Dear Editor,

We truly appreciate your and two anonymous reviewers' valuable comments and suggestions for the paper 'A comparison between Envisat and ICESat sea ice thickness in the Southern Ocean' submitted to The Cryosphere. We have already made a substantial revision according to these comments and suggestions, and reply to them one by one below.

Qinghua Yang and Qian Shi

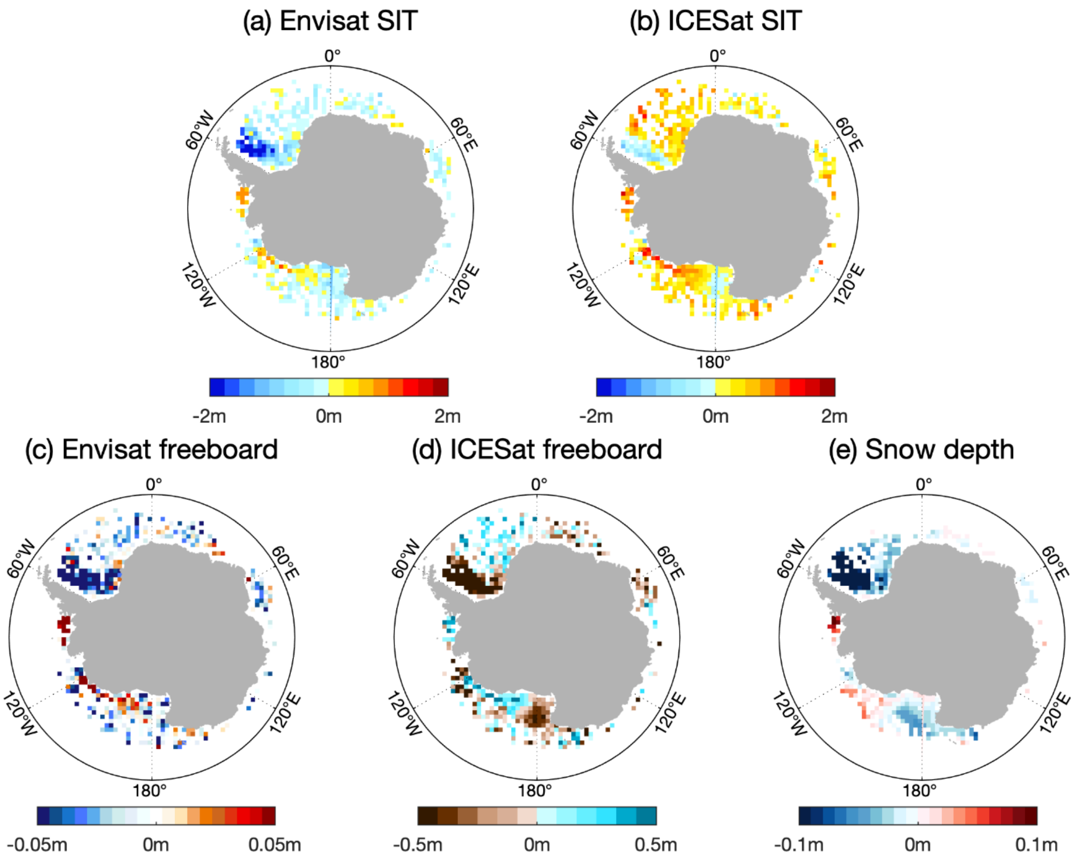
On behalf of all the authors

Responses to editor

1. A refinement of the pairing (in time and location) of Envisat and ICESat data is required. Pls provide further explanation.
   Response: Thank you for your comment. We have refined the description and the figures of paring between Envisat and ICESat SIT following the referee's and your comments: "We employ a time-weighted average of the monthly Envisat data to match the ICESat period. For example, considering the ON04 period from Oct 3 to Nov 8 in 2004, which is 37 days long – 29 days in October and 8 days in November, we calculate the corresponding Envisat SIT as: $SIT_{ON04} = (29/37)*(SIT_{October}) + (8/37)*(SIT_{November})$. We use this weighing equation only for grid cells where valid Envisat SIT data exist in both months, while the weighing is not conducted for grid cells where valid data only exist in either one month. It is noted that this approach can lead to considerably larger coverage of Envisat SIT data than ICESat, thus we only show grid cells where both Envisat and ICESat have valid SIT and only take those values in the statistical computation." *(please see P6 line 166-172 in the revised manuscript)* "Both Envisat and ICESat SIT have been interpolated onto each ULS location in the nearest neighbour way." *(please see P7 line 182-183 in the revised manuscript)*

2. Expand and consolidate the definition and validity of the dynamic freezing-degree-day [FDD]. The dyn FDD concept is introduced in very brief notes (9lines), but as it carries some weight in the argumentation this requires expansion. The "seasonal" approach taken here requires justification.
   Response: Thank you for your valuable comment.
   (1) Our procedures on deriving dynamic FDD are listed as follows: a. On Day1, the historical FDD and the newly increased FDD are interpolated to the regular NSIDC ice velocity grid position (X1, Y1); b. Accumulated FDD moves to irregular positions (X2, Y2) with sea ice motion derived from NSIDC v4; c. At the beginning of Day2, the FDD distribution of the irregular Day1 is interpolated to the regular grid (X1, Y1), then repeating steps 1-3. The ice divergence and deformation situations cannot be represented through our method.
   (2) However, according to another referee's suggestions, we have decided to remove the FDD parts and focus on the intercomparison between Envisat and ICESat since the results of FDD cannot explain the reason for the differences. However, according to one of the referee's comments, we have decided to remove this part and conducted further research on the difference during MJON. The results according to the new figure are added as follows: "Therefore, we further compare the mean variations of Envisat SIT, ICESat SIT, Envisat freeboard, ICESat freeboard and snow depth climatology used in Envisat retrieval from autumn (MJ) to spring (ON), shown in Fig. 8. The average fields are calculated with grid cells where both Envisat and ICESat SIT have valid

values in all three years from 2004 to 2006. Figure 8 shows that Envisat SIT experiences general decreases from May/June-October/November (MJON) except Bellingshausen Sea and part of Amundsen Sea. Significantly large decreases exist in Western Weddell Sea. In contrast, ICESat SIT present large-scale increases except Western Weddell Sea and Ross Sea where slight decreases exist. By comparing the SIT and freeboard changes of both products, we find that the different changes of freeboard dominantly explain the SIT differences. One thing we can give a speculation based on the analyses in autumn and the regular rule during freezing seasons is that Envisat freeboard is probably overestimated in autumn, which has been pointed out in several studies before (e.g., Willatt et al., 2010; Kwok and Kacimi, 2018; Kacimi and Kwok, 2020). Moreover, the snow depth climatology also shows a decrease in Western Weddell Sea and Ross Sea (Fig. 8e), which has been reported by Kern and Ozsoy-Cicek (2016) that AMSR-E snow depth is likely to underestimate the snow depth evolution during MJON, also contribute to the Envisat SIT decrease." *(please see P9-10 line 269-281 in the revised manuscript)*

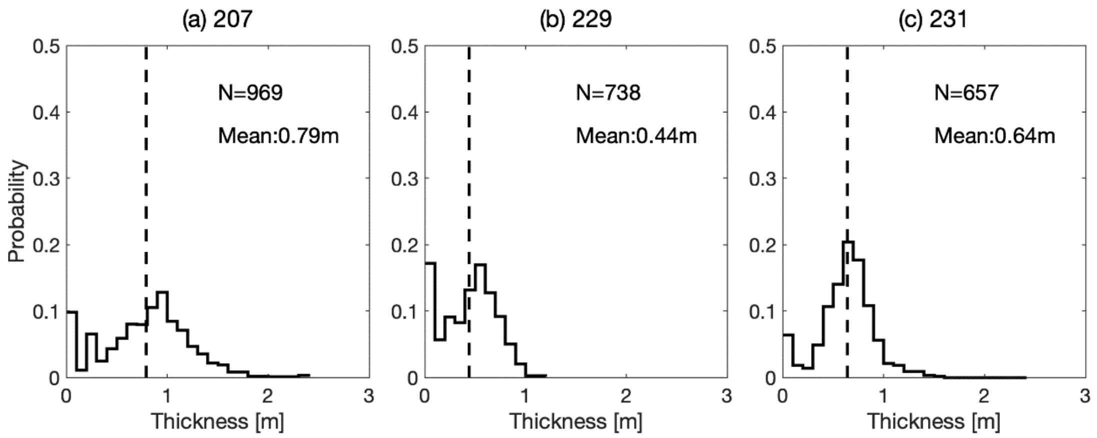


RFig. 1: The average changes of Envisat SIT, ICESat SIT, Envisat freeboard, ICESat freeboard and snow depth climatology used in Envisat retrieval from autumn to spring (MJON) calculated from 2004, 2005 and 2006.

3. The footprints of ULS vs IceSat vs Envisat are stretching magnitudes. I suggest to show the full thickness distribution of ULS-derived data and contrast this with the

ULS-derived means.

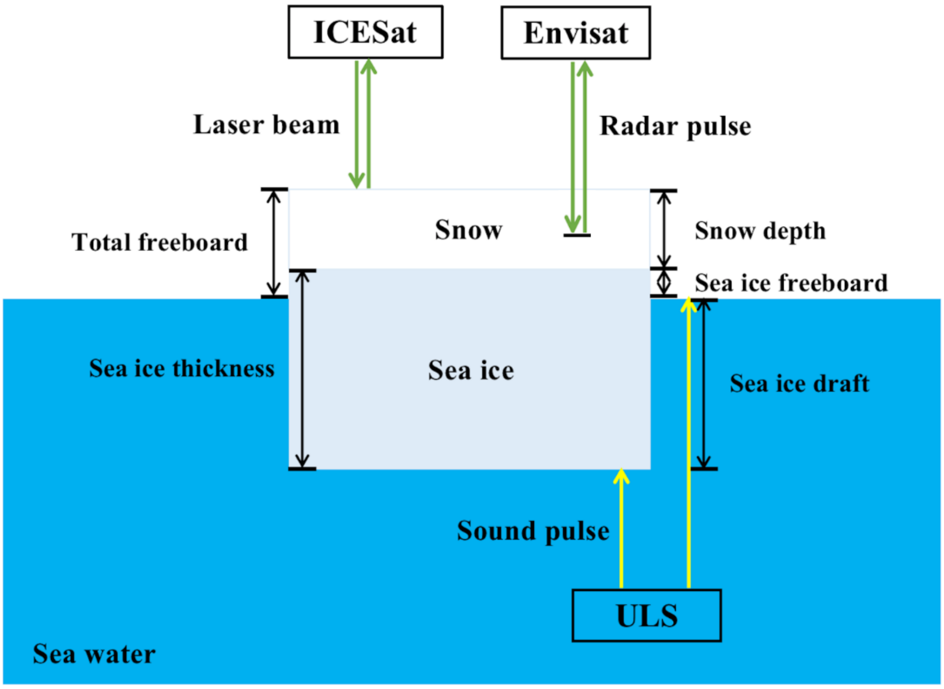
Response: We appreciate for your valuable comment. We have investigated the ULS thickness distribution of three sites (excluding open water) following your comments and find that the modal and mean thickness of all distributions agree with each other well and usually present a little lower than the modal ice thickness. Therefore, we think the mean ice thickness of ULS can represent the dominant ice thickness condition during the study period.



RFig. 2: Probability distribution function of the daily ULS SIT excluding open water. The dashed lines indicate the mean ice thicknesses. The bin size is 0.1 m and the probability distribution is normalized.

