We sincerely thank the Reviewer for the constructive comments on the manuscript. The reviewer's insights and suggestions have been extremely helpful in improving the quality of our work. We have thoroughly considered each comment and have made the following responses and revisions. The amendments are marked in red in the revision.

Next, we respond point by point to the comments.

General Comments

This paper presents a new time series of Arctic sea ice thickness over nearly 30 years based on altimetry observations with an unprecedented resolution of 5km. This is an important subject because only one other series of this length exists to date, and it may help to confirm the initial results and the relevance of this type of monitoring of the state of the sea ice. The comparison is even more interesting as the method used is new and totally independent of the previous ones. It relies on the multiplication of altimetric freeboard measurements in each 5km x 5km grid cell, to determine the thickness of the ice without preconceived ideas about parameters such as density or snow depth. For these reasons, I believe that this work deserves to be published.

Nevertheless, some important concepts have been overlooked, leading to dubious interpretations of certain results. In particular, the authors do not distinguish between the freeboard measured by Ku-band radar altimeters and the freeboard of the ice, which leads to erroneous equations that mainly affect the validation part. Because snow reduces the speed of propagation of the radar wave, the radar freeboard is necessarily smaller than the ice freeboard, and these 2 freeboards cannot be compared directly. The comparisons with OIB freeboard Figure 3 are therefore questionable. For the comparisons with ULS the used ice density is not specified. No correlation is calculated when comparing with other solutions or within-situ measurements.

While ERS2 is a hard point because of the problem of blurring of its waveforms, no resulting map is shown. Although the data supplied with the paper seems to give consistent results, it would be useful to present comparisons with Envisat over a common month and to discuss any problems encountered, such as the extent of filtering used (Pauta criterion). Also, very strangely, the quality of the results deteriorates sharply, with extremely moth-eaten maps for the Envisat period from October 2002, even though the Envisat measurements are of much better quality than those of ERS2 and their orbits are the same. Coverage became good again with CryoSat-2 from November 2010, but visually the resolution seemed closer to 25km than 5km. This seems to indicate that you forgot to apply the coarse resolution to Envisat, but also that the 5km resolution is far too low to cover the Arctic basin.

All this raises questions about the choice of such a small resolution (5km), compensated by a relatively coarse resolution (25km). For a future study, wouldn't a resolution of 12.5km be more appropriate? Or do you think that 5km really adds value (relevant signal at this scale)?

Finally I would recommend analysing and exporting in the data the parameters a5 and a6, which depend on the densities and the snow depth. This should allow evaluating the consistency of these parameters, and thus the model used.

From a practical viewpoint I would recommend to use the Lambert-Azimuthal-Equal-Area projection with lon0=0, which becomes the reference in our domain, but it’s not mandatory as it represents a lot of work without changing the results (see EASE v2 in https://nsidc.org/data/user-resources/help-center/guide-ease-grids). Strangely, while the figures in the paper show maps with lon0=0, the data are centred on lon0=-45.

Response: We appreciate your recognition of the significance of our work and the potential contributions to the study of Arctic sea ice thickness. Below, we address your concerns in detail:

(1) Concepts on freeboard

As illustrated in the following figure, we define the terminology of freeboard:

- ice freeboard (FB_i): refers to the elevation of the snow–ice interface above the local sea level;
- total freeboard (FB_t): refers to the elevation of the air–snow interface above the local sea level, which is sensed by laser altimetry;
- radar freeboard: since the radar waves do not fully penetrate snow above ice, we here define the term radar freeboard as the elevation of penetration interface above the local sea level (Ricker et al., 2014).

For the ice freeboard, the lower wave propagation speed in the snow layer requires a correction, the radar-ku-freeboard (FB_{ku}) is defined, but is not applied for the radar freeboard in this study. Therefore, the freeboard mentioned in this study specifically refers to radar freeboard.

We have added supplementary explanations on radar freeboard at the beginning of Section 3.1 (Lines 335–344) to clarify these definitions.

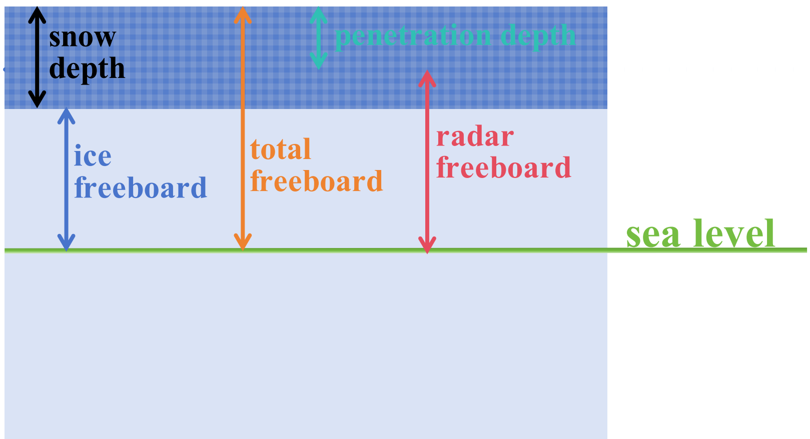

Figure R1 Schematic diagram of parameters regarding different freeboards.

(2) Validation with ULS draft

To avoid potential uncertainties associated with the W99 model in draft-to-thickness conversion, we revised our comparative strategy by directly comparing ULS-measured ice drafts with satellite-derived draft estimates. The draft from satellite-based products is calculated by removing ice freeboard from sea ice thickness

(SIT). Since the AWI-SMOS+CS2 and CPOM datasets do not include ice freeboard parameters, we limited our comparison to the other six products.

(3) Adding correlations while comparing

Following your suggestion, we have added mean error (ME) and correlation coefficients to Tables 4-8 to enhance the robustness of our validation.

(4) Calibration of ERS-2

We acknowledge the issue of waveform blurring over sea ice for ERS-2. Our data processing methods inherently address this problem to some extent.

