

Sea ice in the Baltic Sea during 1993/94–2020/21 ice seasons from satellite observations and model reanalysis

Anonymous Referee #1,

https://editor.copernicus.org/index.php? mdl=msover_md& jrl=778& lcm=oc108lcm109w& acm=get_comm_sup_file& ms=120859&c=269726&salt=5798643141918097389

Thank you very much for taking the time to thoroughly review the manuscript and for providing your valuable feedback. We have carefully considered your comments and are pleased to provide our responses to your questions and remarks below.

General comments:

Rev1.1)

While methodology and results in the paper are properly presented and discussed, I have some questions and remarks on the used datasets and some other major comments below. Satellite data sea ice fraction was taken Copernicus SST product. According to product documentation this sea ice fraction comes from the ice chart in which it based on manual analysis. Thus, sea ice fraction does not come from any automatic algorithm, which must mentioned in the paper.

Response: Description “The sea ice fraction data in the product is taken from the sea ice charts from the national ice services at FMI and SMHI, based on manual interpretation by the operator” has been added in the manuscript at lines 74-76.

Rev1.2)

Sea ice thickness seems to be taken from Copernicus Marine Baltic Sea–Sea Ice Concentration and Thickness Charts product dataset with product id SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_004. This dataset is the manual ice chart, and ice thickness is level ice thickness, and that is why you likely observed model overestimating ice thickness; more off-shore than near the coasts where there is level landfast ice. You refer ice thickness as the SAR & ice chart based product, but ice thickness in the ice chart is based on in-situ data from coastal stations and icebreakers. Or is there an error in the text and you in reality use Baltic Sea - SAR Sea Ice Thickness and Drift, Multisensor Sea Ice Concentration product which has sea ice thickness dataset where ice thickness from the ice chart is spatially enhanced using SAR imagery?

Response: There is no error regarding the sea ice thickness product. The product used in the study for sea ice thickness is indeed from Copernicus Marine Baltic Sea–Sea Ice Concentration and Thickness Charts product dataset with product id SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_004. The product has daily ice thickness data from the ice chart which is adjusted using SAR image, mentioned in

the product user manual¹. It is validated against icebreaker ice thickness data (Berglund et al., 2014) in the QUID file of the product², and shows similar statistics to the Baltic Sea - SAR Sea Ice Thickness and Drift, Multisensor Sea Ice Concentration³.

References (for above text):

1. For Baltic Sea – Sea Ice Observations SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_004/011, Issue: 2.14, section III.1.1 Ice charts of the Finnish Ice Service
2. QUID for SEA ICE TAC Products 011_004, 011_011, 011_019, Ref. CMEMS-SEAICE-QUID-004_011_019, issue 1.1
3. Product id: SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_011, <https://doi.org/10.48670/moi-00133>

Description “The ice parameters in the product are based on SAR image and ice chart produced on a daily basis during the Baltic Sea ice season provided by FMI and SMHI. The product is validated against icebreaker ice thickness data (Berglund et al., 2014) in the Quality Information Document file (CMEMS-SEAICE-QUID-004_011_019, issue 1.1)” has been added at lines 95-97

Rev1.3)

Section 4 should be under Section 5 ‘Results’, and Section 5 could start with short introduction of the section contents.

Response: Suggested changes are made with the added introduction “This section is divided into several subsections, including a comparison of the model with satellite sea ice data for ice extent and thickness; an analysis of sea ice season parameters; a statistical examination of sea ice fraction versus sea ice thickness; and a trend analysis of sea ice characteristics” at lines 146-148.

Rev1.4)

The sea ice fraction threshold for calculating sea ice extent from the model data was tuned against the satellite data SIE. How do you know here that the satellite data SIE is more accurate than the model SIE? Possible that satellite data needs bias correction not model data?

Response: The sea ice data in the satellite product is based on Copernicus SI-TAC products (which includes Ice charts and SAR based sea ice data) and high resolution SMHI data [RD.5] (Product user manual: CMEMS-SST-PUM-010-016-040, <https://doi.org/10.48670/moi-00156>). Although SIE based on this data may have uncertainties, these datasets have consistently been used in studies to validate other datasets such as model products (Karvonen 2021; Leppäranta 2023; Pärn et al. 2021; Mäkynen et al. 2020) and are available for a long term period.

