Review of "An assessment of the variability in temperature and salinity of the Baltic Sea from a simulation with data assimilation for the period 1990 to 2020" by Liu et al.

The manuscript provides a description of a model reanalysis simulation of the Baltic Sea with data assimilation for the study period 1990 to 2020. The generated data are used to study temperature and salinity trends at different depths and different sub-basins. The manuscript spends most of its content on the description, validation and discussion of the model simulation and less content on the temperature and salinity trends. From the current state of the manuscript, I do not know whether the manuscript is intended to be a model validation paper or a paper on the variability of temperature and salinity. Both parts need a lot of improvements in presentation and methods to be acceptable in the future. The trend analysis does not provide new information to the scientific community as trends have been studied a lot before. In addition, previous studies could also partially explain these trends due to changing dynamics and internal variability. This study overlooked this literature and does not add new understanding. The authors should consider splitting the manuscript into two papers in the future: one on the introduction of the model system and detailed validation of the simulation, and an improved version on T and S variability, trends and its dynamical origins, since otherwise the paper would be too long in my opinion. But the authors have to decide. Below are my main comments and suggestions on both topics.

Thank you very much for your positive and helpful comments. We have implemented all requested changes. Please find our detailed response in blue below.

Reanalysis and validation

-For the Baltic Sea, the saltwater inflow from the North Sea is the crucial process that renews most of the bottom water of the Baltic Sea. To see a model validation without a time series comparison of bottom salinities in the different basins is quite surprising. I would expect almost all bottom water trends to be governed by saltwater inflows. As the authors themselves state, the model does not capture this important driver of the Baltic Sea's water masses. How can the reader trust the computed trends? In order to trust the trends, a plot of the time series compared to some central stations is necessary. In general, the model should be configured in such a way that this important physical process is represented by the model's physics and not just included by data assimilation.

The model could capture key physical processes in the Baltic Sea and the North Sea. For example, the inflow/outflow water masses from the North Sea and the Baltic Sea. This has been verified by the Hordoir et al. (2019). However, the model results still include biases due to errors in initial conditions, lateral boundaries, and forcing. To address there, we use data assimilation to correct model biases and obtain a good dataset closer to the observations. For clarify, we add a time series comparison of reanalysis tempeature and salinity with observations at the BY5 and BY15 stations for both the top and bottom waters.

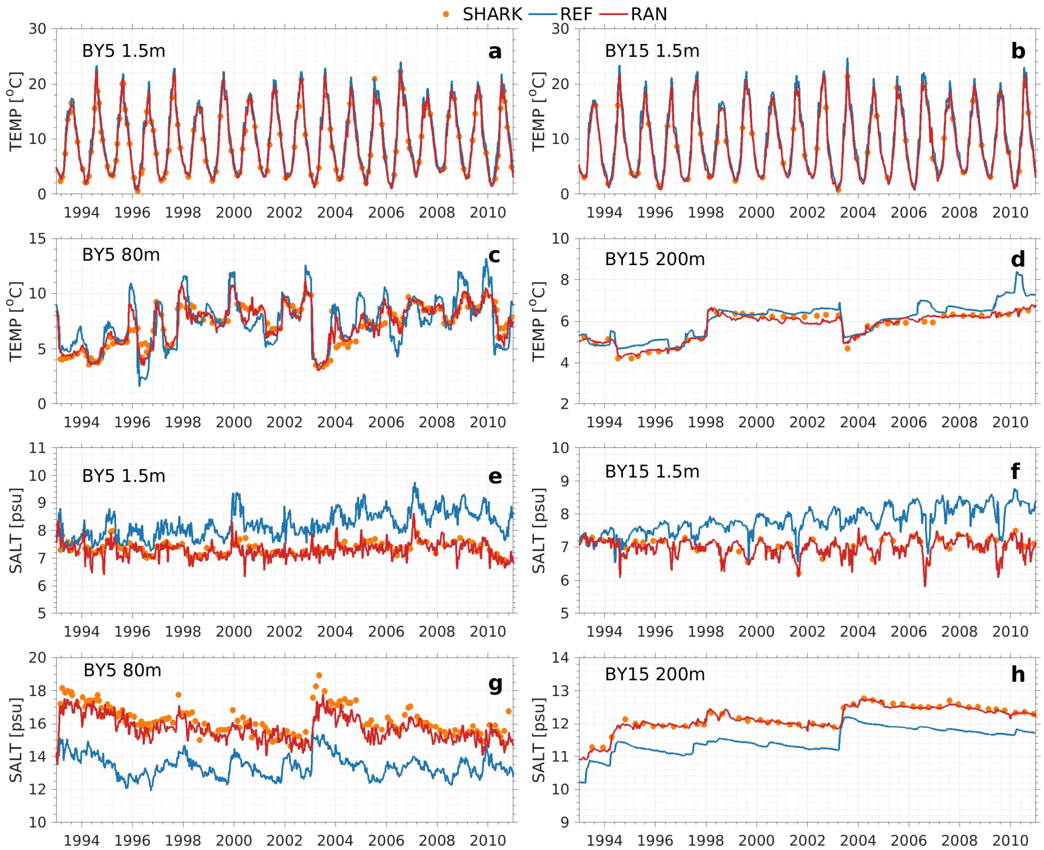

Figure 1. Surface and bottom temperature and salinity from observations and model with and without data assimilation at the BY5 and BY15 stations during 1993–2010.

-In addition, trends may be biased in cases such as the following: a monitoring station was introduced in 2000 and is used for assimilation starting in 2000. Due to the introduction of the data, the model salinity hypothetically increases by 1g/kg in the following. This would artificially create a trend, although the model's physics itself would not support a trend. Similarly, if the data assimilation were to suddenly stop during the model simulation. Do such cases occur in the simulation? If yes, the authors should be transparent about these potential biases in the trends.