Regarding lead detection, we employ a combination of waveform parameter thresholds and the lowest elevation method (LEM). For ERS - 2, we use the pulse peakiness (PP) parameter for lead identification. However, we are aware that the waveform blurring may affect the accuracy of this method, especially in thin ice-covered areas. The LEM, which is based on the premise that the surface height of leads is lower than that of nearby sea ice, helps to correct for misidentifications caused by waveform blurring. This combined approach is a form of correction for the waveform-related issues in ERS-2 data.

Regarding calibration between ERS-2 and Envisat, while the altimeters on these platforms are similar in some aspects, we did not conduct a separate calibration specifically for ERS-2 and Envisat, as we did for Envisat and CryoSat-2. The reason is that the difference in thickness between ERS-2 and Envisat during their common mission period is approximately −0.37 m, which is negligible compared to the difference between CryoSat-2 and Envisat. We applied the monthly correction grid generated from the Envisat-CryoSat-2 comparison to the ERS-2-based thickness, which also helps account for any systematic differences related to waveform blurring or other factors between ERS-2 and Envisat. Introducing an additional calibration between ERS-2 and Envisat could lead to the superposition of multiple errors, particularly residuals between Envisat and CryoSat-2.

We added a discussion section to address the above issues in Lines 704-723.

(5) Coverage and Resolution issues

The discrepancy in spatial coverage is caused by multiple factors, such as changes in sea ice extent and data exclusion. The resolution during the Envisat period appears higher than that of CryoSat-2, primarily because the Envisat results contain more noise, while the CryoSat-2 results are smoother. In reality, we uniformly used a grid with a resolution of 5 km.

The choice of 5 km resolution was made to balance the need for high-resolution details and the availability of data. A 5 km resolution allows us to capture more fine -scale features of sea ice thickness compared to coarser resolutions. Although visually the resolution might seem closer to 25 km in some cases, this could be due to data interpolation and the characteristics of sea ice distribution. We believe that the 5 km resolution provides valuable information, especially in areas with complex sea ice dynamics. However, we also recognize the advantages of a 12.5 km resolution, such as better coverage and potentially less noise. In future studies, we will consider using a 12.5 km resolution as an alternative and compare the results to further explore the optimal resolution for Arctic sea ice thickness monitoring.

We added a discussion section to address the above issues in Lines 724-736.

(6) On the parameters of a_5 and a_6

We have already included these two parameters in the updated products.

As explained in *SP*(20), $a_5 = 1 - \frac{\rho_{si}}{\rho_{sw}}$ and $a_6 = (1 - \frac{\rho_s}{\rho_{sw}} - \theta)h_s$. a_5 is a combination of densities of sea ice and seawater, while a_6 is much more complex and depends on additional factor. In Xiao et al. (2020), we derived sea ice density from a_5 by setting seawater density as a fixed value (1024 kg/m³). Figure R2 shows the sea ice density distribution for the 2018 -2019 Arctic sea ice growth season from October to April. It can be easily found that the thin ice density is larger than thick ice density. Thin ice density ranges from 915 ~ 920 kg/m³, while the thick ice density ranges from 880 ~ 885 kg/m³.

