Response to the Editor

Dear Dr. Treguier,

Thank you for handling the review process of our manuscript entitled "Advances in Monitoring Black Sea Dynamics: A New Multidecadal High-Resolution Reanalysis", and for giving us the opportunity to revise our manuscript once more.

We appreciate the constructive comments provided by both reviewers, which have greatly helped us improve the manuscript. We have carefully addressed all the points raised, and the corresponding revisions are highlighted in red in the tracked-changes version. In particular, following one reviewer's comment, we have revised the title of the manuscript to better reflect the scope and characteristics of the study. The new title is: "Advances in Monitoring the Black Sea: A New Regional Multidecadal Ocean Reanalysis at 1/40º Resolution".

We regret that one of the reviewers remains unsatisfied with the revised version. As noted in the review history, this reviewer initially rated the scientific significance of our work as "good", but after the Interactive Discussion (ID) stage this assessment was lowered to "fair". Throughout the ID phase, we carefully addressed all points raised by the reviewer, implementing several modifications at this stage and providing detailed scientific justifications in cases where suggestions were not incorporated into the manuscript.

In the most recent review round, the same reviewer introduced several additional concerns that had not been raised previously. We nevertheless addressed all these new points in detail and incorporated them, where feasible, into the current revision. Importantly, we also responded thoroughly to one of the reviewer's recurrent concerns regarding the validation of the reanalysis results using independent observations within a forecasting framework and in comparison with other products. Unfortunately, this reviewer has also indicated that they are no longer available to review the revised version of the manuscript and the answers to their questions. We hope that a new reviewer can be found to evaluate our response, without completely restarting the review process.

The second reviewer provided very positive feedback after the interactive discussion, noting only minor comments, which we have addressed carefully in the new revised version.

We remain fully committed to improving the manuscript and appreciate the constructive guidance provided throughout the process. We await your decision and are prepared to proceed with a third review if you consider it necessary.

Response to Reviewer#1

Dear Reviewer #1, thank you for reading and suggesting modifications to our manuscript entitled "Advances in Monitoring Black Sea Dynamics: A New Multidecadal High-Resolution Reanalysis".
We believe that your second review has helped to substantially improve the revised manuscript. The changes in the manuscript have been highlighted in red. Additionally, please find below a list with our point-by-point answers (*in italic*) to your comments and suggestions.

Please note that the original title of the manuscript was "Advances in Monitoring Black Sea Dynamics: A New Multidecadal High-Resolution Reanalysis"; however, following your suggestion, we have revised it to "Advances in Monitoring the Black Sea: A New Regional Multidecadal Ocean Reanalysis at 1/40° Resolution".

 # General Comment

This is my second review of the manuscript. Unfortunately, I am not fully satisfied with the authors' replies to my previous comments. Many of the major issues I raised earlier remain either not sufficiently addressed or only superficially discussed. The revised version still lacks quantitative evidence for several of its central claims, and the justification of the chosen methodology remains unclear in multiple places.

In summary, the authors present a new reanalysis for the Black Sea (BLK-REA). Maintaining an updated reanalysis product for this region is certainly useful, but overall, the system described here does not represent a major technical or scientific advance. Several aspects of the configuration are quite basic: the boundary conditions are based on only four years of U-TSS data and applied as a fixed climatology, the 3DVAR scheme mixes direct assimilation for some variables with relaxation or offline bias correction for others, and a number of model biases remain unaddressed. Many of the manuscript's key claims, such as improved water exchange and better representation of basin dynamics, are not supported by any quantitative evidence. More broadly, it is not clear what the scientific value of the paper is beyond showing that the reanalysis runs and that it can be used to compute some indices. How reliable those indices actually are is never demonstrated.

Despite some revisions, most of my original concerns remain unresolved. The manuscript still does not convincingly demonstrate the claimed improvements or justify several methodological choices. The validation remains largely non-independent, and the climate-trend interpretation is overstated. I therefore recommend to return the manuscript to the authors for another major revision. Substantial additional analysis, clearer justification of methods, and more careful interpretation of the results are required before this work can be considered for publication.

We thank the reviewer for the second review and the detailed comments. We recognize that the main concerns relate to independent validation and *comparisons with other products and earlier reanalysis versions. In the revised manuscript, we clarify (lines 230–235) that fully independent observational datasets were not available and that this limitation should be considered when interpreting the validation results. Nevertheless, an independent assessment is provided through a multi-product ensemble analysis of ocean heat content (OHC), combining BLK-REA, GLORYS12, and objective analyses (ARMOR3D and CORA), allowing uncertainty to be quantified. For specific OMIs, such as the Rim Current index and overturning circulation, comparisons are made with earlier studies based on previous BLK-REA versions, while ensemble-based analyses are not feasible due to the limited availability of high-resolution velocity data. In addition, the reanalysis is assessed within a forecast-based framework, with results presented in this response document.*

Comparisons with previous BLK-REA versions are documented in the Copernicus Marine Quality Information Document (QUID; https://documentation.marine.copernicus.eu/QUID/CMEMS-BLK-QUID-007-004.pdf, *Lima et al., 2024) and are therefore not repeated in the manuscript, but are provided in this response document. The revised manuscript presents in the Appendix, for the first time, a comparison between the regional BLK-REA and a global reanalysis over the Black Sea, including skill assessments for temperature, salinity, and sea level anomaly. The improved performance of BLK-REA for these variables supports the scientific relevance of the study and provides a quantitative basis for maintaining a dedicated regional reanalysis for the Black Sea.*

Other major and specific comments are addressed below.

 # Major Comments

1. The paper repeatedly states that the new system improves the representation of water exchange and basin dynamics, but this is never shown. There are no quantitative comparisons with the previous version or with independent observations such as Bosphorus transports, salinity sections, or regional sea-level trends. Most of the discussion is qualitative. Without clear numbers or sensitivity tests, it is impossible to judge whether the new configuration genuinely performs better or simply differs from the old one.