The model biases are mainly due to imperfect initial conditions, which can greatly impact the accuracy and reliability of the results. As shown in Figure 1 and supported by the findings of Hordoir et al. (2019), it is clear that the model successfully captures various physical processes and represents climate feedback mechanisms effectively. This indicates that the model can simulate important Baltic dynamics, such as the inflow and outflow of water masses. However, it is important to acknowledge that model biases, arising from both forcing and initial conditions, can cause discrepancies between the modeled results and observed values. For example, the intensity of inflow and outflow events might be underestimated, or these events may be delayed within the model. To minimize these biases, data assimilation combines observational data with model predictions, producing a reliable reanalysis dataset by reducing initial biases to a small level.

It is worth noting that the data assimilation can affect the local variation of T/S. The variability and trends reported in this study emphasize overall or long-term changes, which aren't significantly affected by local adjustments of data assimilation.

Moreover, when data assimilation is stopped due to unavailability of observations, small differences between the model and observations can be maintained autonomously by the model itself. Data assimilation does not alter the internal logic or mechanisms of the model. Therefore, the bias in the presented trend statistics resulting from data assimilation can be considered negligible.

-In general, the validation lacks a validation of time series. Most validation focuses on the mean state, but as this study focuses on trends, the validation should ensure that the model can be trusted in this regard, e.g. by showing time series.

We have addressed the validation of time series in original manuscript by including a comparison of the simulations and observations in Figure 3. To further clarify, we have added another time series comparison of the observations and model with and without data assimilation at the BY5 and BY15 stations (as mentioned above). This additional comparison helps verify that the NEMO-Nordic model used in this study captures key dynamics of the Baltic Sea.

Trends and variability

- Regarding this part of the manuscript, all results lack a lot of critical information for the reader to trust the results, as no errors, uncertainty ranges, and significance checks are presented.

We acknowledge the importance of presenting uncertainty information for the reader's confidence in the results. All variability and trends in temperature and salinity are derived from the reanalysis dataset. To address this concern, we have validated the reanalysis and included uncertainty estimates in Figures 3–8. Additionally, we have provided uncertainty ranges in the trend statistics in the revised Table 1 and Figures 10 and 12 as followinig:

Table 1. The temperature and salinity variability in the Baltic Sea over the period 1990-2020.

Parameter	Trend [year $^{-1}$]	Mean	Maximum	Minimum
SST [^{o}C]	0.037±0.010	8.16±0.60	20.08±1.54	0.67±0.54
T60 [^{o}C]	0.044±0.008	4.16±0.55	6.76±0.52	2.31±0.62
T100 [^{o}C]	0.051±0.006	4.77±0.54	5.53±0.57	4.09±0.51
SBT [^{o}C]	0.041 ±0.008	5.34±0.53	10.76±0.51	1.96±0.49
SSS [PSU]	-0.004±0.002	5.83±0.10	6.50±0.10	5.01±0.20
S60 [PSU]	0.026±0.003	7.48±0.28	8.48±0.42	6.54±0.13
S100 [PSU]	0.049±0.005	9.16±0.51	9.63±0.55	8.61±0.51
SBS [PSU]	0.015 ±0.003	7.39±0.19	8.34±0.26	6.54±0.15

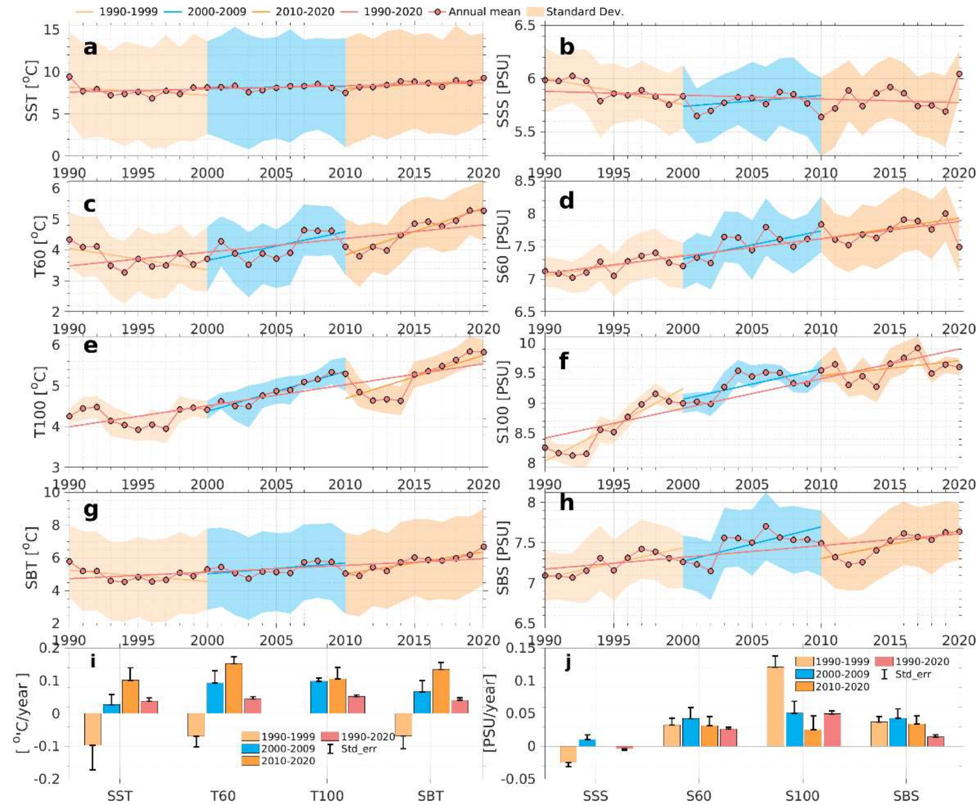

Figure 10. The annual mean temperature (left panel) and salinity (right panel) at surface (a,b), 60 m(c,d), 100 m (e, f), and the bottom (g, h) of the Baltic Sea for the period 1990-2020 and their linear decadal trends (i, j). Linear trends are showed by solid lines and the standard deviations are showed by the shaded area.