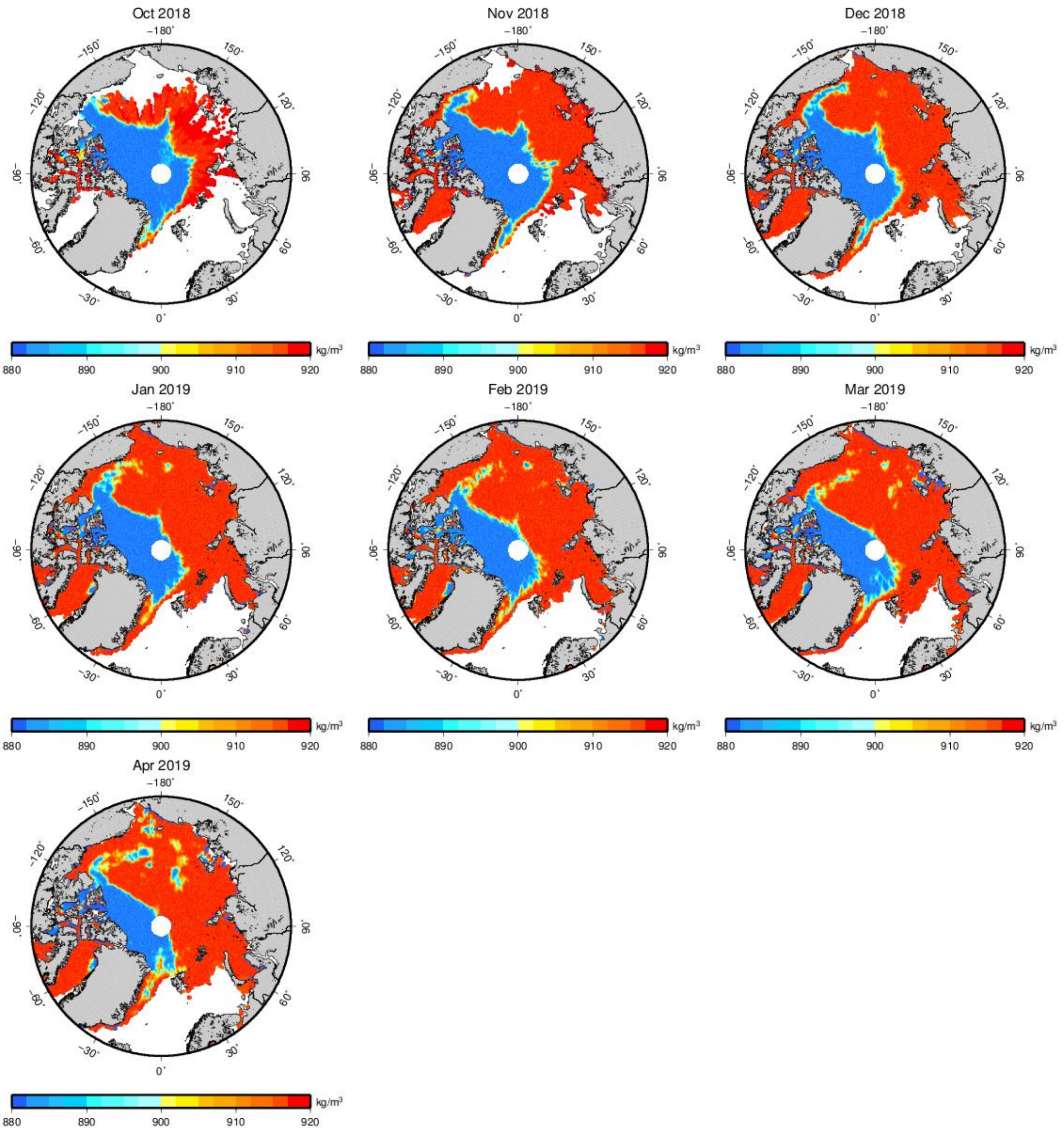

Figure R2 Arctic sea ice density with the LSA method for the 2018 – 2019 Arctic sea ice growth season from October to April.

(7) On the projection

In this study, we used the NSIDC’s Polar Stereographic Projection, detailed information can be found in https://nsidc.org/data/user-resources/help-center/guide-nsidcs-polar-stereographic-projection.

In the .nc file, the key parameters of this projection are set as follows: +proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +a=6378273 +b=6356889.449 +units=m +no_defs.

In the manuscript, we used the Generic Mapping Tools (GMT, https://www.generic-mapping-tools.org/) to present the distributions of SIT. The following command was used:

gmt plot -R-180/180/60/88 -Js0/90/2i/45 *thicknessfile* -Sp -C

Specifically, we adopt the polar stereographic projection with a central longitude of 0° and a central latitude of 90°, which means we choose the North Pole as the projection center. The standard parallel of this projection is set at 45°.

Specific Comments

1. l.24 : The only mention of the projection used. Should be specify within the paper with all the requested parameters to use this projection, in particular the True Latitude (lat_ts). Also we would recommend to use the EASE v2 https://nsidc.org/data/user-resources/help-center/guide-ease-grids, which becomes the reference and which is much more convenient as the resulting grid is a regular Cartesian grid in meters and allows to compute directly distances, surfaces and volumes in ISU, which is not the case for the stereopolar projection.

Response: Thank you for your valuable suggestion regarding the projection used in our study. We appreciate your recommendation to consider the EASE v2 projection, which offers several advantages, particularly in terms of its regular Cartesian grid format that facilitates direct calculations of distances, areas, and volumes in ISU.

In this study, we employed the NSIDC's Polar Stereographic Projection, as detailed in the NSIDC's Polar Stereographic Projection Guide. The specific parameters used in the .nc file are as follows:

+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +a=6378273 +b=6356889.449 +units=m +no_defs.

The true latitude (lat_ts) is set to 70°, which minimizes distortion near the marginal ice zone, a critical region for sea ice analysis.

While we recognize the benefits of the EASE v2 projection, our choice of the Polar Stereographic Projection was driven by its specific advantages for sea ice research in polar regions. This projection is tangent to the Earth's surface at 70°N/S, ensuring minimal grid distortion in areas of interest, such as the marginal ice zone. This is particularly important for accurately analyzing the distribution, movement, and changes in sea ice. Additionally, many NSIDC-archived datasets, including brightness temperature and sea ice products, utilize this projection, underscoring its reliability and widespread applicability in sea ice research.

That said, we acknowledge the convenience of the EASE v2 projection for certain applications. To accommodate diverse user needs, we are open to providing an alternative data version in the EASE grid format in future updates. This would allow users who prefer or require data in this grid system to conduct their analyses more effectively.

We appreciate your feedback and will consider incorporating this enhancement to improve the accessibility and utility of our dataset.

2. l.46: please specify that the Arctic could become ice free in less than a decade in summer.

Response: Thank you for your suggestion. We have revised the statement on Line 48 to clarify that the Arctic could become ice-free in summer within less than a decade. The updated text now reads:

A recent study revealed that the Arctic could become ice-free in summer in less than a decade even in the lowest-emission scenarios.

3. l.95: I was surprised by these snow depth reduction announced over FYI and MYI but in fact in Webster et al. 2014, they do not speak about FYI/MYI but about specific seas: “For the 2009–2013 period, the products show that snow has decreased by 37 ± 29% in the western Arctic and by 56 ± 33% in the Beaufort and Chukchi seas, compared to the 1954 - 1991 snow depth climatology produced by W99.” Please correct it or provide the original citation if any.

Response: Thank you for pointing this out. We have carefully reviewed the reference and corrected the statement on Line 96. The revised text now accurately reflects the findings of Webster et al. (2014), which highlight regional snow depth reductions rather than differences between FYI and MYI. The updated sentence reads:

According to Webster et al. (2014), the snow depth during the 2009-2013 period has decreased by 37 ± 29% in the western Arctic and by 56 ± 33% in the Beaufort and Chukchi seas, compared to the depth in W99.

4. l.148: I suppose there is an error in this sentence: “coarse across-track spacing of 25 km at 75° and 4 km at 60° provided by ERS-2 and Envisat” as the across track spacing decreases with the latitude.

Response: Thank you for catching this error. We have revised the sentence on Line 155 to accurately reflect the across-track spacing of CryoSat-2, ERS-2, and Envisat. The corrected sentence now reads:
The across-track spacing of CryoSat-2 is approximately 2.5 km at 75° and 4 km at 60°, which is a significant improvement compared with the coarse across-track spacing of 25 km at 75° and 40 km at 60° provided by ERS-2 and Envisat.

5. l.152: CryoSat-2 orbit is not any more a repeat cycle since several years, however there is still a sub-cycle of about 30 days.

Response: Thank you for pointing this out. We have revised the statement on Line 159 to accurately reflect the current status of CryoSat-2's orbit. The updated sentence now reads:
While CryoSat-2 no longer follows a strict repeat cycle, it still maintains a sub-cycle of approximately 30 days, which enables monthly coverage of Arctic sea ice.