We thank the reviewer for this comment. The aim of the manuscript is to document the latest Black Sea reanalysis (BLK-REA) by providing a quantitative assessment of its core variables (SST, SSH, temperature, and salinity) and by introducing a set of ocean monitoring indicators (OMIs). Quantitative skill metrics for temperature, salinity, and sea level anomaly are *presented in the revised manuscript and constitute the primary quantitative evaluation of the reanalysis performance.*

*More extensive quantitative comparisons between the current and previous BLK-REA versions have been carried out as part of the product development and are documented in Section VI of the BLK-REA QUID (*https://documentation.marine.copernicus.eu/QUID/CMEMS-BLK-QUID-007-004.pdf, *Lima et al., 2024). These results show that the new BLK-REA generally performs better for temperature, salinity, and sea level anomaly over most of the basin and time period. The QUID is now explicitly referenced in the manuscript, and representative figures illustrating these improvements are provided in this response document (Figures 1-4).*

Direct quantitative comparisons of Bosphorus transports are not feasible, as the previous BLK-REA version employed a closed Bosphorus configuration, which prevents a meaningful comparison of exchange flows. In addition, independent and publicly available observations for the Bosphorus region remain very limited. For this reason, basin-scale circulation features are assessed using OMIs, which are intended as diagnostic tools to evaluate the consistency of the simulated circulation. Comparisons with earlier studies (e.g. Peneva et al., 2021; Ilicak et al., 2022), which are based on previous BLK-REA versions, are used to assess whether the diagnosed patterns fall within the expected range of Black Sea variability.

In addition, the revised manuscript presents, for the first time, a comparison between the regional BLK-REA and a global reanalysis over the Black Sea. Skill assessments for temperature, salinity, and sea level anomaly show improved performance of the regional system, providing quantitative evidence of the added value of maintaining a dedicated regional reanalysis for the Black Sea. This is further supported by a multi-product ensemble analysis of ocean heat content (OHC), combining BLK-REA, GLORYS, ARMOR3D, and CORA (Figure 5), which allows both quantitative comparison and uncertainty estimation using independent products. A similar ensemble-based analysis cannot be performed for velocity-based OMIs due to data limitations in the Black Sea.

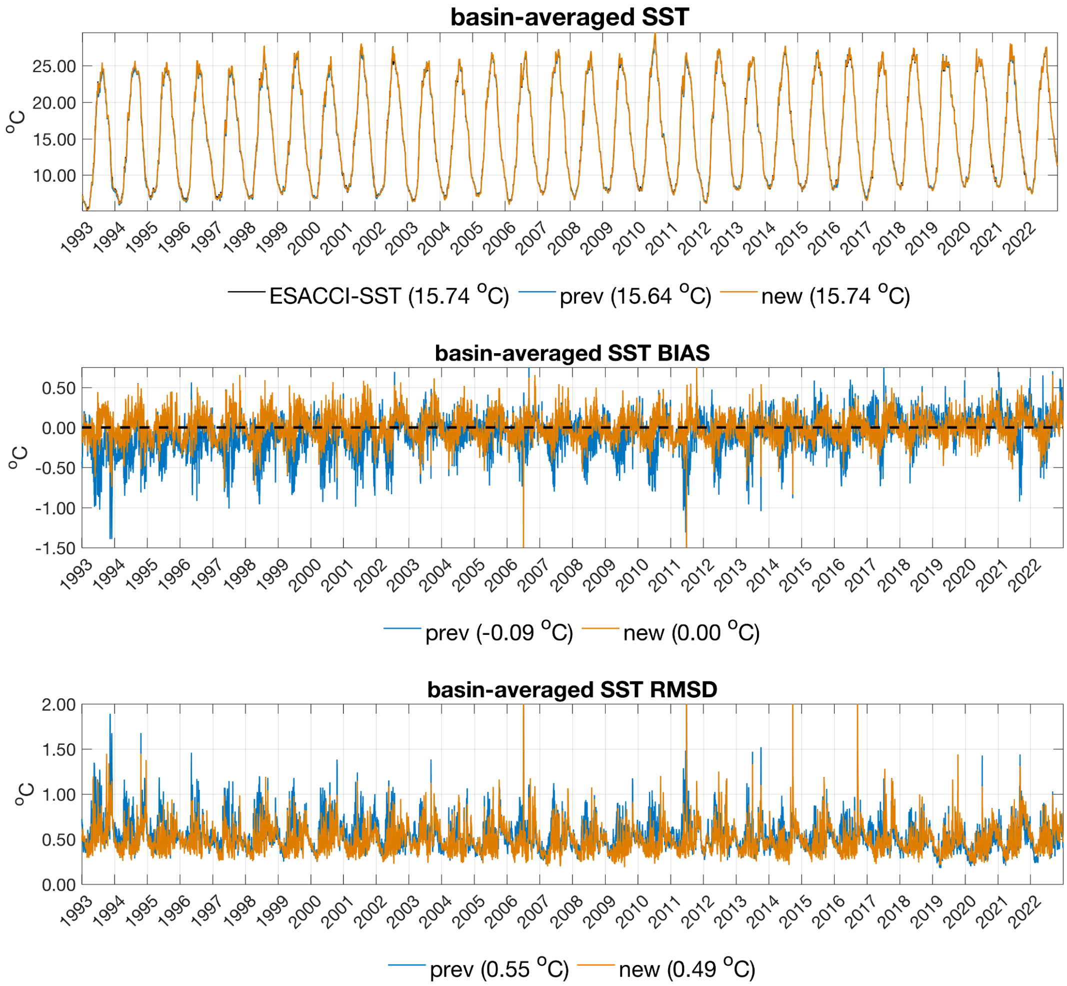

Figure 1: Time series of basin-averaged SST (top), SST bias (middle), and SST RMSD (bottom), comparing the previous (in blue) and new (in orange) versions of BLK-REA against ESACCI-SST. The figure is reproduced from Lima et al. (2024).