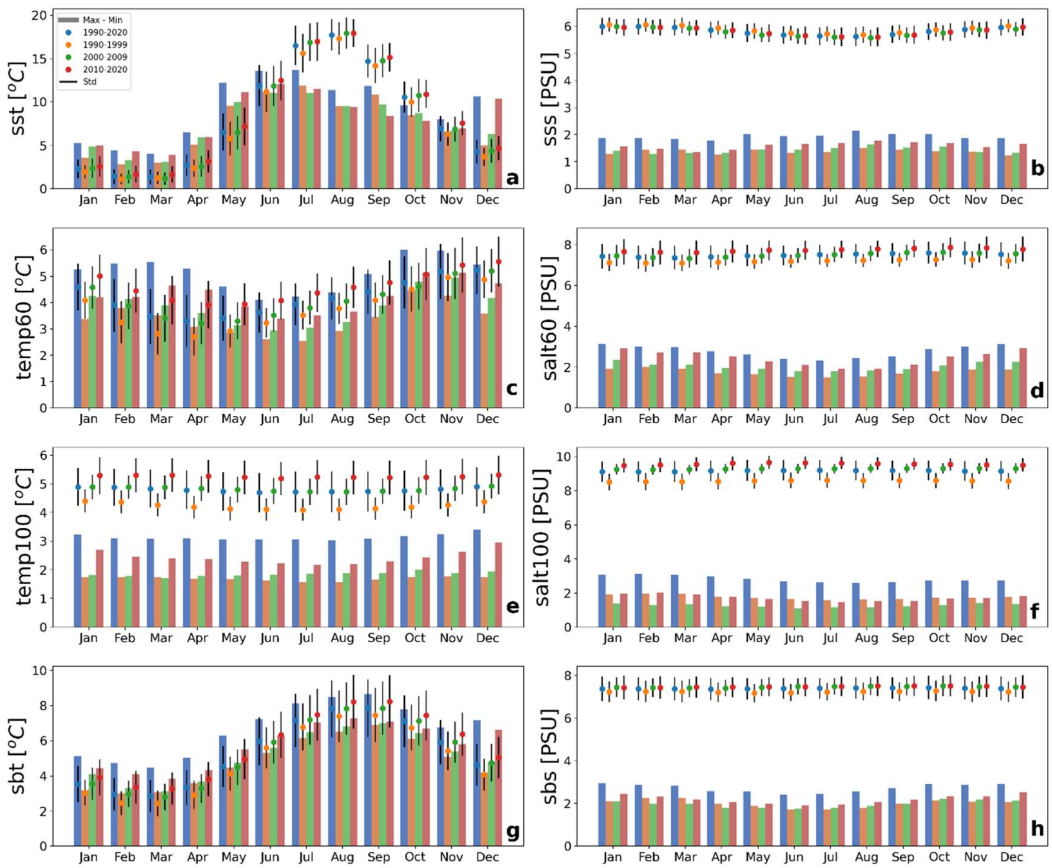

Figure 12. The monthly mean and variability of temperature and salinity of the Baltic Sea at the surface (a,b), 60 m (c,d), 100 m (e,f), and the bottom (g,h) for different decades, derived from reanalysis.

-How do the trends compare to the trends of observations over the same time period? Comparing the results with trends from other studies may be biased by the different time periods considered.

We have made the comaprison between our results and other studies over different period in the discussion section. We acknowledge the referee's point that comparing results from different time periods may introduce biases. However, these comparisons still provide us with confidence in the reliability of our study's results.
Additionally, we have compared our results with observed trends and included two recent studies on the South and North Baltic Sea—Zalewska et al. (2023) and Kankaanpää et al. (2023). These studies further verify that our results are indeed reasonable and consistent with current research.

"To the entire Baltic Sea, this study reported a warming rate of 0.037 °C/year in the Baltic surface waters for the period 1990 to 2020, which is very similar to previous estimates from in-situ observations: 0.03–0.06 °C/year for the period from 1982 to 2016 (Liblik and Lips, 2019) and 0.028 to 0.039 °C/year in the southeastern Baltic Sea for the period 1950 to 2020 (Stockmayer and Lehmann, 2023). Further, spatial pattern of the SST trend shown in the present study is very similar to earlier studies from both model or observations. Specifically, a smaller warming trend is observed in the southern Baltic Sea, while a larger warming trend appears in the northern Baltic Sea, consistent with the results of Siegel and Gerth (2019), Liblik and Lips (2019), and Jamali et al. (2023). Additionally, a significant warming trend is evident in the Gulf of Finland, which has been noted by Liblik and Lips (2019) and Stockmayer and Lehmann (2023).

