Summary

This paper presents a novel approach for estimating daily sea ice freeboard across the Arctic, using the Bayesian inference approach of Gaussian Process Regression (GPR). Benefits of such an approach include 1.) fewer days of data required to estimate Arctic-wide sea ice freeboard and 2.) improved temporal variability of a daily Arctic-wide freeboard product. It's great to see data from CryoSat-2, Sentinel-3A and Sentinel-3B being utilized together in this way. It was also refreshing to read a paper that has a good understanding of the relevant literature and other's methodology, so thank you to the authors for that. I do have a few concerns that should be addressed before publication, and these are summarized in my General and Specific Comments below.
Thank you very much for your enthusiastic feedback, and for taking the time to review our work! Please see our comments below, which we hope address your concerns.

General Comments

My one major concern with the paper was the limited assessment of improvements in temporal variability of daily sea ice freeboard (presented in Section 5). The authors show in In Fig. 6 we can see how the day-to-day variability is increased with the CS2S3 product, compared to the CryoSat-2 and Sentinel-3 31-day running means. Then, lines 265-266 state that "A natural question is then whether the variability we see in the time series in Fig. 6 represents real physical signal, or is just noise related to observational uncertainty". I'd suggest that this isn't just a natural question, but really the main question, and one I had throughout the paper until this point. It's really the crux of "why bother doing this work"? While I appreciate the development of innovative methods for improving sea ice products, the reader still needs to be sold on its benefits. Although Figure 6 is very interesting, I'd like to see a more quantitative assessment of the temporal variability from GPR and monthly running means, compared with the benchmark (especially in regions where there are less training data). How much of an improvement in "true" temporal variability does GPR provide? The authors have clearly done most if not all of the relevant work, so please expand. Then, add mention of this in the abstract to strengthen the importance of the study.
Determining whether our interpolation algorithm captures 'real' daily freeboard variability is an important feature of this work, so thank you for helping us to strengthen this section. Although we use the benchmark to ensure that the signal does not originate from spatial sampling, it is difficult to identify what exactly is causing the daily temporal variability. One thing we know to alter the radar freeboard is snowfall, therefore (building on the work of Lawrence 2019), we have compared our daily freeboard timeseries to snowfall from ERA5 to see whether any correlation emerges – see Figure 1 below. Here we break down the analysis into first-year-ice (FYI) and multi-year-ice (MYI), since the roughness and snow depth are typically different for the two ice types (Tilling et al., 2018) and therefore variability of radar freeboard with snowfall may also show different signals. We can see here that daily CS2S3 freeboard anomalies are positively correlated with ERA5 snowfall data, with an average Pearson correlation of 0.4 for FYI and MYI zones. While it goes beyond the scope of this study to investigate the specific drivers of this correlation (see Lawrence 2019 for a discussion on why radar freeboard correlates with snowfall at 9-day timescales), we believe that this relationship is encouraging, as it suggests that the CS2S3 data are able to capture freeboard variability at synoptic time scales. We will include these results in the revised manuscript, and update the abstract accordingly.

References

Lawrence, I. R.: Multi-satellite synergies for polar ocean altimetry, Ph.D. thesis, UCL (University College London), 2019.

Tilling, R.L., Ridout, A. and Shepherd, A., 2018. Estimating Arctic sea ice thickness and volume using CryoSat-2 radar altimeter data. *Advances in Space Research*, *62*(6), pp.1203-1225.

