The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-286-AC1, 2021

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

Gemma M. Brett et al.

gemma.brett@canterbury.ac.nz

Received and published: 26 January 2021

Authors Response to Anonymous Referee #1

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.

Referee 1: General Comments The article and language are clear and easy to follow and it is an interesting demonstration of the use of CryoSat-2 to retrieve information about ice shelf-influenced fast ice using satellite remote sensing. It would be helpful to

briefly set out the significance of the detection of ISW in terms of the remote sensing and climate impacts this study and similar studies could have, by outlining which parts of the method are novel and the potential insights to be gained. (Insights are discussed in Section 5.4 but would be useful summarised briefly in the introductory remarks/study motivations.)

Author Comment: We thank the reviewer for their suggestion and have made the following changes to the introduction:

1) To highlight the potential implications and significance of ISW detection with satellite remote sensing, we have we have restructured the introduction and combined it with the first sub-section of section 2.

We made the following changes: - moved the sentence on L96 to L70; - moved paragraph L102-114 to L73 and added the following sentence after Line 114:

'Using ground measurements, Brett et al. (2020) demonstrated a correlation of SPL thickness and volume in late spring with a higher frequency of strong southerly wind events in the western Ross Sea which drive polynya activity, HSSW production and ISW formation and circulation within the McMurdo-Ross ice shelf cavity over winter.'

- And additionally, we have added the following statement to L76:

'A means to identify these regions in large-scale satellite assessments is highly desirable, and if effective, has the potential to provide a satellite-based method to monitor the interactive system at play between the atmosphere, coastal polynyas, and circulation within ice shelf cavities with further development. The detection of ISW influence on fast ice via satellite altimetry is in theory possible through the identification of regions with 'anomalously' higher freeboard driven by combination of thicker ice shelf-influenced sea ice and the buoyant forcing of a SPL, if present (Price et al., 2014) but to date has not been assessed.'

- The two sentences on L97-100 have been moved to L127

2) To emphasise that the main method used in the study has been developed in detail in previous satellite altimetry work in McMurdo Sound, we have moved the paragraph in section 2 (L115-124) to L85 and added the following sentence at the end of this paragraph:

'Price et al. (2015) developed the method applied in this study to obtain CS2 fast ice freeboard in McMurdo Sound in 2011 and 2013 and the relevance of this work to this study is described in more detail in section 2.2'

Referee 1: It is positive that the study considers the potential impact of the dominant backscattering surface being somewhere other than the upper ice surface, this could be expanded to include further quantification relating to snow conditions.

Author Comment: Thank you for this comment. However, to quantify and constrain the effects of the snow layer on the CryoSat-2 radar waveform, one must carry out highly detailed assessments of the dielectric properties of the snow cover including grainsize, layering, brine content, temperature profiles and snow metamorphosis. This detailed snow information was not collected in our field campaigns. Price et al. 2015 have already assessed the effects of the geometric and radar roughness of the snow layer, snow depth, density and grain size on the returning radar waveform and freeboard retrievals from three different retrackers in McMurdo Sound in late spring of November 2011 and 2013.

As described in L183-185 (of this study), Price et al. 2015 found that the ESA Level 2 retracker tracked between the snow surface and snow-ice interface. They also state that one would need to know the backscattering coefficient of snow and ice to quantify what impact the snow cover has on the retrieved freeboard. In this study, the best we can do is relate the backscattering interface to interannual variability in snow depth and wind-compaction which we do on L256-257; L301-303; 306-307; L406-417 but this can only be qualitative for reasons given in the response to the specific comment about L255-257 below.

Referee 1: There is a heavy reliance on the assumption of hydrostatic equilibrium holding which is true for entire floes. Using this assumption requires careful sampling and the way this has been conducted in this study needs to be explained (point-to-point measurements an infrequent sampling over long length scales may not characterise the floe sufficiently well enough for an assumption of hydrostatic equilibrium to hold using measured thicknesses and densities.)

Author Comment: The sampling strategy at field sites has been described in detail in previous studies (e.g., Gough et al. 2012, Price et al. 2014) and we were initially reluctant to repeat that information in this study. However, we agree that the spatial distribution of freeboard measurements at field sites is important when assuming hydrostatic equilibrium and have now included the following statement after line 131 in section 2.1.

