

## Review of “Bayesian Inversion of satellite altimetry for Arctic sea ice and snow thickness”

This manuscript focuses on a new method of retrieval of sea ice thickness and snow depth. The authors use an inverse bayesian method which has been previously applied in the research of sea level changes. Freeboard data from CryoSat-2, AltiKa and ICESat-2 is used in different combinations to apply the inversion method. One of the main advantages of this method is the retrieval of snow and ice thickness simultaneously. Four inversion setups are run: three combination of CryoSat-2 and ICESat-2 (CS-IS-2p, CS-IS-3p, and CS-IS-4p), and a combination of CryoSat-2 and AltiKa (CS-AK). The authors assess the results using several metrics against a number of different datasets. The results look promising, with good agreement against existing satellite SIT datasets and validation data. The paper is also well written and the layout is well thought out.

### *Novelty*

The study produces sea ice thickness and snow depth simultaneously using an inversion method for the first time. The method shows good agreement with other SIT data. The study is insightful as it further highlights the uncertainty around the distribution of ice thickness in the Arctic. The study also provides interesting insight into the penetration of the satellite signal into the snow/sea ice, which will be of interest to others in the field. The insight into the spatially and temporally varying penetration factor is also interesting. The paper will primarily be interesting to those interested in sea ice. It may also be interesting to others in the climate community who may be able to apply the method to their own field.

### *Positioning*

All relevant literature appears to be cited by the authors and the study is well placed with respect to studies in the same field from the past. The study is also well placed with relevance for the future CRISTAL satellite mission.

### **General comments**

The authors should consider also using the BGEP ULS moorings for an additional SIT validation product, as they only use OIB for this, and OIB missions were only run during April 2019, while BGEP ULS data is available throughout their experimental period.

The authors find unphysical values of penetration factors (though it can be explained by laser scattering above the snow layer), do they also find similar for ice thickness or snow depth post-inversion? Or do the authors correct for these in some post-processing?

Did the authors test how the inversion method results vary if the prior distributions are changed. It could be particularly useful to analyse how the results change if the penetration factor bounds are chosen to be above 0 in the prior.

The authors should use panel labels (a), (b) etc. and then refer to them in the caption instead of using (left), (right), (first column) etc. This would also help for references to the figures in the text. In some cases (e.g. figure 8) the captions of the figures are missing some key details about the figure.

The authors should use a different colour range when plotting figures of maps of the penetration factor, as using the Red-Blue symmetric scheme makes these plots harder to read. The colour range they use for the snow depth/thickness maps would be better for this. I added specifics about the figures at the bottom of this report.

### **Minor comments**

Line 7: Statistically encouraging is a bit strange wording.

Line 21: Could just say “especially in the Arctic”. Can also add a sentence or two looking at impact of climate change on the Arctic region in comparison to other regions.

Line 58: Good to mention CPOM-CS2 modifies the warren climatology by halving snow depth over first year ice.

Line 83: SIT retrieval can also depend on the choice of retracker. It would be good to mention the impact of different retracker choices here.

Table 2: May be good to also mention that  $r$  is linear correlation coefficient in the table caption.

Line 229-230: confirmed -> be confirmed

Line 280-284: What does it mean when the authors say SIT and SD are “important”? Just thick?

Line 337: Sentence that starts with “Thanks to figure 12” needs rewording.

Line 375: Should be “Given a user-defined”

Line 425-440: The language in the conclusion is a bit informal in some cases, and there are also some spelling errors: e.g. “could even be unknown”, “of course not exhaustive”, “in order of efficiently construct”.

### **Figures**

Figure 3, Figure 6, Figure 10, Figure 13: use subplot labels (a), (b) etc and then reference to these in the caption text, and reference in the manuscript text if necessary.

Figure 7, Figure 11: Use a different colormap than Red-Blue for the second column.

Figure 8: The caption should mention which experiment this result is for.

Figure 9: Difficult to see the dashed coloured lines. No line of best fit for AWI in bottom right subplot. Also need subplot labels and references to them in the caption text and in the manuscript text if necessary.

Figure 12: Use a different colormap than Red-Blue.

Figure 14: Use a different colormap than Red-Blue and also add subplot labels.