The uncertainties have been highlighted in the QUID file (QUID for SEA ICE TAC Products 011_004, 011_011, 011_019, Ref. CMEMS-SEAICE-QUID-004_011_019, issue 1.1): The daily ice chart Sea ice

concentration (SIC) was compared with the radiometer product of University of Bremen, which showed a difference of $\pm 10\%$. Taking into account the restrictions of the radiometer product (poor/moderate resolution, mixed pixels) (Spren et al., 2008), the agreement was good. The ice chart-based ice thickness results were compared with ice thickness results measured on Finnish and Swedish icebreakers. The locations of the IB measurements during the season 2022-2023 were mostly over the Gulf of Bothnia where most of the ice was located and only a few measurements were made in the northern parts of the Gulf of Finland. Over 214 observations, Bias and RMSD value were 5 cm and 9.8 cm respectively.

Since there is not yet a better automatic tool for interpretation of sea ice in high resolution imagery, and due to the lack of systematic long term field observations, ice charts are considered being the data sets that best describes the true state of the sea ice, and thus other sea ice data sets use these as reference.

(CMEMS-SI-QUID-011-001to007-009to014, QUALITY INFORMATION DOCUMENT

For SI TAC Sea Ice products 011-001, -002, -004, -006, -007, -009, -010, -011, -012, -013, -014, issue 2.10).

Description “Although ice chart-based sea ice data may have some uncertainties, these datasets have been reliably used in numerous studies to validate other products such as model products (Mäkynen et al., 2020; Karvonen, 2021; Pärn et al., 2021; Leppäranta, 2023) and are available over an extended period. Due to the lack of a better automated tool for interpreting high-resolution sea ice imagery and the limited field observations, ice charts are considered the most accurate datasets for representing the true state of sea ice, and thus other sea ice data sets use them as reference (CMEMS-SI-QUID-011-001to007-009to014, issue 2.10)” has been added at lines 99-103.

Rev1.5)

In Section 4.2 explain how corrected ice thickness was calculated, diving by 1.814?

Response: Yes, that is correct.

Description “The corrected ice thicknesses (by dividing the model ice thickness values by factor 1.814)” has been added at lines 192-193.

Rev1.6)

How results of the trend analysis would change if you use different time intervals, e.g. five or ten Years?

Response: In our study, the trends patterns for different time intervals are still somewhat similar with varying magnitude but due to smaller sample size, the trends are not significant at 95 percent confidence interval. Example figure for trend of last 10 years mean sea ice thickness (cm) attached below.

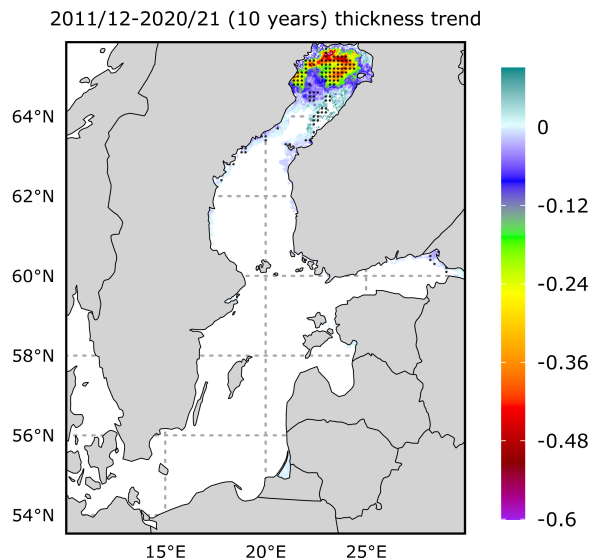


Figure R1.6: Linear trend of ice thickness (in cm/year) for Nov–May mean ice thickness from 2011/12 to 2020/21. Black dots mark the areas with 95 % significance level

Specific Comments:

Rev1.7)

line 7: “recent period (2007–2021)”

Definition of this recent period here is vague without defining what is the preceding period. Figure 1 is not introduced and discussed in Section 1. Same color is used for Bothnian Sea and Danish Straits.

