Dear F. Garnier,

Thank you for submitting the manuscript tc-2021-79 with the title: “Advances in altimetric snow depth estimates using bi-frequency SARAL/CryoSat-2 Ka/Ku measurements.” I find the paper very interesting, and with a lot of information – a very comprehensive piece of work. I in particular find it nice to see some results for the Antarctica. In general, I find the paper well organized and the figures and tables are clear. The methods and results are also well described. I do find the discussions part a bit short, please, see further questions raised in the general comments.

I have a few general comments and a longer list of technical comments, which I urge you to address:

General Comments:

Validation data:

You are absolutely right, there are not many have observations of snow depths in Antarctica.

Did you look at the AWI snow depth buoys yourself, or from where did you draw the conclusion that these data are not reliable ? Do you have a reference for this choice ? I do understand to exclude the AWI snow depth buoys in the Arctic, as most of the data was obtained north of 81.5N. Please, find the location mapped in Figure 1.

You state (Line 130) that there are no ASPeCT data for the period 2013-2019. This is not completely true. You can find the data including snow depths up to 2019 from Hamburg (https://icdc.cen.uni-hamburg.de/en/seaiceparameter-shipobs.html)

Also for future validation data sets the AWI IceBird campaigns have since 2019 carried a snow radar (https://www.awi.de/en/science/climate-sciences/sea-ice-physics/projects/ice-bird.html).

In line 129-130: You also state that neither the OIB nor CryoVEx data are available yet in Antarctica. This is not entirely true, the level-1 processed data is available (https://earth.esa.int/eogateway/campaigns/cryovex-karen-antarctica-2017-2018), but higher level freeboard and snow depth data is not yet publicly available. For OIB there are freeboard but no snow for 2009-2010 missions.

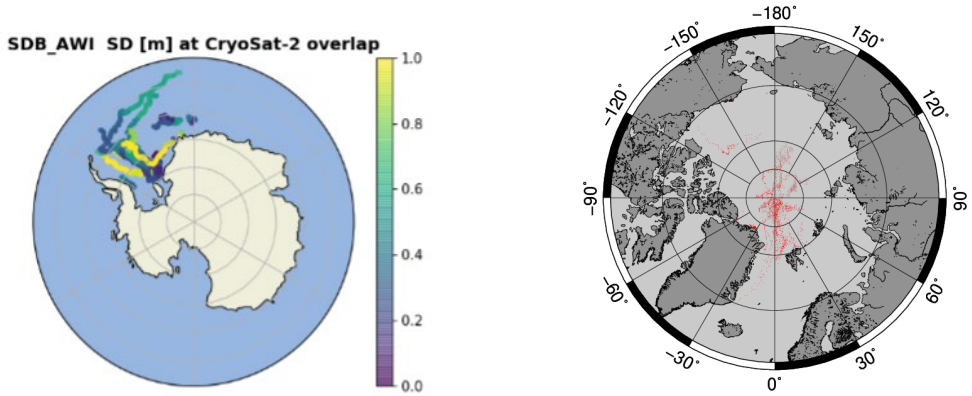

Figure 1: AWI snow depth buoys Antarctica (left) and Arctic (right)

CryoSat-2 Baselines:

I am a bit confused about the different baselines, which you use, and why you do not use the most recent one.

In line 150 you refer to the GOP CryoSat-2 Baseline C Product User Handbook, but later in the same section (line 154) you write that you are using Baseline-B. Is Baseline B latest baseline for the GOP data set ? And If Baseline B is not the latest, which changes would you expect in the final ASD product if you used a later baseline ?

Further down the document Line 425) you use Baseline C for SIT estimation ? The most recent Baseline is Baseline D. Why did you not use this, and what would you expect for changes if you used Baseline D ?

Periods:
I find it a bit confusing with the different time-periods, sometimes you include 2013-2018 and at other times 2013-2019. e.g. data based on input to Fig. 3 (2013-2018) and Fig. 4 (2013-2019)?. Then also the values in Table A1 (2013-2019) for ASD is not similar for those 2 as stated in e.g. line 307.

I cannot find anything consistent when and why you are using different time-intervals.

I urge you to go for the 2013-2019 period.

Also why did you discard the OIB data from 2019, and 2013 for the climatology?