4. Fig1: Some indication about the uncertainty of the reflectance horizon in Envisat radar signals should be included. I.e., Willatt et al. (2010): "The authors suggest that one reason for this is that the radar does not always penetrate to the snow/ice interface but sometimes to somewhere between the air/snow and snow/ice interfaces. The range resolution of satellite radar altimeters is not sufficient to resolve layers within the snow pack."

   Response: Thank you for your comment. We have added the information about the penetration uncertainty in Fig. 1.



RFig. 3: An illustration of measuring freeboard using ICESat and Envisat, and the ULS measurement principle. Noted that radar altimeter on Envisat usually penetrates to somewhere between the air/snow and snow/ice interfaces (Willatt et al., 2010).

5. Colourbars for Fig 4 - 6 should share the same max/min bounds for "SIT" and the "Difference".
   Response: Thank you for your comment. We have unified the bounds for color bars in Fig. 4-6., setting 0~3 m as the "SIT" bounds and -2~2 m as the "Difference" bounds.

Responses to referee #1

Dear Reviewer:

We would like to express our gratitude to you for the helpful comments to improve this manuscript. We have modified the spatial pairing between Envisat and ICESat SIT by showing grid cells where both products have valid values. Besides, we have replaced the FDD analyses by the freeboard and snow depth changes during MJON. We also added a sensitivity analysis of ICESat SIT to sea ice density. The specific responses and revisions are shown below. They are in blue font for clarity.

Qinghua Yang and Qian Shi
On behalf of all the authors

1. L118-122: Both, the ATBD as well as the CRDP data set description state that the snow depth climatology is based on AMSR-E and AMSR2 data. You might ask your co-authors from AWI who have been part of the CCI project for this information. Therefore, you should correct your wording accordingly.
   Response: Thank you for pointing this out and we are sorry for making the mistake. We have checked the description of dataset and corrected the sentence as: "This snow depth climatology is derived from the passive microwave sensor Advanced Microwave Scanning Radiometer-EOS/2 (AMSR-E, 2002-2011; AMSR2, 2012-2017) and is based on a revised approach with different tie point retrieval plus addition of retrieval errors and provided by the Integrated Climate Data Center (ICDC)." *(please see P4-5 line 121-124 in the revised manuscript)*

2. L163-165: I recommend that you explain this in more detail, because ERA-5 reanalysis temperatures are available at a specific temporal sampling (hourly, 3-hourly, 6-hourly, daily?) and you need to explain which temporal resolution applies and how you computed the FDD from presumably sub-daily resolution air-temperatures.
   Response: Thank you for your comments. We used daily average temperature fields from ERA-5 to calculate the FDD values because the definition is based on daily resolution. Albeit too simple, FDD shows how cold it has been and how long it has been cold. However, according to your suggestions, we have decided to remove the FDD parts and focus on the intercomparison between Envisat and ICESat since the results of FDD cannot explain the reason for the differences.

3. L167: "we add sea ice motion data and convert it to a dynamic FDD" --> This has to be explained in more detail. It is not clear how you derive this dynamic FDD. You should invest a paragraph describing what you did. How did you, in particular, cope with divergent or convergent situations?
   In addition, in my view, the motivation you wrote in L166 (snowfall, freezing rain,

ridging) to carry out this forward advection of grid cells having a specific FDD does not match with what you did. All you take into account here is that the sea ice is moving. While being at a certain location at day 1 it will be at a different location at day 2 and hence may experience a different forcing by the air temperature. With your approach you don't take into account any of the mentioned processes that could also be responsible for a SIT change. Hence, the resulting FDD field or distribution might be more realistic than a FDD field without advection but not for the reasons laid out. Still you only take into account thermodynamic ice growth. Please correct your writing accordingly.

Response: We gratefully appreciate for your comment.

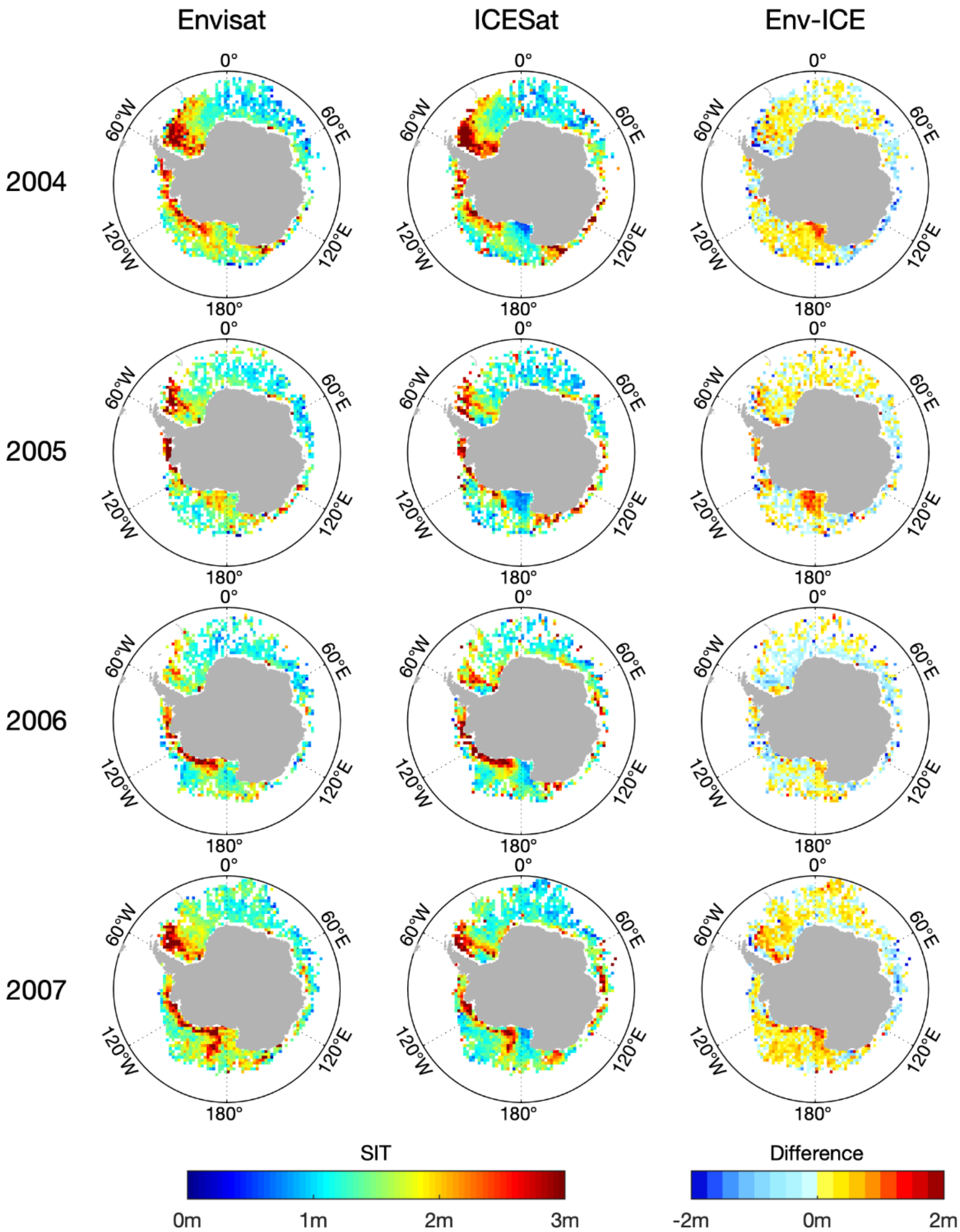
(1) Our procedures on deriving dynamic FDD are listed as follows: a. On Day1, the historical FDD and the newly increased FDD are interpolated to the regular NSIDC ice velocity grid position (X1, Y1); b. Accumulated FDD moves to irregular positions (X2, Y2) with sea ice motion derived from NSIDC v4; c. At the beginning of Day2, the FDD distribution of the irregular Day1 is interpolated to the regular grid (X1, Y1), then repeating steps 1-3. The divergent and convergent situations cannot be represented through our method, which might have impacts on the FDD changes in western Weddell Sea and Amundsen-Bellingshausen Seas.

(2) We agree with your assessment that we only improve spatial distribution of the thermodynamic growth and we apologize for our incorrect descriptions. What we should say is: “In order to achieve a more realistic FDD field with advection, we convert it to a dynamic FDD.” However, according to your suggestions, we have decided to remove the FDD parts.

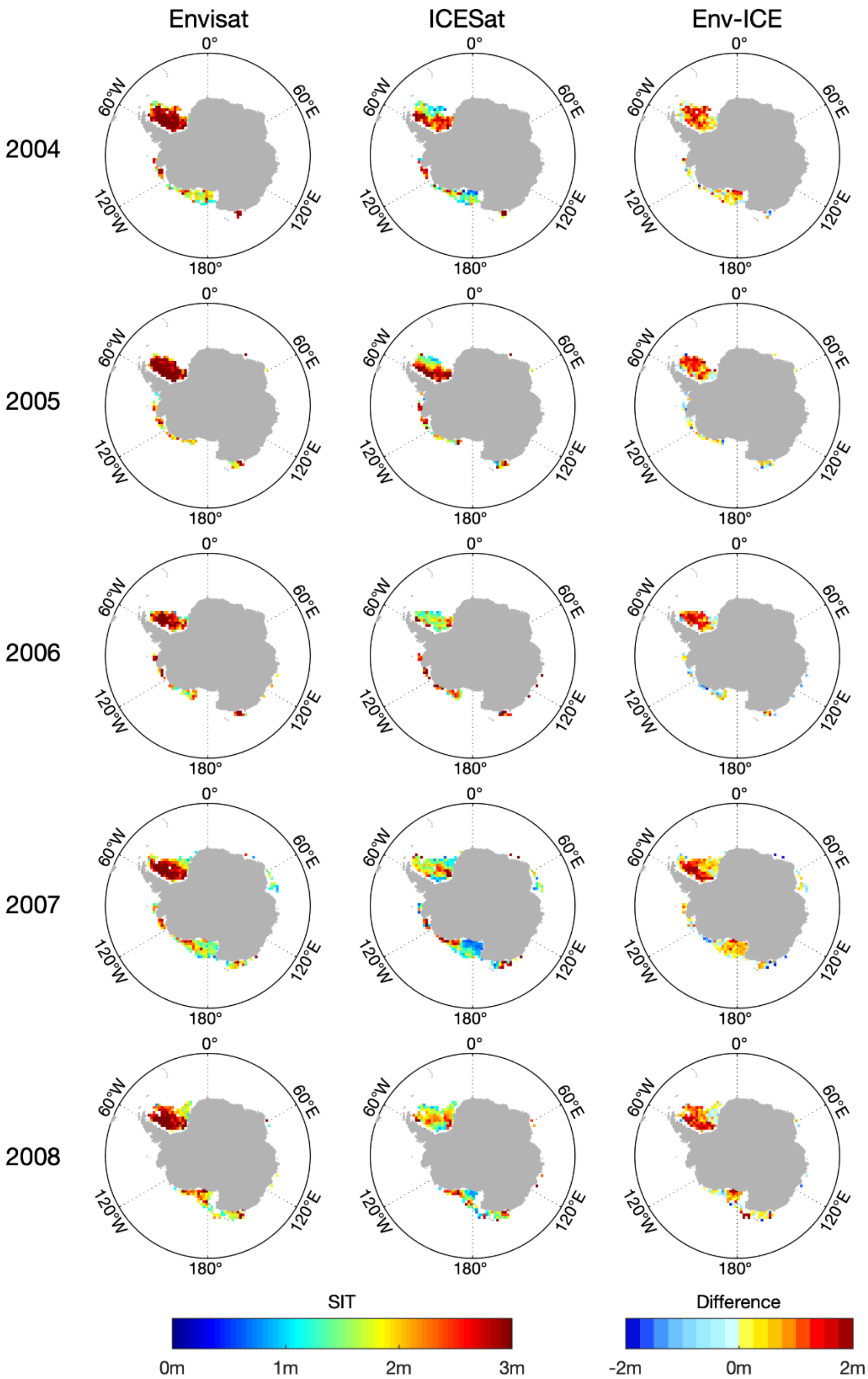
4. L170-172: The areas covered by the sea ice differ substantially between the seasons. Did you carry out the comparison only for those parts of the sea-ice covered regions where you have valid SIT (or FDD) data in both seasons? Or do you derive, for instance, a mean FM SIT and a mean MJ SIT (regardless of the sea-ice cover) and compute the difference from these values. Please be more specific in the description of the methodology.