6. l.185,248,270,285,286,293,294: It’s very pertinent to recall the uncertainties for each product. I would just recommend to always use the same units (meters or centimetres).

Response: Thank you for your suggestion. We have unified the units of uncertainties across the mentioned lines to ensure consistency. All uncertainties are now expressed in meters.

7. l.195: CryoSat-2 ICE baseline-E L1B is the official ESA product, not an AWI product. Please specify if you use the AWI product or the ESA product.

Response: Thank you for pointing this out. We have clarified the statement on Line 204 to specify the source of the data used. The revised text now reads:

In the latest version of AWI-CS2 (V2.6), CryoSat-2 ICE baseline-E L1B data serve as the input for the AWI-CS2 sea ice thickness product (Hendricks and Paul, 2023).

Reference:

Hendricks, S. and Paul, S. 2023: Product User Guide & Algorithm Specification - AWI CryoSat-2 Sea Ice Thickness (version 2.6), https://doi.org/10.5281/zenodo.10044554.

8. l.238: This longtime series is described in Bocquetetal. 2024 https://doi.org/10.1029/2023JC020848. Bocquet et al. 2023 explains the methodology and is only over Arctic from 1995 to 2021 (without ERS1).

Response: Thank you for pointing this out. We have updated the reference on Line 247 to reflect the correct source.

9. l.249: "RMSE of 12-28 cm for Envisat period and 15-21 cm for CryoSat-2 period (Guerreiroetal., 2017)." Guerreiro or Bocquet? It's not the sametime series.

Response: Thank you for catching this inconsistency. We have revised the sentence on Line 256 to clarify the source and provide accurate information. The updated text now reads:

The draft of CTOH, compared with ULS measurements in BGEP and in Fram Strait, was overestimated by about 0.2 m for the CryoSat-2 period and underestimated by 0.11 m and 0.16 m for the Envisat and ERS-2 periods, respectively (Bocquet et al., 2024).

10. l.300: DTU18MSS is endowed with discontinuity problems close to the MIZ and you should use DTU21MSS. See: "The DTU21 global mean sea surface and first evaluation" in Earth System Science Data 15(9):4065-4075 10.5194/essd-15-4065-2023

Response: Thank you for your valuable suggestion. We have rigorously re-processed all datasets using the updated DTU21MSS model and systematically regenerated our sea ice thickness product. All affected components of the manuscript—including figures, tables, and related analyses—have been thoroughly revised and updated to reflect these improvements.

We appreciate your feedback and are confident that this update significantly strengthens the quality of our work.

11. l.366: The MSS includes the geoid (MSS=geoid+MDT). Also I'm surprise that you don't correct for the usual altimetry corrections such as the wet tropo, the dry tropo, the ocean tide, load tide, pole tide, DAC, etc. You would get even more flat measurements.

Response: Thank you for your insightful comment. To clarify, the geoid undulations and mean dynamic topography (MDT) were removed in the calculation of relative elevation. Additionally, we applied standard geophysical corrections—including wet tropospheric, dry tropospheric, ocean tide, load tide, pole tide, and dynamic atmospheric correction (DAC)—using the models or datasets provided in the CryoSat-2, Envisat, and ERS-2 products before subtracting the mean sea surface (MSS) height.

These corrections ensure that the measurements are as accurate and flat as possible, minimizing errors and improving the reliability of our results.

12. l.367: I did not know about Pauta criterion, I think it would be interesting to explain it here in few words.

Response: Thank you for your suggestion. To provide clarity, we have added a brief explanation of the Pauta Criterion (also known as the 3σ rule) on Line 382. The revised text now reads:

The Pauta Criterion, also known as the 3σ rule, is a statistical method used to identify outliers in a dataset. It is based on the characteristics of the normal distribution, where approximately 99.73% of the data lies within the interval of the mean plus or minus three standard deviations ($\mu \pm 3\sigma$). Data points falling outside this range ($x < \mu - 3\sigma$ or $x > \mu + 3\sigma$) are considered outliers (Shi et al., 2023).

Reference:

Shi, H., Guo, J., Deng, Y. et al. Machine learning-based anomaly detection of groundwater microdynamics: case study of Chengdu, China. Scientific Reports 13, 14718 (2023). https://doi.org/10.1038/s41598-023-38447-5.

13. l.375: interpolated is between 2 measures, here I would say extrapolated.

Response: Thank you for pointing this out. We have revised the term on Line 395 from "interpolated" to "extrapolated" to accurately describe the process. The updated text now reads:
For sections without identified leads, the local SSH was extrapolated from adjacent sections.

14. l.380-388: this part is not clear at all because you mixed-up the ice-freeboard (FB_i, the real freeboard of the ice), the radar-ku-freeboard (FB_{ku}, the freeboard measured by the radar) and the total-freeboard (FB_t, ice+snow freeboard that is measured by the lidar of OIB or ICESat-2). They are linked by the following relations: $FB_t = FB_i + SD$ and $FB_{ku} = FB_i - (c_v/c_s - 1) \times SD$, where SD is the Snow Depth and c_v/c_s is the ratio of the speed of light in vaccum and in snow. This ratio depends on the snow density ρ_{snow}. From Ulaby 1986 we have: $c_v/c_s = (1 + 0.00051 \times \rho_{snow})^{1.5}$ (Tiuri et al. 1984 suggest: $c_v/c_s = (1 + 1.7\rho_{snow} + 0.7\rho_{snow}^2)^{0.5}$. Each time you speak about freeboard you must specify which freeboard you are speaking about.

Response: Thank you for your detailed feedback. To clarify the terminology and improve the clarity of this section, we have added supplementary explanations at the beginning of Section 3.1:

- ice freeboard (FB_i): refers to the elevation of the snow–ice interface above the local sea level;
- total freeboard (FB_t): refers to the elevation of the air–snow interface above the local sea level, which is sensed by laser altimetry;
- radar freeboard: as the radar waves do not fully penetrate snow above ice, we here define the term radar freeboard as the elevation of penetration interface above the local sea level (Ricker et al., 2014).