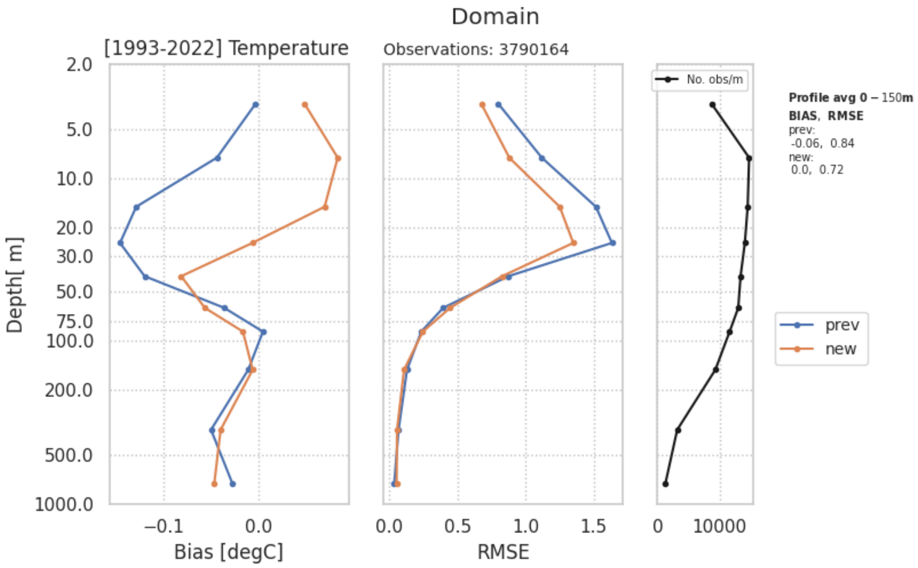

Figure 2: Vertical profiles of RMSD (left), bias (middle), and number of observations (right) for temperature (°C), comparing the previous BLK-REA version (in blue) and the new version (in orange) against in-situ profiler data in the Black Sea from 1 January 1993 to 31 December 2022. The figure is reproduced from Lima et al. (2024).

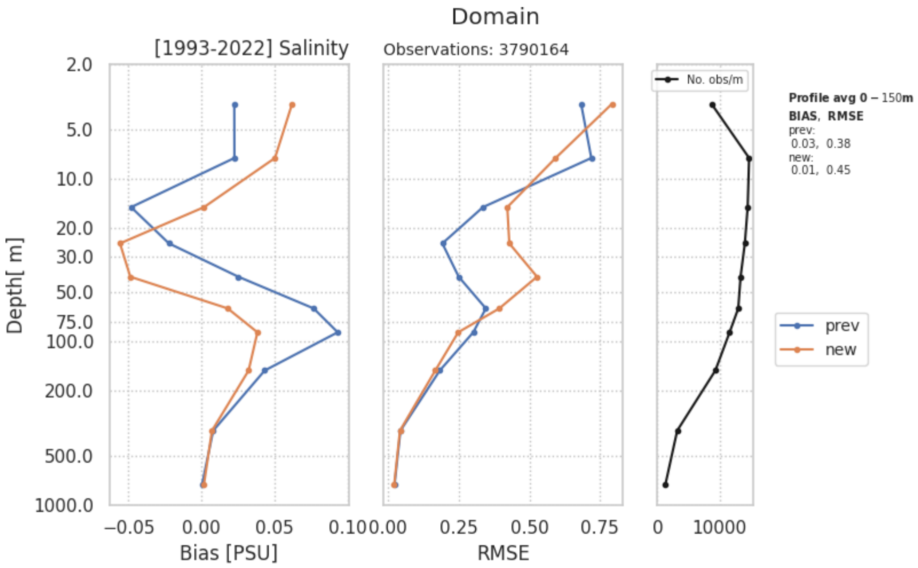

Figure 3: Vertical profiles of RMSD (left), bias (middle), and number of observations (right) for salinity (psu), comparing the previous BLK-REA version (in blue) and the new version (in orange) against in-situ profiler data in the Black Sea from 1 January 1993 to 31 December 2022. The figure is reproduced from Lima et al. (2024).

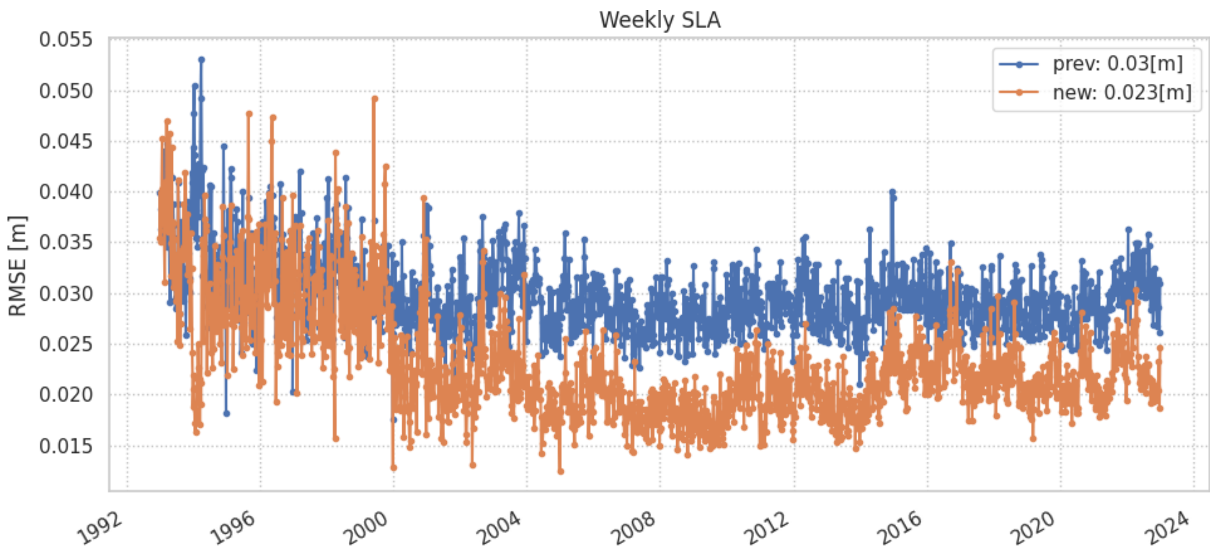

Figure 4: Time series of sea level anomaly RMSD for the Black Sea, showing the previous BLK-REA version (in blue) and the new version (in orange) compared with along-track observations. The figure is reproduced from Lima et al. (2024).

