

Reviewer RC1, Alice Petry

We thank the reviewer, Alice Petry, for their helpful comments and the work they put into the review. Our answers start with “Reply” in bold, *following the original reviewers’ comments in italics*.

General comments:

I would like to thank the authors for implementing the reviewer suggestions. Overall, the revised manuscript has improved significantly. The authors have greatly improved the readability of the manuscript. The purpose of the work is now clearly articulated. The result and discussion sections are concise and easy to read. Well done.

Reply: Dear Alice, we thank you for your positive evaluation of our manuscript and your detailed reviews which helped us to improve the readability of our paper.

Minor comments / suggested corrections:

In-situ vs in situ: The authors use both forms of the word. Consider choosing either the hyphenated form or the unhyphenated form for consistency.

Reply: We thank you for the suggestion and changed all the versions of “in situ” to its unhyphenated form, as it follows the journal guidelines.

Figure 2 Caption: “Panel (c) shows the contour plot of FYI density evolution from hydrostatic weighing with bulk density values for each coring event shown in blue and grey shaded areas representing snow or surface scattering layer thickness.” Consider placing a comma “(...) shown in blue, and grey shaded areas (....)”.

Reply: We thank you for the suggestion and added the suggested comma to the caption.

Table 1 Caption: “Bulk physical properties of level first-year ice at the coring and ROV sites” A period is missing at the end of the caption.

Reply: We thank you for the suggestion and added the suggested period to the caption.

Figure 4 caption: “Dotted blue line in (b) represents sea-ice density estimate corrected for coring measurements performed in unponded areas as described in Section 4.6.” Consider adding an article at the beginning of the sentence, “The dotted blue line in (b) ...”.

Reply: We thank you for the suggestion and added the suggested article to the caption.

Figure 4 caption (and Figure 2 caption): “Time axis is not continuous.” Consider adding an article at the beginning of the sentence, “The time axis is not continuous.”

Reply: We thank you for the suggestion and added the suggested article to the two captions.

- Figure 7 panel (d): The scatter plot shows FYI in blue and SYI in orange, while the lines show FYI in orange and SYI in blue. The legend labels or line colours might have been mixed up here.

Reply: We thank you for noticing this error. We swapped colors of lines representing FYI and SYI temperatures to be consistent with other panels.

Figure 10: I think something went wrong when rendering the figure. The legends are not aligned. Lines delimiting the individual legend boxes are missing. Additional boxes are floating left of panel (b) and panel (e).

Reply: We thank you for the suggestion and aligned horizontal lines of panels and legend in Fig. 10. The legend is shared between different panels, so delimiting lines were not added.

Lines 471-472: “Upscaling of these estimates during winter is complicated by the large-scale spatial variability of snow depth due to variability of ridge fraction.” Consider changing the sentence to “(...) is complicated due to the large-scale variability of snow depth and/given the variability of the ridge fraction.”

Reply: We thank you for the suggestion and adjusted the text as you recommended.

Reviewer RC2:

We thank the reviewer for their helpful comments and the work they put into the review. Our answers are starting with “Reply” in bold, following *the original reviewers’ comments in italics*.

I want to thank the authors for the work they put into the revision of the manuscript. The manuscript improved a lot, and the scientific contribution presented very well. I only have a couple of minor comments, which mostly are technical.

Reply: Dear reviewer, we thank you for your positive and constructive evaluation of our manuscript.

Minor comments:

L35: The word “accurate” is confusing here, maybe it can be removed. Why does the data needs to be extended if it is already accurate?

Reply: We agree with your suggestion and removed the word “accurate”.

L47 and L56: “outside of the melt season” - the article “the” is missing.

Reply: We agree with your suggestion and added “the” to “outside of melt season”.

L115: There is an article missing before coring site. Is it “the coring side” or “each coring side”.

Reply: We agree with your suggestion and added “each” in front of “coring site”.

Figure 7: “ridge” is sometimes written with a capital R or a small r in the legend. Maybe the figure would become less busy, if it had one shared legend outside of the plots similar to Figure 10.

Reply: We agree with your suggestion and capitalized “ridge” in Fig. 7g. Unfortunately, legends within eight panels of Fig. 7 are mostly different, with five various contents. This makes a shared legend not very practical.

L276: I suggest to add a descriptor/noun after “this” to enhance reading comprehension, e.g., “this discrepancy”. There are also other places where “this” is alone with a descriptor (e.g., L281 and L322) and could benefit from it.

Reply: We agree with your suggestion and added “this discrepancy”, “this potential explanation”, and “these observations” instead of “this” in lines 276, 281, and 322, respectively.

L278: “may be seen” could be replaced with either “could be seen” or even a stronger implication.

Reply: We agree with your suggestion and substituted “may” with “could”.

L290-291: It is not clear to me, how a different “sea-ice density parametrization” helps alleviating an effect of snow load? Maybe this could be explained with another additional sentence.

Reply: We agree with your comment and added the following clarification “This is due to the observed snow freeboard decrease in July being equivalent to the CryoSat-2 ice thickness decrease (Fig 5b)”. This relates to the observed snow freeboard decrease and ice freeboard increase during melt season in July. Using constant ice density would not allow for any ice melt unless snow freeboard is not false identified as ice freeboard due to low radar penetration.

L295: From your reviewer comments I understand that the purpose of the Antarctica densities is to compare seasonality. Nevertheless, this is for me not clear in this section of the text yet. Additionally, it is not clear what values afterwards are for the Arctic and the Antarctic. Maybe this needs to be two

different paragraphs, as the ideas are a) comparison to other seasonal products and b) comparison to other Arctic values or at least somehow made clear what values are for which region.

