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Interactive comment on "Seasonal and interannual variability of landfast sea ice in Atka Bay, Weddell Sea, Antarctica" *by* Stefanie Arndt et al.

Anonymous Referee #1

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Note: full reference information can be found at the end of this report.

General Comments:

This manuscript presents the results of a semi-continuous 9-year study of sea ice, platelet ice, freeboard and snow conditions in Atka Bay, an embayment in front of the Ekström Ice Shelf located on the coast of Dronning Maud Land in the eastern Weddell Sea, Antarctica. This is a novel data set that is analyzed in the manuscript to elucidate seasonal and interannual variability and determine whether there are any noticeable trends. The results of the analysis indicate that the seasonal character of the fast-ice regime in Atka Bay predominates and no noticeable trends were observed.

The manuscript provides a very valuable dataset for evaluating the fast-ice conditions

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Discussion paper

in Atka Bay in the context of local and regional atmospheric and oceanic conditions, including the effect of the adjacent Ekström Ice Shelf on the formation of platelet ice. It thus represents an important contribution to the current understanding of how Antarctic fast-ice regimes adjacent to ice shelves are affected by sub-ice-shelf processes, such as the formation of frazil laden Ice Shelf Water plumes.

I think the manuscript represents substantial progress beyond current scientific understanding and merits publication once the comments I have made in the following sections have been addressed. My principal comments are that the authors have not cited in the manuscript a number of studies that have investigated the fast-ice regime in McMurdo Sound, which, similar to Atka Bay, is an area of fast ice growth adjacent to an ice shelf. The inclusion of these studies will, I believe, add greatly to contextualizing and interpreting the data presented in the manuscript. I also would like the authors to review how they use the concept of freeboard in the manuscript, as their definition of freeboard in the text does not align with their Equation 1 and Figure 5.

Specific Comments:

Line 52, I recommend the authors also cite Leonard et al. (2006) as another example of Antarctic landfast sea ice that reached a thickness greater than 2 m and was not perennial.

Line 69. I didn't have Foldvik (1977) in front of me when reviewing the manuscript, but I still feel comfortable enough to question the statement that supercooled ISW favors the formation of floating ice crystals "deep" in the water column. Can the authors define what they mean by "deep" – buoyant ISW needs to rise some distance through the water column to become sufficiently supercooled to initiate frazil crystal formation.

Line 70. The authors have not mentioned other studies that have reported on field observations of frazil laden ice shelf water plumes advecting out from an ice shelf cavity that then rise to the surface, e.g. Mahoney et al. (2011) and Hughes et al. (2014).

Line 71. I suggest the authors include the work of Price et al. (2014) and Brett et al. (2020) as they also report on the accumulation of sub-ice platelet layers under the sea ice.

In Figure 2, what is the uncertainty with the annual fast ice extent estimates? It would be useful to report what the average and standard deviation of the extent was over the study period. Did the authors consider showing fast ice extent anomalies instead of fast ice extents? This would negate the need to repeat the average extent for each year of the study.

Section 2, Line 173. I did not understand what was meant by “An additional metal bar . . .”. Does that mean the measuring tape had two metal bars at its base? I don’t understand how this would work. The authors mention that this is a “modified” thickness tape, but don’t describe the characteristics of an “unmodified” thickness tape and hence it is not clear to the reader how the “modified” thickness tape is meant to perform better.

Section 2, Lines 178 – 182. It would be useful for the reader for the authors to explain here why they are both measuring and calculating the freeboard. I believe “Archimedes law” should be “Archimedes principle”. Equation 1 is not consistent with the manuscript’s statement that a “snow/ice interface above sea-water level is referred to as positive" with respect to freeboard. For example, if there were no snow or platelet ice, Equation 1 would produce a negative freeboard. I assume that the densities of ice and water have been interchanged in line 182 as the density of sea ice cannot be greater than the density of seawater! Authors need to state the “indices” in Equation 1 are thicknesses and should show how the density of the platelet ice is calculated from the ice volume fraction.

