Reviewer #2

Dear Reviewer,

Many thanks for your help to improve our work significantly. We made various changes in response to your constructive comments and suggestions, including but not limited to optimizing the data processing methods, a further analysis of the differences between the reanalysis and observations as well as polishing the language. Below, we repeat each comment and reply to them one by one. All responses are in blue font for clarity of reading.

Hao Luo

On behalf of all the authors

1. How do the authors "convert the GIOMAS data to the observed grid"? Do the authors use a nearest neighbor approach? How do you handle multiple entries in case of large resolution differences? Mean? Median? Min? Max? Please elaborate!

Response:

Thanks for your suggestion. **The data processing method is further stated as follows:**

Firstly, when compared with satellite-based observations, daily GIOMAS data is interpolated to the grid of satellite data using the linear approach and converted to monthly averages to eliminate the differences in resolution between daily GIOMAS data and monthly satellite observations.

Secondly, for the comparisons between GIOMAS and ULS observations, we convert 15-minutely ULS data into daily averages for comparison with daily GIOMAS data and use the nearest neighbor approach to find the GIOMAS grid cells closest to the ULS locations.

Thirdly, for the comparison between GIOMAS and ship-based and air-based observations, since the observations are very dense in space and the temporal resolution is always shorter than one day, we average them into daily and gridded data based on the GIOMAS grid to create proper datasets that can be used in direct comparison with daily GIOMAS data.

In the revised manuscript, **we revised the data processing method and added more details about the method as described above.**

2. How exactly do the authors define the "climatological annual cycle"? From all years available in GIOMAS? Following some standard reference period like, e.g., 1970-2000? Please elaborate. Additionally, do the authors only use the averages or also daily GIOMAS data for their comparisons?

Response:

Thanks a lot for pointing this out. The "climatological annual cycle" is defined as the multi-year averages in each month. For observations, the climatological annual cycles are calculated from all years available in each observation dataset. For GIOMAS, when compared with satellite observations, GIOMAS data that coincides with the time

spans of satellite observations are selected (2002-2011 for ES and 2010-2017 for CS2) to calculate the climatology. When compared with ULS observations, all years available in GIOMAS (1979-2018) are used for the computation of climatology. Besides, daily GIOMAS data is used for the comparisons.

In the revised manuscript, **we added the definition of the climatology to the method part. We also declared daily GIOMAS data is used in the evaluation.**

3. What exactly do the authors mean by "spliced together"? This definitely needs clarification!

Response:

Thanks for your comment. We combined the sea-ice volume (SIV) anomalies of ES and CS2 in the time dimension. In the computation of SIV trends, the SIV anomalies of CS2 during the coincident period (November 2010 to November 2011) are chosen since no matter which dataset is selected, the trend changes little (i.e., the trend before 2013 is 2016.7 km^3 per month when choosing ES data and 2039.6 km^3 per month when choosing CS2 data in the coincident segment). Thus, the SIV anomalies of ES from December 2002 to October 2010 and CS2 from November 2010 to April 2017 are combined to obtain a relatively long and continuous time series for trend computation.

In the revised manuscript, **we revised the paragraph and added more precise descriptions to the computation of the trends of SIV anomalies.**

4. L130-L136 and L145-L150: I disagree with some of the authors suggestions. For example, while the resolution, i.e. the spacing between footprints I assume the authors mean(?), and the footprint size and shape differ substantially between both sensors, the used retracker algorithms are intentionally the same. Following your mentioned reference of Paul et al. (2018), the effort of the SICCI project was to keep things a consistent as possible between sensors to also allow for an as consistent as possible time series.

Response:

We are so sorry for this mistake. As Paul et al. (2018) indicated, the mismatch between the ES and CS2-derived sea-ice thickness (SIT) is likely owing to the physical processes that are unresolved such as the flooding in the snow/ice interface.

In the revised manuscript, **we revised the reason why ES dataset differs from CS2 dataset as Paul et al. (2018) indicated**.

5. Furthermore, following the authors own illustrations between Envisat/Cryosat and GIOMAS, the made statements following Schwegmann et al. (2016) are just not applicable anymore. Both references, Paul et al. and Schwegmann et al. refer to different versions of the SICCI data and can to my understanding not be compared. I strongly urge the author to reiterate this paragraph. This also relates to L145/146

Response:

We are sorry for this mistake again. In the revised manuscript, **we reiterated this paragraph and revised the reasons for the differences between ES and CS2 observations according to Paul et al. (2018).**

6. In L146, I disagree with the fact that this is still disputed. I think there is a clear understanding in the community that the scattering surface is NOT the snow/ice interface but everything in the snow is too complex to be able to say WHERE it scatters

Response:

Agreed. we rephrased the sentence in the revised manuscript as follows: "some of the radar altimeter signals would originate from the snow/air interface or from somewhere inside the snow and result in an overestimation of ice draft".