Discussion:
I find the discussion to be rather short. Some points which I find interesting to discuss further is:

You come up with suggestions of how to produce a snow depth climatology prior the SARAL/CS-2 overlap period, which I find great, however, I miss suggestions for post SARAL/CS-2 period. You mention CRISTAL, but there will most likely be a gap. How should this be covered ?

Do you expect all months to be equally representative considering the different temperatures, and effect of melt versus reduced penetration depths of the Ku-band radar signal ?

Do you expect any degradation of the ASD after SARAL went into drifting orbit ?

Even though you discuss a bit about the limitations of the individual validation data sets, you still draw the conclusion that ASD is the “best” option, when you compare with the validation data. What would happen if you, e.g. used another processing of OIB, would DuST then be the “best” option ? How can we secure the most optimal observations in the future to validate satellite derived snow depth products ?

Technical comments:

For consistency, please, consider which of the following options you would like to include in the manuscript with respect to:

- Re-analysis or Reanalysis
- Ka band (Ku band) -> Ka-band (Ku-band)

1 Introduction:

Line 10: It is **further** validated in the Arctic …

Line 42: in **the** Arctic

Line 49: in **the** Arctic

Line 54: CRYOsat Validation Experiment -> CryoSat Validation Experiment

Line 54-56: I am not quite sure why you have picked these references, i.e. Haas et al. 2006 and Helm et al. 2006. In case you want to add these you should in principle include all reports from all CryoVEx campaigns since 2003. Overviews along the way are provided in Hvidegaard et al. 2006 and Skourup et al. (2012). For later campaigns, please, refer to relevant CryoVEx technical reports to be found at https://earth.esa.int/eogateway/search?category=Campaigns&filter=cryosat

Skourup, H., S. M. Hvidegaard, R. Forsberg, I. Einarsson, A. V. Olesen, L. S. Sørensen, L. Stenseng, S. Hendricks, V. Helm and M. Davidson: CryoVEx 2011-12 airborne campaigns for CryoSat validation. Proceedings paper (ESA-SP-710), 20 years of progress in radar altimetry, 24-29 September, Venice, Italy, 2012

Hvidegaard, S. M., R. Forsberg, and H. Skourup: Sea ice thickness from Airborne Laser Scanner. Arctic Sea Ice Thickness: Past, Present and Future, edited by P. Wadhams and G. Amanatidis. Climate Change and Natural Hazards Series, Brussels, 2006

Line 56: Their measurements include bi-frequency altimetry snow depth estimations as of 2017 (see Sect. 3.3). -> Their measurements include bi-frequency altimetry snow depth estimations as of 2017 (Skourup et al., 2019) (see Sect. 3.3).

Skourup, H., A. V. Olesen, L. Sandberg Sørensen, S. Simonsen, S. M. Hvidegaard, N. Hansen, A. F. Olesen, A. Coccia, K. Macedo, V. Helm, R. S. Ladkin, R. Forsberg, A. E. Hogg, I. Otosaka, A. Shepherd, C. Haas and J. Wilkinson. ESA CryoVEx/KAREN and EU ICE-ARC 2017 - Arctic field campaign with combined airborne Ku/Ka-band radar and laser altimeters, together with extensive in situ measurements over sea- and land ice. Technical Report, National Space Institute, Danish Technical University (DTU Space), ISBN-978-87-91694-45-5, August 2019

Line 56: cover.Their -> cover. Their (that is insert space after dot)

Line 61: snow depth measurements **in the Arctic** (Kurtz …)

Line 70: several CryoVEx and OIB missions have been conducted in Antarctica -> several OIB missions and the CryoVEx 2017/18 campaign (Hvidegaard et al., 2020) have been conducted in Antarctica

Hvidegaard, S. M., R. Forsberg, H. Skourup, M. L. Kristensen, A. V. Olesen, A. F. Olesen, A. Coccia, K. Macedo, V. Helm, R. S. Ladkin, R. Tilling, A. E. Hogg, Adriano Lemos and A. Shepherd. ESA CryoVEx/KAREN Antarctica 2017-18 - Antarctic field campaign with combined airborne Ku/Ka-band radar and laser altimeters, together with extensive in situ measurements over sea- and land ice. Technical Report, National Space Institute, Danish Technical University (DTU Space), ISBN 978-87-91694-50-9, October 2020

Line 104: its -> It is

Line 104: its -> It is

Line 113: Mode(LRM) -> Mode (LRM)

Line 48: I suggest you add the more local/regional climatologies such as Forsström et al. (2011), which provides snow depths for e.g. the Fram Strait, which represent an area outside the central Arctic where W99 climatology is not working properly due to extrapolation.

