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

We appreciate your feedback.

Rev 2.1:

the reader is not interested in the software used – so the sentence with the explanation of the function 'R' should be removed.

Response: The sentence "(the lm function from R, lm is used to fit linear models and can be used to carry out regression)" is removed.

Rev 2.2:

Firstly, it sounds strange or it is a big issue that the reanalysis of sea ice included in the Copernicus database looks like it is wrong. I have no idea what should be fixed, but based on figure 6, the modeled sea ice thickness is excessively overestimated, which suggests problems in the circulation model or wrong parameterizations in the ice model – sea ice is created at the boundary between the ocean and air or between the ocean and sea ice. However, it should be described in the Copernicus database – somebody paid for those data and it has been accepted. To me, the data in the Copernicus database should be treated as a reference, and such dataset should not be accepted.
The SD in the paper differs, and I feel there is a problem with the circulation model which is also visible in figure 6.

Response: The issue is resolved, as after clarification from the Copernicus support team, the product SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_004 has level ice thickness as opposed to total ice thickness. Hence values are much lower than the model dataset.Relevant reference (Ronkainen et al., 2018) is added for the comparison. So the model reanalysis ice thickness data is used in the analysis without any correction.
The SAR & Ice charts data is only consistently available for a short period as compared to the model reanalysis data, which is consistent and available for the whole study duration. Also ice thickness in the model when compared against the level ice thickness from SAR & ice charts, are in the reasonable range indicated by earlier study by Ronkainen et al., 2018).
The Copernicus model reanalysis data is compared with the global ocean and sea-ice reanalysis (ORAS5: Ocean Reanalysis System 5) dataset, which is the monthly mean sea-ice reanalysis data prepared by the European Centre for Medium-Range Weather Forecasts (ECMWF) OCEAN5 ocean analysis-reanalysis system. The comparison between the two products shows similar ice thickness values (see Fig. rev2.2 below). The mean bias of Baltic sea physics reanalysis dataset is -3.7 cm, against the ORAS5 dataset. Thus, the Copernicus products have similar quality as the ECMWF product.

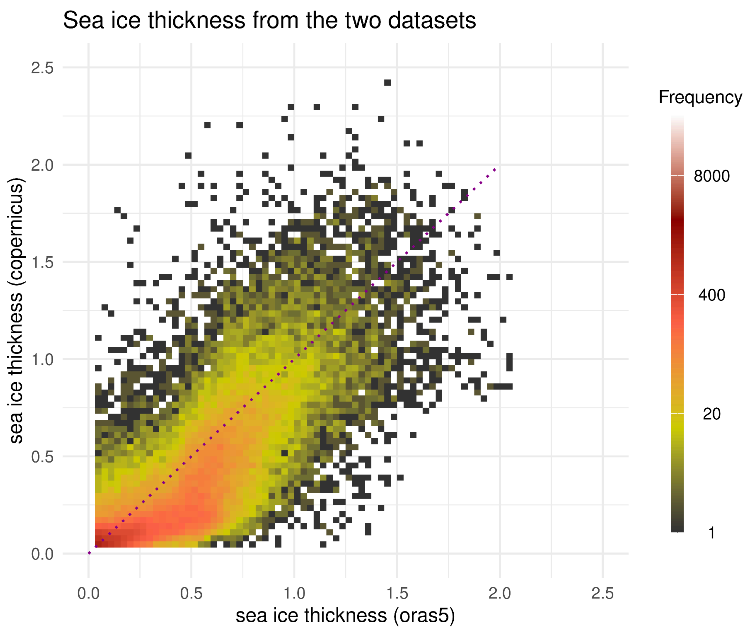

Fig. rev2.2: Sea ice thickness: Global ocean and sea-ice reanalysis (ORAS5: Ocean Reanalysis System 5) vs Baltic sea physics reanalysis, from 1993 to 2014. Dotted red line (1:1) is added for reference.