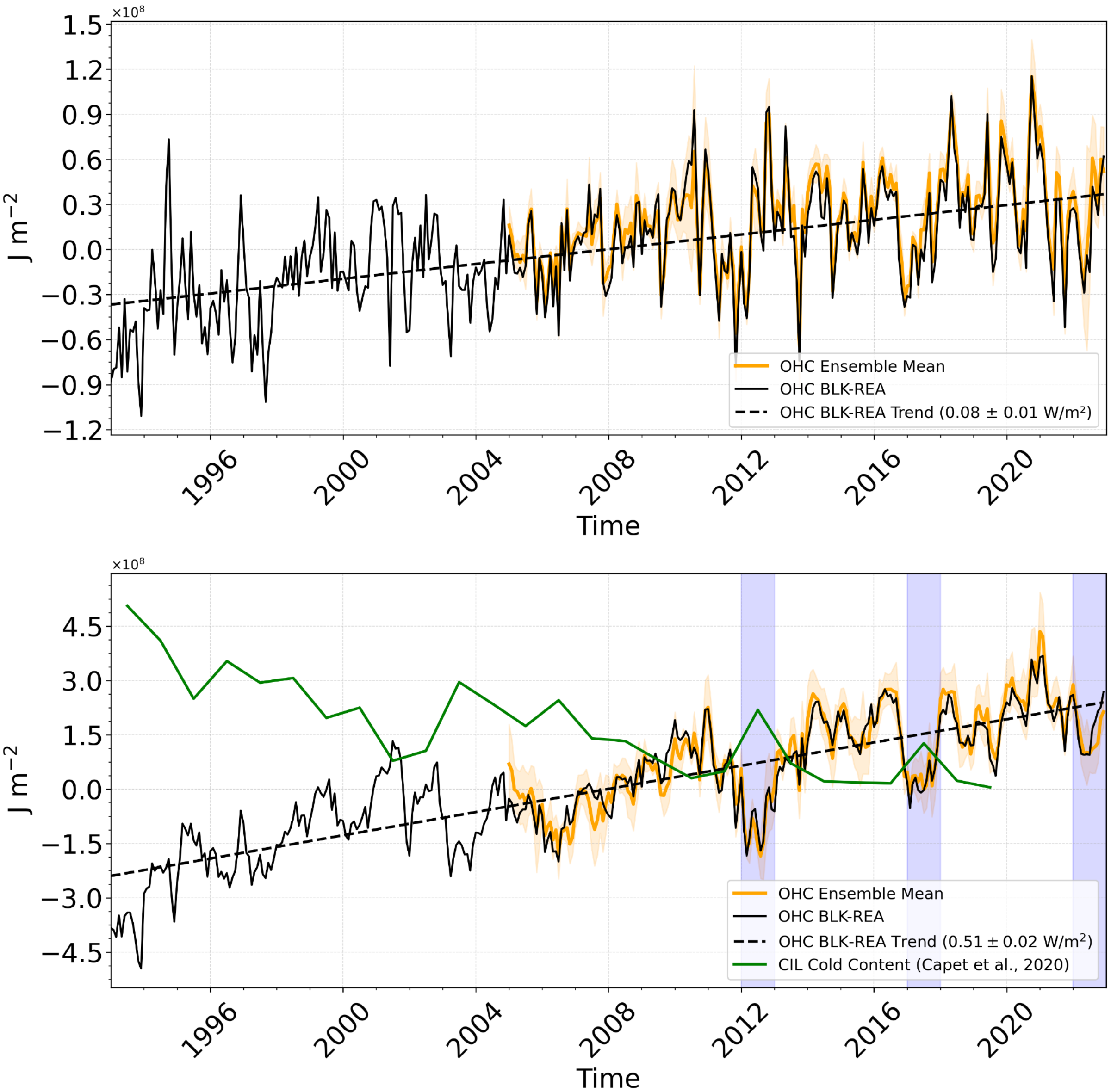

Figure 5: Monthly basin-averaged ocean heat content anomalies (10^{-8} J m^{-2}) for the 0–10 m (top) and 0–100 m (bottom) layers. Anomalies are defined as deviations from the monthly climatological mean (1993–2014). The black curves show the BLK-REA OHC anomalies, while the orange curves represent the OHC estimates from the 4-member ensemble, which includes a global reanalysis (GLORYS), the regional BLK-REA, and objective analyses (e.g., ARMOR3D, CORA). Mean trend values are reported for each layer (bottom-right corner). In the 0–100 m panel, the green curve corresponds to the Cold Intermediate Layer (CIL) cold content from Capet et al. (2020), and the blue shading highlights the years when the CIL is present (2012, 2017, and 2022).

2. The validation is based almost entirely on the same observations that are assimilated in the system, so the reported errors reflect how well the analysis fits the data, not how well the model performs independently. The "quasi-independent" validation mentioned in the text is still drawn from the same datasets, excluding only those filtered out during quality control. For the results to be credible, the authors should test the system against independent data or show forecast-skill statistics. At present, the validation does not prove that the reanalysis is physically or dynamically realistic.

As suggested by the reviewer, we prepared plots (see Figures 6, 7 and 8 below) to generally show the errors of the reanalysis (BLKREA in blue) compared to *what we call the "forecast" (Fcst in orange). In this context, we define the "forecast" as the third day of the model integration before the increments are applied (or the mean of the first day immediately after the analysis at time t), which allows the comparison to observations that have not yet been assimilated. While it is clear that the reanalysis demonstrates superior performance, the forecast errors remain within acceptable limits and are comparable to the forecast skill of the Black Sea Physics Analysis and Forecast (BLK-NRT) product provided by the Copernicus Marine Service:* [*https://data.marine.copernicus.eu/product/BLKSEA_ANALYSISFORECAST_PHY_007_001/description*](https://data.marine.copernicus.eu/product/BLKSEA_ANALYSISFORECAST_PHY_007_001/description)

Nevertheless, to preserve the manuscript's focus and coherence, we limit our analysis in the main text to the reanalysis fields, which represent the main product delivered to users, and do not include Figures 6 - 8. These figures are therefore provided solely in response to the reviewer's comments. As a reference, for users specifically interested in forecast products, the BLK-NRT system offers a dedicated dataset, and its QUID is cited in the paragraph above.

To partially address the lack of independent validation, a new Appendix A has been added to the revised manuscript, presenting fully independent SST validations in which BLK-REA and GLORYS12 (global reanalysis) are evaluated against a high-resolution reprocessed Level-4 satellite SST product for the Black Sea at 1/20° resolution (Pisano et al., 2016; Embury et al., 2024). These independent assessments show that BLK-REA consistently outperforms GLORYS12, with lower RMSD and reduced bias, supporting the added value and physical realism of the regional reanalysis.