Forsström, S., Gerland, S., & Pedersen, C. (2011). Thickness and density of snow-covered sea ice and hydrostatic equilibrium assumption from in situ measurements in Fram Strait, the Barents Sea and the Svalbard coast. Annals of Glaciology, 52(57), 261-270. doi:10.3189/172756411795931598

Line 130: AspeCt data including snow depths are available up to 2019 from Hamburg (https://icdc.cen.uni-hamburg.de/en/seaiceparameter-shipobs.html)

2 Data processing of ASD

Line 145: which is assumed to be reflected near the top of the snow pack, **i.e.** the

air/snow interface

Line 150 Why do you refer to CryoSat-Baseline-C Product user handbook when you are using Baseline-B as stated in Line 153-154 ? See also general comments.

Line 159-162: You explicitly mention DTU15 MSS, but not the other models why is this the case ?

Line 167-68: Does these limitations on PP apply to both Ku- and Ka-band ?

Line 170: Threshold First Maximum Retracker Algorithm (TMFRA; -> Threshold First Maximum Retracker Algorithm (T**FM**RA;

Line 177: we need to take into account the decreasing of the Ku radar echo velocity when it penetrates into the snow pack -> we need to take into account the **decrease** of the Ku radar echo velocity **as** it penetrates into the snow pack

Line 186: radarKu -> Ku_r (as you also made this for the snow sd_r)

Line 192-193: In the Arctic, it also shows that these data are different from the Warren 99 modified (W99m) climatology, where nearly everywhere the W99m climatology exhibits thicker snow layers over sea ice. -> In the Arctic, it also shows that these data are different from the W99m climatology, where the W99m climatology tend to exhibit thicker snow layers over sea ice.

3 External data sets

Line 197-199: For both hemispheres, the time period of model and satellite products that have been used is explained in Fig. 2 (ranges from 2014–2019 for the Arctic, and 2013–2019 for the Antarctic with limitations for some data products for both hemispheres). -> For both hemispheres, the time period of model and satellite products ranges from 2014–2019 for the Arctic, and 2013–2019 for the Antarctic (with limitations for some data products for both hemispheres), as explained in Fig. 2.

Line 208: located near the Canadian Archipelago (and the Beaufort Sea, and only -> located near the Canadian Archipelago and the Beaufort Sea, and only

Line 219: cover over FYI Because of this limitation, -> cover over FYI. Because of this limitation,

Line 222: Other months are only available on FYI -> Other months are only available over FYI

Line 232: description can be found in Schweiger et al. (2011) -> description can be found in Schweiger et al. (2011).

Line 238: Louvain-la-Neuve sea Ice Model (LIM2) (Fichefet and Maqueda, 1997; Vancoppenolle et al., 2012) -> Louvain-la-Neuve sea Ice Model (LIM2) (Fichefet and Maqueda, 1997; Vancoppenolle et al., 2012).

Line 230: OSISAF -> OSI SAF

Line 252: CRYOsat Validation Experiment -> CryoSat Validation Experiment

Line 256: (Haas et al., 2017), -> (Skourup et al. (2019), Haas et al. (2017)), Please, also use DOI for the CryoVEx 2017 campaign data: https://doi.org/10.5270/esa-enocas0 - CryoVex-KAREN 2017 Campaign: "ESA CryoVEx/KAREN and EU ICE-ARC 2017 - Arctic field campaign with combined airborne Ku/Ka-band radar and laser altimeters, together with extensive in situ measurements over sea- and land ice" obtained from the ESA campaign site: https://earth.esa.int/eogateway/campaigns/cryovex-karen-2017?text=CryoVEx+2017

Line 260: OIB is one of the largest airborne mission in polar -> OIB is one of the largest airborne mission**s** in polar

Line 264: (Kurtz et al., 2012 (Updated 2015; King et al., 2015) I am not sure I understand this ?

Line 267: Why did you not include OIB from 2019 ?!?