Rev 2.3:

The freezing and melting seasons depend on time but also on location, which means that the time depends on location, but in this work, it is divided only in time (DJF and MAM). I think it is a wrong approach and should be fixed.

Response: The ice season was divided into DJF and MAM periods to study changes during these two seasons separately, as previous studies (such as Pärn et al., 2022) have inferred rapid warming during spring (MAM) season. We agree the terminology of freezing and melting season was not correct and hence it is not used anymore, and they are referred to as winter and spring season instead throughout the whole paper.

Freezing and melting periods (which are defined as the periods before and after the max ice thickness at each grid respectively) statistics are provided below, incase of interest (Fig. rev2.3.1 and Fig. rev2.3.2).

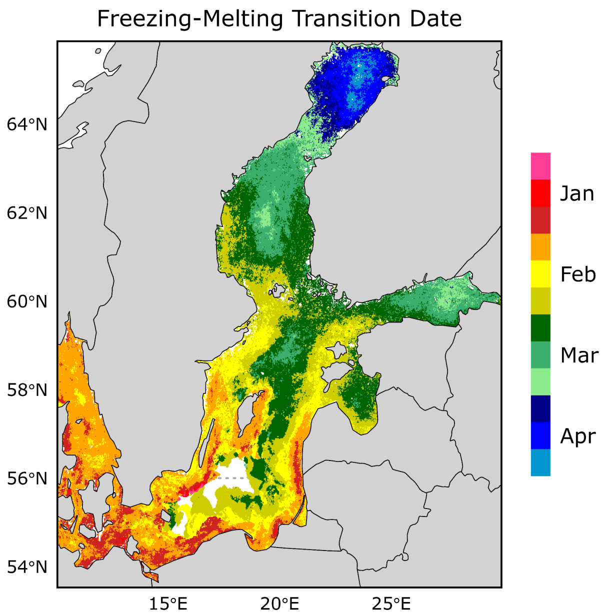

Fig. rev2.3.1: Spatial map for date of transition from freezing to melting phase averaged over all ice seasons, the freezing and melting phases are the ice periods before and after the max ice thickness respectively