As for the ice freeboard the lower wave propagation speed in the snow layer requires a correction, the radar-ku-freeboard (FB_{ku}) is defined, but is not applied for the radar freeboard in this study. Therefore, the freeboard mentioned in this study refers to radar freeboard.

15. l.381: “The OIB **total (or lidar)** freeboard was modified with snow depth”. Here you should also specify if you have just removed the snow depth to get an **ice freeboard** or if you also have corrected for the speed propagation to get a **radar-ku-freeboard** for the following comparisons.

Response: Thank you for your clarification. We have revised the statement on Line 400 to specify the process more accurately. The updated text now reads:
The OIB total freeboard was first modified to ice freeboard by removing the snow depth derived from the snow radar before comparison.

16. l.382: “The mean **radar? ice? yours from OIB? yours from satellite?** freeboard along this track in this study”

Response: Thank you for pointing out this ambiguity. We have revised the statement on Line 402 to clarify that it refers to the mean radar freeboard. The updated text now reads:
The mean radar freeboard along this track in this study was approximately 0.280 m, while the mean radar freeboard from the Baseline E product was 0.238 m.

17. l.383: “while the mean **radar** freeboard from the Baseline E”.

Response: Thank you for your feedback. We have revised the statement on Line 403 for clarity.

18. l.384: “The mean value of the modified OIB freeboard was 0.261” -> The mean value of the **ice? radar?** freeboard obtained from OIB was 0.261 m.

Response: Thank you for your clarification. We have revised the statement on Line 403 to specify that it refers to the ice freeboard. The updated text now reads:
The mean value of the modified OIB ice freeboard was 0.261.

19. l.387: The following sentence is wrong: “the waveform threshold method leads to an underestimation of the freeboard ... ”. The threshold method sometimes overestimates the FB and sometimes underestimates it as you show it later on in this paper. It mainly depends on the roughness of the ice, i.e. on ice type (FYI/MYI).

"*... which explains why the freeboard in the Baseline E product was smaller than our estimates and the modified OIB freeboard*." No, this is explained by the following equation $FB_{ku} = FB_i - (c_v/c_s - 1) \times SD$, which shows that the **radar freeboard is always smaller than the ice freeboard** and it can even be negative for small FB_{ice} and large SD.

Response: Thank you for your detailed feedback. We have revised the statement on Line 406 to address the inaccuracies and clarify the explanation. The updated text now reads:

the misidentification of leads in the waveform threshold method leads to an underestimation of the radar freeboard, which explains why the freeboard in the Baseline E product was smaller than our radar freeboard estimates.

Additionally, we have provided further context to clarify the relationship between radar freeboard and ice freeboard:

- The radar freeboard in the Baseline E product is computed as:
  [radar_freeboard_20_ku] = [height_1_20_ku] - [ssha_interp_20_ku].
  A correction for pulse delay due to snow depth is provided in [snow_depth_cor_20_ku] but is not applied.
- In this study, the radar freeboard refers to the elevation of the penetration interface above the local sea level, while the ice freeboard refers to the elevation of the snow–ice interface above the local sea level. Therefore, the radar freeboard will generally be larger than the ice freeboard.
- As shown in Figure 3 in the revision, when the radar burst is reflected from thin ice, specular echoes occur and may be misidentified as leads. This leads to an overestimation of the sea surface height (SSH) and, consequently, an underestimation of the radar freeboard.

Reference:

CryoSat Ice netCDF L2 Product Format Specification, Issue 2.1. IPF1 L1B Product Formats (esa.int).

20. l.406: This equation is not the equation of the hydrostatic equilibrium between FBi, SIT and SD!
    Here it is: $FB_i = SIT(1 - \rho_{ice}/\rho_{water}) - SD \times \rho_{snow}/\rho_{water}$

What you have written is the equation that links FB_{ku} with *SIT* and *SD* (ie, what you call h_{fb} is in fact FB_{ku} and what you call theta is c_v/c_s including possibly a penetration factor $P * c_v/c_s$).

Response: Thank you for pointing this out.

Under the assumption of hydrostatic equilibrium, sea ice thickness can be calculated as (Ricker et al., 2014; Tilling et al., 2018):

$$h_{si} = \frac{\rho_{sw}}{\rho_{sw} - \rho_{si}} h_{fb\_ice} + \frac{\rho_s}{\rho_{sw} - \rho_{si}} h_s \tag{1}$$

where h_{si} is the sea ice thickness; h_s is the snow depth on sea ice; and ρ_{sw}, ρ_{si}, and ρ_s are the densities of sea water, sea ice, and snow, respectively. We have to be aware that h_{fb_ice} here refers to the ice freeboard.

As the radar signal cannot penetrate the snow thoroughly, we defined the radar freeboard in this study. As shown in Figure R1 and Figure R3 below, the radar freeboard (h_{fb}) refers to the elevation of penetration interface above the local sea level, and h_{ps} is the penetration depth of radar signals. The model for the conversion of freeboard to thickness can be modified as:

$$\begin{aligned} h_{si} &= \frac{\rho_{sw}}{\rho_{sw} - \rho_{si}} h_{fb} + \frac{\rho_s - \rho_{sw}}{\rho_{sw} - \rho_{si}} h_s + \frac{\rho_{sw}}{\rho_{sw} - \rho_{si}} h_{ps} \\ &= \frac{\rho_{sw}}{\rho_{sw} - \rho_{si}} h_{fb} + \frac{\rho_s - \rho_{sw}}{\rho_{sw} - \rho_{si}} h_s + \frac{\rho_{sw}}{\rho_{sw} - \rho_{si}} \theta \cdot h_s \end{aligned} \tag{2}$$

where θ is the penetration factor of radar signals.