Response: Relevant description in abstract has been changed to “The sea ice characteristics during the recent period (2007/08–2020/21) show decreased sea ice fraction and thickness compared to the preceding period (1993/94–2006/07) of the study” at lines 6-8.

Figure 1 is introduced with “The geographical boundaries of the sub-basins used in current study are based on the PLC-6 project, obtained from Helsinki Commission (HELCOM, 2018), shown in Fig. 1 “ and discussed at lines 104-105. Color used for the Danish Straits sub-basin has been changed in Fig 1.

Rev1.8)

I. 28: BACC II Author Team, 2015

This reference is missing from reference list.

Response: Reference “Rasool, S. I., Menenti, M., and Bolle, H.-J.: Second assessment of climate change for the Baltic Sea basin, Springer, 2015” is added in the manuscript at line 499.

Rev1.9)

*l. 42: "Remote sensing techniques have evolved to enhance the efficacy of ice information services"
Include here some newer references, e.g. papers by Karvonen et al.*

Response: Newer references "Karvonen 2017; Karvonen 2021" are added in the manuscript at lines 43-44.

Rev1.10)

*l. 55: ice state over previous model products (QUID_REAN).
Explain QUID_REAN, or give reference.*

Response: Reference "(Panteleit et al. 2019, CMEMS-BAL-QUID-003-011)" is added in the manuscript at line 56.

Rev1.11)

l. 71: spell out SMHI and FMI when first time used.

Response: SMHI and FMI are spelled out when used for the first time at lines 73-74.

Rev1.12)

*l. 80: "The system is forced by ECMWF ERA5 meteorology (ref)."
give reference*

Response: Reference "(Hersbach et al. 2020)" is added in the manuscript at line 85.

Rev1.13)

*l. 123: "the dataset (the lm function from R)"
explain this lm function from R*

Response: Description "(the lm function from R, lm is used to fit linear models and can be used to carry out regression)" is added in the manuscript at lines 137-138.

Rev1.14)

*l. 131: "The quality information document (QUID) ..."
Give reference for the QUID document, it is not Karvonen et al. 2007.*

Response: Reference “(Panteleit et al. 2019, CMEMS-BAL-QUID-003-011)” is added in the manuscript at line 150.

Rev1.15)

Figure 3 is introduced in the text after Figure 4.

Response: Relevant part has been restructured to introduce figure 3 first in the manuscript at lines 175-176.

Rev1.16)

Figure 8: very difficult to see black contour lines.

Response: Instead of contour lines, discrete color shading has been used to improve visibility for the figure 8.

Rev1.17)

Table 3: maybe SIT data with 0.1 cm accuracy

Response: SIT data in table 3 is rounded off to one decimal point.

Verdana fonts have been used in all the figures for better visibility.

Sea ice in the Baltic Sea during 1993/94–2020/21 ice seasons from satellite observations and model reanalysis

Anonymous Referee #2

https://editor.copernicus.org/index.php?_mdl=msover_md&_jrl=778&_lcm=oc108lcm109w&_acm=get_comm_sup_file&_ms=120859&c=270362&salt=1013438105556683178

We greatly appreciate your thorough review of our manuscript and the valuable feedback you provided. We have carefully addressed your comments and are happy to present our responses, along with additional analysis to support our study.

General comments:

Rev2.1)

I do have major concern in the period split: why you choose 2007 as the threshold for the date division, please provide some explanation.

Response: According to Pärn et al. 2022, a new regime of sea ice began in 2008 and in all basins of the Baltic Sea, a rapid warming during spring could be detected. Hence the study period is divided into two halves. It is mentioned in paper as well “Based on the regime shift detected by Pärn et al. (2022) we split our study period into two parts: 1993/94–2006/07 (preceding period) and 2007/08–2020/21 (recent period)” at lines 236-237.

Rev2.2)

Another concern is the data usage in SST_BAL_SST_L4_REP_OBSERVATIONS_010_016 (satellite product) and SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_004 (SAR & ice charts-based product). How do you consider the uncertainty in the satellite and SAR & ice charts-based product considering you use the satellite product to determine/correct the sea ice fraction threshold in the reanalysis data, it is important to know the accuracy or uncertainty of the satellite product.