In the revised manuscript, we also present a validation of OHC from BLK-REA using a 4-member ensemble (see Figure 5), which includes GLORYS, BLK-REA, and objective analyses (ARMOR3D, CORA). This ensemble provides an independent context for evaluation, allowing us to assess OHC and quantify the uncertainty of the estimates, thereby providing a robust basis for interpreting the results. A similar ensemble-based analysis cannot be performed for other indicators, such as the Rim Current index or overturning circulation, due to the lack of high-resolution u and v velocity data with sufficient spatial and temporal coverage for the Black Sea.

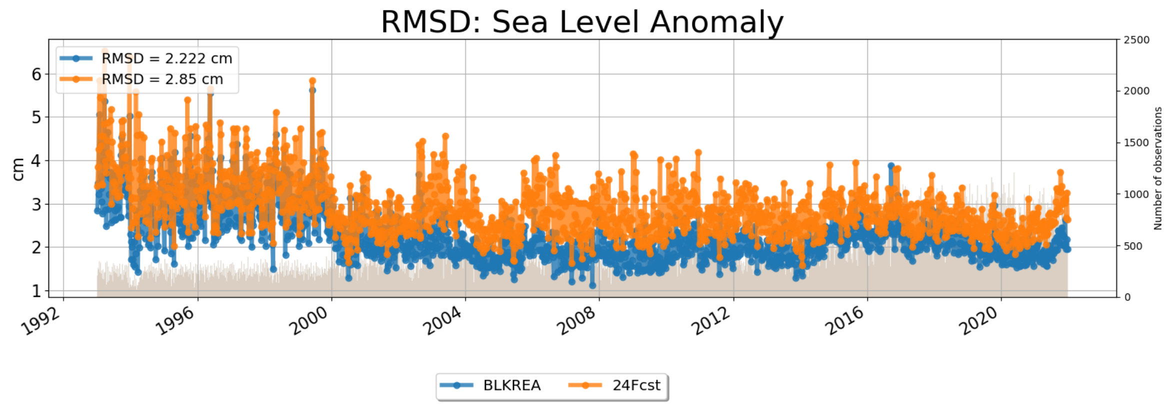

Figure 6: Time evolution of basin-averaged SLA RMSD, by comparing the reanalysis (BLKREA in blue) and "forecast" (24Fcst in orange) results with satellite along-track SLA data, with a 7-day moving average applied to smooth short-term variability.

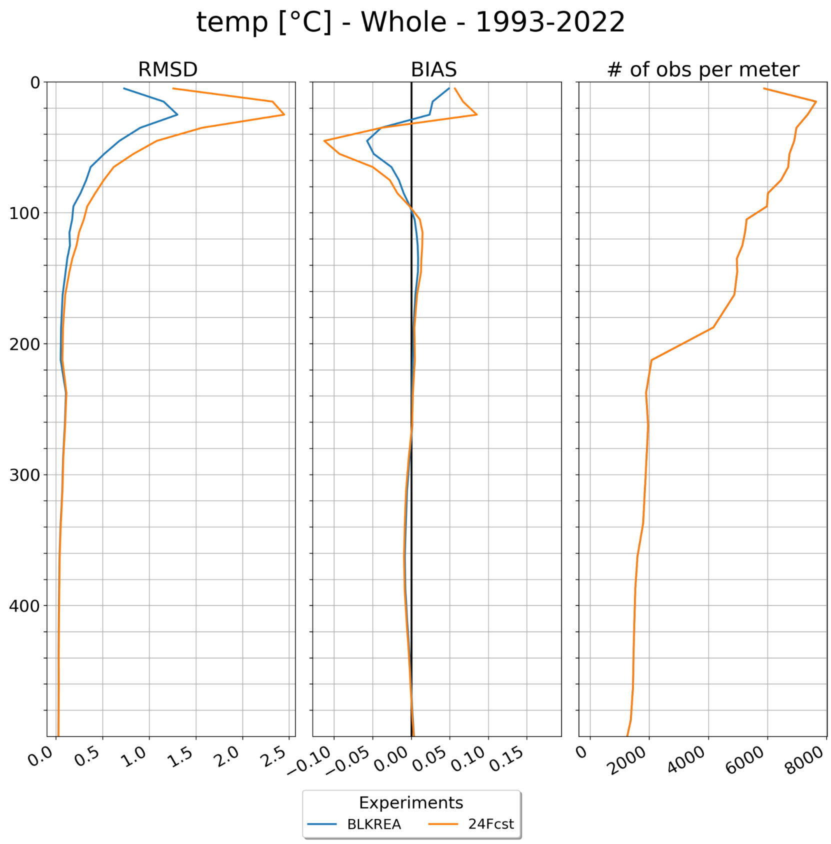

Figure 7: Vertical profiles of the RMSD (left panel), bias (middle panel) and number of observations (right panel) for temperature (in °C), by comparing the reanalysis (BLKREA in blue) and "forecast" (24Fcst in orange) results against in-situ profilers in the Black Sea domain from 1 January 1993 to 31 December 2022.