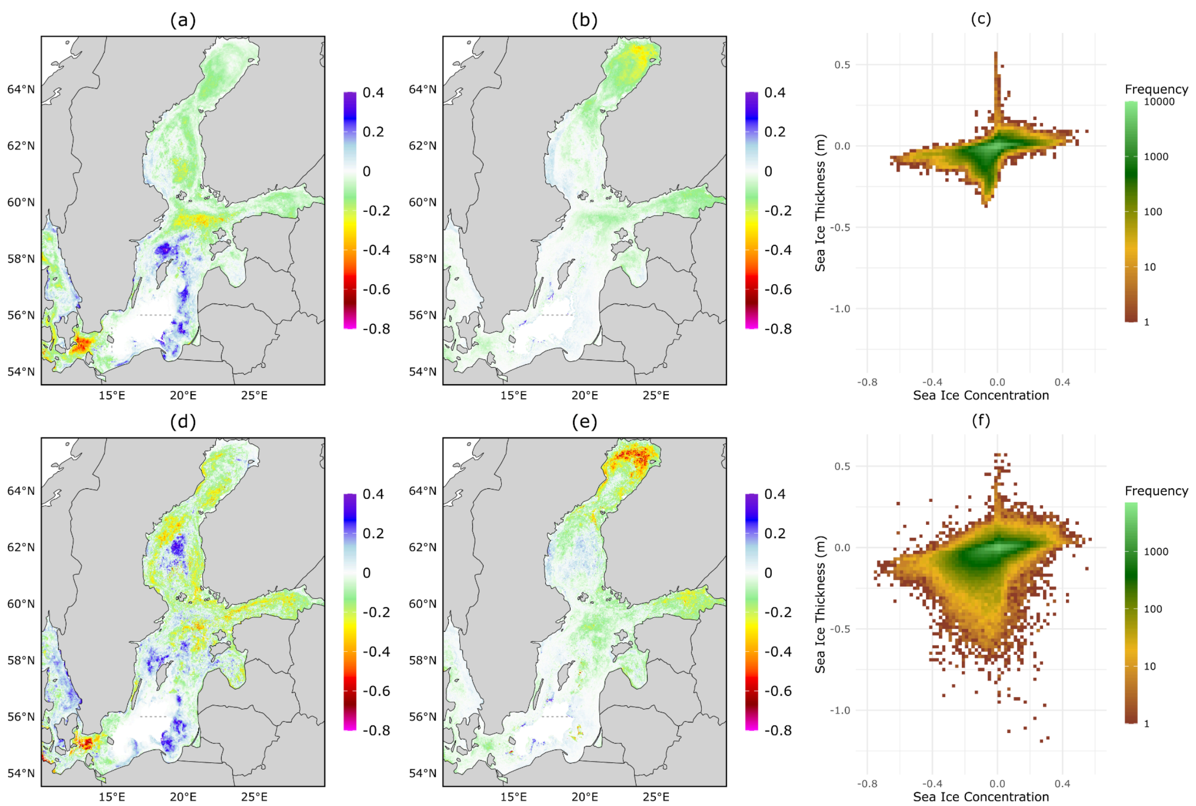

Fig. rev2.3.2: The changes of the SIF and SIT during the recent period 2007/08–2020/21 compared to preceding period 1993/94–2006/07, Panels (a) and (d) show the sea ice fraction (SIF) differences; (b) and (e) the sea ice thickness differences (SIT, in m); while (c) and (f) shows the 2D histograms plotted for the fraction vs thickness differences, shaded according to their frequency.

Upper panels are for the freezing period and lower panels are for the melting period.

Rev2.4

The paper presents a simple analysis of the three datasets in the Copernicus database. There is nothing special about the paper except the numbers that could be used by other researchers.

Response: Thank you for your feedback. While it is true that the paper provides numerical data and statistics, we believe the study offers new valuable insights for the ice climatology for the whole Baltic Sea and its sub-basins, and has important implications for the scientific community, policymakers, and industries operating in the Baltic Sea region.

The operations in this region are greatly influenced by the presence of sea ice. Accurate modeling and forecasting of sea ice seasons are essential for ensuring safe navigation, particularly for maritime transport, fishing fleets, and commercial activities such as the construction of offshore wind farms. Our study provides detailed spatio-temporal insights into ice conditions, enabling better planning and risk management for the stakeholders of these sectors. The influence of sea ice on the Baltic Sea ecosystem is significant, as ice duration impacts the timing of spring blooms, phytoplankton composition, nutrient cycles, and overall ecosystem dynamics. These changes are directly tied to the fisheries industry, and our study helps to quantify the decrease in sea ice, offering insights into its ecological implications.

The research also contributes to a broader understanding of environmental and climatic changes in the region. By providing detailed analysis on seasonal ice coverage patterns (e.g ice thickness and coverage relationship on Fig 9), the study highlights fluctuations in ice extent and long-term shifts in environmental conditions, offering valuable context for understanding regional climate trends. In contrast to earlier studies, which focused primarily on coastal observations, our research extends the analysis to offshore areas for the updated period 1993/94 to 2020/21. This expanded scope reveals a notable reduction in sea ice, particularly in offshore areas, reflecting the impact of recent global warming trends.

Moreover, the detailed analysis and validation of sea ice conditions provided in this study across various spatio-temporal scales, is relevant for the development and usage of the open datasets provided by Copernicus or Destination Earth platforms. Integrating this improved sea ice information into sea ice Digital Twins enables more accurate "what-if" scenario analyses, enhancing the planning and management of offshore activities.

Finally, this study addresses critical gaps in current knowledge about sea ice conditions in the Baltic Sea which are valuable insights for further sea ice modelling and validation analysis. Recent research on this topic has been limited, and discrepancies in existing ice models highlight the need for updated and thorough analyses like ours.