Response: The sea ice data in the satellite product is based on Copernicus SI-TAC products (which includes Ice charts and SAR based data) and high resolution SMHI data [RD.5] (CMEMS-SST-PUM-010-016-040, Product user manual: <https://doi.org/10.48670/moi-00156>). Although Ice charts based sea ice data may have uncertainties, these datasets have consistently been used in studies to validate other products such as model products (Karvonen 2021; Leppäranta 2023; Pärn et al. 2021; Mäkynen et al. 2020) and are available for a long term period.

The uncertainties have been highlighted in the QUID file (QUID for SEA ICE TAC Products 011_004, 011_011, 011_019, Ref. CMEMS-SEAICE-QUID-004_011_019, issue 1.1): The daily ice chart Sea ice concentration (SIC) was compared with the radiometer product of University of Bremen, which showed a difference of $\pm 10\%$. Taking into account the restrictions of the radiometer product (poor/moderate resolution, mixed pixels) (Spren et al., 2008), the agreement was good. The ice

chart-based ice thickness results were compared with ice thickness results measured on Finnish and Swedish icebreakers. The locations of the IB measurements during the season 2022-2023 were mostly over the Gulf of Bothnia where most of the ice was located and only a few measurements were made in the northern parts of the Gulf of Finland. Over 214 observations, Bias and RMSE value were 5 cm and 9.8 cm respectively.

Since there is not yet a better automatic tool for interpretation of sea ice in high resolution imagery, and due to the lack of field observations, ice charts are considered being the data sets that best describes the true state of the sea ice, and thus other sea ice data sets use these as reference.

(CMEMS-SI-QUID-011-001to007-009to014, QUALITY INFORMATION DOCUMENT For SI TAC Sea Ice products 011-001, -002, -004, -006, -007, -009, -010, -011, -012, -013, -014, issue 2.10)

Description “Although ice chart-based sea ice data may have some uncertainties, these datasets have been reliably used in numerous studies to validate other products as model products (Mäkynen et al., 2020; Karvonen, 2021; Pärn et al., 2021; Leppäranta, 2023) and are available over an extended period. Due to the lack of a better automated tool for interpreting high-resolution sea ice imagery and the limited field observations, ice charts are considered the most accurate datasets for representing the true state of sea ice, and thus other sea ice data sets use them as reference (CMEMS-SI-QUID-011-001to007-009to014, issue 2.10)” has been added at lines 99-103.

Rev2.3)

And when I look at the Table 1, I am also wondering how is the RMSE and Bias look like during 0.15 and 0.25? What about other thresholds, such as 0.18 or 0.23? And since you've showed two criteria for threshold selection, how do you coordinate them together, such as in RMSE, 0.20 reanalysis threshold has the lowest value while in Bias, 0.25 seems to have the lowest Value.

Response: Bias is used as the primary criteria to select optimal threshold, RMSE and CC are calculated to confirm the results. Results from other thresholds are given below. The selection is made out of traditionally used ice fraction thresholds which are generally factors of 0.05 like 0.15, 0.20 etc., especially considering 0.20 gives reasonably low bias.

Table R2.3: Comparison of sea ice extent calculated using different threshold values of SIF for the model dataset is shown by means of statistical methods such as correlation coefficients (CC), root mean square error (RMSE), and mean bias

TH_SIF (Satellite)	TH_SIF (Model)	Bias (km ²)	RMSE (km ²)	CC
0.15	0.15	1783	4887	0.994
0.15	0.16	1490	4648	0.995
0.15	0.17	1208	4439	0.995
0.15	0.18	935	4260	0.995
0.15	0.19	671	4110	0.995

0.15	0.20	416	3991	0.995
0.15	0.21	168	3900	0.996
0.15	0.22	-73	3837	0.996
0.15	0.23	-309	3803	0.996
0.15	0.24	-539	3795	0.996
0.15	0.25	-764	3810	0.996

Due to formatting, the negative sign for bias values corresponding to 0.25 model TH_SIF was missing in the table which is added. Required changes are made to reduce ambiguity for the selection criteria.

Descriptions “Bias is used as the primary criteria to select optimal threshold, RMSE and CC are calculated to confirm the results” and “The selection is based on traditionally used ice fraction thresholds, typically in increments of 0.05, such as 0.15 and 0.20, especially considering 0.20 gives reasonably low bias” have been added at lines 167-168 and lines 171-173 respectively.