We firstly model the freeboard as a quadratic function of the local ice surface terrain within the grid:

$$h_{fb}(x, y) = \overline{h_{fb}} + a_0 x + a_1 y + a_2 x^2 + a_3 y^2 + a_4 xy \tag{3}$$

where $\overline{h_{fb}}$ indicates the mean freeboard of the grid cell and *x* and *y* represent the longitudinal and latitudinal surface distances between the observation and the central point of the grid cell, respectively. According to Equation (2),

$$\overline{h_{fb}} = (1 - \frac{\rho_{si}}{\rho_{sw}})\overline{h_{si}} + (1 - \frac{\rho_s}{\rho_{sw}} - \theta) h_s \tag{4}$$

Thus, Equation (3) can be rewritten as follows:

$$h_{fb}(x,y) = (1-\frac{\rho_{si}}{\rho_{sw}})\overline{h_{si}} + (1-\frac{\rho_s}{\rho_{sw}}-\theta)h_s + a_0x + a_1y + a_2x^2 + a_3y^2 + a_4xy$$
$$= a_0x + a_1y + a_2x^2 + a_3y^2 + a_4xy + a_5\overline{h_{si}} + a_6 \quad (5)$$

Details of the LSA method are introduced in Xiao et al. (2020).

Reference:

Ricker, R., Hendricks, S., Helm, V., Skourup, H., and Davidson, M.: Sensitivity of CryoSat-2 Arctic sea-ice freeboard and thickness on radar-waveform interpretation, Cryosphere, 8, 1607–1622, https://doi.org/10.5194/tc-8-1607-2014, 2014.

Tilling, R. L., Ridout, A., and Shepherd, A.: Estimating Arctic sea ice thickness and volume using CryoSat-2 radar altimeter data, Advances in Space Research, 62, 1203–1225, https://doi.org/10.1016/j.asr.2017.10.051, 2018.

Xiao, F., Li, F., Zhang, S., Li, J., Geng, T., and Xuan, Y.: Estimating arctic sea ice thickness with cryosat-2 altimetry data using the least squares adjustment method, Sensors, 20, 1–18, https://doi.org/10.3390/s20247011, 2020.

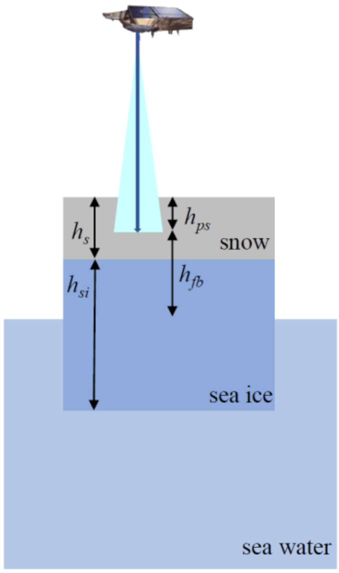

Figure R3 Schematic of the radar altimeter observing the sea ice thickness

21. l.407-409: Please specify which are the inputs and which are the unknown. It looks like that h_{fb}, x and y are the inputs and a0-a7 and h_{si} are the 8 unknown, right?

Response: Thank you for your clarification. We have revised the text on Line 429 to explicitly specify the inputs and unknowns in the equation. The updated text now reads:

In this model, h_{fb}, x, and y are the inputs, while $a_0 - a_6$ and $\overline{h_{si}}$ are the 8 unknown parameters to be solved.

This revision ensures the distinction between inputs and unknowns is clear and unambiguous.

22. l.410: x and y are really lat and lon? It's strange with your grid projection. Using EASE2 they could be directly in meters ;-)

Response: Thank you for your observation. On Line 428, we clarified the definition of *x* and *y* in the text:

x and *y* represent the longitudinal and latitudinal surface distances between the observation point and the central point of the grid cell.

23. l.418: I suppose it's 25km here, not 10km. as you have just computed the 25km x 25km grids. However, when you look at the data supplied, the maps appear very patchy. Can you explain this? (not enough measurements, even at 25km resolution?).

Response: Thank you for pointing this out. We have corrected the resolution to 25 km on Line 436.

Regarding the patchy appearance of the maps, this is primarily due to insufficient measurements. Despite the 25 km resolution, data collection in certain areas has been limited, as we require at least 8 observations to accurately determine the sea ice thickness (SIT) in a given grid. While interpolation methods could be used to fill these gaps, they would introduce additional error sources. In future studies, we plan to reduce the number of necessary observations by fixing certain parameters (e.g., seawater density), thereby minimizing the amount of blank data and improving the spatial coverage of our results.

24. l.426: typo: antimeres -> altimeters

Response: Thank you for catching this typo. We have corrected "antimeres" to "altimeters" on Line 444.

25. l.427: "The pulse-limited altimeters have a large footprint of 2–10 km" radius or diameter?

Response: Thank you for pointing this out. We have clarified the statement on Line 445 to specify that the footprint is 2–10 km in diameter. The updated text now reads:
The pulse-limited altimeters have a large footprint of 2–10 km in diameter over sea ice.

26. l.441: typo: Bocquest -> Bocquet

Response: Thank you for catching this typo. We have corrected " Bocquest " to " Bocquet " on Line 451.

27. l.442: “for calibrating freeboard measurements from Envisat and ERS-2.” -> for calibrating Envisat freeboard measurements from CryoSat-2 and ERS-2 from calibrated Envisat.

Response: Thank you for your suggestion. We have revised the statement on Line 459 to clarify the calibration process. The updated text now reads:
Bocquet et al. (2023) presented a multiparameter neural-network-based method for calibrating Envisat freeboard measurements from CryoSat-2 and ERS-2 from calibrated Envisat.

28. l.443: “Tilling et al. (2019) developed a physical-based approach to correct Envisat SIT … ” Could be confusing with the retracker physical-based approach and it’s not more physical than considering the ice roughness as it is usually done, I would avoid this term.

Response: Thank you for your suggestion. We have revised the statement on Line 461 to avoid confusion with the retracker physical-based approach. The updated text now reads:
Tilling et al. (2019) corrected Envisat SIT according to the relationship between the thickness differences between Envisat and CryoSat-2 and the along-track distance between leads and the closest floe in the Envisat measurements.