For the salinity of the Baltic Sea, the present study reported a freshening trend of -0.004 PSU/year at the surface for the period 1990−2020, which is very similar to the previous estimations: -0.005 to -0.014 PSU/year in the upper layers for the period 1982−2016 (Liblik and Lips 2019) and -0.005 to -0.019 PSU/year in the surface waters in the northern Baltic Sea for the period 1957–2021 (Kankaanpää et al., 2023). Furthermore, this study reported a salinization trend of 0.015 to 0.049 PSU/year in the deeper waters, which is consistent with earlier estimates as well: 0.02–0.04 PSU/year in the deeper waters for the period 1982−2016 (Liblik and Lips 2019). The salinity trends are declined by 0.009 PSU/year in northern Baltic bottom in this study, which is consistent to the findings of and 0.007–0.025 PSU/year in Kankaanpää et al. (2023) for the period 1957–2021."

Zalewska, T., Wilman, B., Lapeta, B., Marosz, M., Biernacik, D., Wochna, A., Saniewski, M., Grajewska, A., Iwaniak, M. 2023. Seawater temperature changes in the southern Baltic Sea (1959–2019) forced by climate change, Oceanologia, 66, 37-55. https://doi.org/10.1016/j.oceano.2023.08.001. Its main conclusions are:

Kankaanpää, H. T., Alenius, P., Kotilainen, P., Roiha, P., 2023. Decreased surface and bottom salinity and elevated bottom temperature in the Northern Baltic Sea over the past six decades, Science of The Total Environment, 859, https://doi.org/10.1016/j.scitotenv.2022.160241.

-I do not think that the results add any new information to the Baltic Sea community. It does not add new understanding on the dynamical reasons for the well documented, observed trends which are only recreated.

We acknowledge this concern. However, the primary objective of our study is to evaluate and analyze temperature and salinity trends in the Baltic Sea from 1990 to 2020

Reply: We understand the concern. However, the primary focus of our study is not to provide new insights into the dynamics of the Baltic Sea, but rather to evaluate and analyze temperature and salinity trends in the Baltic Sea from 1990 to 2020. While our study also validates the reliability of the reanalysis dataset, the main focus remains on assessing long-term trends to ensure the dataset's accuracy for such trend analyses. We highlight our contribution to the Baltic Sea community:

- **Improvement of model predictions:** By assimilting observational data (e.g., satellite data, in-situ measurements) into model predictions, the study shows a method to improve accuracy of model precditions in the Baltic Sea by providing more accurate, reliable, and comprehensive models of the sea's dynamics. As a result, the accuracy of the presented dataset is significantly better than that of the dataset from model alone.
- **Assessing T/S trends by combining models and observations**: As Stockmayer and Lehmann (2023) highlighted, discrepancies between observed and simulated trends emphasize the importance of combining models and observations for accurate trend analysis. Most of the Baltic variability studies were focused on surface or bottom trends, and only a recent study explored the intermediate temperature trends from in-situ data (Liblik and Lips 2019) and

modeling (Dutheil et al. 2023). This study fills this gap by examining continuous temperature and salinity trends across four depths in the Baltic Sea over the past three decades. This is particularly important for the intermediate waters, where observations are sparse, model biases limit T/S changes assessments.

- **Applications and impact on future research:** With this comprehensive dataset, researchers can now analyze temperature and salinity at any depth in the Baltic Sea. Our dataset also extends predictions beyond short-term observations, making it a key reference for studies on the Baltic Sea's health and sustainability, especially in the intermediate waters.
- **Environmental implications:** Our study highlights a combination of warming and increased salinity stratification, suggesting that the Baltic Sea is experiencing more pronounced layering between surface and deep waters. This enhanced stratification may reduce oxygen transport to deeper layers, exacerbating hypoxia in deep basins and negatively impacting marine ecosystems and fish populations. Additionally, the stronger halocline could hinder nutrient mixing, potentially disrupting primary productivity and biogeochemical cycling. These changes may, in turn, affect food web dynamics and alter fish populations.
- **Policy and management recommendations:** By reliable quantifying the variability of temperature and salinty in the Baltic Sea, this study helps decision-makers in understanding how these factors influence oceanographic conditions. Our findings offer essential insights for policy development in coastal management, marine ecosystem protection, pollution control, and fisheries sustainability. Based on our results on Baltic Sea warming and salinity trends, we recommend that fishery management and coastal planning incorporate strategies for adapting to these changes, alongside enhanced monitoring of ecosystem shifts tied to warming and salinity changes.

-The whole presentation, from the introduction to the discussion to this part of the paper, is missing some critically important points, such as the large internal variability of the Baltic Sea (~30-year cycle). Due to the large natural variability in the Baltic Sea system, looking at trends over a period of similar length will most likely lead to aliasing artefacts. The authors touch on this part with their Figure 11, but do not discuss this critical property of the Baltic Sea.

We appreciate the referee for pointing out this limitation of this study. Clarifying this limitation will certainly strengthenthe study's reliability.

The Baltic Sea is affected by decadal oceanic and atmospheric cycles (e.g. Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation (NAO)). During positive NAO or warm AMO phases, increased atmospheric pressure gradients and stronger wind forcing enhance the influx of saltier water from deeper or surrounding areas, increasing the salinity at intermediate depths. The variability of the Baltic SST is closely linked to the AMO and NAO (Kniebusch et al., 2019). For instance, the negative phase of the AMO in the early 1990s contributed to a cooler SST trend, while the positive phases of the AMO and NAO from the mid-1990s through the 2010s contributed to a general warming trend in the Baltic Sea. Particularly, an unusual warm period in the late 2010s produced a stronger decade variability in the Baltic temperature compared to other decades. Additionally, the increasing frequency of heat waves in recent years has exacerbated warming trends in surface waters, further impacting the seasonal and interannual dynamics of T/S in the Baltic Sea.