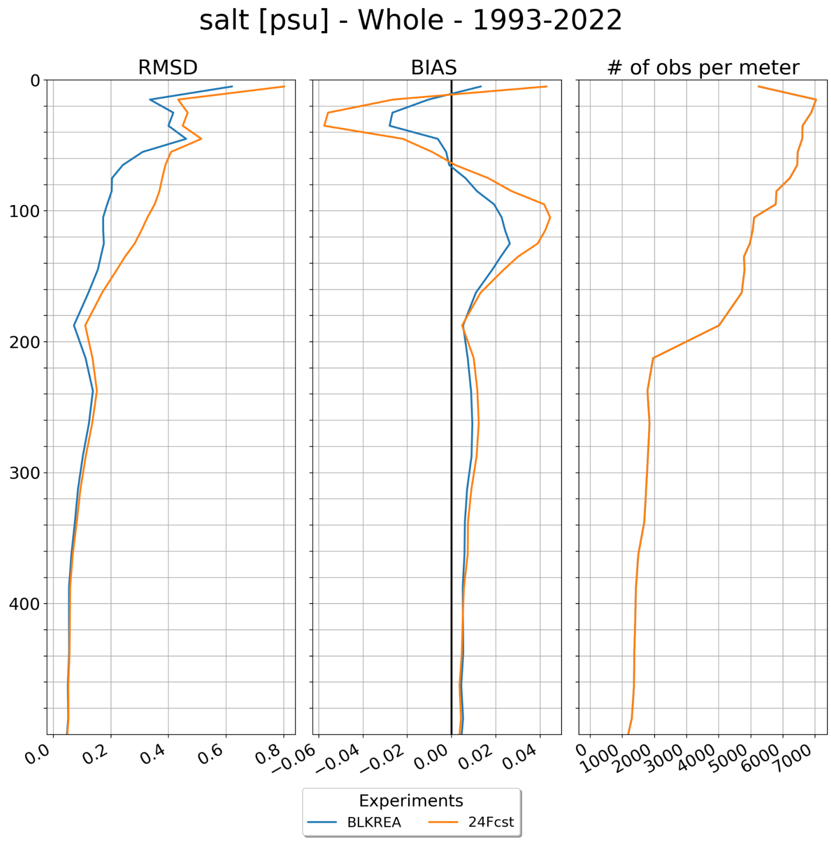

Figure 8: Vertical profiles of the RMSD (left panel), bias (middle panel) and number of observations (right panel) for salinity (in psu), by comparing the reanalysis (BLKREA in blue) and "forecast" (24Fcst in orange) results against in-situ profilers in the Black Sea domain from 1 January 1993 to 31 December 2022.

3. The title, "Advances in Monitoring Black Sea Dynamics," gives the impression that this is a dynamically consistent reanalysis that improves our understanding of Black Sea circulation. In reality, the product depends on frequent assimilation, static boundary climatology, and bias corrections. It is not a tool for studying the basin's intrinsic dynamics, only for producing a constrained reconstruction. The title and framing should reflect this more clearly; otherwise, it risks misleading readers about what the system can actually do.

We thank the reviewer for this comment. We agree that neither the model alone nor the available observations can provide a fully unconstrained, dynamically free three-dimensional reconstruction suitable for studying the intrinsic dynamics of the Black Sea. In BLK-REA, model uncertainties are reduced through data assimilation and additional constraints, while the model integrates freely between assimilation cycles, allowing dynamical propagation of information within the basin.

As a regional reanalysis specifically designed for the Black Sea, BLK-REA aims to provide a physically consistent, observation-constrained reconstruction rather than an unconstrained dynamical simulation. Its main advances lie in the higher spatial and vertical resolution (1/40° and 121 vertical levels) and in the improved representation of key regional features relative to coarse-

resolution global reanalyses. In the revised manuscript, this is supported by direct comparisons with a state-of-the-art global reanalysis over the Black Sea, which show improved skill for temperature, salinity, and sea level anomaly. These results underline the practical value of maintaining a dedicated regional reanalysis system, while we have revised the title and framing of the manuscript to more clearly reflect the nature and scope of the product.

4. The choice to compute decade-specific EOFs for the 3DVAR background covariance is an interesting idea, but the implementation raises several concerns. Changing covariance sets at decade boundaries can create discontinuities, especially since early decades are data-poor and rely heavily on model-derived variability. No diagnostics are shown, and no sensitivity tests are performed to demonstrate that this approach helps. Without such evidence, it is unclear whether the "decadal" design improves the system or simply introduces artificial changes from one period to another.

Regarding the background-error covariance (B-matrix), 3DVAR uses static covariances that do not evolve in time. EOFs use the model variability during a particular period as a measure of the model error. Using the full period of the reanalysis as a basis for the EOF calculation would be an overestimation, as it would attribute any variation observed in four decades of data to model error. On the other hand, the covariance between the prognostic variables is inherently linear, therefore it is also important that the model does not significantly deviate outside the range observed in the EOF period. To better represent temporal variability, we chose to compute monthly EOFs that vary across decades. The resulting choice of 10 years is a compromise between capturing sufficient variability and the representativeness of each period, which we have found to produce good results and improve the system.

The model error is not directly estimated from observational data, but rather from the model variability in an assimilative run. While the quality of the reanalysis in the early, data-poor, decades is certainly less than in the more recent decades, we do not believe that this method creates any problems. If anything, the decadal EOFs will limit the negative influence of the early periods on the more recent periods.

As we mentioned in our response during the "Interactive Discussion" review phase, several tests were conducted before selecting the above-mentioned configuration. We consider it beyond the scope of this manuscript to include these test results, as they form only a small part of the extensive experiments and evaluations conducted over nearly three years of reanalysis development.

During this period, we consistently aimed to identify the most robust and thoroughly validated configuration.

5. The paper presents trends in heat content, overturning circulation, and Rim Current intensity derived directly from BLK-REA. These analyses are questionable because the observing system changes dramatically over time; the start of altimetry, improved satellite SSTs, and the introduction of Argo profiles after 2000 all affect the data coverage. These changes can easily produce artificial trends. No attempt is made to test the sensitivity of these results to data availability. The authors should either limit such analyses to the well-observed period or clearly acknowledge the associated uncertainty.

We thank the reviewer for the comment. We agree that changes in the observing system can affect the information available to the reanalysis. However, we emphasize that these changes do not create "artificial" trends in the usual sense: because observations are the closest representation of reality, their increased availability actually helps the reanalysis converge toward the true ocean state. In other words, the evolving observing system improves the constraint on the model rather than imposing spurious signals.

At the same time, the indicators we study (heat content, overturning circulation, and Rim Current intensity) cannot be reliably estimated from the model alone, since the model itself contains uncertainties and simplifications, nor from the sparse and discontinuous observations available for the Black Sea. A dedicated reanalysis such as BLK-REA remains the only consistent approach to integrate all available observations into an ocean model, producing spatially and temporally complete fields suitable for long-term analysis.

For OHC, we included an analysis based on an ensemble of different products in the revised version (see Figure 5 above). This ensemble approach allows us not only to evaluate the OHC but also to provide an estimate of the associated uncertainty. However, it is not possible to perform a similar ensemble-based analysis for the Rim Current index or for indicators of the overturning circulation, as high-resolution u and v velocity data with adequate spatial coverage are not available for the Black Sea. Instead, these indicators are compared with results from previous studies, which were themselves based on earlier versions of the Black Sea reanalysis.