'At each site, five drill holes were made in the sea ice at the centre and end points of two 30 m cross-profile lines. Sea ice freeboard, snow depth and the thicknesses of sea ice and the SPL were measured at each drill hole using the technique described in Price et al., 2014 and then averaged to give a representative value over the 30 m by 30 m area.'

To the best of our knowledge, the fast ice assessed in this study is likely to be in or at least very close to hydrostatic equilibrium as it was not measured in close proximity to narrow pressure ridges or the coast. Importantly, we focussed on regional (kms) trends (Table 1 and Figure 3 and 4) and spatial patterns (Figure 5) in our comparison of in situ and CS2 freeboards and not on variability in the small-scale (10's or 100's metres). In multiple field seasons in McMurdo Sound, we observed smooth gradients in the sea ice, SPL and snow which are comparable on the scale of the CS2 footprint. Brett et al. 2020 assessed the drill hole measurements presented in this study for 2011, 2013, and 2017 with a ground-based electromagnetic induction (EM) device to measure coincident sea ice and SPL at a 10 m sampling interval. The high resolution EM measurements showed that the distribution of sea ice and SPL thicknesses (which mostly determine the resultant freeboard) in McMurdo Sound have smooth gradients on the kilometre scale.

Referee 1: Other studies looking at this area have found that sediments are present in large amounts which could also affect the ice and should be commented on (Rack et al., 2013 and Glasser et al, 2017) – it is important to outline whether this could this affect the assumptions used in the study.

Author Comment: The Glasser et al. 2017 study focuses on the significant sediment load on the land-ice of the McMurdo Ice Shelf (as do Glasser et al. 2006) and not on the adjacent sea ice which is the subject of this study. We find no mention of land-fast sea ice in the Glasser et al. 2017 study.

Rack et al. 2013 predominately assessed the debris contribution to the density of the McMurdo Ice Shelf. They did calculate a theoretical debris load to account for the overestimate in fast ice thickness in the centre of McMurdo Sound. However, they also state that this could be explained by the contribution of sub-ice platelet layer buoyancy to higher freeboard. The sub-ice platelet layer contribution to overestimates in calculated sea ice thickness from anomalously higher freeboard in McMurdo Sound was validated and quantified in a later study by Price et al. 2014 which is described and referenced in this study.

It is unlikely that the windblown sediment load is significant for the land-fast sea ice in McMurdo Sound as it is typically first-year ice of 6-8 months age and would not have time to accumulate the comparable sediment loads observed on the adjacent McMurdo Ice Shelf (likely 1000's of years of accumulation of surface deposition and marine/anchor ice from the bottom). We only consider First-Year ice in the linear and spatial trend analyses in this study.

Importantly, sea ice grows downwards with congelation growth at the base of the ice, and additionally in McMurdo Sound with platelet ice consolidation at the sea ice base, and augmented growth through heat flux to the heat-deficit in the ocean driven by

supercooled Ice Shelf Water. This is in contrast to the typical mass contribution to land ice/ice shelves of surface snow accumulation where sediment can become more readily incorporated. We are aware that McMurdo Ice Shelf is 'unusual' in that basal freezing is a major contributor to its mass balance and that sediments entrained in the anchor/marine ice reach the surface of the ice shelf as it ablates.

Referee 1: A constant ice density from the literature is assumed in this study – it would be good to determine the sensitivity of the conclusions to this considering its uncertainty, variability and validity for this study.

Author Comment: Price et al. 2013 and Price et al. 2014 assessed error contribution from sea ice density in detail and provide a sound justification (based on a range of sea ice density measurements in McMurdo Sound) for the selected value of 925 kg m-3. To clarify that this has already been assessed in detail we have added the following sentence at L241:

'. . .to adhere to the rationale and error propagation in Price et al. 2014 where a range of snow and sea ice density measurements made in McMurdo Sound were assessed.'

Additionally, on L396-399 we referenced the findings of Price et al., 2013 and Price et al., 2014 who found in their detailed error analyses that the main error contribution to calculated ice thickness is the freeboard.

Referee 1: The methodology is sometimes not sufficiently detailed to assess what has been done, for instance there are many mentions of spline fitting without discussing the order or justification for the choice, noted in the Specific Comments.