   Response: Thank you for your careful reading and we are sorry for not clarifying the comparison method. We conduct the comparisons for the ice-covered regions where valid SIT exist in both seasons during FMMJ and MJON. Although we didn’t show the same coverage for Envisat and ICESat/FDD in Fig. 8, we calculate the statistical values for the same coverage in Table. 6. Our methodology should be described as: “We compare the dynamic FDD with the SIT variations from February/March to May/June (FMMJ) and from May/June-October/November (MJON) represented by Envisat and ICESat SIT. Specifically, FMMJ represents the differences that mean FDD/Envisat SIT/ICESat SIT in MJ minus that in FM consistent with ICESat operating periods and so does MJON. <u>The comparisons are conducted for the same coverage where all three products have valid SIT difference values.</u>” However, according to your suggestions, we have decided to remove the FDD parts.

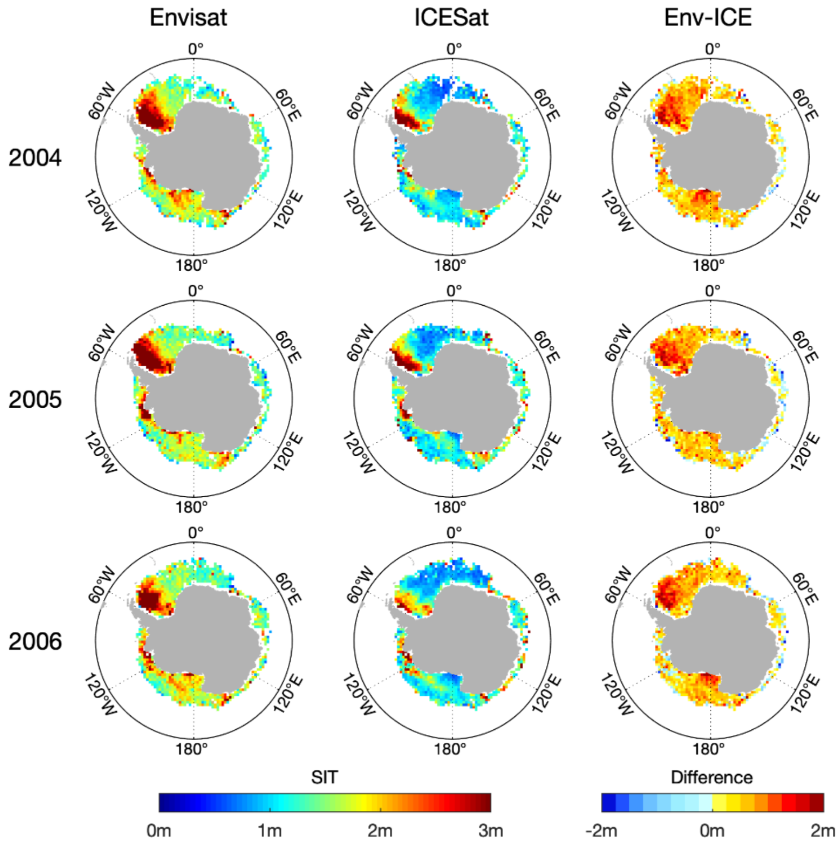
5. L181/182: I keep my notion of my previous review that it is confusing to see that basically all Envisat SIT maps show a sea ice coverage that corresponds to the maximum sea ice cover of the two months considered. I can understand that you don't want to redo the maps but particularly for summer this seems to be very recommendable in order to avoid further misleading comments such as the one in Lines 254-256 wherein you state that ICESat SIT maps of summers 2005 and 2006 don't show sea ice in the Ross Sea because the SIC is below 60% while Envisat detects sea ice (even though the threshold used is 70%). This is misleading.
   Therefore: Please redo Figures 4 to 6, showing Envisat SIT values only for those grid cells where ICESat also shows SIT values - similar to the spatial distribution of the difference map - and only take those values in the computation of the statistics.
   Response: We appreciate your kind suggestions and we have amended the Figures 4 to 6 accordingly as follows. Besides, we have also amended the descriptions of comparison method here: "It is noted that this approach can lead to considerably larger coverage of Envisat SIT data than ICESat, thus we only show grid cells where both Envisat and ICESat have valid SIT and only take those values in the statistical computation." *(please see P6 line 170-172 in the revised manuscript)*



RFig. 1: Comparisons of Envisat versus ICESat sea ice thickness for each ICESat operating period in spring (October & November). The first and second columns show the sea ice thickness distribution of Envisat and ICESat respectively, and the last column shows the difference field (Envisat minus ICESat) of sea ice thickness. Each row represents a year from 2004 to 2007. The maps are all interpolated onto the polar-stereographic grid of the ICESat product and only show grid cells where both data have valid SIT. The white cells denote sea ice concentration less than threshold or missing data.



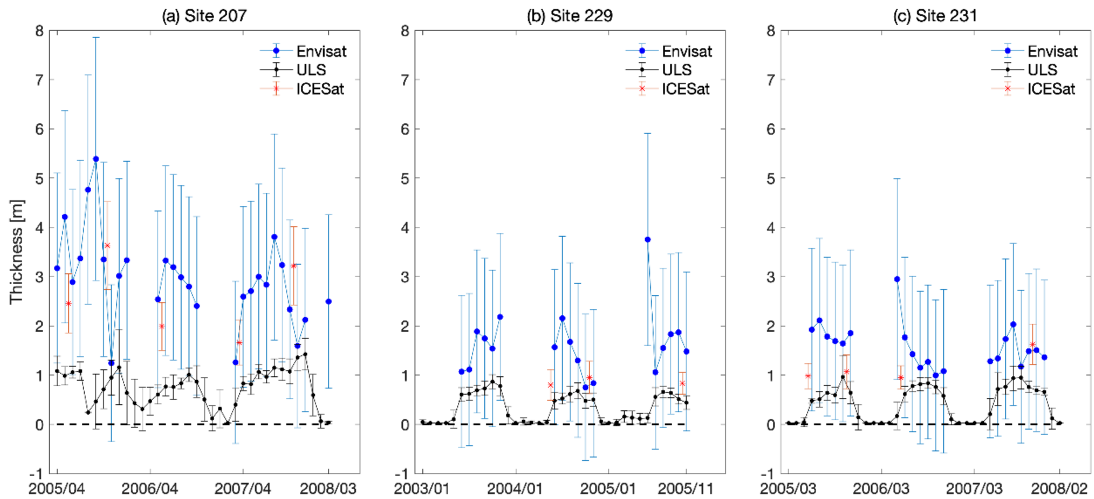
RFig. 2: Same as RFig. 1 but for summer (February & March).



RFig. 3: Same as RFig. 1 but for autumn (May & June).

6. L204 / Fig. 3: I am certainly a fan of error bars. But you can simply delete those for the ULS data because i) the spatial scales are so different that it does not make sense to add ULS SIT error bars, ii) "following Belter et al. (2020)" is likely not the right thing to do (and cite) here because that paper is using different instruments and a different geographic region (Arctic, Laptev Sea). You need to figure out what is written inside the 3 or 4 papers related to the ULS measurements in the Weddell Sea. One solution to obtain a more reasonable ULS SIT error bar could be the compute the standard deviation of the SIT at the mooring location recorded over the period of the respective months.

   Response: We appreciate for your comment. We have calculated the standard deviations of the ULS SIT for each month as the error bars since no uncertainty values are given in former studies on Weddell ULS. Therefore, we amended the descriptions to: "We also add the ULS error bars by calculating SDs of the ULS SIT for each month." *(please see P7 line 195 in the revised manuscript)*



RFig. 4: Time series of sea ice thickness and their uncertainties for the Weddell Sea ULS data, Envisat and ICESat. The numbers on the top represent the location of each site for the comparisons. The site locations can be searched in Fig. 2. ICESat SIT values are placed between the two months that each period covers. The error bars of ULS thickness are the standard deviations of daily ULS SIT in each comparison period.

7. L205/206: From what you know about sea-ice conditions in the western Weddell Sea: Do you believe that these SIT values are reasonable? In addition: Please make a comment why you don't observe a clear seasonal cycle at this location.
   Response: Thank you for your comments.
   (1) Williams et al. (2015) compared the ULS data at site 207 with autonomous underwater vehicles (AUV) data in November 2010. Their Fig. 2b shows that a large proportion of thin ice and undeformed ice exist in the northwestern Weddell Sea, having modal drafts of 1.2–1.5 m. Therefore, although this site is located in the western Weddell Sea, the existence of thin ice ranging between 0 and 1.5 m are reasonable.
   (2) This site is located at the boundary between first-year ice to the east and predominantly multiyear ice to the west and the sea ice here are experiencing strong motion due to Weddell Gyre. According to the large SDs of ULS SIT which is an indication of large sea ice temporal variability, we think that a mixture of deformed and undeformed sea ice is the main reason for the lack of seasonal cycle at this location. Therefore, we have amended this sentence as: "In the western Weddell Sea along the coast of the Antarctic Peninsula (at site 207), the ULS thickness ranges between 0 and 1.5 m, <u>without a clear seasonal cycle due to a mixture of deformed and undeformed sea ice (Williams et al., 2015).</u>" *(please see P7 line 196-198 in the revised manuscript)*

8. L208/209: "ICESat thickness ... exceeds ... ICESat has a few overestimations ..." --> What is missing here is the notion that the ICESat SIT is the total SIT and hence

includes the snow depth. Given typical snow depths on sea ice in the two regions considered it appears reasonable to assume that particularly at site 207 the "true" ICESat SIT would be considerably (by 30-40cm - depending on the season of course) smaller than the total ice thickness. While you do not need to speculate about the actual difference it is important to make the statement that ICESat is the total thickness.

Response: Thank you for your careful check and we have added a sentence here to point out this problem: "Noted that the realistic ICESat SIT would be considerably smaller due to the retrieval method mentioned in Sect. 2.2, about 0.2–0.4 m at site 207 and 0.15–0.3 m at site 229/231 depending on the seasons (Fig. S3)." *(please see P7 line 201-203 in the revised manuscript)*

9. L229-231: These lines require more writing and more explanations. Please write explicitly in the paper how you computed the region from within during the period of one month sea ice arrives at the respective ULS. You need to explain how you did carry out this computation and how you end up with your number of 100 km. You also need to justify why doing this computation for one sample month is representative for the entire period of overlap between ULS and satellite SIT data.

   I note that the blue data points for the ULS moorings along the Greenwich Meridian are located to the southwest of the ULS locations and hence NOT upstream but off the track - in contrast to the blue points for the ULS near the Antarctic Peninsula which are located upstream. To me this figure (S1) provides not a credible justification for your approach.

