Reviewer 1

Review of « Baltic Sea freshwater content » by Urmas Raudsepp et al.

This article is a study of the Baltic Sea freshwater content, based on outputs of re-analyzed models. I think the study is clear and simple, and deserves publication, but there are some points which require further explanation.

General comments:

You mention several times that the FWC is affected by the sea ice cover. That might be true from a seasonal point of view, but I fail to understand why this would have any effect from an inter-annual point of view since the freshwater stored in sea ice is totally released every year in the water column. That is really the only thing that appears strange for me in this article, and that I think requires further explanation.

We agree that FWC stored in sea ice is totally released every year. On the other hand, seasonal formation of sea ice affects FWC in the water on an annual scale, if the volume of ice and freshwater stored in the ice is not taken into account in calculation of the FWC in the fixed volume of water. The latter is usually the case in the calculation of the salinity (and FWC) in the ice covered water column. Annual mean FWC is calculated by averaging daily FWC over the year. If the sea ice is formed, then some amount of freshwater is “removed” from the water and “stored” in ice. When the daily volume of ice is larger then more freshwater is stored in the ice. As a consequence, annual mean FWC is smaller when accumulated daily ice volume is larger and vice versa.

In the seasonally ice-covered seas, the ice coverage acts as temporal internal freshwater storage. In a closed water basin without any other sources and sinks, annual mean FWC and accumulated daily ice volume reverse relationship. Therefore our results of the negative trend in annual ice volume and positive trend in FWC in the Bothnian Bay are consistent.

We will provide a detailed explanation of the effect in the revised manuscript.

Another point, less critical though, is the explanation of the decrease of FWC in the Baltic Proper, which is especially obvious for the deeper parts. You relate this point to an intensification of salt inflows to the Baltic, could you please explicitate what is the scientific consensus, is it related to climate change and/or sea level rise ?

We are not sure that consensus has reached about the question what has caused intensification of salt transport to the Baltic Sea.

Lehmann et al. (2022) published an overview about the salinity dynamics of the Baltic Sea, where the potential effect of climate change and sea level rise to the salt inflows to the Baltic was discussed. Lehmann et al. (2022) show salinity increase in the deep layer of the Eastern Gotland basin from 1993 until 2018. They add that the frequency of barotropic and major Baltic inflows did not increase during the period. In their overview paper Lehmann et al. (2022) did not give an explanation of the deepwater salinity increase. Also, we do not provide a solid explanation of the decrease of the FWC in the southern Baltic Proper (Eastern Gotland basin is included) (Fig. 2). We show that vertically, decrease of the FWC occurs throughout the water column of the southern Baltic Proper (Fig.

4). We suggest that the most likely reason for the decrease of FWC in the deep layers of the Baltic Sea could be an intensification of salt inflows to the Baltic.

Generally, westerly winds force inflow of saline water and easterly winds force outflow of brackish Baltic Sea water. Over the period 1978-2020, the inflow conditions during months January, February and March were observed more frequently since the 1990ies (Hindrichen et al., 2022). Thus, if climate change is manifested by an increase of westerly winds in the Baltic Sea region, then an increase of saline water inflows could be resulted.

Hordoir et al. (2015) investigated the influence of sea level rise on saltwater inflows into the Baltic Sea and found an increase in saltwater inflow intensity and frequency with rising sea level (Lehmann et al., 2022). According to Meier et al. (2017) and Saraiva et al. (2019) in future high-end global mean sea level projections, reinforced saltwater inflows result in higher salinity compared to present conditions (Lehmann et al., 2022). Assuming a negligible impact of GMSL rise, the intensity and frequency of MBIs were projected to remain unchanged, with a potential tendency of a slight increase (Schimanke et al., 2014).

One of the key findings of the BACC II assessment was that “Climate model scenarios show a tendency towards future reduced salinity, but due to the large bias in the water balance projections, it is still uncertain whether the Baltic Sea will become less or more saline.”

Meier et al. (2022) concluded that “due to the uncertainties in projections of the regional wind, regional precipitation and evaporation, river discharge, and global mean sea level rise, projections of salinity in the Baltic Sea are inherently uncertain, and it remains unknown whether the Baltic Sea will become less or more salty.”

We will add discussion about this matter into the revised manuscript.

Lehmann, A., Myrberg, K., Post, P., (...), Lips, U., Bukanova, T., 2022. Salinity dynamics of the Baltic Sea, Earth System Dynamics, 13(1), pp. 373-392.

Markus Meier, H.E., Kniebusch, M., Dieterich, C., (...), Weisse, R., Zhang, W., 2022. Climate change in the Baltic Sea region: A summary, Earth System Dynamics, 13(1), pp. 457-593

Hinrichsen, H.-H., Barz, K., Lehmann, A., Moritz, T., 2022. Can sporadic records of ocean sunfish (Mola mola) in the western Baltic Sea be linked to saline inflow events? Journal of Marine Systems 236,103802. https://doi.org/10.1016/j.jmarsys.2022.103802

Hordoir, R., Axell, L., Löptien, U., Dietze, H., and Kuznetsov, I.: Influence of sea level rise on the dynamics of salt inflows in the Baltic Sea, J. Geophys. Res.-Oceans, 120, 6653–6668, https://doi.org/10.1002/2014JC010642, 2015.