29. l.453: I do not agree with this conclusion: “Compared with CryoSat-2 thickness, Envisat thickness showed an overestimation of 0.19 ± 0.67 m in January 2011.” As it is shown in your maps and histograms, LRM gets thinner ice over thin ice

and thicker over thick ice relatively to SAR as it was explained in Laforge et al 2021 https://doi.org/10.1016/j.asr.2020.02.001

Response: Thank you for your feedback. We have revised the statement on Line 470 to more accurately reflect the findings. The updated text now reads:
The difference between Envisat-SIT and CryoSat-2-SIT was 0.19 ± 0.67 m in January 2011. However, as shown in Figures 6 and 7, LRM tends to retrieve thinner ice over thin ice and thicker ice over thick ice relative to SAR, consistent with the findings of Laforge et al. (2021).

30. l.473, Table 5: Is 'Mean' the Mean Bias? Is STD the STD of the difference or of the product? Would be very pertinent to add the Correlations.

Response: Thank you for your suggestion. We have clarified the terminology on Line 483 and added the correlations as requested in Table 5 (now referred as Table 4 in the revised manuscript).

- Mean: The mean bias between Envisat and CryoSat-2 thickness.
- STD: The standard deviation of the differences.
- R: The correlation coefficient between the two datasets.

31. l.480: The main problem with ERS-1 and ERS-2 is related to the blurring of their waveforms over sea ice. You don't mention it and it looks like that you don't have applied specific correction for this problem. Any other calibration between ERS2 and Envisat, as for Envisat versus CryoSat2? As it is an important problem it would also be important to see the maps you obtain in front of Envisat map for the same period. And once again the correlation is an important criteria that should also be added.

Response: Thanks for your valuable comments and suggestion. We acknowledge the issue of waveform blurring over sea ice for ERS-2 and have addressed it in our data processing methods. We have added the following detailed discussion to the manuscript in Section 6 to ensure transparency and clarity:
In this study, we employed multiple radar altimetry data to retrieve Arctic SIT. The data processing of early satellites, particularly ERS-2, presents challenges primarily due to waveform blurring issues. Our data processing strategy inherently mitigates

this problem to a certain extent. We utilized a combination of waveform parameter thresholds and the LEM while detecting leads. The LEM, which is based on the premise that the surface height of leads is lower than that of nearby sea ice, helps to correct for misidentifications caused by waveform blurring. This integrated approach serves as a corrective measure for waveform-related issues in ERS-2 data.

Regarding the calibration between ERS-2 and Envisat, although the altimeters on these two satellites share some similarities, we did not perform a separate calibration specifically for ERS-2 and Envisat as we did for Envisat and CryoSat-2. This decision is based on the observation that the thickness difference between ERS-2 and Envisat during their overlapping mission period is approximately -0.37 m, which is negligible compared to the difference between CryoSat-2 and Envisat. Instead, we applied the monthly correction grid derived from the Envisat-CryoSat-2 comparison to the ERS-2-based thickness data. This approach not only corrects for systematic differences related to waveform blurring but also accounts for other potential factors between ERS-2 and Envisat. Introducing an additional calibration between ERS-2 and Envisat could introduce residuals between Envisat and CryoSat-2, potentially leading to the superposition of multiple errors.

We have added the correlations in Table 4 according to your suggestion.

32. l.484: typo: gird -> grid

Response: Thank you for catching this typo. We have corrected " gird " to " grid " on Line 503.

33. l.487, caption Fig 8: what is kermesinus?

Response: We have updated Figure 8 (now referred as Figure 9 in the revised manuscript) and replaced "kermesinus" with "purple" in the caption. The updated caption now reads:

Histogram of sea ice thickness in April 2003 from Envisat (in blue) and ERS-2 (in purple).

34. l.497: “The sea ice extent did not show any significant changes during this growth.” How do you determine the sea ice extent? It’s from NSIDC-0051 with

concentration>75%? Would worth to recall it here. It is a very important point as the mean SIT highly depends on it (if you consider or not the thin ice in MIZ).

Response: Thank you for your suggestion. We have revised the statement on Line 626 to clarify how sea ice extent is determined. The updated text now reads:
The sea ice extent, defined as regions with a sea ice concentration greater than 75% in the NSIDC-0051 dataset, did not show any significant changes during this growth period.

35. l.505: what do you mean by “normal distribution”?

Response: Thank you for your question. A normal distribution, also known as a Gaussian distribution, is a probability distribution that is symmetric about the mean, with data points forming a bell-shaped curve.

36. l.510: what do you mean by “sinistrality”?

Response: Thank you for your question. We have revised the term "sinistrality" to "left-skewed" on Line 640.

37. l.535: “The mean MYI thickness decreased by 0.017 m/yr during the research period,”. Please provide explicitly the period.

Response: Thank you for your suggestion. We have revised the statement on Line 668 to explicitly specify the research period. The updated text now reads:
The mean MYI thickness decreased by 0.018 m/yr during the research period from 1995/1996 to 2022/2023.

38. l.538-570: I’m not fully convinced of the interest of mean SIT for all the Arctic as this value mainly depends on the considered sea ice extent. For instance it can remains about no ice but only some remaining fast ice at the coast to obtain large mean SIT but it means nothing. To make this type of comparison meaningful you could for instance always consider the same mask (region) for each given month. Or an alternative would be to compute to total volume instead of the mean SIT. However I will not ask you to change this, but at least you should explain

specifically how you define the mask, for instance do you always use the area provided by NSIDC-0051 with concentration>75% for each month of each year?

Response: Thank you for your insightful suggestion. We acknowledge the limitations of using mean sea ice thickness (SIT) for the entire Arctic, as it can be influenced by changes in sea ice extent. In this study, the mask was defined using the NSIDC-0051 dataset with a sea ice concentration threshold of >75% for each month of each year.
We recognize that the mask changes month to month, which can affect the comparability of mean SIT values. In future research, we plan to address this limitation by presenting total sea ice volume, which provides a more robust metric for assessing Arctic sea ice changes.

39. l.574: Please specify if you use the same mask for all the products. It's important to make them comparable.
    l.582: The information of the mask is even more important for the CS2SMOS product because it can cover larger region as it also considers thin ice at the margins thanks to SMOS.