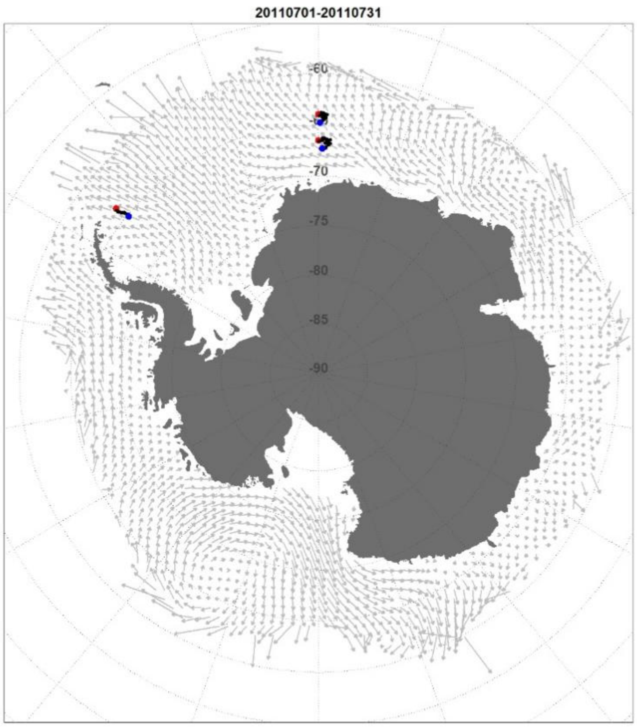
   Then you write "proves the heterogenity of the sea ice measured by each ULS" --> I don't understand what you want to stress here. I don't see any heterogenity in SIT given the location of the blue dots in Figure S1. Certainly it is not a proof. Also, "proves ... the validity of ULS data usage in comparison with satellite products" is not a credible statement given how Figure S1 looks like and given the fact that you did not describe adequately what you did. This must be improved.

   Response: Thanks for your careful check.

   (1) In Figure S1, we plot the locations after 30-days backtracking of sea ice at the ULS sites for the period from July 2 to July 31 and the background monthly sea ice motion (from July 1 to July 30) only corresponding to the data in July 31. Here, we present the complete trace (black dots) for the period from July 2 to July 31 (RFig. 5) and they are consistent with the monthly mean sea ice motion field, though the trace presents high variation. So, other blue dots seem not consistent with the sea ice motion because the time doesn't match.

   (2) The "heterogeneity" indeed made reader confused. We want to emphasize that though the footprint of ULS is smaller than Envisat and ICESat, continuous ULS observations can still represent the sea ice thickness over a large area due to its continuous sampling and irregular sea ice motion. In a sense, ULS sampling can be analogized to randomly drilling in a range of sea ice cover. In

order to make our explanation clearer, we amended the statement as: “With the sea ice motion data from NSIDC introduced in Sect. 2.4, the 30-day origins of the sea ice passing the three ULS sites from July 2 to July 31, 2011 is shown in Fig. S1 and it is spatially representative”. *(please see P8 line 222-223 in the revised manuscript)*



RFig. 5: 30-days backtracking of sea ice at the ULS sites for the period from July 2 to July 31.

10. L232: As written in the context of Section 2.5 I ask you to redo figures 4 to 6 to avoid confusion and misleading statements about the different coverage with valid data (see L254-256).
    Response: Thank you for your valuable suggestion. We have reproduced figures 4 to 6 (please see our answers for Comment #5) and amended the statements about the SIT differences in the Ross Ice Shelf polynya carefully (please see our answers for Comment #13).

11. L241/242: "Deformed sea ice along the coast ..." --> How do you know this sea ice is deformed?
    "but thicker than ..." --> How did you compare the data? The Worby et al data set ends in March 2005. So, is this statement related to ship-based observations of months October and November from the entire Worby et al data set basically BEFORE your time period of investigation? Please either be more specific about what you did to arrive at this statement or delete it.
    Response: Thank you for your valuable suggestions.
    (1) We are sorry for using an inappropriate word here and we have replaced

"Deformed sea ice" with "Thick sea ice". *(please see P8 line 233 in the revised manuscript)*

(2) We compared the SIT in the western Pacific Ocean from both satellites with ship-based observations in 2004 spring achieved by *Aurora Australis* and we have clarified the comparison following your comment: "……but their mean SIT in 2004 are thicker than the ship-based observations (0.63 m; Worby et al., 2008a)." *(please see P8 line 233-234 in the revised manuscript)*

12. L250/251: It is not clear how you derived the statistics. Does that mean that in order to obtain a seasonal mean SIT value, valid SIT values need to be available in the ICESat-measurement-period-mean maps (shown in Figs. 4 to 6) for all 3 years in fall, at least 3 of 4 years in spring and at least 3 of 5 years in summer? How many grid cells are used to compute the seasonal mean values then?

ICESat has more data gaps than Envisat. Do you compute the seasonal mean values only from grid cells where BOTH data sets are available and fulfil the condition just mentioned above?

Response: Thank you for your careful check.

(1) Yes, we only used grid cells if valid SIT values are available for all 3 years in fall, at least 3 of 4 years in spring and at least 3 of 5 years in summer. The numbers of grid cells used in the calculation are listed in the last column in Table. 5 and also listed below.

Season	N
Summer (FM)	170
Autumn (MJ)	735
Autumn (MJ)	886

(2) Yes, we computed the seasonal mean values only from grid cells where both data sets are available.

To clarify the statistical method, we have amended the description here: "Note that in order to obtain the seasonal mean SIT, we compute the seasonal mean SIT only from grid cells where values are available from both data sets and available for all 3 years in autumn, at least 3 of 4 years in spring and at least 3 of 5 years in summer. The numbers of grid cells used in the calculation are listed in the last column in Table. 5." *(please see P9 line 243-246 in the revised manuscript)*

13. L254-256: As mentioned earlier, the fact that the Envisat SIT maps show values in 2005 & 2006 where ICESat doesn't, is not caused by the fact that ICESat cuts off the retrieval at 60 % (Actually, Envisat does so already at 70% so that, in principle, ICESat should show more SIT values than Envisat) but is the result of the way how you constructed these SIT maps. All Envisat SIT maps shown in Figs. 4 to 6 show the maximum sea ice cover of the two months considered.

Response: We gratefully appreciate for your valuable comment. We are sorry for incorrectly explaining the reasons for the SIT differences in the Ross Ice Shelf polynya. The SIT differences in that region mainly come from the way we construct our time-weighted SIT maps because we considered all valid SIT data from both months. Therefore, we have amended the statements as follows: "As for the Ross Ice Shelf polynya, ICESat displays thin ice lower than 1 m in 2004, 2007 and 2008, while Envisat detects sea ice of up to 1.5 m, much larger than expected seasonal ice thickness." *(please see P9 line 249-250 in the revised manuscript)*

14. L266: Looking back at the these three paragraphs I did not find any notion that the ICESat SIT values compared here denote the total thickness, hence include snow depth.
    Response: Thank you for your careful check. We are sorry for missing this point in the analyses and we have complemented the information in the manuscript following your comments:
    "However, these differences have to be seen in the light of the large SDs (~0.6 m) and the fact that ICESat SIT values include the snow depth." *(please see P9 line 241-242 in the revised manuscript)*
    "Considering the ICESat SIT excluding snow depth, the real differences should be larger." *(please see P9 line 252-253 in the revised manuscript)*

15. L272-274: As it is not entirely clear from Figs. 4 to 6 how you did compute these values I ask you to one more time provide the information whether both data sets presented here, i.e. Envisat mean SIT and ICESat mean SIT are based on the same number of identical grid cells.
    In addition I find it worthwile to add the information that for Envisat in addition to the mean SIT also the modal SIT decreases from autumn to spring.
    Response: Thank you for your comments.
    (1) Yes, both Envisat and ICESat mean SIT presented here are based on the same number of identical grid cells and we have added this in the manuscript: "To investigate the development of two SIT data from the end of melting to end of freezing, we provide the probability distribution of the Envisat SIT and the ICESat SIT for all the valid individual comparison pairs <u>where both Envisat and ICESat have valid SIT</u>, shown in Fig. 7." *(please see P9 line 262-264 in the revised manuscript)*
    (2) We have added the information that Envisat modal SIT decreases from autumn to spring. We amended the sentence as: "In addition, we find that ICESat mean SIT increases while Envisat mean and modal SIT decreases from autumn to spring." *(please see P9 line 267-268 in the revised manuscript)*

16. L325-327: Please confirm from these two papers by Nandan et al. that both the season as well as the type of ice for which this bias in CS2 sea-ice freeboard is suggested, match Antarctic conditions discussed in your paper. I am wondering whether particularly during Antarctic summer sea ice and snow conditions are not completely different from those touched upon in the two cited papers.
    Response: Thank you for your comments. These two papers focus on the role of **saline snow** on first-year sea ice (FYI) in late winter (April and May) from 2004 to

2017. This condition is more consistent with our **autumn** Antarctic conditions with large-scale FYI. Meanwhile, former studies reporting radar altimeter reflection biases (e.g., Massom et al., 1997; Willatt et al., 2010; Kwok and Kacimi, 2018; Kacimi and Kwok, 2020) conducted their experiments in autumn and winter, leaving the potential biases in summer unsolved. Haas et al. (2001) showed that summer snow salinities are significantly lower than measurements in other seasons, mostly below 0.1‰, but the wetness is high at the snow bottom. Liquid water content is sufficient to dominate the snow dielectric properties (Barber et al., 1995). Therefore, we amended and complemented the discussion accordingly: "For typical sea ice freeboard biases caused by saline snow (7 cm for the Arctic nominal adjustment for first-year ice suggested by Nandan et al. (2017, 2020)), the sea ice density variations induce the thickness changes ranging from ~0.5 m to ~0.8 m. This could potentially account for the differences between Envisat and ICESat SIT in autumn (0.57 m). Therefore, we assume that in autumn freeboard-biases-induced SIT changes happen frequently. In summer, when snow salinities are significantly lower than measurements in other seasons (mostly below 0.1‰) but the wetness is high at the snow bottom (Haas et al., 2001), the freeboard biases also matters because liquid water content affects the snow dielectric properties (Barber et al., 1995). Besides, based on previous studies (Willatt et al., 2010; Kwok and Kacimi, 2018; Kacimi and Kwok, 2020), the displacements of radar retracking points and thus the freeboard biases are significant in spring. Considering the small differences between Envisat and ICESat SIT, we suggest that underestimations of snow depth and biases in ICESat total thickness might play an important role in spring. However, detailed sensitivity discussions are limited due to lack of seasonal and regional sea ice density and adjustments to sea ice freeboard." *(please see P11-12 line 323-333 in the revised manuscript)*

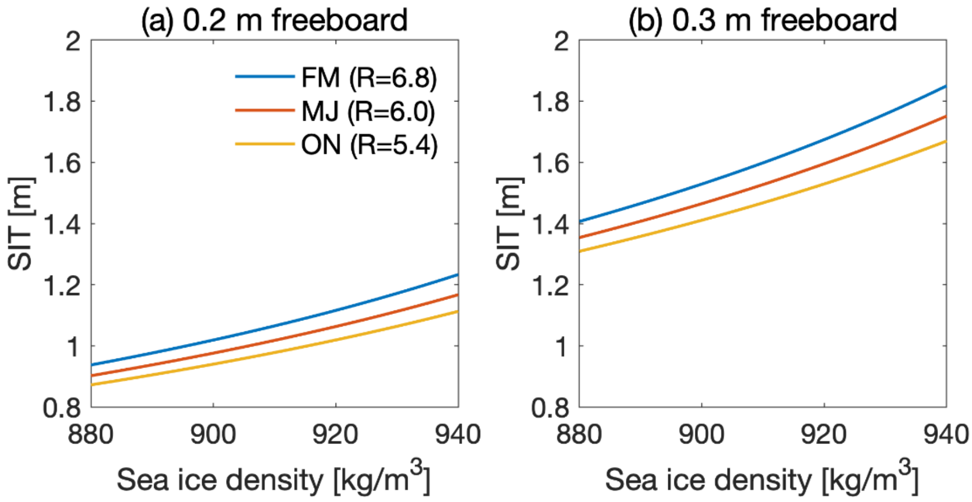
17. L337-342: I am not sure the lead detection capability is really the relevant issue here. As you write, the specular reflection of the radar signal over a smooth lead can be quite effective and the lead detection is possibly not that bad - it is worse though for Envisat than for CS-2. More problematic might be reflections from off-nadir leads which are not of a problem for ICESat but have considerable potential to cause elevation biases for radar altimeters such as the Envisat RA-2. I would not call this "over-representation" or leads, though. Note that for ICESat the lead detection is a combination of low albedo and low elevation. Hence, in short, I recommend to give your argumentation more weight into the direction of surface type mixing and, as described by Tilling et al., the preferential sampling of large (and hence comparably thick) ice floes that applies to Envisat RA-2.
What I am missing in Section 4.1 are considerations towards the sensitivity of the ICESat total freeboard with respect to variations in sea-ice density (and additional parameters?) You might want to put this into section 4.3.
Response: We gratefully appreciate for your valuable comment.
(1) We have rephrased the term "lead detection skill" to "lead surface response" and expanded the description in the paragraph to improve the explanation how

the laser and radar altimeter characteristics differ over lead surfaces. Our point is that a single lead may dominate the radar backscatter for several consecutive Envisat footprint and thus indeed result in an overrepresentation of leads in Envisat waveform data.