On a related note, the authors state that the lines in Figure 5 are “freeboards”. They are not “freeboards” (i.e. vertical separation between the water surface and a point of interest, in this case the snow / ice interface). Rather they are measurements and

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Discussion paper

estimates for where the water surface is relative to the snow/ice interface, with different assumptions (coloured lines). The caption attempts to describe what these lines are, but still incorrectly and confusedly refers to them as freeboards.

The authors generally present what are assumed to be mean values and standard deviations when reporting their observations, but do not explicitly state that this is the case. The authors should confirm what they are presenting, and also, provide an estimate of the uncertainties associated with their measurements.

The authors make a number of references to “thermodynamically grown ice” in the manuscript, but do not provide a definition of what they mean by this, and also do not provide any direct evidence of the mechanism behind sea ice growth, as they have not presented fabric crystal structures as per Hoppmann et al. (2015). At the very least, reference should be made to the Hoppmann et al. study as those measurements were made within the time frame of this study (2010 - 2018) in Atka Bay.

I suggest that the authors re-consider the naming convention they have used for what they term “platelet ice” to help distinguish columnar sea ice from sea ice that has formed by “consolidating” platelet ice. For example, see Hughes et al, 2014, where the term “sub-ice platelet layer” is used to describe the loose platelet crystals under the sea ice, and “consolidated platelet ice” is used to describe that part of the sea ice that formed by congelation ice growing down into the sub-ice platelet layer and consolidating the platelet ice. This approach might also clarify whether the authors are using the term “thermodynamically grown ice” to refer to just columnar ice, or columnar ice and consolidated platelet ice.

I feel this manuscript could benefit greatly from more contextualizing of the results presented here with other studies. For example, in the discussion, there is no mention at all of the body of work on sub-ice platelet layers under fast ice in McMurdo Sound, including both observational and modelling studies. Sub-ice platelet thickness gradients have also been observed (and modelled) in the McMurdo Sound studies. See for

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Discussion paper

example Hughes et al. (2014), Dempsey et al. (2010), Robinson et al. (2014) and Cheng et al. (2019).

I would also suggest the authors consider producing spatially interpolated plots of the measured variables, similar to what is presented in Price et al. (2014) so that they could better present spatial trends in their data. This would help to strengthen the discussion where they consider mechanisms driving changes in the measured variables, e.g. the "washing-out" mechanism invoked to explain the thinning of platelet ice.

Reference is made in the discussion to oceanographic drivers influencing the platelet ice in Atka Bay, but no oceanographic data is presented or referenced. In particular, reference is made to "underwater topographic features of the ice shelf" potentially leading to "blocking of oceanic circulation patterns", but these features are not shown or cited in other works. Their hypothesis could be strengthened by including supporting oceanographic observations / modelling output.

In Lines 439 – 445 of the Discussion, arguments are put forth for dynamical growth and compaction of the platelet ice layer dominating over thermodynamic growth. Although I agree with the authors that this is probably the case, without fabric crystal structure information, this cannot be said definitively. I also would like the authors to discuss the compaction of platelet ice (referred to as consolidation in other studies) in more detail, as this process has a strong thermodynamic element (refer to Wongpan et al. (2015).

Technical Corrections:

Below is a list of technical corrections / suggestions for the authors to address and consider:

Note: Line numbers over 99 are assumed as the leading digit was cut off in the preprint.

Section 1: Line 12, change "of fast ice of Atka Bay. . ." to "of fast ice in Atka Bay. . .".

Line 15, change ", sea-ice-. . ." to "and sea-ice".

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Discussion paper

Line 17, insert a comma after “Neumayer Station” and a second comma after “satellite images”. Also insert “us” after “allows”.

Line 19, change “meters snow” to “meter thick snow cover”.

Line 20, insert “interannual” before “trend”.

Line 23, replace “event” with “of landfast sea-ice”.

Line 28, replace “on” with “of”.

Line 36, replace “extent” with “seaward edge”.

Line 54, replace “but also to” with “and”.

Line 57, replace “the” with “an”.

Line 58, re-arrange “for the Arctic recently” to “recently for the Arctic”.