Response: Thank you for your suggestion. We have clarified the methodology for comparing different products on Line 510. The updated text now reads:
When comparing different products, we exclusively calculated the differences for grids where all products had valid values. Grids with missing values in any product were excluded from the comparison. This ensures that the analysis is based on consistent spatial coverage across all datasets.

40. l.592, Table 6: The mean bias and the correlation should be added.

Response: Thanks for your suggestion. We have added the statistics of ME and R to Table 6 (now referred as Table 5 in the revised manuscript). We can find that the WHU SIT shows a good correlation with other products, with the highest correlation of 0.977 with AWI-CS2, and the smallest correlation of 0.879 with GSFC-IS2.

41. l.598: it's really important to know which ice density and which snow depth you have chosen to convert the draft to SIT. If these values are not coherent with the product you compare you will necessarily get higher differences for this product.

Please also provide the used equation and the input parameters (mainly ice density, SD is based on WC or MWC?).

Response: Thank you for your suggestion. To avoid potential uncertainties associated with the W99 model in draft-to-thickness conversion, we revised our comparative strategy. Instead of converting ULS-measured ice drafts to sea ice thickness (SIT), we directly compared the ULS-measured ice drafts with satellite-derived draft estimates. The draft from satellite-based products was calculated by removing the ice freeboard from SIT. Since the AWI-SMOS+CS2 and CPOM products do not include ice freeboard parameters, we limited our comparison to the other six products. This approach ensures a more direct and accurate comparison, minimizing errors introduced by the conversion process.

42. l.606: typo: "The STDs of WHU were close …" -> "The STDs of WHU are close … "

Response: Thank you for catching this typo. We have removed the original sentence.

43. l.618-620, Tables 7 & 8: Please add the Mean Bias and the Correlation in these tables. Indeed, if there is a significant bias, both the MAE and the STD will be high, but if the correlation is good it will indicate that the tendencies are coherent, which is the most important point to study change rate. (Also it is not necessary to recall the units in each column ;-).

Response: Thank you for your suggestion. We have added the Mean Bias (ME) and Correlation (R) to Tables 7 and 8 (now referred as Tables 6 and 7 in the revised manuscript). WHU demonstrates consistent performance across all four ULS sites, maintaining correlation coefficients exceeding 0.65 with in situ measurements. The observed discrepancies between ULS measurements and SIT products appear methodology-dependent, particularly regarding sensor data selection. Analysis indicates that products incorporating Envisat data (CCI, CTOH, and WHU) prior to October 2010 exhibit relatively lower accuracy compared to CryoSat-2-based solutions. This distinction is quantitatively substantiated in Table 7, which presents post-October 2010 statistics showing marked accuracy improvements for these three products when transitioning to CryoSat-2 data. The comparative results clearly demonstrate the enhanced precision of CryoSat-2-derived thickness estimates over Envisat-based methodologies.

44. l.624: “Then, the mean thickness of the OIB within the grid was compared with the corresponding grid values.” OIB products do not include SIT, how do you compute it? Please provide the equation and the input parameters used from OIB data.

Response: We obtained SIT from the IceBridge L4 and Quick Look Sea Ice Freeboard, Snow Depth, and Thickness products. The OIB L4 and quick look SIT datasets can be found at https://nsidc.org/data/idcsi4/versions/1 and https://nsidc.org/data/nsidc-0708/versions/1.

45. l.636, Figure 16: For some products the count reaches nearly 1500 and for others it is lower than 300. The shape of the histograms being similar, it means that the number of measurements from one product to another can differ by a factor 3. How can you explain it? Is it because of the resolution of the original product?

Response: Thank you for your question. The disparity in the number of measurements across products is primarily due to differences in the resolution of the original datasets. For example, WHU and CPOM have a higher resolution of 5 km, resulting in a larger number of measurements compared to other products with coarser resolutions.

46. l.643, Table 9: Please add the correlations.

Response: Thank you for your suggestion. We have added the correlations (R) to Tables 9 (now referred as Table 8 in the revised manuscript). Specifically, our product had an MAE of 0.38 m, and an STD of 0.37 m and a correlation of 0.86, presenting a moderate accuracy among the seven products.

47. l.647: “… error propagation of the input uncertainties including radar freeboard, ice density, snow depth … ”

Response: Thank you for your feedback. We have revised the statement on Line 596 for clarity. The updated text now reads:
the uncertainty of SIT can be computed as the error propagation of the input uncertainties including radar freeboard, ice density, snow depth and snow density.

48. l.655: “Thus, the uncertainties of the SIT can be calculated by the difference of h_{si} in the last two iterations.”. I don't understand why the last two iterations are more relevant than the previous ones. To me, this is more a reflection of the speed of convergence of the LSA than the uncertainties. Please justify this solution. For example, you could more naturally assess the distance between the model and the measurements by calculating the STD or MAE between the model and the measurements.

Response: Thank you for your detailed question. We have revised the explanation on Line 655 to clarify why the difference in sea ice thickness (SIT) values between the last two iterations is used to calculate uncertainties. The updated text now reads:
"Here we calculated the uncertainties of the SIT based on the difference in $\overline{h_{si}}$ values between the last two iterations. This approach is related to the convergence behavior of the iterative process. As iterations progress, the calculated SIT values gradually converge toward a stable solution. In the early iterations, values may fluctuate significantly as the model adjusts to find the optimal fit. However, as convergence is approached, changes between consecutive iterations become smaller. The difference between the last two iterations represents the residual change just before the model reaches its final state, providing a measure of the uncertainty in the calculated SIT. "
While metrics such as standard deviation (STD) or mean absolute error (MAE) between the model and measurements could also provide valuable insights, a direct calculation is complicated in our case. The input data to our model is freeboard, while the output is SIT, making it challenging to directly compute STD or MAE.

49. l.678: Please replace the link https://www.legos.omp.eu/ctoh/fr/produits-ctoh/ by a more direct one: http://dx.doi.org/10.6096/ctoh_sit_2023_01

Response: Thank you for your suggestion. We have replaced the link with the more direct one as requested.