The preferential sampling of large and comparable thick floes in Envisat data described in Tilling et al., is not a physical characteristic of pulse-limited radar altimetry, which preferentially samples high backscatter targets. It rather needs to be understood as a matter of specific surface type classification and filtering algorithms designed to exclude off-nadir returns in the freeboard retrieval. The Envisat retrieval algorithm in Tilling et al. differs from the one in the CCI sea ice project and thus the finding may not be directly applicable to our results.

Therefore, we amended the statements as: "While this is also directly applicable to radar altimeters with different footprints, the response to lead surfaces of laser (ICESat) and radar (Envisat) altimeters is not directly a function of footprint size but also of altimeter concept. Leads dominate radar backscatter even if the leads are already covered by thin sea ice for nadir and off-nadir cases and thus cause an overrepresentation of lead detections with range biases for off-nadir leads in Envisat data. Off-nadir reflections are usually detected and removed from the freeboard retrieval resulting in an underrepresentation of areas with mixed surface types in the Envisat freeboard statistics. Lead laser backscatter instead is a function of the surface albedo thus leads return lower laser backscatter power and since ICESat footprints do not overlap, the lead oversampling and necessary filtering of off-nadir reflections is not an issue for laser altimetry. For variable ice surfaces, the smaller footprint of ICESat has the capability to provide more detailed observations in areas with heterogeneous ice conditions than the pulse-limited Envisat footprint." *(please see P12 line 340-349 in the revised manuscript)*

(2) We have added a sensitivity discussion of ICESat total freeboard with respect to variations in sea-ice density in section 4.3. We set ρ_{snow} = 300 kg m^{-3}, R = 6.8(FM), 6.0(MJ), 5.4(ON), freeboard = 0.2/0.3m, and sea ice density ranging from 880 to 940 kg m^{-3} to analyse the sensitivity (RFig. 6). Therefore, we stated the results as: "We analyse the sensitivity of ICESat SIT to sea ice density and find an increase of ~0.2–0.4 m SIT when sea ice density rises from 880 to 940 kg m^{-3} under seasonal R values and total freeboard." *(please see P14 line 418-419 in the revised manuscript)*



RFig. 6: Sensitivity of ICESat SIT to sea ice density under different total freeboard and R values.

18. L376-377: I don't understand which AMSR-E data set is used here. Please provide a reference and describe in more detail how this data was obtained (daily / monthly) and what you did to compute the SIT shown in Fig. S2.
    Response: Accepted and corrected. We have clarified the source and computing method of AMSR-E snow depth in the text as: "To further quantify the differences between snow depth climatology and actual snow depth contributions, we conduct the retrieval of Envisat SIT by replacing the snow depth climatology with monthly SICCI AMSR-E snow depth provided by SICCI (Kern et al., 2015). The new Envisat SIT is converted through Eq. (1) with Envisat monthly gridded sea ice freeboard data, monthly AMSR-E snow depth and the same density values mentioned above. The new Envisat SIT is compared with ICESat SIT and the changes to former Envisat-ICESat differences are shown in Table. S1." *(please see P13 line 382-386 in the revised manuscript)*

19. L392-393: I am not sure I understand why you add snow depth to an assumingly correct product (Envisat) instead of subtracting the snow depth from the ICESat total SIT. This would be much more straightforward and - in my eyes - the more correct thing to do. Please change this issue accordingly by computing a new Fig. S3 and changing the text accordingly.
    Response: Accepted and corrected. We have changed our comparison method following your suggestion and turned the heatmap to tables following another referee's comment. We have amended the description as: "To examine this issue, we subtract the snow depth climatology (used in Envisat retrieval) from the ICESat data and compare them with Envisat thickness. The changes to the former differences are shown in Table. S2, which is also a representation of the snow depth climatology itself." *(please see P14 line 406-408 in the revised manuscript)*

RTable. 1 Changes to the differences that Envisat minus ICESat SIT for each comparison period and each region by subtracting snow depth climatology (used in Envisat retrieval) from ICESat SIT. (Unit: m)

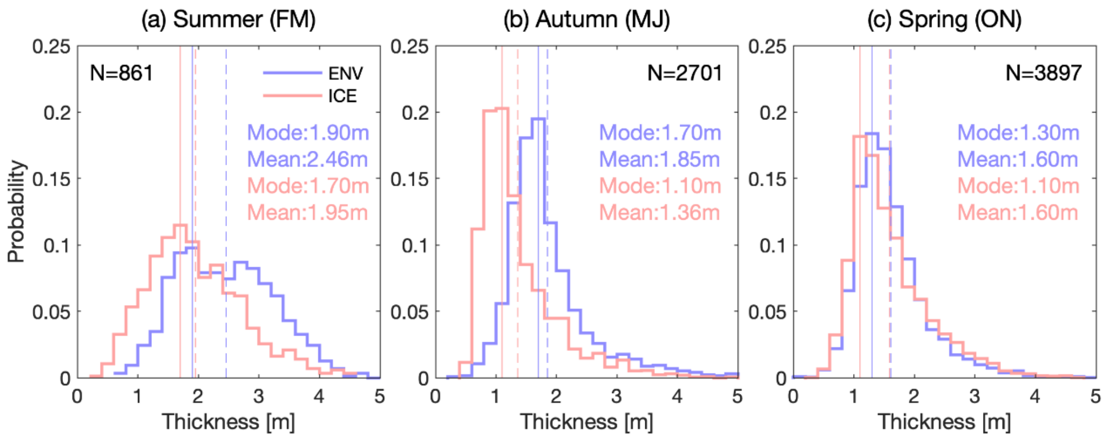
	ABS	WW	EW	EA	RS
FM04	0.31	0.42	0.35	0.28	0.24
FM05	0.32	0.44	0.38	0.27	0.23
FM06	0.31	0.44	0.35	0.24	0.22
FM07	0.23	0.40	0.28	0.18	0.13
FM08	NAN	0.45	0.34	0.26	0.22
MJ04	0.17	0.35	0.20	0.12	0.15
MJ05	0.17	0.35	0.21	0.12	0.15
MJ06	0.18	0.36	0.20	0.12	0.15
ON04	0.20	0.23	0.17	0.12	0.17
ON05	0.20	0.22	0.17	0.12	0.16
ON06	0.19	0.21	0.16	0.12	0.16
ON07	0.19	0.24	0.17	0.12	0.18

20. L398-400: The work of Li et al. is a substantial enhancement of the approach proposed in Kern et al. (2016). I see less a problem in their attempt to justify and evaluate their approach with comparably old in-situ observations than in combining two ICESat approaches making assumptions that kind of exclude their parallel usage. The Kern and Ozsoy-Cicek 2016 snow depth from ICESat approach assumes, in a way, that the sea-ice freeboard is more or less zero and that the total freeboard measured by ICESat is a reasonably good measure of the snow depth on sea ice. In contrast, the Kern et al. 2016 approach very well considers that there are non-zero sea-ice freeboards. But this is of course not your issue here. I would say it does not harm to delete this "in addition ... as well." sentence.
    Response: Accepted and corrected. We have removed this statement following your suggestion.

21. L401-403: What you write here is not entirely correct. The procedure that is used in the ICESat retrieval to approaximate the SSH is not necessarily influenced by the geoid or the SSH itself - the latter is approximated from residuals which are already void of a geoid influence.
    Also, as Kern and Spreen (2015) is the work published earlier, I doubt that "Consequently" is the right beginning of the second sentence here. I suggest to read these two papers once again, to perhaps also read Kern et al., The Cryosphere, 2015, and then come up with a more elaborated estimation of the uncertainties and/or sensitivities of the ICESat SIT product used - including statements about the sensitivity to densities.
    Response: Accepted and corrected. We gratefully appreciate for your comment and these paper articles inspire us a lot. We have corrected our statements and modified the discussion of ICESat SIT uncertainties as: "Apart from the uncertainties from ICESat retrieval method mentioned above, Kern et al. (2016) also discussed the potential biases due to total freeboard and sea ice density. In comparison with the freeboard from Kurtz and Markus (2012), modal and mean total freeboard values

of this product are slightly higher, which might be a potential source of SIT positive biases. The total freeboard retrieved from ICESat has an uncertainty of up to 0.1 m, mainly due to the choice of percentage of observations used as sea surface height tie points (Kern and Spreen, 2015). Meanwhile, a smaller sea ice density will lead to smaller modified ice-snow density and SIT according to Eq. (2) and Eq. (3). **We analyse the sensitivity of ICESat SIT to sea ice density and find an increase of ~0.2–0.4 m SIT when sea ice density rises from 880 to 940 kg m^{-3} under seasonal R values and total freeboard.**" *(please see P14 line 413-419 in the revised manuscript)*

22. Figure 7: Please add the number of the valid data pairs used.
Please add the used binsize. How many data are truncated by not showing values above 5 m? Is the probability shown normalized such that its sum is equal to 1?
Response: Accepted and corrected. We have modified Fig. 7 following your suggestions. Few data are truncated, 2 for summer and spring and 6 for autumn. The probability distribution is normalized and we have added this in the caption.



RFig. 7: Probability of the Envisat SIT and the ICESat SIT for all the individual comparison pairs. The blue stairs represent Envisat ice thickness and the red stairs represent ICESat ice thickness. The solid lines indicate the modal ice thickness and the dashed lines indicate the mean ice thickness of both data sets. The bin size is 0.2 m and the probability distribution is normalized.

23. L655 / Figure 8: I don't see what we can learn from this figure. The combination of SIT differences between ON and MJ periods with the "dynamic FDD" is not really enlightening, is it? Neither in this figure nor in the text in which you describe / interpret the figure solid information comes across. The FDD maps basically show where (a lot) of (new/thin) ice is produced thermodynamically and advected away from its source regions. It is your take, though.