6. The system relaxes SST to satellite observations but does not assimilate SST directly, while applying a large-scale bias correction below 700 m offline toward WOA2018. This seems inconsistent and not well justified. If SST is already being relaxed every few days, it would make more sense to assimilate it properly within the 3DVAR framework to ensure dynamic consistency. Likewise, applying deep bias correction offline interrupts the temporal continuity

of the reanalysis. It would be better handled online as part of the assimilation system. The authors should explain these choices and, ideally, test how much they affect the vertical temperature structure and heat-content trends.

Due to the scarcity of in situ observations available for assimilation in the Black Sea, additional strategies are required to maintain physical consistency and long-term stability.

The assimilation of sea surface temperature (SST) is currently under development and testing for the Black Sea domain. Preliminary experiments show that although direct SST assimilation improves surface temperatures, it can have a negative impact on the subsurface thermal structure, particularly below the mixed layer depth (MLD). Moreover, such a projection would be entirely based on the covariance matrix and in many regions without the stabilising effect of other types of observations nearby. To address this issue, we are evaluating a vertical localization scheme that restricts the influence of SST assimilation to the upper ocean, i.e., above the MLD. As an alternative, the system currently applies SST relaxation toward satellite observations, which effectively corrects surface heat fluxes while preserving upper-ocean stability and avoiding spurious vertical temperature imbalances. Consequently, the flux correction applied using the observed SST differences acts as a gentler damping mechanism that does not directly perturb the deeper layers.

Regarding the large-scale bias correction (LSBC), it is applied online (not offline) in the model integration, but only below 700 m. This approach is especially important in data-sparse regions such as the Black Sea, where the deep ocean is poorly constrained by observations. The LSBC helps prevent the deep temperature and salinity fields from drifting toward unrealistic values and ensures the long-term reliability of the reanalysis. It therefore preserves the temporal stability of the system. In addition, since LSBC is applied only below 700 m, it does not influence the upper-layer heat content. In the manuscript, we show the 0–100 m ocean heat content; therefore, it is not affected by LSBC.

7. The manuscript claims that BLK-REA can be used to study climate-change signals in the Black Sea. With only 30 years of data (1993–2022), this statement is not convincing. Thirty years is barely enough to capture decadal variability, let alone distinguish it from long-term climate trends. The period also coincides with major changes in observing systems and boundary forcing. These limitations make the dataset unsuitable for robust climate-change assessments. The authors should clearly state this and tone down the claim.

We thank the reviewer for highlighting the limitations of the 30-year BLK-REA dataset. We agree that this period is short for robust climate-change assessments. The manuscript has been revised to clarify that BLK-REA is primarily intended for studying long-term physical changes in the Black Sea and supporting regional ocean monitoring.

The new revised version states in the "Abstract":

> *"Furthermore, BLK-REA plays a crucial role in generating Ocean Monitoring Indicators, which are essential for tracking and assessing* ***long-term physical changes in the Black Sea****" (line 24).*

and in the "Introduction":

> *"Previous Black Sea reanalyses, also developed within the framework of the Copernicus Marine Service, have served as valuable tools* ***for understanding the Black Sea's physical variability and supporting assessments of long-term oceanic changes****"(lines 61-62).*

 # Minor Comments

• Figures could be clearer; color scales, units, and captions are sometimes inconsistent. Showing differences from the previous reanalysis would be much more informative.
• Acronyms such as U-TSS, LSBC, and MDT should be defined at first mention.
• A short table listing the assimilated datasets and their temporal coverage would help illustrate the inhomogeneity of the observing system.
• Several small typographical and formatting issues should be corrected before publication. Furthermore, there is large room for improving the overall writing and clarity of the manuscript.

We thank the reviewer for the constructive comments. Minor adjustments have been made accordingly: figures now have consistent color scales, units, and captions; all acronyms (e.g., U-TSS, LSBC, MDT) are defined at first mention; typographical, formatting, and clarity issues throughout the manuscript have been corrected. Regarding the suggestion of a table summarizing the assimilated datasets, all datasets used in the assimilation are described in detail in the methodology, and the spatial and temporal distribution of available data is illustrated in the evaluation figures.

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Response to Reviewer#2

Dear Dr. Y. Kim (Reviewer #2), thank you for reading and suggesting modifications to our manuscript entitled “Advances in Monitoring Black Sea Dynamics: A New Multidecadal High-Resolution Reanalysis”.

We believe that your second review has helped to substantially improve the revised manuscript. The changes in the manuscript have been highlighted in red. Additionally, please find below a list with our point-by-point answers (*in italic*) to your comments and suggestions.

Most of the revisions, including the clarifications on data assimilation procedures, validation methodology, and the explanation of the temperature/salinity anomalies, appropriately address the reviewer’s concerns and significantly improve the manuscript.

However, while the overall response is satisfactory, two minor points still merit further clarification.

First, the limitation associated with the lack of fully independent observational datasets should be explicitly acknowledged as a methodological caveat to enhance transparency.

> *We sincerely thank the reviewer for their constructive comments, which significantly improved the manuscript. Following the reviewer’s suggestion, we have clarified in the revised manuscript (lines 230-235) that “Although efforts were made to validate the model, fully independent observational datasets, in the sense of being completely separate from the assimilated data, were not available, which should be considered when interpreting the validation results.” Nevertheless, the revised manuscript includes an independent evaluation of BLK-REA through a multi-product ensemble analysis of ocean heat content (OHC), combining BLK-REA, GLORYS, and objective analyses (ARMOR3D, CORA), which allows us to quantify uncertainties (Figure 1). For specific OMIs, we retained the comparison of BLK-REA results with previous studies based on earlier BLK-REA versions; ensemble-based analysis was not possible for these indicators due to the limited availability of high-resolution velocity data.*
>
> *To further mitigate this limitation, the revised manuscript now includes an additional independent assessment presented in Appendix A, where BLK-REA and GLORYS12 (global reanalysis) are evaluated against a reprocessed high-resolution Level-4 satellite SST product for the Black Sea. This fully independent comparison shows systematically lower RMSD and reduced bias for BLK-REA, providing complementary evidence of the added value of the regional reanalysis.*