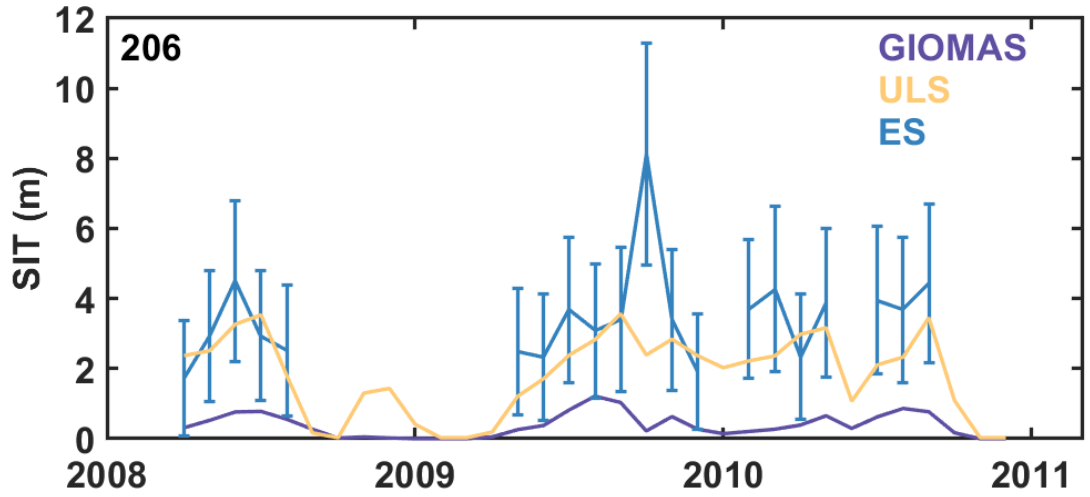
7. A last general point that I find clearly missing in the authors study with all the given data at hand is a proper comparison between all observations, i.e. how do satellite observations and GIOMAS perform directly compared to the observational data? Using not averages but the daily or monthly data. While it is nice to assume the satellite data is correct. As stated above, this is likely not true and an overestimation of reality. A proper analysis of this could really benefit the manuscript and would be of great use to the scientific community!

Response:

Thanks for your suggestion. The inter-comparison among observations and GIOMAS reanalysis can indeed help us figure out where the differences between GIOMAS and satellite observations may come from. Thus, **the ULS observation at site 206 with a relatively long and continuous SIT time series is selected as the ground truth and used to verify the corresponding satellite observations and GIOMAS reanalysis (RFig. 1).**

Result reveals that ES SIT is comparable to that of ULS since 95% of ULS SIT is within the uncertainty of ES. The biases of ES and GIOMAS relative to ULS are 0.89 m and -1.99 m, respectively, while the standard deviations are 0.34 m for GIOMAS, 1.37 m for ES and 1.17 m for ULS. **Those suggest ES SIT is closer to the ground truth and the difference between GIOMAS and ULS is significant**. Notably, the inter-comparison between observations is not involved in our evaluation because such comparison in the Weddell Sea has been done in previous studies (e.g., Kern et al., 2015; Shi et al., 2021).

In the revised manuscript, **we added more discussions about the influence of the uncertainty of satellite observations on the evaluation of GIOMAS.**



RFig. 1 The monthly SIT series of ULS at site 206 from April 2008 to December 2010 (yellow) and corresponding ES (blue) and GIOMAS (purple) at ULS 206. The error bar means the uncertainty of ES SIT.

8. As a non-native English speaker (and writer), I still find some of the phrasing and choice of words unintuitive and I recommend some language editing. Example comprise the lack of several "the"'s, the potential use of correct hyphenation (e.g., sea-ice thickness), as well as multiple sentences starting with "And".
   e.g., L18: "of _the_ model"

Response:

We are sorry for those mistakes. We revised the manuscript and polish the language as suggested.

9. L35: "lack" instead of "short"? or "shortage"?

Response:

Agreed. We changed "short" to "lack" as suggested.

10. L35: What do the authors mean with "freshwater flux of the SO?" by means of melting sea ice?

Response:

We mean the freshwater flux of the Southern Ocean partially comes from the sea ice melting and growth processes. **The sentence was rephrased for clearer description in the revised manuscript.**

11. L38/39: This sounds like a pretty exhaustive list- what other data sets would there be? The way the sentence is phrased suggests this is very limited. While of course the _amount_ of data from these sources might be – its not by the number different available sources if the authors know what I mean.

Response:

Follow your suggestion, the sentence was rephrased in the revised manuscript as follows: "So far, the commonly used types of the Antarctic SIT data are observations, model data, and reanalysis products and each type of data has its own limitations".