Author Comment: In multiple field seasons in McMurdo Sound, we observed smooth gradients in the thickness of sea ice, SPL and the snow layer which were comparable on the scale of the CS2 footprint. We thus applied minimum curvature (i.e., thin plate) first derivative spline interpolations which pass through the data points and no smoothing. We will add this detailed description of the spline interpolation and the justification for applying it to the discussion of the interpolation on L134-138.

Referee 1: It is not clear in the text which aspects of the methodology are novel. These make it difficult to assess in terms of contribution to the field and quality of methodology.

Author Comment: The motivation is to use a standard satellite elevation product (ESA L2 Baseline C SIN product) and existing and proven methods to obtain fast ice freeboard (as developed and demonstrated in Price et al. 2015) to assess whether a satellite altimeter is capable of detecting a known pattern of higher freeboard driven by supercooled ISW outflow in McMurdo Sound. To summarise, much of the method is not novel but the application is. We have made the changes described in response to the first general comment above to emphasise the previous work by Price et al. 2014 and 2015 that underpins the methodology applied in this study.

We will highlight that this is the first study applying satellite altimetry to specifically detect ice shelf-influenced fast ice freeboard by changing the statement on L85 to the following:

'For the first time, we investigate whether the CS2 satellite radar altimeter can detect the influence of ISW on fast ice in McMurdo Sound by consistently identifying the higher ice freeboard caused by thicker ice shelf-influenced fast ice combined with the buoyant forcing of the SPL beneath.'

We will also highlight and emphasise the methods that are novel throughout the text. Novel aspects of the study are as follows: - The application of satellite altimetry to identify a known pattern of higher freeboard caused by thicker ice shelf-influenced fast ice combined with the buoyant forcing of the SPL which both result from supercooled ISW outflow. - The method to identify the best-matching freeboard interface for individual CS2 tracks as described in L251-260 and L401-405. - Calculation of ice thickness from CS2 freeboard in McMurdo Sound for multiple years and comparison with interpolated in situ measured ice shelf-influenced fast ice and SPL and their combined Mass Equivalent Thickness (MET). L236-249; L290-327; Figures 4 and 5. - Assessment and

comparison of regional trends in CS2 freeboard (Table 1), and linear trends in CS2 ice thickness towards the McMurdo Ice Shelf in a region with significant ISW influence (centre) and another fast ice region with less pronounced ISW influence (east) (Figure 4). - Assessment of spatial patterns of CS2 freeboard and CS2 ice thickness and comparison with in situ observed distributions of ice shelf-influenced fast ice and SPL (presented as a combined Mass Equivalent Thickness (MET)) (Figure 5).

Referee 1: Specific Comments Line 57-58: It would be helpful to briefly outline the physical characteristics behind the buoyant forcing and how these influence ice freeboard.

Author Comment: This is stated in L59-63 and L150-161 as the thickness of the layer and the solid ice fraction which is then discussed in detail in the following paragraph. Price et al. 2014 assessed the contribution of the SPL and the solid ice fraction to freeboard in McMurdo Sound and this work is described and referenced several times in the text.

Referee 1: Line 85: Please state which aspects of this methodology are novel.

Author Comment: As above in response to the general comment. The first sentence of this paragraph L85-87 has been changed to the following:

'For the first time, we investigate whether the CS2 satellite radar altimeter can detect the influence of ISW on fast ice in McMurdo Sound by consistently identifying the higher ice freeboard caused by thicker ice shelf-influenced fast ice combined with the buoyant forcing of the SPL beneath.'

Referee 1: Line 124: Are there other potential influences on the freeboard estimates, either from CS2 or in situ, ie not the SPL buoyancy effect. It would be good to confirm and justify as this is so crucial for the study.

Author Comment: The mean 12% and up to 19% overestimation in sea ice thickness calculated by Price et al. 2014 were predominately driven by the sub-ice platelet layer because in that study they specifically isolated the contribution of the SPL (and solid ice fraction) to the higher freeboard.

