MS Record: tc-2021-791:

Title: Advances in altimetric snow depth estimates using bi-frequency SARAL/CryoSat-2 Ka/Ku measurements.

Florent Garnier, Sara Fleury, Gilles Garric, Jérôme Bouffard, Michel tsamados, Antoine Laforge, Marion Bocquet, Rénée Mie Fredensborg Hansen and Frédérique Rémy

Referee#1 global comment

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 do find lots of technical issues, which has been raised together with the general comments in the supplemented pdf-file.

Answers to the anonymous referee#1 comments

We would like to thank the reviewer for her/his careful reading of the manuscript and for the relevant and constructive remarks. In order to fit with your comments and those of the other referees, we have made a complete revision of the manuscript that should have considerably improved the quality of the writing and the readability of the document. Note that we have also broaden the discussion part. We hope that the modifications will meet your requirements. Please find below the details on how your general and specific comments have been taken into account. In this « author's response document », the referee's comments are in bold type, the answers are in italic type, and the corrections to the revised manuscript are in normal type.

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1) Answers to the anonymous referee#1 : general comments

1.1) 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.

Indeed, we have looked at the AWI snow buoys. The main issue is that they provide snow accumulation, which is not exactly the snow depth. In the Arctic, both might be quite comparable but, as you mentioned, the Saral orbit inclination drastically limits the comparison. In addition, we have several other datasets. In Antarctica, we might haven't look deeply enough but, probably mainly because of the flooding, our comparisons did not seem to be consistent. We haven't been able to identify relevant patterns that could be directly linked with the snow depth. A deeper analysis should be necessary but, in any cases, this comparison

wouldn't be sufficient for a proper validation in Antarctica. Then, we have decided not to present these comparisons in this article. In order to clarify this point we have modified the sentence in the introduction as follows:

L81-83: To our knowledge, only the Meereis data portal (https://www.meereisportal.de/) provides snow buoys data of snow accumulation (Grosfeld et al., 2016) (for both hemispheres), but the comparison with snow depth is not direct. It is, for instance, limited by the flooding of ice floes due to the heavy snow loading occurring in the Antarctic.

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).

We do apologize for the inaccuracy of our statement concerning ASPeCt. Of course, for future snow depth validation and comparison in the Arctic, we look forward to the IceBird snow radar datasets. We have modified as the introduction of the revised manuscript as follows:

L84-88: Currently, the main expedition providing snow depth data in the Southern hemisphere, is the ASPeCt program (Worby et al., 2008), established in 1996 to model the role of the Antarctic sea ice in the coupled atmosphere-ice-ocean system. ASPeCt recent standardized data (Kern, 2020) cover the period 2002-2019 but with a too sparse amount of information for a reliable assessment. Future validations in the Antarctic will also benefit from the recent AWI IceBird campaigns carrying a snow radar since 2019 (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.

You are completely right that our phrasing is subject to misunderstanding. We also had this comment when presenting these results for the 10th years of CryoSat-2 conference. L1b of OIB and CryoVeX are available but they need a treatment that would take a lot of time and which is not entirely in our field of expertise. we have modified as follows

L80: Actually, several CryoVEx and OIB missions have been conducted in the Antarctic, but the data are still only available in raw L1b level and difficult to interpret..

1.2) 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 ?

We use the GOP CryoSat-2 Baseline B until 2017 and Baseline C from 2017 to 2019. We did not used the Baseline C for all the time period simply because the Baseline C was not available at the time we processed the data. It is now available. Because

the waveforms are exactly the same in the two Baselines (and then the computed snow depths), we have decided to keep this version for this article. Note that we are currently re-processing the data so that the ASD product will be computed over the 2013-2020 period in both hemisphere from the baseline C only . The only difference is then that it will also cover the SARIN mode zones. You are right that it is important to let the reader (and probable future users) be aware of this. For that purpose, we have modified the revised manuscript as follows :

L166-171 : Since the Baseline-C PLRM GOP product was not fully available at the time we have computed the ASD data, we have used the Baseline B (until 2017 and the Baseline C from 2017 to 2019) that does not include the SARin data. Then, the ASD data does not yet cover the SARin mode zones. The next version of the ASD product will include SARin mode zones. Apart from this spatial coverage, there will be no difference with the ASD version presented in this article since waveforms in L1b products are the identical in Baseline B and C.

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 ?

It is true that the Baseline D is the most recent Baseline (and soon Baseline E...). We did not use the Baseline D because we haven't reprocessed all CryoSat-2 freeboard with Baseline D. The waveforms are identical in the Baselines C and D so that does not change the results on freeboards. Differences between the 2 baselines are especially when you use L2 products. Since we never mention the baseline D in the document, we would prefer not to add this point in order to avoid confusion between the different products.

1.3) 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?