Line 267-268: comparison with the ASD climatology, we compare with all OIB spring campaigns during 2009–2012. Did you use quiklooks here or the IDCS4 ? It is not clear from section 3.3.2

Line 272: et al., 2006; Perovich and Richter-Menge, 2015) Snow depth -> et al., 2006; Perovich and Richter-Menge, 2015). Snow depth

4 Comparison between snow depth data

Line 277: 500×500 EASE2 grid … is the grid in km ? i.e. 500x500km ?

Line 281: of all snow depth monthly maps -> of all monthly snow depth maps

Line 294-296: Note, that when comparing the various snow depth data with the OIB snow radar data, at achieve a corresponding spatial scale, we have applied a 25 km window rolling mean for smoothing the OIB data. -> Note, that when comparing the various snow depth data with the OIB snow radar data, we have applied a 25 km window rolling mean for smoothing the OIB data, to achieve similar spatial scales.

Line 305: zones -> regions

Line 305: and higher snow depths over region of thicker sea ice -> and higher snow depths over regions of thicker sea ice

4.2.1 I do not like the phrasing “Annual means” for means calculated only based on March and April data, maybe rephrase this to seasonal or winter means

Line 319: comparable both in terms -> similar both in terms

Line 330: Although investigating which causes these discrepancies -> Although investigating **what** causes these discrepancies

Line 334: ASD is the only publicly available altimetric snow depth product in Antarctica. -> ASD is **currently** the only publicly available altimetric snow depth product in Antarctica.

Line 337: I would remove: "(equivalent to PIOMAS but for Antarctica)", as you have already mentioned this.

Line 342: east side, -> eastern part

Line 343: One relevant difference between these two data is -> One relevant difference between these two data **sets** is

Line 353: between -> from

Figure text 7: considered -> included

Figure text 6: during -> acquired on

Figure text 6: Remove: "2015 spring campaign)

Line 353: Fig. 6 shows an example the 29th March 2015 track -> Fig. 6 shows an along-track example from the OIB flight on 29th March 2015

Line 354: comparing with the OIB data over the entire 2014-2018 time period -> comparing **the various snow depth products** with the OIB data over the entire 2014-2018 time period

Line 354: Why do you not include OIB from 2019 ?

Line 357: It is almost impossible to see the shading, you might want to upgrade the color in order to be visible

Line 357: data are nearly always included within the ASD envelope of uncertainties (in shaded red). -> data are almost within the ASD envelope of uncertainties (in shaded red) at all times.

Line 369: Remove: "always"

Line 361: overestimate OIB with a level comparable with DuST -> overestimate at a level comparable with DuST, when compared to OIB.

Line 365: MYI Kwok et al. (2017). -> MYI (Kwok et al., 2017).

Figure 6: Out of curiosity., what happens after trackpoint 20000 ? Here there are a huge difference between OIB/ASD/DuST, could be interesting to look further into this.

Line 369: a less optimal solution -> a less optimal solution in this case.

Line 375: Fig. 8 and Table 2 show how the satellite mean values are closer to the in-situ observations than the model -> Fig. 8 and Table 2 show how the satellite **derived** mean values are closer to the in-situ observations than the model**s**

Line 376: seasonal changes in the IMBs -> seasonal changes captured in the IMBs

Line 376: or -> nor

Line 377: localized -> point

Figure 8: Why did you not include the ASD uncertainties as shading in this plot similar to Figure 6 and 9 ?

Line 387: Ka-ASR estimation exhibits very thin snow thickness (< 10cm).

Line 389: Ka band radar -> Ku-band radar

Line 392: (in pink shading). -> similar as for Figure 7 it is difficult to see, and also in figure 7 you called I red shading, please, be consistent.

Line 394: It does not really make sense to use W99/W99m in these areas, but ok since I presume this is what is used in the SIT productss

Line 390: Why is there a gap in the ALS-ASR data ?

Line 390: Except around 71.3N, where a specific event may have occurred, the ASD snow product tracks the magnitude of the CryoVEx airborne data

Line 390-392: I am not really convinced about this. But you are right, that

Line 391: KAREN-ASR

Line 395: The -> the

5 Towards an ASD snow depth climatology

Line 397: the temporal coverage -> the limited temporal coverage

Line 397: (only after 2013) -> (only available post-2013)

Line 399: Remove: “to this limitation”

Figure 10: the ASD and the Warren W99m climatologies considering all the tracks of 2009,2010,2011 and -> the ASD and the W99m climatologies considering all the tracks of 2009, 2010, 2011 and

Line 407: as obtained in Fig. 7 with the ASD data. -> as obtained by direct correlation between ADS and OIB measurements (Fig. 7).