Reply: We agree with your comment and added a more general introduction about a similarity between temperature dependence of our and historical observations for Arctic sea ice. We also moved a comparison between Arctic and Antarctic densities to the end of this paragraph.

L319: The units display density, while you talk about freeboard. Is there something mixed up?

Reply: We are sorry for this mistake, we substituted “freeboard” to “sea-ice density” in that sentence.

Figure 10: There is no dashed line in e). Additionally, I am not sure if I understand what the dashed lines shows. Is it supposed to show the air volume increase based on a density change?

Reply: We thank you for the suggestion and added a dashed line illustrating 10% of brine volume to Figure 10e. Yes, as described in the caption, a line showing air volume equal to 10% of brine volume represents the potential air volume evolution upon warming due to ice and water density differences. This assumption is satisfied if air bubbles are at constant pressure, unlike for our FYI observations.

L319: The units display density, while you talk about freeboard. Is there something mixed up?

Reply: We thank you for noticing this error. Indeed, the presented values are standard deviations of density, not freeboard. We changed “freeboard” to “sea-ice density” in this sentence.

L348: Do you have observed that the ice is columnar in the ice cores or is this an assumption, that the ice is columnar because of its region and age? It would be great if you could clarify that and if possible mention, if/where the ice in the measured profiles in Figure 8 switches from granular into columnar.

Reply: We used the structure characterization based on thin sections of MOSAiC ice cores. One of them is presented in Nicolaus et al. (2022). We hope that all of them will be published by the corresponding principal investigators.

L387: “typical for FYI” instead of “of”

Reply: We thank you for the suggestion and adjusted the text as you recommended.

Reviewer RC4

We thank the reviewer for their helpful comments and the work they put into the review. Our answers are starting with “Reply” in bold, *following the original reviewers’ comments in italics*.

First, thank you to the authors for the great responses to four reviews and a community comment! Considering so many comments, which are also reflected in your response document (33 pages!), it must have been quite some work!

I am very happy with the responses to my comments and the edits made by the authors overall. I believe this version is ready for publication! I did find some (very) minor technical corrections, some of which I am sure will also just be caught in copy-editing by TC. Nonetheless, I list them here for you to keep an eye on. Great work and thank you for this interesting work!

Reply: Dear reviewer, we thank you for your overall positive evaluation of our manuscript.

Minor comments / technical corrections

Line 44. Consider removing “mentioned earlier” and simply referencing Jutila et al. 2022 after “various combinations of remote methods” for clarity.

Reply: We thank you for the suggestion and removed “mentioned earlier” from that sentence.

Line 83. Remove start parenthesis before 2023b in “(ALS, Hutter et al. (2023b).”

Reply: We agree with your suggestion and removed the parenthesis.

Section 2.3. I might have missed it, but I do not see a reference to Figure 3, even though it seems to be a schematic explaining these different melt pond drained/undrained parametrisations.

Reply: Thank you for noticing. We added a reference to Fig. 3 at line 166, where we introduce surface topography classification.

Figure 7. Just for your information, the legend for subfigure (g) is written “ridge,” but (h) is “Ridge.”

Reply: We thank you for the suggestion and made the legend’s caption capitalized.

Line 263. Remove start parenthesis before 2010 in “(e.g., Alexandrov et al. (2010)).”

Reply: We agree with your suggestion and removed the parenthesis.

Line 278. Is “may” the correct word here? Is it, or is it not seen in your observations?

Reply: We agree with your comment. Indeed, we can definitely say that our observations showed the absence of ice freeboard increase during snowmelt in May and June.

Line 431. Suggest rewording “above” to “around”. I am not convinced that much snow accumulates on top of the ridges but rather around them due to wind redistribution.

Reply: We think that the study by Itkin et al. (2023) showed that ridges also accumulated a lot of snow above them. Average snow thickness in April was 0.6 m and 0.14 m for ridges and level ice, respectively. In addition, they estimated that snow drift extended around 25 m to each side of the sail crest. The total length of this snow accumulation of 50 m is comparable to a typical ridge keel width of 30 m (e.g., Ekeberg et al., doi:10.1016/j.coldregions.2014.10.003). Therefore, we changed “above” to “above and around”. We hope that this is a fair compromise supported by the field measurements.

“Data availability” and “Code and data availability” sections. Please include the “Data availability” text in the “Code and data availability” section now that both are relevant.

Reply: We thank you for noticing this error. We moved reference to the code to “Code and data availability” section with data references.

Additional changes

Here we list additional minor changes we implemented in addition to the ones in response to reviewers' comments:

- In several instances, “snow depth” was substituted for “snow thickness” for consistency.
- In Fig. 1, we changed the legend text from “Alexandrov” to “Alexandrov et al.”
- In Fig. 2a we added a color bar with bathymetric depth.
- In Fig 6, we added to the caption an explanation of the “sn,” “fb,” and “d” values displayed in the figure.
- We added to section 4.3 text describing similarities of our sea-ice density observations with the parametrization suggested in Fons et al. (2023) for Antarctic sea ice, suggesting that their parametrization can be also used for Arctic sea ice.
- In the “code and data availability” section, we substituted a GitHub URL for a Zenodo publication based on the same repository with updates following this revision.
- In line 155, we added a reference to a study describing physical properties of surface scattering layer, as this material is often discussed in our manuscript.