12. L42: The sentence starting with “while” reads clunky

Response:

Agreed. We rephrased the sentence as follows: “It is well known that satellite observations have wider spatiotemporal coverage than in-situ observations”.

13. L49: I think the plural from reanalysis is reanalyses.

Response:

Agreed. We revised the manuscript and change all the plural from “reanalysis” to “reanalyses” as suggested.

14. L50: Stop sentence after “alone.” and start the next one with “Reanalyses merge the information […]”

Response:

We rephrased the sentence as suggested.

15. L53: Do not start the sentence with “And”.

Response:

We changed “And” to “Besides”.

16. L63: I think it should be algorithmS.

Response:

Agreed. We modified as suggested in the revised manuscript.

17. L67: see comment to Line 53.

Response:

We changed “And” to “In addition” as suggested.

18. L92: CCI is not properly introduced as abbreviation (only in the context of SICCI)

Response:

Agreed. We added the full name of ESA CCI in the revised manuscript as follows: “European Space Agency Climate Change Initiative (ESA CCI)”.

19. L93: The authors should probably introduce freeboard a bit earlier already.

Response:

Thanks for your suggestion. We rechecked the text and introduced freeboard earlier in the revised manuscript.

20. L108/109: This means an EM Bird like instrument?

Response:

Yes, it is. The airborne electromagnetic system is an EM bird like electromagnetic thickness sensor carried by a helicopter as described in Lemke (2014). In the revised manuscript, **we added a simple description for the instrument**.

21. L120: THE trend!

Response:

We modified as suggested in the manuscript.

22. L158: Maybe this is a result from the coarse resolution of the assimilated SSM/I SIC data? Clearly, this would be unable to resolve especially polynya, fast-ice and thin-ice signatures close to the coast.

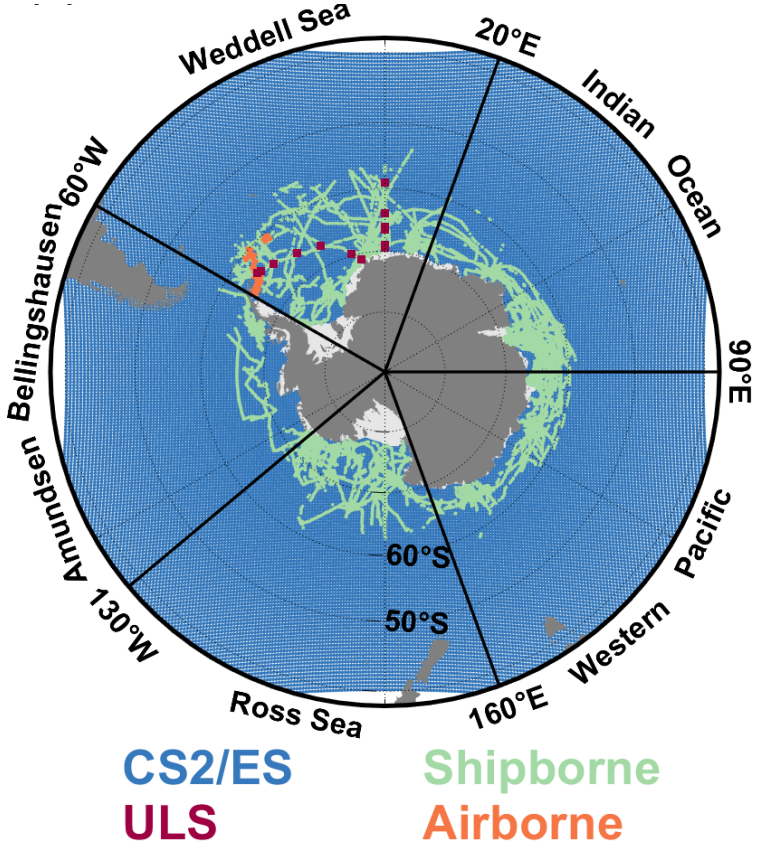
Response:

Agreed. That reason was added to explain the deficiency of GIOMAS in resolving sea ice near the coast as suggested in the revised manuscript.

23. Figure 1: As a figure enthusiast, I would urge the authors to use a better fitting land/ice-shelf mask for their figures. While the Ronne/Filcher areas are shown as "land" the Ross ice shelf is not visible at all. The authors could consider using data from Natural Earth or other similar sources.

Response:

Thanks for your suggestion. As shown in RFig. 2 (Fig. 1b in the revised manuscript), the better land/ice-shelf mask from Natural Earth was used in Fig. 1b as you suggested. It shows the Ronner/Filcher areas in the Weddell Sea and the Ross ice shelf are well distinguished from the land. The same mask was also used in Figs. 3, 4a, 6a and 6b in the revised manuscript.