We agree with the referee that deriving linear trends from a 30-year dataset has its limitations. In this study, we analyzed the linear trends in Baltic temperature and salinity using a 30-year reanalysis dataset. However, due to the limitations of this dataset length, it is not possible to derive long-term trends in Baltic temperature and salinity. The trends reported in this study reflect only the variability of temperature and salinity in the Baltic Sea between 1990 and 2020 and should not be interpreted as representing variability during other periods. The T/S trends reported in this study has been verified by comparison with those from obserations. The purpose of this study is to identify trends in Baltic Sea temperature and salinity using a reliable data assimilation-based dataset, particularly for the Baltic subsurface and subbasins. Our primary focus is not on providing a comprehensive understanding of Baltic Sea dynamics.

-Many recent papers on this topic are not cited, including the Baltic Earth Assessment Report which reviewed the current state of knowledge of the Baltic Sea a few years ago.

Thank you for reminding us of these shortcomings. We have updated our references and add relevant references to further validate our conclusions and arguments. These references are sourced from the latest academic studies in this topic (Dutheil et al, 2023, Meier et al. 2023, Mohrholz, 2018, Zalewska and Lehmann 2023; Kankaanpää et al. 2023; Bittig, et al. 2024, Saraiva et al, 2019.) including the Baltic Earth Assessment Report (Meier et al. 2023).

General and specific comments

Introduction: Much of the recent literature is missing from the introduction. Many key points of the introduction are citing rather old papers, although newer literature with updated analyses is available.

We appreciate the referee's comment regarding the outdated references in the introduction. We have updated the references and incorporated more recent studies, including Dutheil et al, 2023, Meier et al. 2023, Mohrholz, 2018, Zalewska et al. 2023; Kankaanpää et al. 2023; Bittig, et al. 2024, Saraiva et al, 2019.

L35-37: “Although several studies have focused on long-term changes in the Baltic Sea using observations over the last two decades (Fonselius and Valderrama, 2003; Winsor et al., 2001) [...]” It does not make sense to cite papers from two-decades ago to support this statement.

We revised it with newer literatures (Zalewska et al. 2023; Kankaanpää et al. 2023; Bittig, et al. 2024)

L37: “[...] spatiotemporal coverage limitations, especially in the deep Baltic Sea.” The Baltic Sea has one of the best and longest monitoring data coverage **compared** to many other marginal seas.

We agree that the Baltic Sea has one of the best and longest monitoring data coverage compared to many other marginal seas, However, the observation’s coverage is still limited, especially for the subsurface waters of the Baltic Sea.

Section 2: Why are the parameters so different from the NEMO Nordic model of Kärnä et al.?

The model used in this study is NEMO-Noridic 1.0 which has a 2 nm horizontal resolution. However, Kärnä et al.(2021) used NEMO-Nordic2.0 with a 1 nm horizontal resolution.

L71-73: What kind of vertical levels do you use? I assume z*? Can you resolve the halocline and thermocline with these z-levels?

The model uses a z ∗ grid in the vertical direction consisting of 56 levels. Our model is able to capature the Baltic stratificiation and resolve its halocline and thermocline (Hordoir et al. 2019).

L78: This equation of state is outdated. Why not TEOS-10? NEMO 4.0 has it.

Our model is based on the NEMO3.6 with EOS80 state equation.

L81: How is the conversion into in-situ temperature done? With the TEOS-10 equations?

We used the EOS80 equation to do this conversion.

L88: Why do you need isopycnal diffusion to close the Neva river inflow? This seems unusual.

We followed the parameters setup used in the Hordoir et al. (2015), an additional strong isopycnal diffusion is used close to the Neva river inflow (Gulf of St. Petersburg) in order to avoid negative salinities..

L89: 3cm seems like a lot of friction. Why did you choose this high value? Other NEM Nordic setups have smaller values.

Apologies for the confusion in our previous description. The 3 cm roughness was used in a different version of the NEMO-Nordic model, as described in Hordoir et al. (2015). Our model, however, is based on the NEMO-Nordic 1.0 version from Hordoir et al. (2019), which employs a constant roughness of 1 cm. We have corrected this mistake in the revised version.

Hordoir, R., L. Axell, U. Löptien, H. Dietze, and I. Kuznetsov (2015), Influence of sea level rise on the dynamics of salt inflows in the Baltic Sea, J. Geophys. Res. Oceans, 120, doi:10.1002/2014JC010642.

L94: Why is precipitation corrected? Any validation for this change?

We compared the total precipitation from the original UERRA with the EURO4M (Euro-pean Reanalysis and Observations for Monitoring, http://www.euro4m.eu/) and obtained a multiplication factor of 0.8 for correction.

L160: What is the climatology check?

For the OSISAF SST, they have abs(SSTc-SSTclimatology) <=10 °C and abs(SSTc-SSTinsitu) <= 3.0ºC check. The product quality is also identified to 5 levels: 0: unprocessed; 1 cloudy, 2: qualitative use only: 3, 4, 5: usable data of increasing quality. We only used the quality_level >2.

L173/174: What is the source of the sea level data?

The sea level data were downloaded from CMEMS Baltic Sea - near real-time (NRT) in situ quality-controlled observations. https://doi.org/10.48670/moi-00032.

L179-183: Some typos. There are more occasions of wrong grammar and typos. I will not list them all.