Rev2.4)

And I am quite lost in Line 151, when you mentioned, "TH_SIF of 0.15 for the model dataset, provides more accurate estimates of maximum SIE", can you provide more clearly and statistically evidences in why 0.15 the accurate estimate of maximum SIE is.

Response: It can be seen from figure 4 for max SIE. In terms of Statistics, Bias and RMSE are calculated between max SIE time series (similar to figure 3) for these two threshold combinations and shown below in the table. From the table, it is apparent that TH_SIF of 0.15 for the model dataset provides more accurate estimates of maximum SIE compared to TH_SIF of 0.20.

Table R2.4: Comparison of max sea ice extent calculated using different threshold values SIF for the model dataset is shown by means of statistical methods such as root mean square error (RMSE) and mean bias

TH_SIF (Satellite)	TH_SIF (Model)	Bias (km ²)	RMSE (km ²)
0.15	0.15	-1165	14682
0.15	0.20	-5552	16143

Description “When comparing maximum SIE time series, the bias between the satellite TH_SIF of 0.15 and the model TH_SIF of 0.15 is -1165 km² while the bias between the satellite TH_SIF of 0.15 and the model TH_SIF of 0.20 is -5552 km²” is added at lines 176-178.

Rev2.5)

In Section 4.2, when you are trying to correct the reanalysis sea ice thickness based on three years SAR images and ice chart product, I am not sure if it is statistically robust. Given that samplings for grid is large, but when you consider the annual changes, 3 years is quite short, and not long enough to support your ice thickness correction statements.

Response: Beside it being the common period available between the two datasets, the model reanalysis sea ice thickness data shows considerable variations within these 3 years and probability distribution plot shows overlapping thickness distribution for these 3 years compared to the complete 27 years reanalysis thickness data.

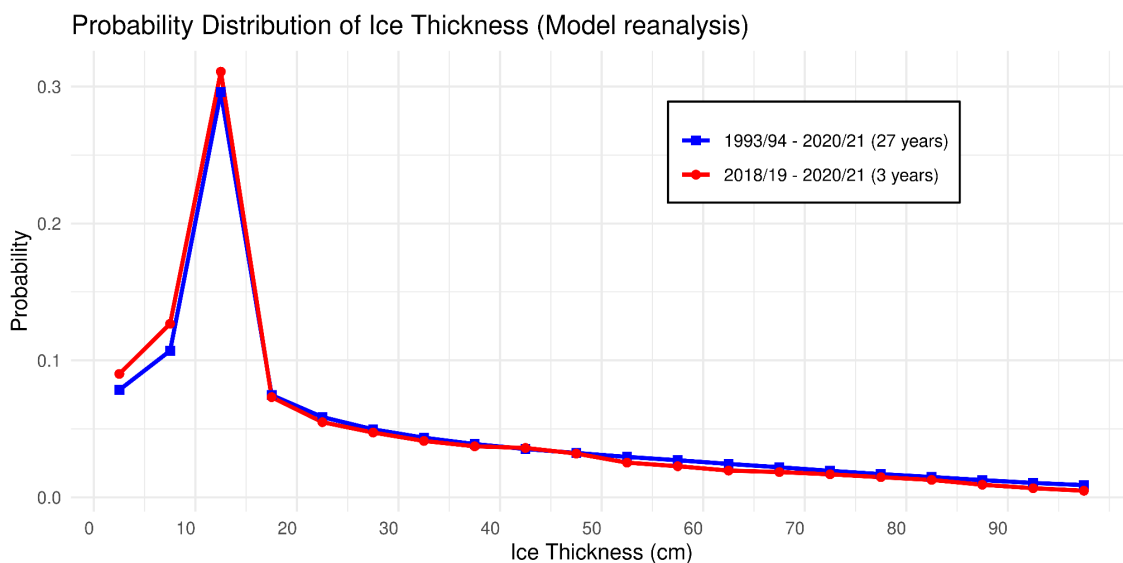


Figure R2.5: Probability distribution of ice thickness at 5 cm intervals for the recent three years of data (2018/19-2020/21), and the whole period available (1993/94-2020/21) from the model reanalysis product

Description “One of the drawbacks of this analysis is the limitation in data availability, which restricts the comparison of ice thickness to only three winters. It’s worth noting that the model reanalysis sea ice thickness data for these three years exhibits considerable variations, with the probability distribution plot (not shown) indicating a similar thickness distribution when compared to the complete 27-year reanalysis dataset.” is added in the manuscript at lines 196-199.