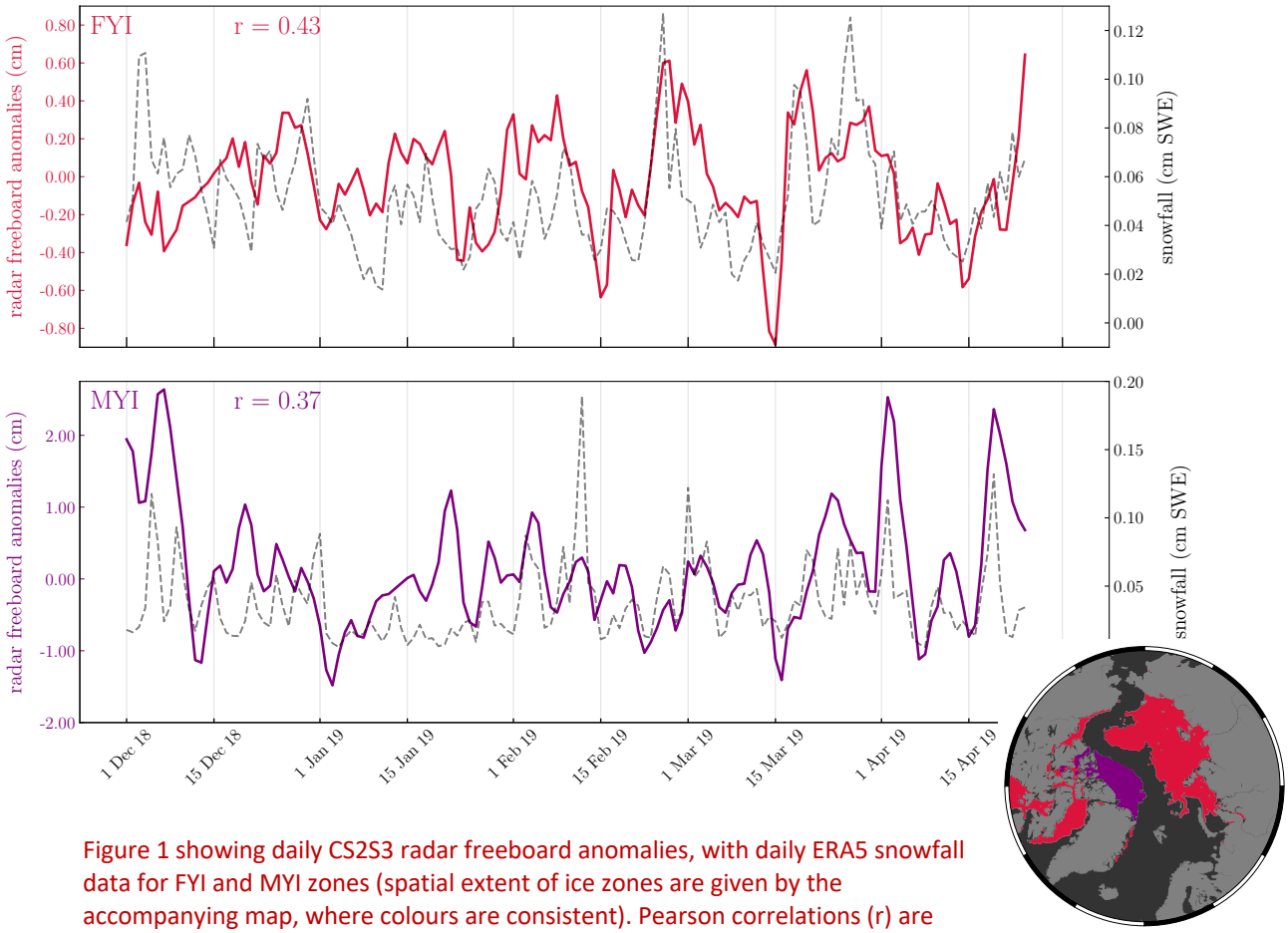

Figure 1 showing daily CS2S3 radar freeboard anomalies, with daily ERA5 snowfall data for FYI and MYI zones (spatial extent of ice zones are given by the accompanying map, where colours are consistent). Pearson correlations (r) are shown for each plot

Specific Comments

We will amend all of the specific comments below in the revised manuscript.

P1 L19: “reductions in the sea ice cover” is too general a statement. Specify what each instrument measures and over what time frame. We haven't seen reduction in thickness from altimetry for four decades, or in summer. We also haven’t seen reduction in extent from altimetry. So, please be more specific here to avoid confusion.

P2 L23: Are AGU talks suitable references (I’m not sure on TC’s stance on this)? If so, please provide a link to the publicly available version of the talk.

P2 L31: I’d consider Allard et al. (2018) to be a key paper that’s missing here

P2 L35: Snow depth is also assumed

P2 L43: I believe Tilling et al. (2016) was 2 days

P2 L55: Change “containing” to “assimilating”, for clarity

P3 L60: This first sentence doesn't add anything. I suggest using at this point to highlight the benefits of the GPR method vs. a monthly moving average that is very simple the produce. It's not just the need for a daily freeboard product based on observations that is well motivated, but a daily freeboard product that more accurately represents temporal variability. This new approach can (in theory) provide both.

P3 L75: For me, Section 5 is currently insufficient at providing "an assessment of the improved temporal variability achieved by the use of a daily product". See my General Comments above.

P4 L99: Introduce the "CS2S3" acronym here

P4 L120: On average, what percentage are co-located?

References

Allard, R. A., Farrell, S. L., Hebert, D. A., Johnston, W. F., Li, L., Kurtz, N. T., et al. (2018). Utilizing CryoSat-2 sea ice thickness to initialize a coupled ice-ocean modeling system. Advances in Space Research, 62(6), 1265–1280.

Tilling, R. L., Ridout, A., & Shepherd, A. (2016). Near Real Time Arctic sea ice thickness and volume from CryoSat-2. The Cryosphere, 10, 2003–2016.

We would like to again thank the reviewer for their invested time in reviewing this work.