If you decide to keep this aspect then I recommend to:

i) skip the top part with the differences between summer and autumn;

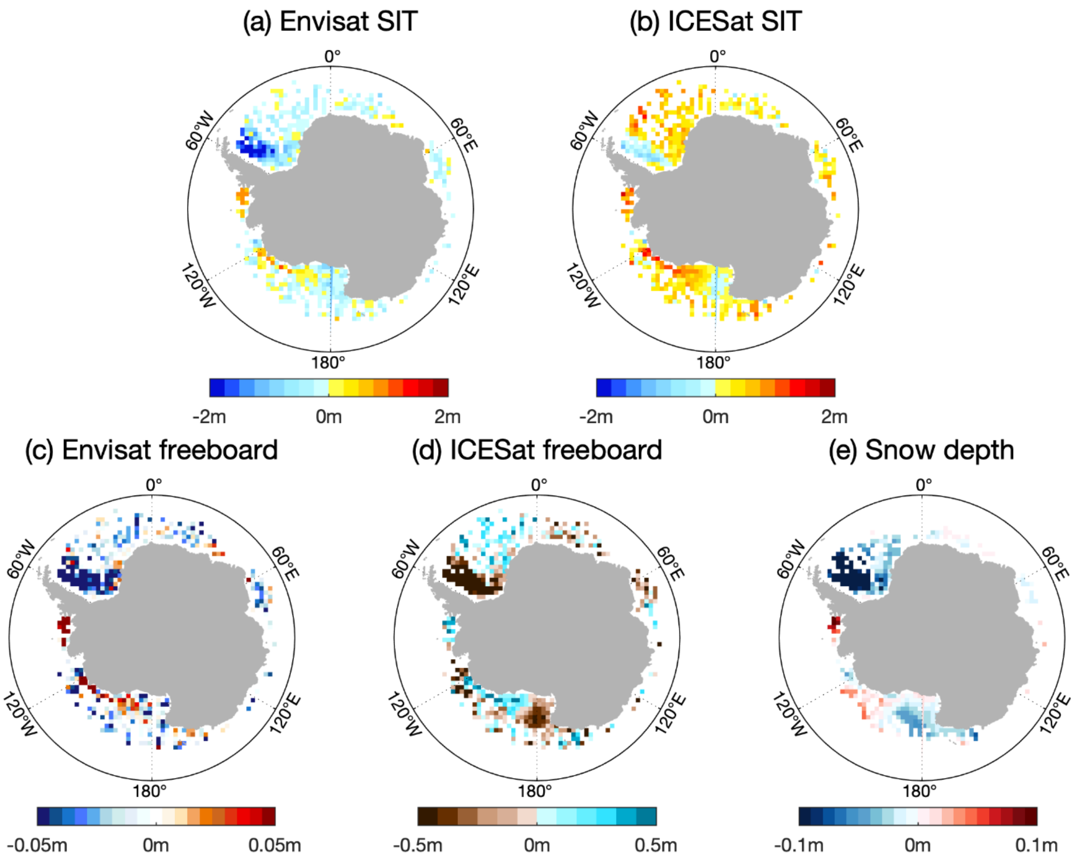
ii) make sure that the difference maps only show values where both periods' ENV-ICE maps (Fig. 4 and Fig. 6) have valid values;

iii) enlarge the maps;

iv) switch the color table of the SIT differences such that an increase in SIT gets blue colors while a decrease gets the red colors.

Response: Thank you for your comment. We have carefully considered your suggestions and agreed that this figure cannot explain the different MJON SIT changes. Therefore, we have removed this figure and analyzed the freeboard and snow depth changes from MJ to ON. Besides, for point *iv* we guess that you want the positive/negative differences to represent sea ice freezing/melting, so labelling the freezing/melting as blue and red does make it more physical. However, considering that most readers will subconsciously associate red with increase, we still want to keep the original colormap.

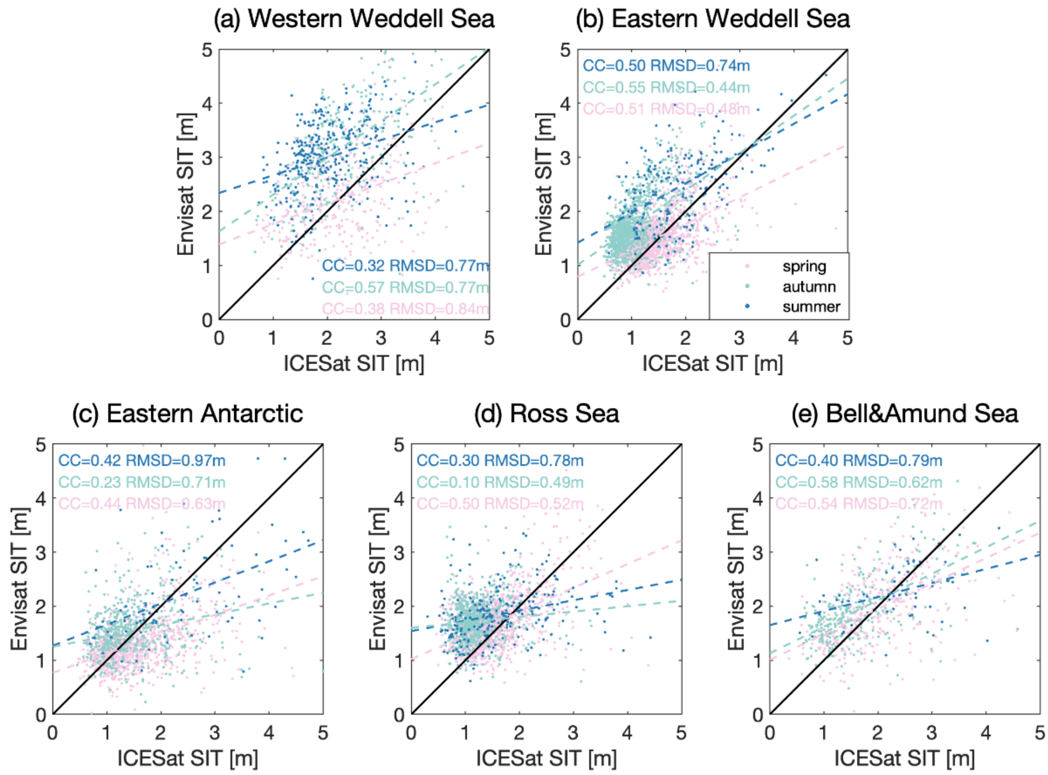
The results according to the new figure are added as follows: "Therefore, we further compare the mean variations of Envisat SIT, ICESat SIT, Envisat freeboard, ICESat freeboard and snow depth climatology used in Envisat retrieval from autumn (MJ) to spring (ON), shown in Fig. 8. The average fields are calculated with grid cells where both Envisat and ICESat SIT have valid values in all three years from 2004 to 2006. Figure 8 shows that Envisat SIT experiences general decreases from May/June-October/November (MJON) except Bellingshausen Sea and part of Amundsen Sea. Significantly large decreases exist in Western Weddell Sea. In contrast, ICESat SIT present large-scale increases except Western Weddell Sea and Ross Sea where slight decreases exist. By comparing the SIT and freeboard changes of both products, we find that the different changes of freeboard dominantly explain the SIT differences. One thing we can give a speculation based on the analyses in autumn and the regular rule during freezing seasons is that Envisat freeboard is probably overestimated in autumn, which has been pointed out in several studies before (e.g., Willatt et al., 2010; Kwok and Kacimi, 2018; Kacimi and Kwok, 2020). Moreover, the snow depth climatology also shows a decrease in Western Weddell Sea and Ross Sea (Fig. 8e), which has been reported by Kern and Ozsoy-Cicek (2016) that AMSR-E snow depth is likely to underestimate the snow depth evolution during MJON, also contribute to the Envisat SIT decrease." *(please see P9-10 line 269-281 in the revised manuscript)*



RFig. 8: The average changes of Envisat SIT, ICESat SIT, Envisat freeboard, ICESat freeboard and snow depth climatology used in Envisat retrieval from autumn to spring (MJON) calculated from 2004, 2005 and 2006.

24. Figure 9: Maybe you did this already but I recommend to use a specific order of plotting the data. I would first plot the data with the highest population, while the data (presumably summer) with the smallest population I would plot last. That way they would be visible better in the scatterplots. I also recommend to decrease the size of the symbols.

    Response: Accepted and corrected. We have modified Fig. 9 following your suggestions.



RFig. 9: Scatterplots of the individual data pairs between Envisat SIT and ICESat SIT for each region and each season. The data are taken from all seasons available. Since the comparison pairs are too few in Indian Ocean and western Pacific Ocean, we combine these two regions into Eastern Antarctic. The respective correlation coefficients and RMSDs are indicated in the panels. The black line is the 1-to-1 fit line and the dashed colored lines stand for linear regression lines.

Editoral comments / Typos:

L21-23: There is a paper by Tilling et al., JGR-Oceans, from 2019, (actually you cite that further down) which suggests preferential sampling of thicker, larger ice floes by Envisat RA-2 which, even though demonstrated in that paper for Arctic conditions, almost certainly also applies to Antarctic conditions (see e.g. Paul et al., 2018). I suggest to mention this additional bias source here in the abstract but also at the respective place within the text further below.

Response: We gratefully appreciate for your valuable suggestion. However, as what we have replied in No. 17 above, the preferential sampling of large and comparable thick floes in Envisat data described in Tilling et al., is not a physical characteristic of pulse-limited radar altimetry, which preferentially samples high backscatter targets. It rather needs to be understood as a matter of specific surface type classification and filtering algorithms designed to exclude off-nadir returns in the freeboard retrieval. The Envisat retrieval algorithm in Tilling et al. differs from the one in the CCI sea ice project and thus the finding may not be directly applicable to our results. However, we have added the biases source of sea ice density here as: "Our findings suggest that both overestimation of Envisat sea ice freeboard potentially caused by radar backscatter originating from inside the snow layer, **as well as the AMSR-E snow depth biases and sea ice density uncertainties** can possibly account for the differences between Envisat and ICESat SIT." *(please see P1 line 21-24 in the revised manuscript)*

L28: Since the Antarctic sea ice cover has been quite dynamic in recent years, I suggest to also add the paper by Parkinson and DiGirolamo, 2022, Remote Sensing of Environment, which illustrates well that Southern Ocean sea-ice coverage did not yet recover from that drop in 2015/16.

Response: According to your suggestion, we have added the information here as: "During 2016-2020, the sea ice coverage in the Southern Ocean did not recover and set eight new Antarctic monthly record lows instead (Parkinson and DiGirolamo, 2021)." *(please see P2 line 30-31 in the revised manuscript)*

L207: The Envisat SIT error bars are not trustable; these are too large. The ICESat error bars do match better what one would expect. The notion "cover few observations" in the context of the error bars is not well chosen. I recommend that you write something along the lines: "Only few ULS observations fall within the possible Envisat SIT range indicated by the error bars" ... but actually you should only write this for the ICESat data.

Response: Thank you for your comment. We have removed the statement of Envisat error bars and modified that of ICESat error bars as: "Envisat thickness exceeds ULS, with a maximum value larger than 5 m. In comparison, ICESat thickness also exceeds ULS and only few ULS observations fall within the possible ICESat SIT range indicated by the error bars." *(please see P7 line 198-200 in the revised manuscript)*

L212/213: I don't second this notion. I am sure that the data set producers did their best to take into account well characterized and quantified contributions and I am sure that you find reasonable descriptions of how the uncertainties are computed in the respective papers and reports. The mere problem I see is the mentioned correlation and the different spatial scales involved.