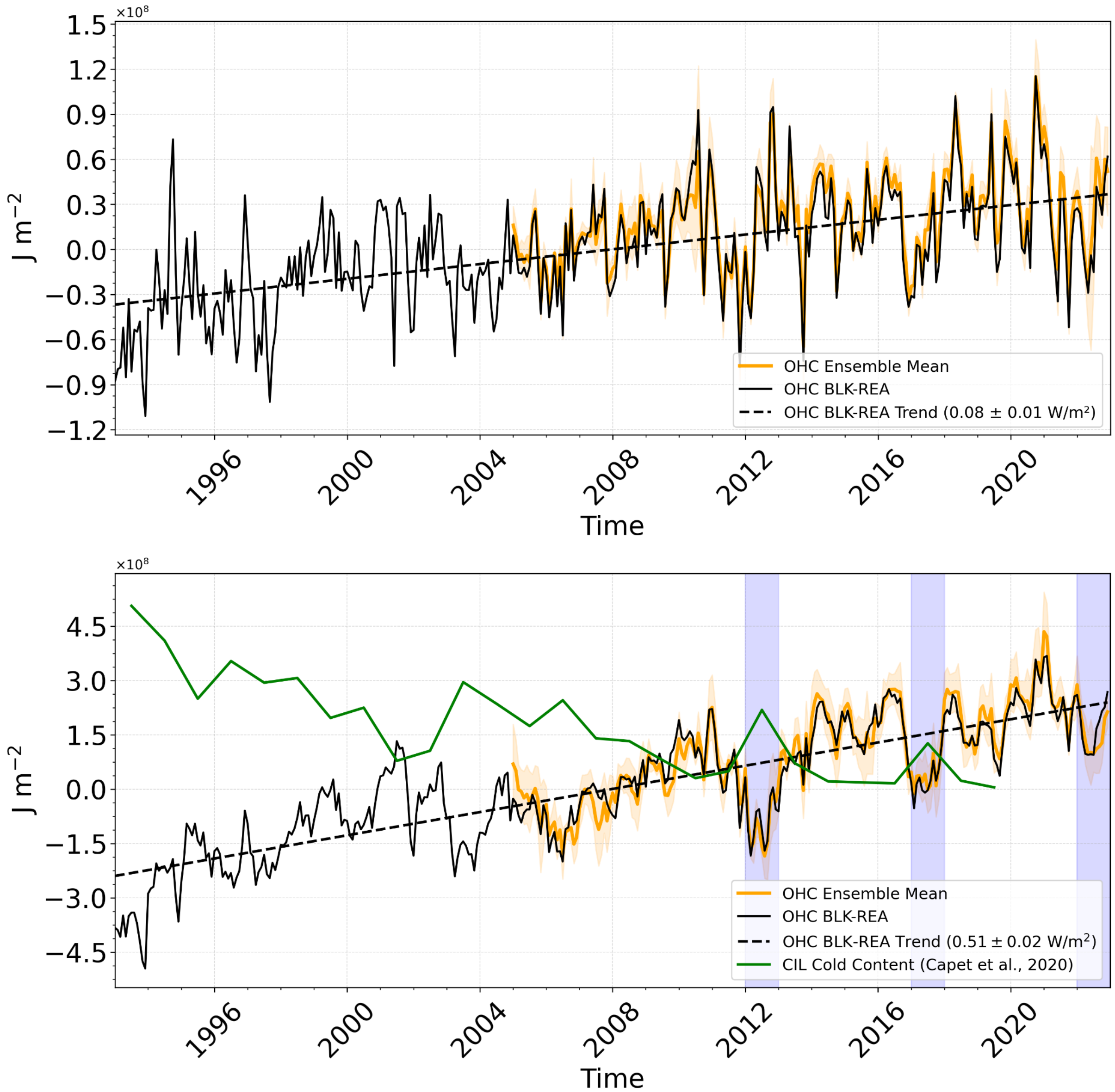

Figure 1: Monthly basin-averaged ocean heat content anomalies (10^{-8} J m^{-2}) for the 0–10 m (top) and 0–100 m (bottom) layers. Anomalies are defined as deviations from the monthly climatological mean (1993–2014). The black curves show the BLK-REA OHC anomalies, while the orange curves represent the OHC estimates from the 4-member ensemble, which includes a global reanalysis (GLORYS), the regional BLK-REA, and objective analyses (e.g., ARMOR3D, CORA). Mean trend values are reported for each layer (bottom-right corner). In the 0–100 m panel, the green curve corresponds to the Cold Intermediate Layer (CIL) cold content from Capet et al. (2020), and the blue shading highlights the years when the CIL is present (2012, 2017, and 2022).

Second, the explanation of how potential observation-induced artifacts were mitigated remains somewhat general. Beyond the mention of standard QC, it would be helpful if the authors could briefly specify additional mitigation procedures (e.g., visual inspection, outlier screening, or temporal consistency checks) used to minimize the impact of spurious data.

We thank the reviewer for their constructive comment. In the revised manuscript, we have added more details in line with the reviewer's suggestion. Specifically, in lines 152-159, we now describe that during the preparation of *the merged in situ dataset, the following checks are performed to mitigate potential observation-induced artifacts:*

In addition to the standard QC flags provided by the data producers, we applied several further checks to reduce the influence of spurious observations. First, we retained only measurements explicitly flagged as good (QC=1) for all variables, including temperature, salinity, time, position, and pressure/depth. We also applied basic range checks for temperature and salinity. For CTD profiles, we kept only the downcasts, following expert guidance that measurements collected during the ascent may be less reliable. Finally, for Argo floats and gliders, we applied a vertical-spacing check in the upper ocean: profiles with data gaps larger than 40 m in the first 300 m were excluded to avoid assimilating observations with insufficient vertical resolution in the thermocline.

In addition to these preprocessing checks applied to the in situ data, there are rare cases in which the assimilation of specific observations, such as T/S profiles or along-track SLA, can introduce shocks into the model state and lead to model blow-ups. In such situations, a targeted visual inspection is performed to identify and remove the problematic observations before rerunning the assimilation, ensuring that spurious data do not contaminate the reanalysis.

Overall, the revisions are well executed and reflect the reviewer's earlier comments well. Addressing these two remaining points would make the discussion even more complete.