Rev2.6)

When I look at the Figure 5, it is quite obviously that Model SIT has the saturation stage in high value compared with the SAR images and ice chart. Then (1) how to explain this condition; (2) instead of the linear relationship, how about using the exponential lines to picture the fitting?

Response: (1) The SAR & ice chart based SIT does seem to get saturated at lower values compared to Model SIT, this could be related to how the data processing and filtering for the SAR & ice charts data is done. Although above 40 cm ice thickness (where SAR & ice charts based ice thickness data is getting saturated), the model has only 3.4 % of the data, and if excluded, it does not affect the slope much in figure 5.

The thickness distribution for the common data from SAR & ice charts based and model based data is given below.

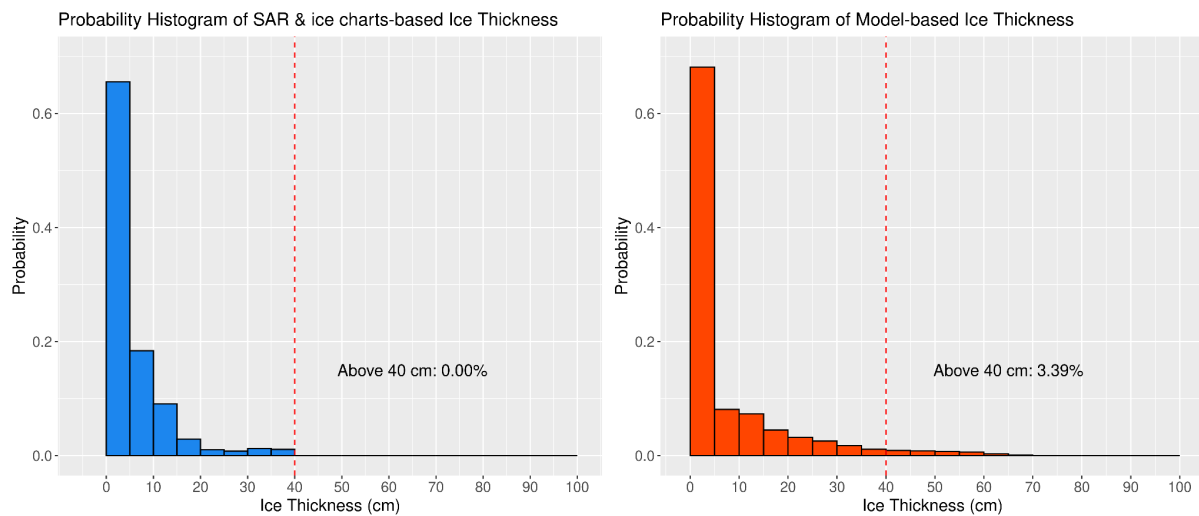


Figure R2.6A: Probability distribution histograms of ice thickness at 5 cm intervals for the recent three years (2018/19-2020/21), from SAR & ice charts-based dataset (left) and model reanalysis dataset (right)

Description “Additionally, it’s important to note that ice charts and SAR-based data tend to saturate at lower thickness values” is added at lines 199-200.

(2) Using non linear fitting slightly improves the fit (Example for nonlinear fit shown below), but the difference of parameters such as R squared value is really small compared to linear fit. So to simplify the analysis, linear fitting is chosen (the below equation can be used to get a slightly better fit).