Response: Accepted and corrected. We have amended the sentence to: "The differences in the error bars between Envisat and ICESat mainly result from their different spatial scales, the inclusion of snow depth uncertainty and lack of adequate regards for potential correlations between the error contribution in Envisat SIT, hence making it difficult to estimate realistic uncertainties." *(please see P7 line 203-205 in the revised manuscript)*

L303: "with an extra ... product" --> "together with a snow depth climatology derived from AMSR-E and AMSR2 data"

Response: Accepted and corrected. We have amended the sentence to: "Envisat directly uses the hydrostatic equilibrium together with a snow depth climatology derived from AMSR-E and AMSR2 data". *(please see P11 line 301-302 in the revised manuscript)*

L346-348: I suggest to reformulate things here because I have the impression that you are mixing some information. While the algorithm has in fact been developed for the Antarctic originally it has later been applied to the Arctic as well. Only there it runs into problems with multiyear ice. In addition, the maximum retrievable value is not caused by the similar signature of thick snow and multiyear ice (which is a problem in general) but is due to the saturation of the signal. Above a certain snow depth there is no change in the brightness temperature gradient ratio used that can be reliably related to snow depth.

Response: Accepted and corrected. According to your comment, we have amended the description as: "According to Markus and Cavalieri (1998), their AMSR-E snow depth product is limited to the maximal retrieval value being around 50 cm because of the saturation of the signal, i.e., there is no change in the brightness temperature gradient ratio with increasing snow depth over a certain limit." *(please see P12 line 353-355 in the revised manuscript)*

L349: You might want to add "Kern and Ozsoy-Cicek, Remote Sensing, 2016" here because they kind of rounded up the problems that exist with AMSR-E snow depths over Antarctic sea ice. This might replace the report by Frost et al.

Response: Accepted and corrected. We have replaced Frost et al. (2014) with Kern and Ozsoy-Cicek (2016). *(please see P12 line 257 in the revised manuscript)*

L381-383: Please provide the reader with an idea of the significance of this correction for Antarctic conditions. Is this an impact of the same size as the one described before?

Response: Accepted and corrected. The biases of this correction are smaller than the ones described before according to Mallett et al. (2019). We have added more information about this correction: "Moreover, the distance between sea ice surface elevations and the sea surface height is computed with vacuum light speed, which is defined as radar freeboard (RFB). A geometric correction used to correct the slower wave propagation speed in the snow layer is applied to convert the radar freeboard into the sea ice freeboard (FB):

$$FB = RFB + 0.22 \times SD \tag{7}$$

But the delay correction is based on a conventional assumption that has been assessed by Mallett et al. (2019), which pointed out that it introduced systematic underestimation of up to 15 cm into SIT estimates. While this systematic bias is small compared to other sources, uncertainties of snow depths and incomplete radar wave penetration would cause larger biases in this way." *(please see P13-14 line 390-397 in the revised manuscript)*

L412-414: Albeit late I need to make the comment that there are many more ICESat SIT products available. Alone in the Kern et al. (2016) paper several are presented and discussed. In that context it might make sense to revisit that paper and check what other approaches exist, e.g. the SICCI-SIT product which uses actual AMSR-E snow depth data, or the Kurtz and Markus product which assumes zero sea-ice freeboard and takes the total freeboard as snow depth. These different products kind of span a possible range within which ICESat SIT values may be located and I recommend that you clearly state that the ICESat product you used is just ONE possible realization of many.

Response: Accepted and corrected. We have added this statement following your suggestion: "While we choose one of the ICESat SIT products to conduct the comparison, there are many other ICESat SIT products using different retrieval algorithms available, e.g., the SICCI product discriminating between positive and negative sea ice freeboard (Kern et al., 2016), or the one assuming zero sea ice freeboard in freeboard-to-thickness conversion (Kurtz and Markus, 2012). These different products provide a range of values within which ICESat SIT may be located, thus the differences between Envisat and ICESat SIT in this study are just one of the possible outcomes." *(please see P15 line 443-447 in the revised manuscript)*

References:

Barber, D. G., Reddan, S. P., and LeDrew, E. F.: Statistical characterization of the geophysical and electrical properties of snow on Landfast first-year sea ice, J. Geophys. Res., 100(C2), 2673– 2686, https://doi.org/10.1029/94JC02200, 1995.

Frost, T., Heygster, G., and Kern, S.: ANT D1.1 Passive Microwave Snow Depth on Antarctic sea ice assessment v1.0, available at: https://icdc.cen.uni-hamburg.de/fileadmin/user_upload/ESA_Sea-Ice-ECV/SICCI_ANT_SIT_Option_D1.1_Issue_1.0.pdf, 2014.

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https://doi.org/10.1109/TGRS.2009.2028237, 2010.
Williams, G., Maksym, T., Wilkinson, J., Kunz, C., Murphy, C., Kimball, P., and Singh, H.: Thick and deformed Antarctic sea ice mapped with autonomous underwater vehicles, Nature Geosci., 8, 61–67, https://doi.org/10.1038/ngeo2299, 2015.

Responses to referee #2

Dear Reviewer:

We would like to express our gratitude to you for the helpful comments to improve this manuscript. We have carefully modified the expressions following your comments. The specific responses and revisions are shown below. They are in blue font for clarity.

Qinghua Yang and Qian Shi
On behalf of all the authors

P3L77-78: Replace "ICESat-1, hereinafter ICESat" by ICESat as this the name of the mission.
Response: Accepted and corrected. According to your suggestion, we have replaced "ICESat-1, hereinafter ICESat" by "ICESat" as: "The Geoscience Laser Altimeter System (GLAS) aboard the Ice, Cloud and land Elevation Satellite (ICESat) allows estimating the total freeboard through the determination of the surface elevation from 2003 to 2009, illustrated in Fig. 1." *(please see P3 line 80-81 in the revised manuscript)*

P3L91-92: Can you specify which independent observations you are referring to?
Response: We have specified the independent observations here according to Kern et al. (2016) as: "…we choose the ICESat SIT derived from the modified density approach for comparison, which seems to agree with average SIT from independent observations **like ASPeCt, ULS and AEM** and has a reasonable winter-to-spring growth (Kern et al., 2016)." *(please see P3-4 line 93-95 in the revised manuscript)*

P4L118: Remove "cover" in snow cover.
Response: Accepted and corrected. We have changed the "snow cover" to "snow". *(please see P4 line 120 in the revised manuscript)*

P6L163: Replace "accumulative" by cumulative.
Response: Accepted and corrected. However, we have removed this sentence because according to another referee's suggestions, we have decided to remove the FDD parts and focus on the intercomparison between Envisat and ICESat since the results of FDD cannot explain the reason for the differences.

P6L166-169: Can you give more details on how the "dynamic FDD" is computed? You mention that "the NSIDC Polar Pathfinder daily 25 km EASE-grid sea ice motion data are applied to produce the forward tracking on daily FDD" but how is this implemented really? How do you link the number of freezing degree days to dynamics and ice deformation?
Response: Our procedures on deriving dynamic FDD are listed as follows: a. On Day1, the historical FDD and the newly increased FDD are interpolated to the regular NSIDC

ice velocity grid position (X1, Y1); b. Accumulated FDD moves to irregular positions (X2, Y2) with sea ice motion derived from NSIDC v4; c. At the beginning of Day2, the FDD distribution of the irregular Day1 is interpolated to the regular grid (X1, Y1), then repeating steps 1-3. The ice divergence and deformation situations cannot be represented through our method. However, according to another referee's suggestions, we have decided to remove the FDD parts and focus on the intercomparison between Envisat and ICESat since the results of FDD cannot explain the reason for the differences.

P7L174: Replace "realized in" by "done for".
Response: Accepted and corrected. We have changed the "realized in" to "done for". *(please see P6 line 164 in the revised manuscript)*

P7L189: Replace "here compare" by "compare here".
Response: Accepted and corrected. We have modified this sentence according to your next comment.

P7L189-190: Replace "We here compare Envisat and ICESat actual SIT with ULS observations, thus we divide ICESat SIT by SIC contained in the data for each grid." By "In order to compare the SIT from the two satellites with the ULS observations, we first compute the ICESat effective SIT by dividing the SIT by the SIC at each grid cell".
Response: Accepted and corrected. We have changed the original sentence to "In order to compare the SIT from the two satellites with the ULS observations, we first compute the ICESat effective SIT by dividing the SIT by the SIC at each grid cell". *(please see P7 line 179-180 in the revised manuscript)*

P8L208: Please rephrase "and the smaller error bars of ICESat also cannot cover the observations" as this is not clear.
Response: Accepted and corrected. "In comparison, ICESat thickness also exceeds ULS and only few ULS observations fall within the possible ICESat SIT range indicated by the error bars." *(please see P7 line199-200 in the revised manuscript)*

P8L215-216: Replace "largest/smallest" by either "the largest/the smallest" or "larger/smaller".
Response: Accepted and corrected. We modified the sentence to: "The statistics show that both MDs are <u>the largest</u> at site 207 (1.63 m for Envisat-ULS and 1.73 m for ICESat-ULS) and <u>the smallest</u> at site 229 (0.72 m for Envisat-ULS and 0.42 m for ICESat-ULS)." *(please see P8 line 207-209 in the revised manuscript)*

P8L229-231: The following statement seems somehow contradictory. You want to prove the validity of the ULS data for comparison with satellite measurements, yet point to the heterogeneity of the sea ice measurements at each ULS? "With the sea ice motion data from NSIDC introduced in Sect. 2.4, the 30-day origins of the sea ice passing the three ULS sites in July 2011 is shown in Fig. S1 and it proves the heterogeneity of sea ice measured by each ULS and the 230 validity of ULS data usage in comparison with satellite products."

Response: Thanks for your comment. The "heterogeneity" indeed made reader confused. We want to emphasize that though the footprint of ULS is smaller than Envisat and ICESat, continuous ULS observations can still represent the sea ice thickness over a large area due to its continuous sampling and irregular sea ice motion. In a sense, ULS sampling can be analogized to randomly drilling in a range of sea ice cover. In order to make our explanation clearer, we amended the statement as: "With the sea ice motion data from NSIDC introduced in Sect. 2.4, the 30-day origins of the sea ice passing the three ULS sites from July 2 to July 31, 2011 is shown in Fig. S1 and it is spatially representative". *(please see P8 line 222-223 in the revised manuscript)*

P9L243: Replace "ICESat maps" by "ICESat fields" here and throughout the text.

Response: Accepted and corrected. We have replaced "ICESat maps" by "ICESat fields" throughout the text. *(please see P8 line 235-236 in the revised manuscript)*

P9L246: Can you clarify the following statement: "consideration of less accurate total freeboard there". Do you mean that ICESat does not provide freeboard estimates within a certain distance of the coast because of freeboard quality requirements?

Response: Yes, and we clarified and amended the sentence as: "This can be attributed to a different land mask used in the ICESat product and consideration of lower freeboard quality there." *(please see P9 line 238-239 in the revised manuscript)*

P9L256: Replace "expectant" by expected.