We rewrite the paragraph ：

"The Danish straits shows the largest number of observed T/S profiles, with 14213 profiles for temperature and 14190 profiles for salinity. In contrast, the Gulf of Riga has the lowest number of observed profiles, with only 466 temperature profiles and 457 salinity profiles. Additionally, the south Baltic Sea has more observed T/S profiles than the north Baltic Sea. Notably, there are significantly more temperature profiles than salinity profiles were observed for the period from 1990 to 2000. Furthermore, there is notable variability in the number of observed T/S profiles across CTD stations. A greater number of profiles are recorded at stations BY5, BY31, ANHE, and BY2 in comparison to other locations. As illustrated in Fig. 2c, BY5 has a largest number of observed profiles, with 956 temperature profiles and 955 salinity profiles, while F16 has the smallest number of observed T/S profiles, with only 55 profiles. Moreover, both SR5 and LL07 has fewer than 100 observed profiles. ”

The method section misses a description of trend analysis.

We added the text to describe the trend analysis method:

”In this paper, Baltic Sea mean refer to the average value for Baltic areas east of 13 °E longitude (Figure 1). The linear regression analyses were performed using the annual mean. The linear regression analysis was performed using the general least square fit method by maximum likelihood. All the trends have been significantly checked (The interpretation of significance levels based on the p value). ”

Section 3.3.: Spell out the acronyms somewhere.

We checked and spelled out all the acronyms.

L209/210: Can you be 100% sure that the different databases have no overlaps and that you do not compare the reanalysis with the data used for assimilation? I do not know the databases, therefore I ask.

The database have overlaps. We compared the reanalysis with assimilated data. For example, the comparison with satellite SSTs.

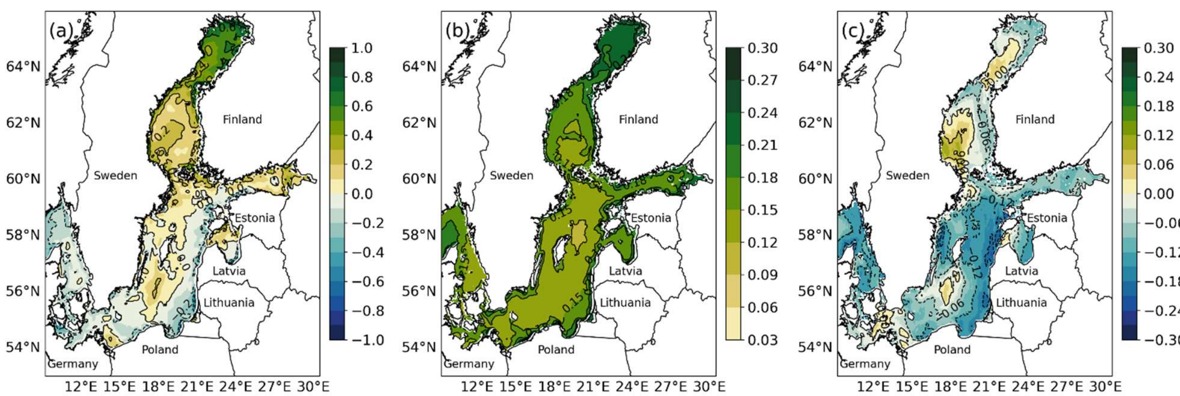

Figure 4. The overall averaged (a) bias, (b) NRMSD of reanalyzed sea surface temperature, and (c) difference in assimilated satellite sea surface temperature relative to the CMEMS L4 sea surface temperature product for the period 1990-2020.

the differences between the DA and validation satellite SSTs could potentially impact the accuracy of the SST validation process. The discrepancy between assimilated combined satellite SST from IceMap and OSISAF and CMEMS-L4 SST varies in time and space (not shown). The CMEMS-L4 SST was warmer than both assimilated satellite SSTs and the reanalysis SST in the southwest of both the Bothnia Sea and the Bothnian Bay and the south of Gotland basin. Therefore, it is reasonable to believe that the differences between assimilated combined satellite SST and CMEMS-L4 SST contributed to the reanalyzed biases of SST in those regions relative to CMEMS-L4 SST. The opposite phenomenon occurred in the eastern Baltic Proper, the Bornholm Basin, Eastern Arkona Basin, southern Gulf of Riga, and the transition region between the North Sea and Baltic Sea (Fig. 7). These results highlight the importance of considering such discrepancies for a comprehensive assessment of the reanalysis results and their implications for understanding SST variations. The reprocessed product on multiple satellites is better to represent a general ocean state than a single satellite product. In this study, we used a reprocessed SST (CMEMS-L4) based on multiple satellites to validate the assimilation results to verify the robustness and generalizability of the reproduced SST

L248-250: This shows that your model does not capture the essential physics of the salt water inflows, which are the central process that determines the bottom water properties. Therefore, I have little confidence in the trends of the model. Also, where does the salt come from in the DA simulation, if the model does not reproduce the physics of the inflows?

The NEMO-Nordic model used in this study is capable of capturing key Baltic dynamics, as confirmed by Hordoir et al. (2019). However, the model exhibited some bias in its simulations, primarily due to imperfect initial conditions and forcing. For instance, the initial conditions showed lower temperatures and salinities in the bottom waters. As a result, the simulated inflows were either weaker in intensity or occurred at incorrect times. By incorporating data assimilation (DA), these model biases were significantly reduced. The inflows generated through DA are now consistent with observed data, and the temperature and salinity in the bottom waters have been adjusted to levels similar to those observed.

Please also refer to the previous response on "**Reanalysis and validation**" for further details.

L258: I disagree because the model does not seem to capture one of the essential mechanisms, the saltwater inflows.

See above reply and the time series at BY15 and BY5. Our model is capable of capturing the essential Baltic dynamics like the inflows/outflows.

Section 4.1.3: SST products from satellites themselves are also imperfect.