We agree that the various time period used for the diagnosis might be confusing. We have used (slightly) different time periods because of the availability of the different products. Our objective is to perform comparisons as reliable as possible, i.e with the exact same amount of data (same spatial and temporal coverage). For instance in Figure 3, we present the AMSR2B data that are only available until 2018. Then we discard 2019. This is also why we did not use the 2019 OIB campaign. We could obviously perform comparisons using,for each product, the maximum of data but we think that statistics are more relevant this way. In order to make the data availability clear for the reader, we added a summary table (Table A4 in appendices) Also the following sentences have been added in the revised document.

L299-300: Note that to improve the consistency of the analyses we always use the larger common time period for all the compared products. Thus, the covered time periods may vary depending on the availability of the snow depth products.
L219: Table A4 specifies the time period of the different satellite and model data.

1.4) Discussions

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 ?

In spite of the uncertainty due to the variability of snow properties and their effects on the signal, we believe that all the 6 winter months should be equally representative. It would not be the case for other months, for instance in spring the melting strongly impact freeboard calculations (at least distinction between leads and floes). Actually, this is one of the reason why we still only compute snow depth over the 6 winter months. Note that we have broaden the discussion part to better mention CRISTAL and highlight the importance of snow properties and the impacts of roughness and penetration. for instance :

L596-604: Since the results of such comparisons with validation data can vary from one methodology to another (e.g., grid sizes, smoothing kernel, dataset versions), they do not aim to assess the best snow depth product. However, they demonstrate how ASD provides a relevant snow depth solution, in good agreement with several validation data, and that ASD allows for characterisation the deviations between the different snow depth products. A more refined comparison with the CryoVEx data 600 (including various tracks) is mandatory to understand the relative impacts of roughness and penetration and their link with snow properties. For instance, Willatt et al. (2011) show that the Ku-band dominant scattering surface can significantly vary with snow temperature, with a reduced penetration when temperatures increase. This feature could enhance an underestimation of ASD data with the warming of temperatures due to climate change. It also points out the difficulty to retrieve snow depth from altimetry beyond the 6 months of winter as variations in snow properties are most important in the summer period.

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 ?

In spite of the uncertainty due to the variability of snow properties and their effects on the signal, we believe that all the 6 winter months should be equally representative. It would not be the case for other months, for instance in spring the melting strongly impact freeboard calculations (at least distinction between leads and floes). Actually, this is one of the reason why we still only compute snow depth over the 6 winter months. Note that we have broaden the discussion part to better highlight the importance of snow properties and the impacts of roughness and penetration. for instance :

L571-576: A more refined comparison with the CryoVEx data (including various tracks) is mandatory to understand the relative impacts of roughness and penetration and their link with snow properties. For instance, Willatt et al. (2011) show that the Ku-band dominant scattering surface can significantly vary with snow temperature, with a reduced penetration when temperatures increase. This feature could enhance an underestimation of ASD data with the warming of temperatures due to climate change. It also points out the difficulty to retrieve snow depth from altimetry beyond the 6 months of winter as variations in snow properties are most important in the summer period.

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

We do not expect any degradation of the ASD for orbits modifications because the snow depths are calculated from the difference of the monthly means.

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 ?

Using another OIB product, in particular the one which is use for calibration, it is quite possible that the comparisons with OIB underline better statistics for DuST than for ASD. However, it won't be drastically different from the results we show in the article. It would rather be a question of magnitude, not annual or interannual variabilities. In addition, different methodologies for the comparisons could give different results. We think that it is not relevant to assess the best product since each has relevant patterns. Our objective is to demonstrate that ASD is a relevant solution to estimate snow depth. The main reason towards the use of ASD compare to other products is that it is available in the two hemispheres which is crucial for data assimilation in global operational systems. We have better specified this point in the last part of the introduction of the revised manuscript.

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2) 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)

We have carefully modified the document in order to use the spellings Ka-band(Ku-band) and Reanalysis.

2.1) 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

The above corrections have been modified in the document

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

The citations have been modified following your recommendations.

L61-64: Since 2003, the CryoSat Validation Experiment (CryoVEx) campaigns (e.g Haas et al. (2006); Helm et al. (2006); Skourup et al. (2013); Hvidegaard et al. (2006)) have provided data with the main goal of investigating radar penetrations into ice and snow cover. Their measurements include bi-frequency altimetry snow depth estimations as of 2017 (H. Skourup and Wilkinson, 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

The modifications and the reference proposed have been added to the revised document

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Line 104: its -> It is

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

these corrections have been added to the revised document

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

We have added the reference of this climatology in the revised document.

L54: The climatology of Forsström et al. (2011) provides snow depths in areas outside the central Arctic where the Warren- 99 climatology is not working properly.

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

This point has already been considered in the revised document. Please see the corresponding answer in section : 1.1) Validation data

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2.2) 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

This modification has been added to the revised document

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.

We refer to this handbook because we partly use the Baseline C (from 2017 to 2019). Please see answer to the general comments section 1.2) CryoSat-2 Baselines. Furthermore, this handbook is valid for the Baseline B as there are only a few changes between the 2 baselines (and L1b waveforms are identical).