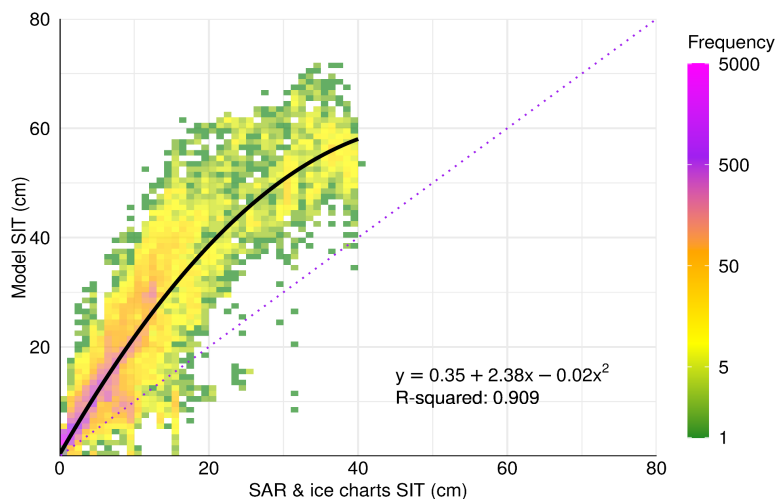


Figure R2.6B: Time averaged sea ice thickness (in cm) 2D histograms: SAR & ice charts vs model based dataset for 2018/19-2020/21 period

Rev2.7)

And I don't understand how to apply the correction coefficient in Line 168, did you overall divide the values by the 1.81?

Response: Yes, that is correct.

Description “The corrected ice thicknesses (by dividing the model ice thickness values by factor 1.814)” has been added at lines 192-193.

Rev2.8)

My next concern is the motivation behind the assessment of the Baltic Sea ice product, which is missing in the Discussion section. For example, what are the limitations of using the current data? What insights can be provided to modelers for improving models? Which updates have improved the product performance compared to previous versions? The current discussion lacks depth and does not provide the audience and the community with sufficient information beyond the assessment Results.

Response: Description “The discrepancies in ice models may stem from both atmospheric forcing fields and uncertainties related to the parameterization of ocean-ice-atmosphere processes (Vihma and Haapala, 2009). The majority of state of art models still lack a full atmosphere-wave-ice-ocean coupling system, which inherits various approximations and model corrections through data assimilation. While the correction of the physical model SST using satellite data assimilation helps reduce SST errors in the Nemo-Nordic 2.0 model, the onset of ice periods is still delayed by approximately a week (Fig 8c). This might mean that there are discrepancies in cooling of sea temperature or errors in early ice formation processes. Given that ice conditions in the Baltic Sea differ from polar regions (e.g. no multi-year ice), bulk parameterizations for ice thermodynamics and rheology processes should be revised according to local ice conditions and ice model should be calibrated using reliable data sources (Pemberton et al., 2017). Additionally, with the development of fine-resolution ice models in dynamic ice regions, it may become relevant to implement more advanced rheology parameterizations, such as brittle ice rheology (Bordeau et al., 2024; Olason et al., 2022).” is added in the manuscript at lines 338-347.

References

“Brodeau, L., Rampal, P., Ólason, E., and Dansereau, V.: Implementation of a brittle sea ice rheology in an Eulerian, finite-difference, C-grid modeling framework: impact on the simulated deformation of sea ice in the Arctic, Geoscientific Model Development, 17, 6051–6082, 2024.”
“Haapala, J. J., Ronkainen, I., Schmelzer, N., and Sztobryn, M.: Recent change—Sea ice, Second assessment of climate change for the Baltic Sea basin, pp. 145–153, 2015.”
“Olason, E., Boutin, G., Korosov, A., Rampal, P., Williams, T., Kimmritz, M., Dansereau, V., and Samaké, A.: A new brittle rheology and numerical framework for large-scale sea-ice models, Journal of Advances in Modeling Earth Systems, 14, e2021MS002 685, 2022.” are added in the manuscript at lines 379-381, 403-404 and 480-481 respectively.

Detailed comments:

Rev2.9)

Line 65, Dataset part: please provide detailed information on the temporal resolution and time span of the three products. Additionally, explain how you coordinate these products with different resolutions and specify the interpolation methods used.

Response: The products are interpolated to a common grid system, using bilinear interpolation. In case of satellite and model data, the common grid resolution used is 0.0277×0.02 , while for Ice charts & SAR and model data, the common grid used is $0.0277^\circ \times 0.0166^\circ$ (2×2 km).