Response: Accepted and corrected. We have replaced "expectant" by "expected". *(please see P9 line 250 in the revised manuscript)*

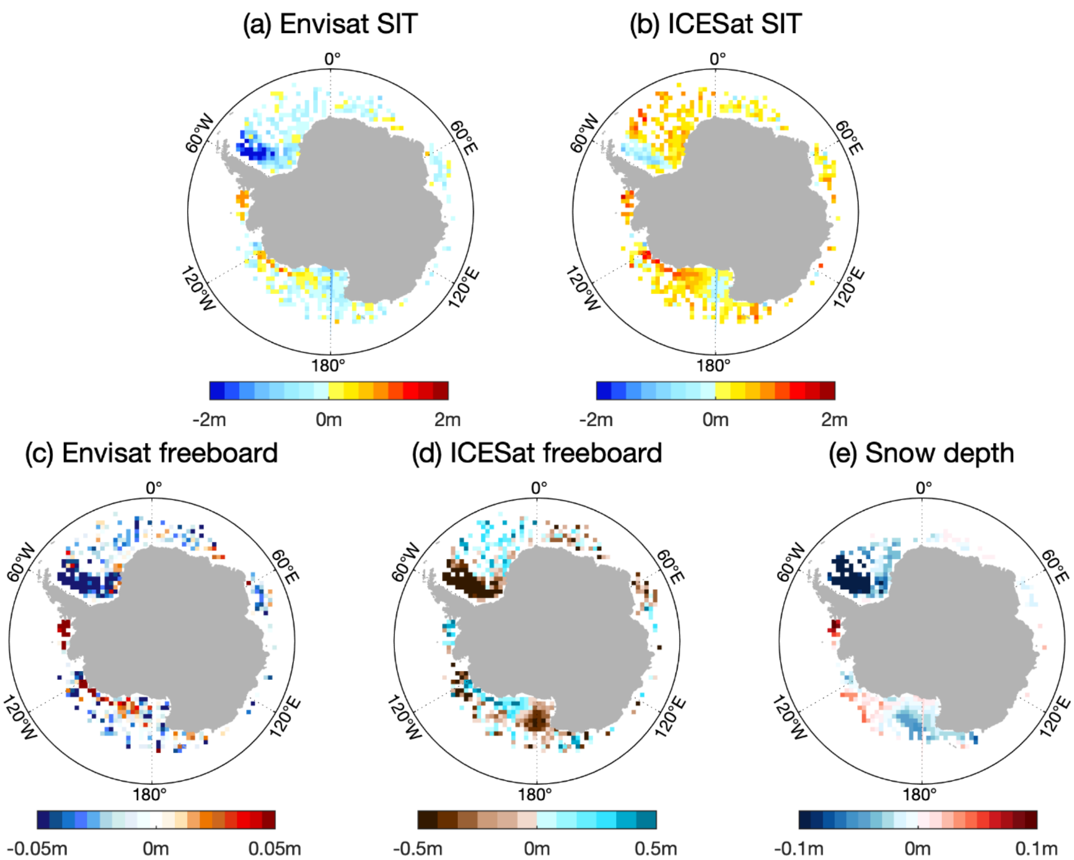
P10L269-270: "In summer, the agreement between Envisat SIT and ICESat SIT is not good, mainly due to their different performances on thick ice above 3 m." Can give more details on why the instruments have different performances over thick ice?

Response: Thank you for your comment. Based on the discussion on the differences in Sect. 4 and previous studies (e.g., Willatt et al., 2010), during FM, snow is deep, potentially wet and/or metamorphous on thick ice, causing substantial penetration difficulties for radar altimeters.

P10L272: "Envisat mean SIT decreases from autumn to spring". Could this be related to the snow depth climatology? For a same freeboard value, a higher snow loading would provide thicker ice. I wonder what is the variability from fall to spring of the Envisat freeboards and snow depth.

Response: Thank you for your comment. We have carefully considered your suggestions and agreed that this figure cannot explain the different MJON SIT changes. Therefore, we have removed this figure and analyzed the freeboard and snow depth changes from MJ to ON.

The results according to the new figure are added as follows: "Therefore, we further compare the mean variations of Envisat SIT, ICESat SIT, Envisat freeboard, ICESat freeboard and snow depth climatology used in Envisat retrieval from autumn (MJ) to spring (ON), shown in Fig. 8. The average fields are calculated with grid cells where both Envisat and ICESat SIT have valid values in all three years from 2004 to 2006. Figure 8 shows that Envisat SIT experiences general decreases from May/June-October/November (MJON) except Bellingshausen Sea and part of Amundsen Sea. Significantly large decreases exist in Western Weddell Sea. In contrast, ICESat SIT present large-scale increases except Western Weddell Sea and Ross Sea where slight decreases exist. By comparing the SIT and freeboard changes of both products, we find that the different changes of freeboard dominantly explain the SIT differences. One thing we can give a speculation based on the analyses in autumn and the regular rule during freezing seasons is that Envisat freeboard is probably overestimated in autumn, which has been pointed out in several studies before (e.g., Willatt et al., 2010; Kwok and Kacimi, 2018; Kacimi and Kwok, 2020). Moreover, the snow depth climatology also shows a decrease in Western Weddell Sea and Ross Sea (Fig. 8e), which has been reported by Kern and Ozsoy-Cicek (2016) that AMSR-E snow depth is likely to underestimate the snow depth evolution during MJON, also contribute to the Envisat SIT decrease." *(please see P9-10 line 269-281 in the revised manuscript)*



RFig. 1: The average changes of Envisat SIT, ICESat SIT, Envisat freeboard, ICESat freeboard and snow depth climatology used in Envisat retrieval from autumn to spring (MJON) calculated from 2004, 2005 and 2006.

P10L273: replace “more thick” by thicker.
Response: Thank you for your comment. We have realized the misunderstanding here and amended the sentence as: “For Envisat SIT, the distribution indicates that more ice is in thinner categories in spring than autumn, while more ice in thicker categories is found for ICESat SIT.” *(please see P9 line 268-269 in the revised manuscript)*

P10L276-278: Please rephrase “We use FDD rather than converted SIT with an empirical equation because they represent the same mechanism and we cannot constrain the uncertainties sufficiently caused by additional assumptions.” I do not understand the meaning or purpose of this statement.
Response: Accepted and corrected. This sentence is used to explain why we didn’t convert the FDD values to SIT values with an empirical equation suggested by Lebedev (1938):

$$\text{Thickness (cm)} = 1.33 * \text{FDD } (℃)^{0.58}$$

We have rephrased this sentence following your comment: “Although the FDD can be converted to SIT with an empirical equation suggested by Lebedev (1938), we use FDD rather FDD-derived sea ice thickness because: (1) FDD represent the same mechanism on the evolution of sea ice thickness as the FDD SIT; (2) avoid the large uncertainties caused by additional assumptions.” However, according to another referee’s suggestions, we have decided to remove the FDD parts and focus on the intercomparison between Envisat and ICESat since the results of FDD cannot explain the reason for the differences.

P10L282-283: “one thing we can give a speculation based on the analyses in autumn and the regular rule during freezing seasons is that the main reason for Envisat SIT overall decrease during MJON is the overestimation of Envisat SIT in autumn.” Can you provide citations that point to the overestimation of Envisat SIT in autumn?
Response: Accepted and corrected. We have provided related citations in the context as: “one thing we can give a speculation based on the analyses in autumn and the regular rule during freezing seasons is that the main reason for Envisat SIT overall decrease during MJON is the overestimation of Envisat SIT in autumn, which is reported in several studies before (e.g., Willatt et al., 2010; Kwok and Kacimi, 2018; Kacimi and Kwok, 2020).” *(please see P10 line 276-279 in the revised manuscript)*

P13L366-367: Can you clarify what you refer to in “the other ICESat period”. Do you mean ICESat-2? Please clarify.
Response: Thank you for your comment. We are sorry for the inappropriate expression here and we have clarified the sentence as: “And for the same reasons, passive microwave snow depth is possibly underestimated on thick ice during FM <u>but also during other seasons</u>.” *(please see P13 line 373-374 in the revised manuscript)*

P13L381-383: “Moreover, snow-depth dependent radar signal delay is applied to convert the radar freeboard into the sea-ice freeboard, but the delay correction is based on a conventional assumption that has been revised (Mallett et al. 2019) since the generation of the SICCI data." Can you give more details about this correction and its revision?

Response: Accepted and corrected. We have added more information about this correction: "Moreover, the distance between sea ice surface elevations and the sea surface height is computed with vacuum light speed, which is defined as radar freeboard (RFB). A geometric correction used to correct the slower wave propagation speed in the snow layer is applied to convert the radar freeboard into the sea ice freeboard (FB):

$$FB = RFB + 0.22 \times SD \tag{7}$$

But the delay correction is based on a conventional assumption that has been assessed by Mallett et al. (2019), which pointed out that it introduced systematic underestimation of up to 15 cm into SIT estimates. While this systematic bias is small compared to other sources, uncertainties of snow depths and incomplete radar wave penetration would cause larger biases in this way." *(please see P13-14 line 390-397 in the revised manuscript)*

Figure S1 to S3: Please change the captions as they are not clear:

-S1: "The origins (30-days ago) of the sea ice (blue dots) that passing through the three ULS sites", could be rephrased to "30-days backtracking of sea ice at the ULS sites".

Response: Accepted and corrected. We have changed the caption to: "Fig. S1 30-days backtracking of sea ice at the ULS sites (red dots) in July 2011 by using backward tracking method based on the NSIDC v4 sea ice motion data. The grey vectors represent the monthly mean sea ice drift derived from NSIDC v4."

-S2: "Changes in the differences between Envisat and ICESat SIT for each comparison period and each region under the experiment of the snow depth climatology impacts.", is not clear. It would be good to specify (Envisat minus ICESat SIT) and stating precisely what changes you make to the snow depth.

Response: Accepted and corrected. We have modified the caption as: "Changes to the differences that Envisat minus ICESat SIT for each comparison period and each region by replacing snow depth climatology with SICCI AMSR-E snow depth during Envisat SIT retrieval. (Unit: m)"

-S2 and S3: I suggest that you remove the colorscale and turn these figures into tables instead because it is confusing and having a colormap does not provide additional information.

Response: Accepted and corrected. We have turned the heatmaps into tables following your comment.

RTable. 1 Changes to the differences that Envisat minus ICESat SIT for each comparison period and each region by replacing snow depth climatology with SICCI AMSR-E snow depth during Envisat SIT retrieval. (Unit: m)

	ABS	WW	EW	EA	RS
FM04	0.25	0.06	-0.07	-0.03	0.08
FM05	-0.14	0.13	-0.05	-0.24	-0.04
FM06	0.11	-0.34	-0.20	0.20	-0.09

FM07	0.03	-0.21	0.09	0.03	0.04
FM08	NAN	-0.08	0.05	-0.04	0.06
MJ04	0.11	0.27	0.03	-0.01	0.07
MJ05	0.24	0.18	-0.07	-0.03	0.11
MJ06	0.06	-0.09	-0.04	-0.03	-0.01
ON04	0.05	-0.01	0.06	-0.06	-0.01
ON05	0.22	-0.02	-0.06	-0.07	-0.01
ON06	0.16	-0.13	-0.01	0.06	0.02
ON07	-0.05	-0.00	-0.01	-0.02	0.11

RTable. 2 Changes to the differences that Envisat minus ICESat SIT for each comparison period and each region by subtracting snow depth climatology (used in Envisat retrieval) from ICESat SIT. (Unit: m)

	ABS	WW	EW	EA	RS
FM04	0.31	0.42	0.35	0.28	0.24
FM05	0.32	0.44	0.38	0.27	0.23
FM06	0.31	0.44	0.35	0.24	0.22
FM07	0.23	0.40	0.28	0.18	0.13
FM08	NAN	0.45	0.34	0.26	0.22
MJ04	0.17	0.35	0.20	0.12	0.15
MJ05	0.17	0.35	0.21	0.12	0.15
MJ06	0.18	0.36	0.20	0.12	0.15
ON04	0.20	0.23	0.17	0.12	0.17
ON05	0.20	0.22	0.17	0.12	0.16
ON06	0.19	0.21	0.16	0.12	0.16
ON07	0.19	0.24	0.17	0.12	0.18

References:

Lebedev, V. V.: The dependence between growth of ice in Arctic rivers and seas and negative air temperature (in Russian). Probl. Arkt. 5-6, 9-25, 1938.

Willatt, R. C., Giles, K. A., Laxon, S. W., Stone-Drake, L., and Worby, A. P.: Field Investigations of Ku-Band Radar Penetration into Snow Cover on Antarctic Sea Ice, IEEE Trans. Geosci. Remote Sens., 48, 365–372, https://doi.org/10.1109/TGRS.2009.2028237, 2010.