We acknowledge that satellite-derived SST, like other satellite products, can be biased and imperfect. However, satellite SST products offer valuable insights by capturing more detailed spatial patterns and smaller-scale features of surface temperature, particularly in regions or on timescales where numerical models may face limitations in representation.

Section 4.2.: Table 1 has no uncertainties, and it is not clear how the numbers were computed. Fig. 9 also needs uncertainty range and significance checks.

We revised the figure and Table 1, we added the uncertainty in the data with standard deviation, and the trend statistics with 95% confidence interval. See our first reply to "**Trends and variability"**

L338: The cold water range is not in Tab. 1

In the revision, we used standard deviations to represent the uncertainty in temperature and salinity. As a result, we no longer mention the cold water or minimum annual mean temperature. The text has been revised to

"The temperature in the Baltic Sea also showed substantial interannual variability throughout the simulation period. For example, between 2010 and 2015, temperatures fluctuated by 0.41–1.01°C. The SD highlighted significant variability in annual mean temperatures, particularly after 2010, indicating that temperature fluctuations have been more pronounced in recent years. This suggests that warming trends may be modulated by fluctuations in seasonal heat uptake, ice cover extent, and short-term climate variability, such as North Atlantic Oscillation (NAO). The annual temperature showed more pronounced fluctuations at the surface and bottom layers, ranged 0.67–20.08 °C and 1.96–10.76 °C, respectively. In comparison, temperature variability at intermediate waters was lower, with values of 2.31–6.76 oC at 60 m and 4.09–5.53 oC at 100 m (Table 1)."

L340: The statement is obvious.

We changed the text to "Compared to the surface waters, the subsurface waters exhibited a less variability in annual mean temperature. This indicates that the surface waters are more influenced by atmospheric variations."

L348-350: Freshest water should not be found on the bottom, except in cells where river discharge is present.

We agree with the comment and have removed the sentence: "It is also noted that both the saltiest and freshest waters occurred at the bottom."

L350-352: This result is not described in the previous text, but reads as a summary of the previous paragraphs. Again, this is not a new finding, see e.g. Kniebusch et al. (2019)

We acknowledge that Kniebusch et al. (2019) analyzed the variability of temperature and salinity trends over the period from 1850 to 2005. In our study, we focus on a more recent period, specifically highlighting the temperature and salinity variability observed between 2010 and 2015. To provide more context and clarity, we have revised the text to emphasize this more recent trend. The updated sentence now reads:

"This study shows that the temperature and SSS of the Baltic Sea showed a decreased between 1990 and 1995, followed by a increase between 2010 and 2015, reflecting clear temporal variations in the T/S trends in the Baltic Sea across the period 1990-2015. The trends observed between 2010 and 2015 indicate a shift in conditions compared to the earlier part of the period, emphasizing the dynamic and fluctuating nature of the Baltic Sea's hydrographic properties."

Section 4.2.1.: Are the trends significant? Without any significance checks, the whole section cannot be trusted.

Thanks, we added the trends significant check and hatched the high significant area (p value smaller than 0.05) and with no significant area (p value larger than 0.033).

Section 4.2.2.: The interdecadal variability of water mass properties is well described in the literature, which is overlooked by the authors, see one of my main comments.

Although the interdecadal variability of water mass properties is well-documented in the literature, as pointed out by the reviewer in their main comments, our study specifically focuses on the variability observed between 1990 and 2020. This period is the primary focus of our analysis, allowing us to highlight more recent trends in water mass properties.

L427: Incomplete sentence or paragraph

We removed this incomplete sentence "On data assimilation scheme, please write"

Figure 2: It would also be useful to see the temporal resolution of each station. Are there stations included which can provide data with very high temporal resolution, e.g. every 10 min? There exist such monitoring stations in the Baltic, e.g. the MARNET stations of the BSH in Germany

As mentioned in the study, the T/S profiles used are from SHARK and ICES data, which provide near-monthly observations, though these are spread across different stations. We did not use higher temporal resolution data, such as those available from the MARNET stations of the BSH in Germany (e.g., measurements every 10 minutes), as our primary goal was to assess long-term variability. Data with such high temporal resolution is not suitable for a 30-year simulation, as it would not be consistent with the long-period trends we aimed to capture.

Fig. 5: The color of the colorbar does not align with the colors of the dots since the dots have alpha values.

We revised it.

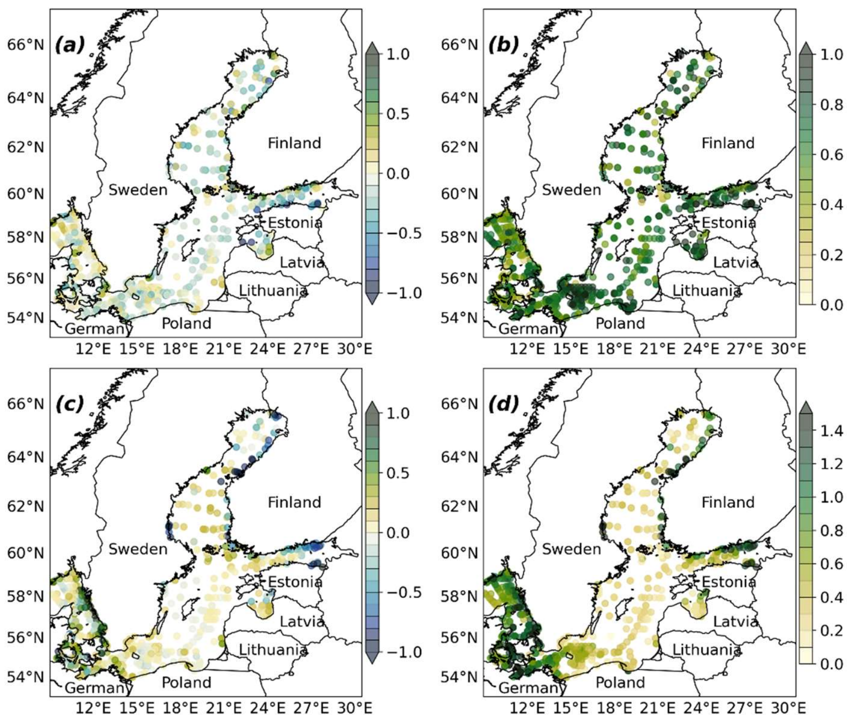

Figure 6. Global averaged bias (a,c) and RMSD (b,d) of salinity (a,b) and temperature (c,d) from reconstructed fields relative to all ICES profiles from 1990 to 2020.

