Response to community comment

ilo and hsk

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We thank Dr. Robbie Mallett for taking the time to comment on our paper and contribute to the discussion. This is greatly appreciated.

1 Answer to community comment by Robbie Mallett

Given what Alek has written about significant inter-product variability in snowradar data, I wanted to briefly raise a point about line 635; it's suggested that snowradar-derived radar freeboards & snow depths can be used to "directly evaluate" the penetration depth of CryoSat-2's SIRAL instrument.

We tried to do exactly this for some recent work, and found that the derived penetration depth depended quite strongly on the snowradar algorithm, such that we could not meaningfully achieve what the authors are suggesting in L635.

Indeed; we fully agree, and this was an oversight. Actually, during the exploration of data presented in recent work under review (Fredensborg Hansen et al. 2024), we also tried evaluating penetration depth using CReSIS snow radar (although not presented in the paper). However, we came to the same conclusion as you - that it depends on the snow radar algorithm since the snow depth from that radar is used as the "true snow depth", and since there it yet to be a convincing case of the "best" product, this is not trivial.

Our investigation is documented in Section 2 of the supplementary material of Nab et al. (2024). The authors are right that if there were some roughly constant CS2 "penetration factor", then it could be estimated by regressing the difference in the CS2 & OIB radar freeboards against the coincident OIB-derived snow depths. Higher snow depths would lead to bigger mismatches in the radar freeboards, as the impact of limited penetration would grow. The rate at which the mismatch scales with snow depth would reveal the penetration factor: if the mismatch remained the same as the snow got deeper, the CS2 penetration factor would be 100%. If the mismatch grew in a 1:1 ratio with the snow depth, then the inferred CS2 penetration would be zero (i.e. operating as a laser altimeter).

When we did this, we found the regression slope is 0.21 (penetration = 80%) for the QL product, but 0.6 (penetration = 40%) for the wavelet and peakiness retrackers deployed with pysnowradar. So we couldn't estimate the penetration depth in this way, without assuming one algorithm is so good as to be "the truth". It's possible that there is a "best" algorithm, but I'm yet to see a convincing case made.

Agreed. Also here, the inter-comparison of (Kwok et al. 2017) highlights the differences in snow radar algorithms.

There is an alternative way of doing this where you assume penetration happens by absolute (not fractional) depth. I.e. Let's imagine the CS2 return originates X cm below the snow surface, vs X % of the snow depth below. This approach also leads to an unacceptable level of variability in the derived penetration depth based on snowradar algorithm.

For what it's worth, our inability to figure out the CS2 penetration depth with snowradar data led to our use of ULS moorings in the main part of the paper. The ULS data allowed us to calculate some penetration depths a bit more reliably. If the authors are looking for a way in which the reference measurements compiled here allow us to learn about CS2 penetration depths/factors, this is potentially a good example.

Nab, C., Mallett, R., Nelson, C., Stroeve, J., & Tsamados, M. (2024). Optimising interannual sea ice thickness variability retrieved from CryoSat-2. Geophysical Research Letters, 51(21), e2024GL111071.

Thank you for raising this point and for pointing us towards your very interesting paper. We completely agree with your observations and will revise our statement on line 635 accordingly, and incorporate references to your work (Nab et al.). We agree that your use of ULS data, rather than OIB data, serves as an interesting case study demonstrating the importance of discussing reference data limitations. In line with our response to reviewer #1, we will expand our discussion on the limitations of OIB data, particularly highlighting differences between snow retrieval algorithms.

References

Kwok, R. et al. (2017). "Intercomparison of snow depth retrievals over Arctic sea ice from radar data acquired by Operation IceBridge". In: *The Cryosphere* 11.6, pp. 2571–2593. DOI: 10.5194/tc-11-2571-2017. URL: https://tc.copernicus.org/articles/11/2571/2017/.

Fredensborg Hansen, R. M. et al. (2024). "Exploring microwave penetration into snow on Antarctic summer sea ice along CryoSat-2 and ICESat-2 (CRYO2ICE) orbit from multi-frequency air- and spaceborne altimetry". In: *EGUsphere* 2024, pp. 1–53. DOI: 10.5194/egusphere-2024-2854. URL: https://egusphere.copernicus.org/preprints/2024/egusphere-2024-2854/.