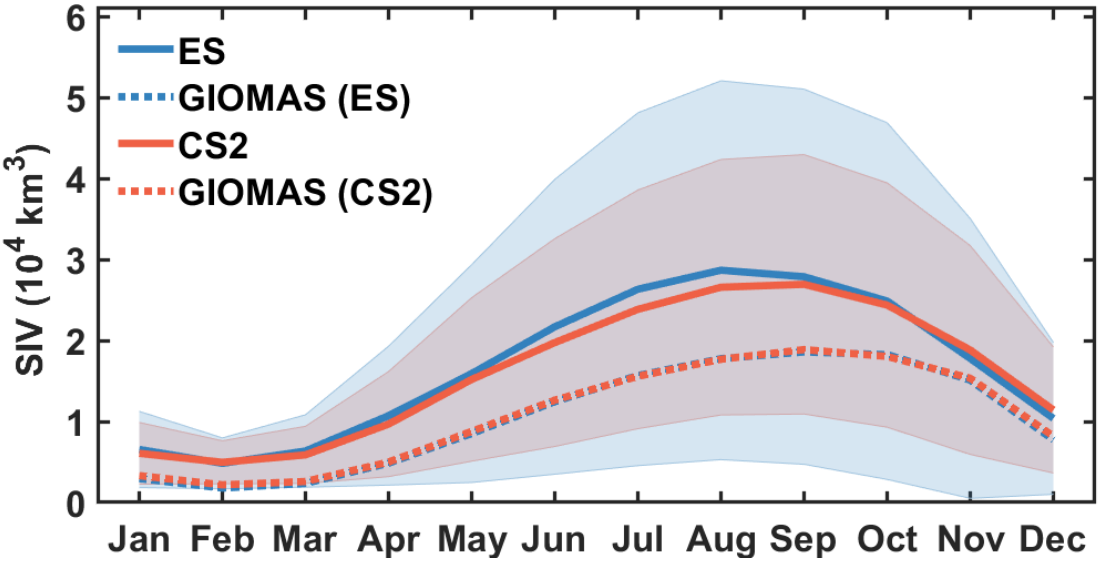


RFig. 2 The spatial coverage of data used in this study.

24. Figure 2: It might be my printer, but the two different shade colors for the uncertainty are hard to differentiate. I would assume the wider ones belongs to Envisat but I cannot tell for sure.

Response:

We are sorry for this problem. As shown in RFig. 3 (Fig. 2 in the revised manuscript), the new color scheme was used to better distinguish the two shades.



RFig. 3 The climatological annual cycle of Antarctic SIV. The blue and red denote data related to ES and CS2, respectively. The solid and dashed curves denote satellite observations and corresponding GIOMAS data. The shading denotes the SIV uncertainty of satellite observations.

References:

Kern, S., and Coauthors, 2015: The impact of snow depth, snow density and ice density on sea ice thickness retrieval from satellite radar altimetry: results from the ESA-CCI Sea Ice ECV Project Round Robin Exercise. The Cryosphere, **9**, 37-52.

Lemke, P., 2014: The Expedition of the Research Vessel Polarstern to the Antarctic in 2013 (ANT-XXIX/6). 21, Number of 1-154pp.

Paul, S., S. Hendricks, R. Ricker, S. Kern, and E. Rinne, 2018: Empirical parametrization of Envisat freeboard retrieval of Arctic and Antarctic sea ice based on CryoSat-2: progress in the ESA Climate Change Initiative. *The Cryosphere*, **12**, 2437-2460.

Schwegmann, S., E. Rinne, R. Ricker, S. Hendricks, and V. Helm, 2016: About the consistency between Envisat and CryoSat-2 radar freeboard retrieval over Antarctic sea ice. *The Cryosphere*, **10**, 1415-1425.

Shi, Q., Q. Yang, L. Mu, J. Wang, F. Massonnet, and M. R. Mazloff, 2021: Evaluation of sea-ice thickness from four reanalyses in the Antarctic Weddell Sea. *The Cryosphere*, **15**, 31-47.

Wang, J., C. Min, R. Ricker, Q. Yang, Q. Shi, B. Han, and S. Hendricks, 2020: A comparison between Envisat and ICESat sea ice thickness in the Antarctic. *The Cryosphere Discussions*, **2020**, 1-26.

Willatt, R. C., K. A. Giles, S. W. Laxon, L. Stone-Drake, and A. P. Worby, 2010: Field Investigations of Ku-Band Radar Penetration Into Snow Cover on Antarctic Sea Ice. *IEEE Transactions on Geoscience and Remote Sensing*, **48**, 365-372.