2nd review of 'Simultaneous estimation of wintertime sea ice thickness and snow depth from space-borne freeboard measurements', Shi Hoyeon et al.
By Isobel R Lawrence

General comment

The authors have done a thorough job responding to and addressing my comments. In particular, the application of the methodology to *radar* freeboard from CryoSat-2 has been demonstrated (I apologise for assuming it would not be possible!). The only thing outstanding is an uncertainty estimate for the CS2-derived snow depth and ice thickness. The sensitivity analysis that has been included in the appendix explores the impact $\Delta\alpha$ has on snow depth and sea ice thickness, but this alone is not sufficient to describe the uncertainty on these products since, for example, error on radar freeboard should also be accounted for. If these products are to be made available, in particular to the modelling community, they must come with an error budget.

The methodology presented in this manuscript is a novel and valuable addition to the sea ice community. I therefore recommend the paper for publication following minor revisions.

Minor revisions

The accuracies of CS2 retrievals / Error budget

I find the final paragraph of section 4.3 (L359-369) extremely difficult to follow. Indeed, after studying Figure 9 for some ten minutes I am still at a loss as to what these plots actually tell us. If the aim is to perform a validation against OIB measurements, why not just show a scatter plot of h_s^{OIB} vs $h_s(\alpha^{sat}, F_r^{CS2})$ and H_i^{OIB} vs $H_i(\alpha^{sat}, F_r^{CS2})$? That would be a far simpler and more relevant plot which the reader will understand immediately.

I think an uncertainty estimate for the satellite-derived products needs including in section 4.3. A simple propagation of errors could be performed on Equation 12 to estimate the error on H_i, and similarly error on h_s could then be propagated from Equation 3. For this, the uncertainty on radar freeboard and α are required. In the manuscript $\Delta\alpha$ is estimated to be 0.036, equal to the RMSE between observed and regressed α, where regressed α are derived from buoy-measured interface temperatures. Does the same $\Delta\alpha$ apply for α derived from satellite temperatures? Evidently errors in T_{si}^{sat} and T_{as}^{sat} will result in errors in α. This should at least be discussed in section 4.3, even if it is not possible to incorporate errors on T_{si}^{sat} and T_{as}^{sat} into the final uncertainty budget (if for example the satellite temperature products do not come with an uncertainty). Errors on radar freeboard should be available with the CS2 product you are using. If not, see discussion in Tilling et al (2018) for their estimate of CS2 radar freeboard uncertainty.

Other minor comments

L15: "retrieved ice thickness was found to be better than the methods relying on the use of snow depth climatology as input, in terms of mean bias and RMSE." - This is

not true, RMSE on ice thickness from radar freeboard is smaller using the MW99 method (0.344 vs 0.5 α-method, figure 7)

L68: “Other satellite remote sensing approaches include the snow depth retrieval using dual-frequency altimetry (Guerreiro et al., 2016; Lawrence et al., 2018, 70 Kwok and Markus, 2018), multilinear regression (Kilic et al., 2019), and a neural network approach (Braakmann-Folgmann and Donlon, 2019).” – I think here you need to add something about the limitations of these methods. Otherwise it is unclear why a new snow product is necessary.

L170: “A sensitivity test indicated that the influence of a 0.3°C difference in the freezing temperature on α was negligible”. Could you give a percentage value or some quantification of it being negligible?

L233: The Quicklook dataset URL you provide takes you to ‘Bootstrap Sea ice concentrations”. Please check the DOI. Also I suggest moving the url to the end of the sentence.

L235: “The OIB data are also reformatted into the 25 km grid format for comparison. If the location of one OIB individual data point falls within a certain 25 km grid area, then the point data is binned in a corresponding grid. After completing the grid assignment, grid value is determined by calculating a simple arithmetic mean of all data within that grid area.” – Do you just mean “the OIB data are averaged on the same 25km grid” ?

L251: I find lines 245 to 250 slightly confusing. I suggest you move the equation for η_s to after equation 14. I.e:
“[Eq 14],
where η_s = […] and ρ_s is taken from the Warren climatology, after Kurtz (2017)”

Figure 3 caption: “The period number is equivalent to the number of time-averaging bin.” – I do not understand what the period number is.

Typos / Grammar

L19: “…buoyancy equation and radar penetration…” -> “…buoyancy equation or the radar penetration…”

L26: “…the height from the sea surface in cracks and leads to the snow surface.” -> “...the height from the sea surface in leads, to the snow surface.”

L51: “variation of snow–ice system” -> “variation of the snow–ice system”

L58: “TB’s” -> “TBs”

L156: Remove “respectively”

L181: “…by multiplying the obtained sea ice thickness and α.” -> “…by multiplying the obtained sea ice thickness and α (Eq. (3)).”

L194 “…as parts…” -> “…as part…”

L201: “depending” -> “dependent”

L248: “In this dataset, η_s was parameterized as a function of the snow density” -> “η_s was parameterized as a function of the snow density” – The ‘in this dataset’ suggests to me that you mean your dataset!

L253: “…values are used for comparison.” -> “…values are used for comparison with results from our simultaneous method.”

L307: “scatterplots of comparing retrievals” -> “scatterplots comparing retrievals”

L351: “shows α values that is generally larger than that over” -> “shows α values that are generally larger than those over”

L353: “H_i shows a similar geographical distribution as shown in the freeboard (the first row)” -> “H_i shows a similar geographical distribution to radar freeboard (the first row)”

L356: “and results are given at the bottom” -> “and results are shown in the bottom row”

L356: “The obtained snow distribution indicates that thicker snow areas are generally coincident with thicker MYI areas. Likewise, the thinner snow area coincides with the thinner FYI area” -> “The obtained snow distribution indicates that thicker (thinner) snow areas are generally coincident with thicker MYI (thinner FYI) areas.”

L385: “As a matter of fact, the ice thickness results were more accurate than they were from the current retrieval methods relying on the input of snow depth (this time MW99 snow climatology), in terms of mean bias and RMSE.” – This sentence is not accurate. RMSE on ice thickness from radar freeboard is smaller using the MW99 method (0.344 vs 0.5 α-method, figure 7)

L406: “The results that radar freeboard and the total freeboard yielded had nearly the same outputs when the α -approach was used” – This sentence does not make sense to me.

L455: “hard wind slap” -> “hard wind slab”

L471: “Because h_s is a combination of freeboard and α” - Do you mean “Because H_i is a combination of freeboard and α” ?

L476: “With $\Delta\alpha$ = ±0.03, which is an RMSE range in the α -prediction equation” – From figure 4b, the RMSE = 0.04, not 0.03.

L483: “a much small number” -> “a much smaller number”

Figure 8 caption: “Grey areas in the second row denote where α retrieval is failed because T_{as} is warmer than T_{as}.” -> “Grey areas in the second row denote where α retrieval failed because T_{as} is warmer than T_{si}.”