Ice Shelf Water influenced thicker fast ice also has an inherently higher freeboard. In this study, we identify higher freeboard driven by both the thicker ice shelf-influenced fast ice combined with the SPL buoyancy. We state this multiple times in the text including the abstract and in particular on L150-152. The CS2 measured freeboard is influenced by the snow which is relatively thin in McMurdo Sound and which we constrained to the best of our abilities using the in situ measurements as described. There is no evidence of other influences on the sea ice freeboard displayed in the region nor expected from the physical forces at play. Snow depressed negative freeboard or surface flooding was not observed, and we have added the following sentence on line 152 to clarify this:

'The snow layer can depress the freeboard and result in flooding of the sea ice surface and the formation of meteoric ice which can contribute to freeboard (Maksym and Markus, 2008). Snow-depressed negative freeboard or surface flooding were not observed at drill hole sites in McMurdo Sound in late spring. Multiple ice core studies carried out in the region over winter and in late spring revealed no contribution of meteoric ice to the fast ice cover in McMurdo Sound (e.g. Dempsey et al., 2010, Gough et al., 2012)'

We discuss how the snow layer in McMurdo Sound would affect the results of this study on L412-417 highlighting that the snow distribution from west to east was advantageous in that we could have confidence in that the trends in higher freeboard in the centre of the sound (where the snow is thin and loosely-packed) did not result from the addition of the snow layer which would have a more significant effect in the east where the snow is deeper.

We have also now included a discussion of the findings of Arndt et al., 2020 in section 5.4 on L435:

'The smooth gradients in fast ice and SPL thickness and low snow coverage in McMurdo Sound present favourable conditions for the CS2 radar altimeter to detect higher ice shelf-influenced freeboard. However, more challenging conditions for satellite altimetry are likely to be presented elsewhere on the Antarctic coastline. A recent drill hole assessment of supercooled ISW-influenced fast ice in Atka Bay observed deep snow accumulations of up to 0.89 m which resulted in frequent negative fast ice freeboard regardless of the buoyant forcing of a substantial SPL beneath (Arndt et al., 2020). As far as we are aware, Atka Bay and McMurdo Sound are the only two locations on the Antarctic coastline with multiple years of in situ measurements of ice shelf-influenced fast ice, SPL and snow highlighting the need for a satellite-based method to identify other regions where ISW is present in the upper surface ocean and influencing fast ice formation.'

Referee 1: It would be good (either here, or further down) to justify the sampling strategy which ensured that hydrostatic equilibrium could be assumed, given that the whole floe will be in equilibrium whilst point measurements at limited locations may not indicate this. The spline fits cover huge areas but appear to be based on limited measurements.

Author Comment: Please refer to the responses given to general comments on the hydrostatic equilibrium assumption and justification for a spline interpolation.

Referee 1: Line 144: Please explain the spline interpolation including the order and a justification for this choice. Similar to the previous comment, are the drill holes single point measurements at each location and what is their uncertainty – and how does this compare to the lateral variation across a floe, and the justification for using hydrostatic balance to relate these quantities?

Author Comment: Please refer to the responses given to general comments on the hydrostatic equilibrium assumption and justification for a spline interpolation.

Referee 1: Line 160: Please explain the choice of a 'lower to mid-range SPL solid fraction'

Author Comment: We chose this as an intermediary value between that of Gough et al. 2012 (0.25) and Price et al. 2014 (0.16) and have changed the sentence on L160 to the following to clarify this:

'To calculate MET from the interpolated drill hole measurements, an intermediary value of 0.2 between the values determined by Gough et al. 2012 (0.25) and Price et al. 2014 (0.16) was assumed for the solid fraction each year.'

Referee 1: Line 172: I have seen the SAR Interferometric mode sometimes referred to as SARIn, and sometimes (including here) as SIN. I don't know if the editor would have a preference for use in this journal?

Author Comment: We do not have a strong preference.

Referee 1: Line 187: Please briefly justify whether you think the snow and ice characteristics are similar to November 2011, to explain the likely relevance or differences in comparison with your data.

Author Comment: They are the same drill hole measurements and fast ice conditions assessed in November 2011 by Price et al 2019 and we have now clarified this on L187.

'Price et al. (2019) assessed the sensitivity of CS2 Level 2 SIN product derived sea ice thicknesses to variable penetration depths into the snow layer in McMurdo Sound using the same in situ measurements in late spring November 2011.'

Referee 1: Line 198-199: Please state why this is only in general (do you mean for your study or for others?) and how close the open water is relative to the study location – the distance is likely to be important in being able to compare local sea level.