Line 62, replace “particular” with “particularly”.

Line 78, replace “in” with “over” and “parts” to “portions”.

Line 88, replace “for” with “in”.

Line 96, replace “in McMurdo Sound at Scott Base” with “working out of Scott Base in McMurdo Sound” and put “e.g.” in front of “Smith et al., 2001) – Smith et al. (2001) is one of the earlier manuscripts but there are many more, such as Smith et al. (2015).

Line 97, replace “Fimbul ice shelf” with “the Fimbul Ice Shelf”.

Line 99, replace “the knowledge gap” with “a knowledge gap”.

Section 2: Line 112, add “depth” after “275 m”.

Line 115, add “the” in front of “sea ice”.

Line 117, remove the two semi-colons.

Figure 1a, replace “Grounded ice sheet” with a more accurate description in the caption as this looks to me to be the “land” feature in the Antarctic Digital Database. If it is, add a citation to the Antarctic Digital Database. Add a north arrow.

Figure 1b, add a bounding rectangle to show the extent of Figure 1c.

Line 123 -Figure 1 citation – re-word “in same distance” to improve clarity.

Line 126, replace “the sampling sites” with “adjacent sampling sites” and re-word “all sampled additionally” to improve clarity. Add “is” before “a Sentinel” and provide the required citation for the Sentinel imagery as per https://sentinels.copernicus.eu/documents/247904/690755.

Line 127, delete the “s” from “images”

Line 129, replace “. . . sea ice, attached” with “. . . sea ice that is attached”

Line 133, replace the comma with a semi-colon and the add “and” after it.

Line 140, insert “of” before “Atka”.

Line 141, replace “currents, winds” with “currents and winds,”.

Line 145, replace “causing” with “resulting in”.

Line 147, insert “for” in front of “a second time”.

Line 149, replace “summer afterwards” with “the following summer”.

Line 160, be consistent with spelling of “kilometer” etc. Here it is “kilometer”, but the rest of the manuscript uses “. . .meter”.

Line 163, replace “one” with “four more” and replace “5 meter” with “5 meters”.

Line 164/165, replace “measurement frequencies” with “the number of observations”

Line 166, re-word the sentence from “however,” onwards to improve clarity.

Line 169, replace “Figure 1” with “Figure 1c”.

Line 184, replace “we use” with “was used”.

Line 192, replace “today” with something like “and beyond the end of the study period”.

Line 193, add “sea” in front of “ice”.

Line 196, mention that the meteorological data used in this study included 2m air temperatures and 10 m wind velocities.

Line 200, re-word from “The second mode in in the wind. . .” to improve clarity.

Line 204 or thereabouts, provide some more information on the MET data such as sampling frequency, averaging (if there is any), uncertainties, etc.

Figure 3, x axis title, these are wind speeds, not wind velocities.

Line 207 in Figure 3 caption, again these are wind speeds not wind velocities that are related to the wind directions.

Section 3: Line 219, add “the” in front of “highest snow. . .” Confirm that accumulations are per year.

Line 223/224. This sentence is confusing. The mean thickness of all of the sea ice in the bay is not varying between 1.74 m, and 2.58 m. These are the means at particular sampling locations. I take it that the mean ice thickness over the entire bay was estimated as being 1.99 m based on the measurements.

Line 229, clarify what is meant by the statement “an average of additional . . ..” Additional as referenced to what?

Line 230, clarify what is meant by “. . . increased by another . . .”

Line 231, How do the authors know that there is “second-year” platelet ice at these sites? The platelet ice /sub-ice platelet layer is not attached to the overlying sea ice, so could have a different history to the sea ice directly above it. The authors again refer

to “additional” accumulation, how was this determined?

Line 232, add “the” before “highest”

Figure 4, refer to the comment in the Specific Comments section regarding the naming convention for platelet ice.

Figure 4 caption, Line 239, remove “has” before “strongly”.

Line 249, correct equation reference to read “Equation 1”.

Figure 5, refer to the comments in the Specific Comments section regarding the use of the term freeboard. Correct misspelling “freedboard” in legend.