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

It is true that we specify the MSS but not the other corrections because : 1) it is the most important correction in the freeboard calculations and 2) some of the other geophysical corrections are not exactly identical for SARAL and CryoSat-2. We believe that it would be confusing for the reader, without added value, to specify all the corrections and differences for both satellites as it has almost no impact on the freeboards (freeboards are calculated from a difference of heights).

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

We apply exactly the same criteria for SARAL and CryoSat-2. To make sure this is clear for the reader we add the following sentence:

L186-187: This criteria is the same for SARAL and CS-2.

Line 170: Threshold First Maximum Retracker Algorithm (TMFRA; -> Threshold First Maximum Retracker Algorithm (TFMRA;

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 -> Kur (as you also made this for the snow sdr)

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.

These modifications have been added to the revised document.

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

The above modifications have been added to the revised document.

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/ca karen-2017?text=CryoVEx+2017

These references have been added to the revised document. A reference to the technical report has also been added:

L279: For further informations, please see the technical report at https://earth.esa.int/eogateway/documents/20142/1526226/CryoVEx2017-final-report.pdf.

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

This modification has been added to the revised document.

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

An update of the Kurtz et al., 2012. has been made in 2015. For a better understanding we just kept Kurtz et al., 2012 in the revised manuscript.

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

We did not include OIB from 2019 in order to consistently compare with DuST and AMSR2B snow depths for which 2019 was not available. Please see section 1.3) Periods, for a complete answer to this comment.

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

We use the same quicklook OIB product version to compare with the ASD climatology. It is explicited by the sentence L273: OIB snow depth data presented in this paper are the NSIDC OIB Quicklook version.

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

This modification has been added to the revised document.

Comparison between snow depth data

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

500x500 is the number of pixel of 12.5km (in the Arctic grid). To clarify this point, the sentence has been modified has it follows:

L284: Model and satellite snow depth estimations are projected onto a 12.5km pixel size EASE2 grid similar of ASD using a linear two-dimensional multivariate interpolation.

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

These modifications have been added to the revised document.

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

The phrasing Annual means has been replaced by « seasonal » 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.

These modifications have been added to the revised document.

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

This sentence in brackets has been removed.

Line 342: east side, -> eastern part

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

These modifications have been added to the revised document.

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

Please see the previous answers explaining why we have decided to discard these data.

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

We have upgraded the red shading in figures 6,8 and 9 of the revised manuscript.

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 359: 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).

These modifications have been added to the revised document.

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

Trackpoint 20000 is a coastal region. The differences mainly come from the larger freeboard uncertainties in these zones.

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 models

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

Line 376: or -> nor

Line 377: localized -> point

These modifications have been added to the revised document.

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

Similar to Figure 6 and 9 we have added the ASD uncertainties as shading in Figure 8.

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

This modification has been integrated to the revised document.

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

This sentence does not refers to the Ku-band but to the snow depth computed from Ka-band. To avoid misunderstanding we have modified this sentence as it follows :

L431: The main difference between the snow depths calculated from the laser and the Ka-band radar snow depth estimations seems to be a bias.

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.

According to your suggestion, we always refer to "red shading" and the contrast of figure 7 has been increased for a better readability.

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 products

We agree that it does not make sense to use the W99 climatology in these areas. As it is used in SIT products, we still want to keep it in figure so that it emphasises the need not to use the W99 climatology.

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

There is a gap because the laser is more sensitive to meteorological conditions, for instance the cloud cover, than the Ka-band altimeter. Some data are then missing. Note that this is also the case with ICESAT-2.

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

This modification has been integrated to the revised document.

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

We did not fully understand this comment.

Line 391: KAREN-ASR

Line 395: The -> the

These modifications have been integrated to the revised document.

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"

These modifications have been integrated to the revised document.

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

Please see our comment on section 1.2) CryoSat-2 Baselines.

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

We have modified some colours and line styles in Figure 11 in order to increase it readability.

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: 4.103km3 -> 4 x 103km3 Line 449: 3.5.1015 -> 3.5 x 1015 Line 450: 2.108 -> 2 x 108
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.

These modifications have been integrated to the revised document.

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

It is exact. We have corrected this point.

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 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: 76cm -> 76cm

Line 508: for constraining models -> to constrain models

Line 509: initiative -> initiatives

Line 512: Polar Week -> Polar Science Week

These modifications have been integrated to the revised document.

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.

These modifications have been integrated to the revised document.

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

We have added this sentence.

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

Indeed it is 2009-2012. It has been corrected

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

These 2 modifications have been added to the revised document.

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

Higher impacts are mainly in coastal and marginal zones. We modified the sentence as it follows:

L638-639: Deviations between SIT estimations reached up to 77 cm (55% of global mean SIT) in marginal and coastal zones.

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

These 2 modifications have been added to the revised document.

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.

There is already a link in the paper to access the data. In addition, the data link has also been added L146 of the revised document.

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