Author Comment: We use the term 'In general' referring to this as a standard method used in satellite altimetry. To clarify, we have changed the sentence to the following:

'In satellite altimetry, freeboard is generally determined relative to a local reference sea surface height (SSH) obtained over open water along the satellite track.'

The distance on the fast ice to open water never exceeded 25 km and this is stated on L379-380. For clarity, we will state the following on L219:

'The distance on the fast ice to open water did not exceed $\sim$25 km in all study years.'

Referee 1: Line 215: Please explain how well you think these corrections will have improved the freeboard estimates, can you give the level of remaining uncertainty and its causes? (Especially given the information in lines 523-532 and uncertainty about geiod detrending.)

Author Comment: Detailed descriptions of the geophysical corrections are given in Bouzinac (2012) and Webb and Hall (2016) as stated on L200-202. In our study region, the magnitude of most of the geophysical corrections ranges from sub-centimetre to 1-2 centimetres and generally does not vary much over the small fast ice area. The Dynamic Atmospheric Correction is on the order of 10's cm but again varies very little in the small study area (<1 cm). The Mean Sea Surface varies from 8-11 m and is important to apply as it introduces a steep slope in the surface as demonstrated in Figure A1. We used the in-situ measurements to remove tracks that had erroneous profiles. This tended to occur close to high topography such as Ross Island and was rather significant and easy to identify. The in situ measurements were up to 10 km apart but the gradients in sea ice thickness and SPL are quite smooth in McMurdo Sound. The remaining uncertainty is likely driven by variability in the snow, the dominant backscattering horizon and noise in the CS2 measurement which should be captured in the standard deviations given in Table 1. To clarify, we add the following sentence to L377:

'The remaining uncertainty in the CS2 measurement, captured in the standard deviations given in Table 1, is likely to be driven by noise and variability in the snow layer, and the penetration depth of the radar wave along-track.'

Referee 1: Figure 2: It appears there may be a periodicity in the CS2 freeboards, is there a reason this might be the case and could it relate to corrections not entirely removing other effects in these data?

Author Comment: The assessment of the geophysical corrections in Appendix A was undertaken to ensure that the corrections were of good quality and produced along-track CS2 surface elevation profiles with minimal residual curvature remaining from geophysical effects. We are unsure why there is an apparent periodicity on this individual track. We examined the geophysical corrections along this specific track and found that the majority of corrections were of small magnitude (<1cm) and either a constant value was applied along-track or it varied very little ($\sim$1 cm). This periodicity was not observed consistently in other tracks. The noise in the CS2 measurement is considerable and is impossible to account for. There was more snow and wind-compaction in this region in 2017 (L301-303) which may have contributed to the apparent signal in the CS2 freeboard in the track shown in Figure 2.

Referee 1: Line 255-257: It is a useful and interesting insight to see that the 'freeboard interfaces' were variable. Can you relate this to snow properties such as density if any data are available (you mention snow depth – can you quantify the effect of snow depth – is there a threshold value above which the ice surface is no longer the dominant scattering surface or do you think other variables are influencing this also?) You mention this in Section 5.2 but do not quantify, but as you mention in Section 5 knowledge of the snow characteristics will be crucial.

Author Comment: We thoroughly agree that this would be a very useful endeavour but as previously described, highly detailed information about the properties of the snow would be required to do this with any confidence. Even relating the backscatter behaviour to snow depth is ambiguous because snow layering or wind-compacted layers could play a more important role and this information was not collected in a systematic way except for in November 2011 and 2013. This has already been assessed and described in detail in Price et al. 2015. We are of the opinion that a detailed assess-

ment of the snow is of enough importance to merit a separate study in itself, if the field information was available.

Referee 1: Line 380: Sea surface height can vary over 25 km scales – it will be important to justify why this is not a problem for this study (the following sentences discuss this but it is not clear how this can be discounted as a source of bias.)

Author Comment: We agree that it cannot be discounted as a source of bias but to ensure minimum error in the relative SSH, we carried out the following steps:

1. We first assessed the geophysical corrections (ocean, tidal, Mean Sea Surface and geoid) applied to the L2 SIN product in our study area (77.4-78° S) in Appendix A. We did this to ensure that the corrections were of good quality and produced along-track CS2 surface elevation profiles with minimal residual curvature remaining from these geophysical effects. This is stated on L371-376.