Line 409: product for the years of Envisat -> product representing the Envisat-era.

Line 409. Remove: “Warren”

6 Impact of snow depth on SIT estimation

Line 425: Baseline C ?!? See general comment.

Figure 11: The red and blue colors for the different representations are difficult to separate, i.e. ASD, DuST, SIT min-max. I encourage you to find another solution for this.

Line 431: taking into account the radar speed velocity decreasing which depends on the snow depth data -> taking into account the reduction of radar velocity within the snow layer, which depends on the snow depth data

Line 436: lower -> low

Line 439: comprised -> distributed

Line 446: 4.10^3km^3 -> $4 \times 10^3km^3$

Line 449: 3.5.1015 -> 3.5 x 1015

Line 450: 2.10^8 -> 2×10^8

Line 459: maxdevy,m(SIT) -> (maxdevy,m(SIT))

Line 459: Eqs.(9) -> Eqs. (9)

Line 459 and onwards, be consistent to refer to equations in a similar way, e.g. Eqs. (9) or Eqs 9

Line 466: Eqs. 11 to 13. Ny is the number of years. -> Eqs. (11) to (13), where Ny is the number of years.

Line 471: I do believe Eq. (13) should be on the rightside of the summation in Eq. (12) ?

Line 480: due only to snow depth -> caused by the snow depth

Line 481: We distinguish two cases: the case « obs snow products », which considers ASD, DuST, W99m and AMSR2B and the case « all snow products », which includes in addition the PIOMAS, MERCATOR and NESOSIM model solutions. -> We define two cases: 1) « obs snow products », which considers ASD, DuST, W99m and AMSR2B and 2) « all snow products », which includes in addition the PIOMAS, MERCATOR and NESOSIM model solutions.

Line 484: Remove: “For similar reasons, AMSR2-NSIDC is also not taken into account”, as this has not been in the Arctic analysis

Line 485: Eqs.(11) to (17) -> Eqs. (11) to (17)

Line 485-486:

Kine 488; (spatial mean of SITy,m,p maps are also included -> (SITy,m,p) are also included

Line 489: at the ocean/ice transitions -> marginal ice zones

Line 495: snow depth from -> snow depth **variability** from

Line 495: an other -> another

Line 499: 76*cm* -> 76cm

.Line 508: for constraining models -> to constrain models

Line 509: initiative -> initiatives

Line 512: Polar Week -> Polar Science Week

7 Conclusions and Discussions

Line 519: and a CryoVEx airborne campaign -> and CryoVEx airborne campaign data

Line 519: Ka-Ku snow depth -> Ka-Ku and ALS-Ku snow depths

Line 523: always exhibits higher snow depth patterns -> is always biased high.

Lone 530: always far lower the -> always biased low when compared to the other products.

Line 531: in -> on

Line 540: Weddell sea are not represented -> Weddell sea are not captured by the model

Line 554: would need to be done -> is needed

Line 557: versions, etc...), -> versions),

Line 560: is its temporal coverage, imposed by SARAL (only from 2013). -> is its **limited** temporal coverage, imposed by SARAL which is only available since 2013.

Line 563: Please add: which strongly overestimates snow depths**, and is useless outside the central Arctic due to extrapolation**.

Line 564: 2009-2013 … wasn't it 2009-2012 ?

Line 565-566: has a mean bias of about 14 cm with -> on average is biased ~14 cm high with

Line 568: could -> should

Line 570: pacts of the snow depth on SIT -> pacts of different snow depth products on SIT

Line 575: 14.2% -> 14%

Line 576-577: Please, add some of the locations here.

Line 584: uncertainty -> uncertainty budget.

Line 585: which still to be further investigated -> which still **needs** to be further investigated

Line 587: or -> and/or

Data availability:
It is nice with a link to the data set presented in this paper. In some journals you need to link or provide information about all the data sets used, but I am not sure whether this also is the standard for TC, or whether the links provided in the text is enough.