Line 263, why have the authors referred to “loose platelet ice thickness” here where elsewhere the have used the term “platelet ice”?

Line 277, insert “the” before “highest”.

Line 287, how do the authors define “typical thermodynamic sea-ice growth”? 1 m per month sounds very high to me for ice that has only grown “thermodynamically”, i.e. by heat being removed from the ocean though the ice to the atmosphere. Are the authors including the growth of consolidated platelet ice as “thermodynamic growth”? If so, this will include ice that has formed within the supercooled ISW.

Line 289, remove “even” in front of “sea-ice melt”.

Lines 288 and 289. Line 288 uses “sea-ice thickness rates” and Line 289 uses “melt rate”. Suggest authors stick to “thickness rate” and use positive values for growth and negative values for melt. I.e. in Line 289, change “melt rate” to “thickness rate” and change value to a negative.

Figure 6 y axis label. Please change to growth / accumulation rates in m month-1.

Line 303, please clarify what is meant by the statement “the fast-ice thickness over the bay in the south-north and west-east direction is rather constant with . . .” I assume for

the preceding statement that this pertains to the “additional” transect measurements, but this should be made more clear.

Line 304, replace “higher” with “greater”.

Line 305, replace “decrease” with “decreases”.

Line 306, Figure 7 strictly shows changes in platelet ice layer thickness, not accumulation. This change in thickness can be due to in-situ growth of the platelet ice crystals or the accumulation of new ice crystals flushing out from underneath the ice shelf.

Line 307, add “the” before “lowest”.

Line 310, add “the” before “south-to-north”.

Figure 7, these plots do not show freeboard, instead they show the height of the water surface relative to the snow/ice interface.

Figure 7 caption, line 315, replace “Overview on” with “Overview of”. Line 319 and 320, remove space between “Figure 1” and “c”.

Line 329, replace “that” with “the”.

Line 333. Re-word “snow cover completely isolates heat fluxes”. The heat fluxes are not isolated, rather the snow cover acts as an insulator that reduces the heat fluxes.

Line 336. There are other key studies that should be referenced regarding the consolidation of platelet ice, such as Dempsey et al. (2010).

Line 341, add “of” before “the platelet”.

Line 347, replace “Massom et al. (2018) has” with “Massome et al. (2018) have”

Line 352, add a comma after “bay” and replace “strongest” with “strong”.

Line 353, add “is observed” after “(Figure 6)”. Remove the comma after “both”.

Line 354, remove space between “8” and “a”.

Line 355, remove “watch”.

Line 358, replace “9-year’s time series “ with “9-year time series”.

Line 361. Rates should be expressed as a quantity per unit time, i.e. m year-1.

Line 362, replace “shelfs” with “shelves”; remove “even”.

Figure 8a – use units of m to be consistent with other plots. Figure 8a does not show a correlation between 2-meter air temperatures and snow accumulation. Rather it shows a scatter plot comparing these two variables. The authors should include a linear regression if they want to show correlation.

Figure 8 caption. State the dates of the two surveys and whether all sampling sites were included, and confirm that the MET data are averages between these two dates. Replace “Chapter” with “Section”. Line 367, add “of” before “fast-ice”.

Line 407, this sentence is confusing, please re-word.

Line 412, replace “reveals” with “revealed”.

Line 431, replace “plate” with “platelet”.

Line 434, replace “caused” with “led to”.

Line 446 + 447, this sentence is confusing, please re-word.

Line 453, replace “on” with “of”.

Line 479, replace “to quantify” with “for quantifying”.

Line 482, remove the space before “ice” in “sea- ice”.

Line 488, replace “principle” with “principal”.

Line 542, I found online that this publication date should be cited as 2016, but the Polarforschung date is 2015?

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Brett, G.M., Irvin, A., Rack, W., Haas, C., Langhorne, P. J., Leonard, G. H., (2020), Variability in the distribution of fast ice and the subâĂŘice platelet layer near McMurdo Ice Shelf, J. Geophys. Res., doi: 10.1029/2019JC015678.

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