Descriptions “The product data is available daily from 1 Jan 1982 to 31 Dec 2023”, “It offers a comprehensive reanalysis of physical conditions in the Baltic Sea available daily from 1 Jan 1993 to 31 Dec 2021”, “This dataset has 1×1 km spatial resolution and is available daily from 1 Jan 2018 to 5 Jun 2024” and “The products are resampled to a common grid system using bilinear interpolation for comparison” are added at lines 76, 82-83, 94-95 and 141-142 respectively.

Rev2.10)

Line 80, please fill in the reference.

Response: Reference “(Hersbach et al. 2020)” is added in the manuscript at line 85.

Rev2.11)

Figure 2, I suggest moving either panels (a) and (b) or (c) and (d) to the appendix, as they seem to replicate information.

Response: Panels (a) and (b) from figure 2 are moved to the appendix figure named Figure A1.

Rev2.12)

Figure 10: specify the units in panels (a) and (d). I’m quite interested in the fitting process in panels (c) and (f). When focusing on the density plot, consider showing how the linear fitting looks when focusing on high-intensity values or averaging bin values, and then performing the linear fitting.

Response: Figure 10: panel (a) and (d) are ice fraction differences hence unitless, for panel (b) and (e) units are specified in figure caption. Figure for Linear fitting when focusing on high intensity values (ice thickness difference more than 15 cm) is shown below (For MAM density plot). The higher thickness difference values here correspond to mostly the Bothnian Bay basin where thickness changes have been the largest during spring (Fig. 10e).

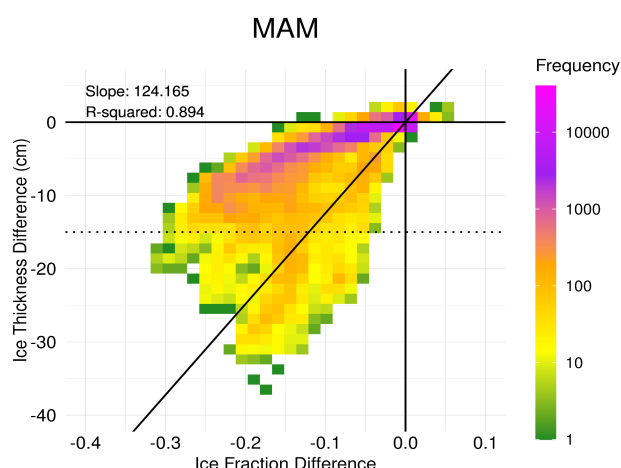


Figure R2.12: 2D histograms for the MAM fraction vs thickness differences (the recent period 2007/08–2020/21 compared to preceding period 1993/94–2006/07), shaded according to their frequency. Linear regression line is plotted, only focusing on thickness changes larger than 15 cm.

Rev2.13)

Line 231: could you provide an interpretation of why the Gulf of Finland sub-basin exhibits the most significant reduction during the melting season compared to the freezing season?

Response: Although our study has not focused on the underlying reasons for these changes, it is evident that recent research has detected rapid warming during the spring season (Pärn et al. 2022). Given that the Gulf of Finland is a shallow basin, this warming could have contributed to the significant reduction in ice fraction observed during the melting phase (spring season).

Description “Although our study has not focused on the underlying reasons for these changes, it is evident that recent research has detected rapid warming during the spring season (Pärn et al. 2022). Given that the GoF is a shallow basin, this warming could have contributed to the significant reduction in sea ice observed during the melting phase (spring season)” is added in the manuscript at lines 263-265.

Rev2.14)

Figure 11 and 12, could you overlay the trend with the 95% significance level? For example, use stipples to indicate the 95% confidence level or plot only the trends that are above the 95% confidence level.

Response: 95% significance level in the figure 11 and 12 is overlaid using stipples.

Rev2.15)

Figure 12(b): verify the values around 55°N, 21°E, and explain why this area shows the largest reduction in ice thickness.

Response: Around 55°N, 21°E (Curonian lagoon), the absolute trend values for ice thickness are really low for the area, but in terms of percentage of reduction the larger because the area has very thin ice and is separated by Curonian Spit from the Baltic Sea. But we are not focusing on this region in the study hence it is not mentioned in the manuscript.

Rev2.16)

Line 261, wrong reference format.

Response: Reference format for “Åström et al. 2024” is corrected in the manuscript at line 295.

Verdana fonts have been used in all the figures for better visibility.