Fig. 8: An additional panel with bar plots would be helpful for comparison, since the 60m range is quite large and could mask substantial MLD deviations

We agree the 60m range is large. However, a map of these stations is easier to show where we do the comparison. We revised the figure to shows both the station positions and the size of the mixed layer thickness:

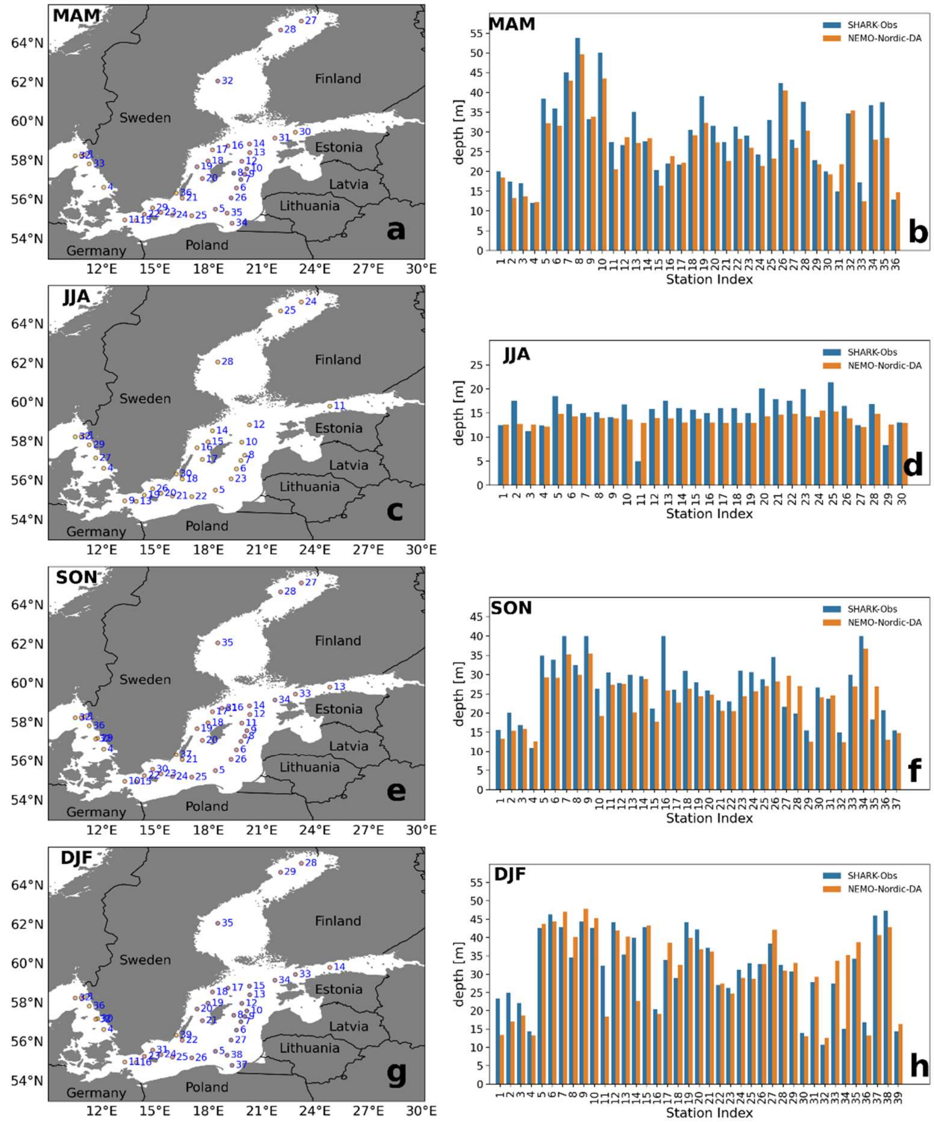

Figure 7. Seasonal mixed layer depth for the period 1990-2020: MAM: March-April-May; JJA: June-July-August; SON: September-October-November; DJF: December-January-Feburary. The left pandel shows the station positions and the right panel shows the size of the mixed layer depth.

Fig. 9: This should include time series and trends from observations. This would help the reader to have confidence in the model results.

We appreciate this comment. We have validated our simulation results using both in-situ and satellite observations. The results show that the temperature and salinity dataset agree well with the observations. Additionally, trends derived from observations helped to verify the trends in our results. A detailed comparison of our results with those from observational data has been included in the discussion section.

Fig. 10: Indicate where the trends are statistically significant.

We added the significant check.

Fig. 11: This could also be included in Fig. 9.

We changed it. See above response.

Fig. 12: Is this for basin averaged values? If yes, does the SD include both spatial and temporal variability? What would the same climatology look like for an observation?
It is calculated for region mean of the whole Baltic Sea. Therefore, SD include both spatial and temporal variability. We showed the climatology from observations at the figure 4.