sentence according to this suggestion.

Referee 3: Line 140 Change to: Here we summarize those descriptions to show general patterns and also include the fast ice conditions in 2018.

Author Response: Okay, thank you.

Referee 3: Line 146 give a value for more substantial deposition of snow

Author Response: Thank you. We have included a range of magnitudes observed for snow depth in the east and southeast as $\sim$0.2-0.4 m

Referee 3: Figure 1. Give some intermediate SPL values on the color bar rather than just the High and Low. Might also include a few (4 or 5) of these as identified contour lines on the map plot. In the caption point out that the red square on the inset map is the area (McMurdo Sound) shown on the MODIS image to the right.

Author Response: Thank you, we will provide intermediate values following this suggestion.

Referee 3: Figure 5 need intermediate values on the color bar (Freeboard, C2-2 Ice

thickness, Drill Hole MET) and address concerns about the same color bars but different scales for a, b and c.

Author Response: We will add intermediate values and use different colour bars for the three parameters.

Referee 3: Line 490 Appendix A Seems hard to read,

Author Response: Apologies, we are uncertain what you refer to here. The processing applied to the CS2 product is very technical and could easily dominate this study. Here, we aimed to build on previous assessments of CryoSat-2 by others (e.g., Price et al., 2015) to focus on our objective of using satellite altimetry to detect an ice shelf/fast ice process. In Appendix A, we are ensuring that the geophysical corrections and the geoid detrending are robust and produce along-track CS2 surface elevation profiles with minimal residual curvature remaining from these geophysical effects over open water in late summer, and expected fast ice freeboard magnitudes and trends in late spring. As commented below, we will better clarify the applied corrections for each surface type and we will make the text easier to read throughout Appendix A.

Referee 3: Line 530 This indicates that the geoid is de-trended for twice (?? Don't understand this sentence)

Author Response: The Mean Sea Surface (MSS) is a combination of the geoid surface and Mean Dynamic Topography. Therefore, applying the MSS correction should account for the geoid surface. However, we observed that the geoid is not accounted for in the 7 years of CS2 measurements of the open ocean surface (in the shape and magnitude of the CS2 height). We would expect surface elevation retrievals of an approximate magnitude of -2 m relative to WGS84 ellipsoid (Figure A1b) when the geoid has been detrended and not -55 m (Figure A1a). The residual curvature in the shape of the surface was very similar to the EGM 2008 geoid and when we detrended for the EGM 2008 modelled geoid we obtained the desired flat profiles. We additionally assessed this phenomenon in late spring fast ice conditions and the resultant detrended

profiles aligned with in situ measured freeboard. We explored and read extensively about the CS2 data product and associated corrections but could find no solution or explanation to this phenomenon. As stated in the text the information provided by ESA was very limited and we were unable to clarify what MSS model was being applied in our study region. . .. . . We suspect it may be a processing error but we could not confirm this. We will clarify in the text that this is a potential processing error in the product and rewrite L528-531 according to information given in this response.

Referee 3: Lines 516-532 (Appendix A). I find this discussion rather confusing, perhaps hampered by my own limited knowledge of Geodesy. For example, the sentence (Line 507) "The open ocean surface with MSS and ocean/tidal corrections removed was consistent from 2011 to 2017." Is this both MSS and ocean/tidal corrections removed (Item 4) or Is it Item 3, MSS applied and ocean /tidal corrections removed? I infer that the authors' find the best practice for surface elevation is Item 6. in their first list but this is difficult to suss out from their discussion. Suggest a Table listing the various options and some index of performance e.g. Good, Fair , Poor along with better referencing of the number of the option in the accompanying text would help to clarify.

Author Response: We thank the reviewer for this comment and we will better clarify the applied corrections for each surface type and make the text easier to read throughout Appendix A.

Referee 3: Line 542 "The in situ data included in this study will not be available at the time of publication but it is intended that it will be deposited in a data repository." However from the Journal Data Policy:"Copernicus Publications requests depositing data that correspond to journal articles in reliable (public) data repositories, assigning digital object identifiers, and properly citing data sets as individual contributions: : :.. Authors are required to provide a statement on how their underlying research data can be accessed. This must be placed as the section "Data availability" at the end of the manuscript."

Referee 3: Reviewer Comment: Further revisions should include the citation to Data Availability required by this journal. A substantive further review may require the reviewers' and editor to examine the data used in the paper before final approval and the paper cannot be examined by others without the ability to further examine the data and conduct their own analyses.

Author Response: All CS2 data used in this study is available as stated in the 'Data Availability' section and this can be used to replicate most of the analyses. The in situ data will be made available and the following data availability statement will be included on L542.

'The remaining data will be made available at the World Data Center PANGAEA https://www.pangaea.de.'

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