2. We then applied a supervised retrieval procedure where open water was manually identified in satellite imagery. Sea surface conditions such as waves will have a more significant effect for automatic retrievals which interpret the backscatter or pulse peakiness of the signal to identify open water as assessed and discussed in Price et al. 2015.

3. We then assessed the resultant CS2 freeboards through comparison with in situ measured freeboard. This is stated on L382-383.

We used 25 km of open water to calculate the median relative sea surface height because this distance provides $\sim$80 CS2 measurements from which to obtain a representative median value from the noisy CS2 measurement. The same 25 km distance was applied by Price et al., 2015 for their supervised freeboard retrieval which they assessed in detail. We will add the following sentence at L219:

'This distance provided approximately 80 CS2 surface elevation measurements to obtain a representative median value from the noisy CS2 measurement as demonstrated by Price et al, 2015 in their supervised freeboard retrieval.'

Additionally, we have focussed on linear and spatial trends in CS2 freeboard and ice thickness in this study, e.g., Figures 4 and 5. Any small error in the relative sea surface height should not overly affect the trends because a constant median SSH value (obtained from the ∼80 CS2 measurements) is subtracted from the CS2 surface elevation measurements over fast ice to obtain CS2 freeboard for each individual track.

To clarify, we have now rewritten the paragraph on L378-385 to the following

'The geophysical corrections should not have a major impact on obtained freeboard if the retrieval of the relative SSH is robust (Ricker et al., 2016). Identifying the relative SSH along-track is complicated by interference and noise introduced by sea surface conditions and by the presence of pack ice. We observed thin nilas or some pack ice beneath several CS2 tracks. However, sea surface conditions will have a more significant effect for automatic freeboard retrievals which interpret the backscatter or pulse peakiness of the returning radar signal to identify open water (Price et al. 2015). To ensure minimum error in the relative SSH, we applied a supervised freeboard retrieval procedure where open water was manually identified in satellite imagery. The distance on the fast ice to open water did not exceed ∼25 km in all study years. We used in situ measurements to assess the accuracy of the relative SSH identification by comparing the magnitude of the resultant CS2 freeboards against drill hole measured freeboard. Additionally, we assessed linear and spatial trends in CS2 freeboard and CS2 ice thickness in this study. Any error in the relative sea surface height should not overly affect the trends because a constant median SSH value is subtracted from CS2 surface elevation measurements to obtain CS2 freeboards along each individual track. However, for automated freeboard retrievals and for regions of coastal sea ice without in situ measurements or open water nearby, poor identification of the relative SSH could introduce significant error and bias in the CS2 derived freeboard.'

Referee 1: Line 427-431: Please quantify these so that a comparison can be made

by specifying the increase you observed, using the SPL thickness measurements, to demonstrate how close the agreement is.

Author Comment: We have added the following statement to L426:

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

Referee 1: Please include the magnitude of the higher freeboard in Price et al. (2013) and give an indication of the magnitude of the additional buoyant forcing of the sub-ice platelet layer.

Author Comment: Price et al. 2013 do not explicitly state the magnitude of the higher Multi-Year snow freeboard measured in the centre of McMurdo Sound. However, a maximum IceSat-1 measured freeboard of ∼1.6 m is suggested in their Figure 10. Sea ice thickness measurements would be required to estimate the contribution of the SPL to this MY snow freeboard.

Referee 1: Technical Corrections Line 167: It would help to show individual tracks if they were plotted with slightly slimmer lines, especially for the East. Author Comment: Thank you for this comment, we will change the line thickness.

Referee 1: Figure 3: Missing label for x-axis Author Comment: Okay, thank you.

Referee 1: Line 355: Should 'd' be followed by a bracket ')'? Author Comment: Okay, thank you.

Additional References ARNDT, S., HOPPMANN, M., SCHMITHÜSEN, H., FRASER, A. D. & NICOLAUS, M. 2020. Seasonal and interannual variability of landfast sea ice in Atka Bay, Weddell Sea, Antarctica. The Cryosphere, 14, 2775-2793.

MAKSYM, T. & MARKUS, T. 2008. Antarctic sea ice thickness and snowâĂŘtoâĂŘice conversion from atmospheric reanalysis and passive microwave snow depth. Journal of Geophysical Research: Oceans, 113.

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2020-286, 2020.