

Response to Reviewer #2

The reviewer's comments are highlighted in *blue italic fonts*, while the authors' responses are presented in black regular fonts. Modified texts of the manuscript are presented in *black italic fonts*.

Like the other reviewer, I found this manuscript difficult to follow, mainly because of how it was structured. For example, there are many instances in Sections 2 and 3 where background information on the Baltic Sea sea level and known mass/volume transports are presented for the first time. This background should all go in Section 1 as motivation for the exact problem the authors are investigating. Then Section 2 should be on specific methods used, and Section 3 on an analysis of the results and comparing them to previous studies. Section 3 is not the time to introduce background/motivation information, as it distracts from the actual results.

First, we would like to thank you for your comments, suggestions, and the time you dedicated to reviewing our manuscript. In the following, we will answer the comments and improve the revised version of the manuscript accordingly. We appreciate your concern about the structure of the manuscript, and we improve the text in the revised version as follows:

- Section 2.1 is deleted and moved to section “2. Background and Dataset” to explain the background of this study. Accordingly, one will be added to the number of the following sections (e.g., “3. Method”). Also, some background information from the introduction has been merged into this section.
- Datasets are introduced in Section “Background and Dataset”. For instance: L291-293; L425-429; L460-466; deleting Figure 9a.
- “Results” section is renamed to “Results and Discussions”, and information regarding datasets is transferred to “Background and Dataset”.
- Figures 3 and 4 are moved to the Section 3.1 and renamed it to “Dynamic Water Volume and Co-oscillation of Sub-Basins”. Subsequently, we have minor modifications in this section.
- We have also made minor textual edits to other parts of the manuscript for better readability (please refer to tracking mode of the revised version)

The authors make a big deal (multiple time throughout the paper) that'll theirs is the first to do this with a model and observations related to a geoid. Okay. But please, this only needs to be stated once in the introduction and you don't have to keep repeating it. It is distracting!

Thanks for your observations. The repeated sentences are removed, and we keep the relevant explanation in “Background and Dataset” section. For instance, these lines are deleted/modified to avoid repeating: L80; L201-202; L207; L226-227; L278-279; L291-293 (moved to Sec. 2); L314-315.

I really do not see the point of section 2.1, comparing geostrophic currents. First of all, this is mixing methods and results. Second, as far as I can tell, this has nothing to do with the motivation of the paper (looking for overall mass transports into/out of the Baltic). It seems this is mainly to further motivate that their geoid-referenced model DT is good, but this has been demonstrated in other papers. While there is nothing wrong with the analysis, it is distracting from the main goals of this manuscript. I would cut this completely.

Thanks for your comment. We agree that this section needs to be modified. We removed this section from the "Method" section because it explains the background and has mistakenly leaked into this section. As explained above, we added one more section to explain the previous study, background and datasets. Please refer to the revised version.

I also do not see the point of Section 3.1 -- yes, the DT varies differently in different sub-basins. But how is this relevant to the overall goals of the paper, to assess transport between the Baltic and North Sea, and to estimate river inflow from the DT variations? It feels like it is tacked onto the study, but is not really motivated in Section 1.

Thanks again for this comment. The internal dynamics of the Baltic Sea are also our interest in this manuscript. The DT anomaly in sub-basins reflects the internal dynamics of the Baltic Sea and the variation/co-oscillation of water volume within the sub-basins. While this section may not directly be related to the assessment of the overall water transport between the Baltic and North Sea or river inflows, it provides valuable insight into the co-oscillations among the sub-basins and their seasonality. This understanding is particularly relevant during inflow and outflow events, as it helps characterize the Baltic Sea's response to external forcing. We believe this section adds value to the overall analysis.

The section is modified as follows:

- Title is change to "Dynamic Water Volume and Co-oscillation of Sub-Basins"
- Figures 3 and 4 (results that were wrongly presented in section 3.2) are moved to this section.
- Modifying/adding the text of the introduction, for example:

L76: ... *The multitude of processes contributing to sea level variations in the Baltic Sea complicates the interpretation of its dynamics and inflows (Weisse et al., 2021). Therefore, quantifying the dynamics of the water column within the Baltic Sea and its interactions with the North Sea and river inflows provides important insights into regional hydrodynamics and water exchange processes.*

L104-106: *This study aims to use DT of the corrected HDM for 2017-2021.5 to quantify: (i) the dynamic water volume of the Baltic Sea; (ii) the seasonal and spatial distribution of DT anomalies, which represents internal dynamics and the variation/co-oscillation of water volume within the Baltic sub-basins; (iii) barotropic water exchange between the Baltic and North Seas; and (iv) total river runoff to the Baltic Sea using the water budget equation.*

Finally, I have one methodology concern. It is not at all clear to me (although it may be buried in the introductory material in Section 3) that the authors have considered annual and low frequency steric (density) variations that contribute to the volume changes. The volume balance equation being used is based on a mass balance (barotropic) approach, where the density is unchanging (e.g., basically freshwater density). The authors emphasize the north-south mean density gradients in the Baltic, but do these change in time? Have the authors quantified if this is small enough to ignore, or is it even included in their model. My concern is that some of the volume changes are not actually related to the water fluxes into and out of the Baltic, but changes in the density structure.

We appreciate your concern regarding the steric variations. We confirm that the corrected model includes the seasonal change (low-frequency) of steric variations, as it has been corrected by the geoid-referenced observations. Therefore, the volume change related to the density structure is

included in the corrected model and the term of dV/dt in this equation also retains the density-related volume changes. We added the following sentence to the paragraph following Figure 3:

It would be worth noting that the steric effect correction was also included in the corrected DT (Jahanmard et al., 2023a), which may contribute to the seasonal difference.

Also, L310:

It should be emphasized that the steric correction is incorporated into the corrected HDM, which as a result, the density-related volume changes are included in the term dV/dt . In addition, the volume change due to land uplift was accounted for through the definition of using absolute DT relative to a reference epoch.

The steric variation in the Baltic Sea is only 10% of the sea level variation and becomes more significant over the decadal timescale (Virtanen et al., 2010; Karimi et al., 2022). On shorter timescales, the north-south density gradient in the Baltic is almost constant, and the sea level variation in the Baltic Sea is dominated by the barystatic component. The permanent density gradient causes a permanent northward sea surface tilt in this basin (shown in Figure 6a). It is also noteworthy that the water exchange between the Baltic and North Seas is determined using Eq. (5), and river runoff, computed from the volume balance equation, includes steric variations in the corrected model. However, the original model may not account for seasonal steric variation.

References:

Karimi, A. A., Ghobadi-Far, K., & Passaro, M. (2022). Barystatic and steric sea level variations in the Baltic Sea and implications of water exchange with the North Sea in the satellite era. *Frontiers in Marine Science*, 9, 963564.

Virtanen, J., Mäkinen, J., Bilker-Koivula, M., Virtanen, H., Nordman, M., Kangas, A., ... & Thomas, M. (2010). Baltic sea mass variations from GRACE: comparison with in situ and modelled sea level heights. In *Gravity, Geoid and Earth Observation: IAG Commission 2: Gravity Field*, Chania, Crete, Greece, 23-27 June 2008 (pp. 571-577). Springer Berlin Heidelberg.

Sincerely,

Vahidreza Jahanmard

On behalf of the co-authors