Meier, H. E. ., Höglund, A., Almroth-Rosell, E., and Eilola, K.: Impact of accelerated future global mean sea level rise on hypoxia in the Baltic Sea, Clim. Dynam., 49, 163–172, https://doi.org/10.1007/s00382-016-3333-y, 2017.

Saraiva, S., Meier, H. E. M., Andersson, H. C., Höglund, A., Dieterich, C., Gröger, M., Hordoir, R., and Eilola, K.: Uncertainties in projections of the Baltic Sea

ecosystem driven by an ensemble of global climate models, Front. Earth Sci., 6, 244, https://doi.org/10.3389/feart.2018.00244, 2019.

Schimanke, S., Dieterich, C., and Meier, H. E. M.: An algorithm based on SLP-fluctuations to identify major Baltic inflow events, Tellus A, 66, 23452, https://doi.org/10.3402/tellusa.v66.23452, 2014.

Radtke, H., Brunnabend, S.-E., Gräwe, U., and Meier, H. E. M.: Investigating interdecadal salinity changes in the Baltic Sea in a 1850–2008 hindcast simulation, Clim. Past, 16, 1617–1642, https://doi.org/10.5194/cp-16-1617-2020, 2020.

Kniebusch, M., Meier, H. E. M., and Radtke, H.: Changing salinity gradients in the Baltic Sea as a consequence of altered freshwater budgets, Geophys. Res. Lett., 46, 9739–9747, 2019b.

Specific comments:

Line 60, can you explicitate the FWC formula so that the reader does not need to read Boyer 2007. Basically my understanding is that your formula is equivalent to saying that

*FWC= rho(Sref,Tref,p)/rho(0,Tref,p) * (S-Sref)/S*

which is very different from the usual formula (Sref-S)/Sref since now the variability in time becomes part of the denominator. It would be nice to know what this formula mean, especially why is there a ratio of densities?

This formula is derived from mixing of two water masses with different salinities by using the conservation of salt:

FWC= -rho(Sref,Tref,p)/rho(0,Tref,p) * (S-Sref)/S (1)

This formula has been used e.g. by Boyer et al. (2007), von Schuckmann et al. (2009), Watelet et al. (2020).

The usual formula FWC~(Sref-S)/Sref is derived from a salt conservation statement also:

FWC= rho(Sref,Tref,p)/rho(0,Tref,p) * (Sref-S)/Sref (2)

In several papers, where (2) is used, the reference is given to Boyer et al. (2007), which in our mind creates confusion.

Conceptual difference between the two formulas is as follows. In case of (1) in a fixed volume (Vtot) initially filled in with water Sref, the share of water Sref is replaced by freshwater (VFw) (VSref=Vtot-VFw) and then mixed to obtain defined salinity S. In case of (2) in a fixed volume (Vtot) initially filled in with water Sref, the freshwater VFw is added and two water masses are mixed to obtain the mixture with salinity S. Then a share of mixed water (VFw) is “removed from the system” to conserve the volume Vtot.

Two formulas result in different FWCs. The FWC by (1) is inverse proportional to the water salinity, while FWC by (2) is proportional to water salinity. The FWC anomalies calculated by (1) and (2) for the Baltic are shown in Fig. R1.

The FWC (1) is always greater or equal to FWC (2). Equality of two FWC is achieved when S=Sref. The FWC (1) approaches infinity when S approaches zero.

To clarify the meaning and differences of FWC (1) and FWC (2) we will add Appendix to revised manuscript.

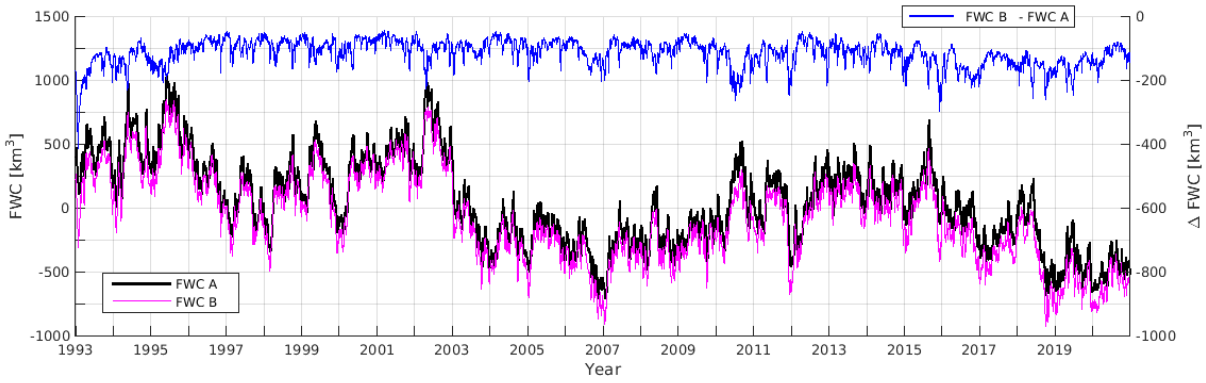

Figure R1. Time series of FWC in the Baltic Sea as calculated according to (1) (black) and (2) (violet) and difference between (2) and (1) (blue).

Boyer, T., Levitus, S., Antonov, J., Locarnini, R., Mishonov, A., Garcia, H. and Josey, S.A., 2007. Changes in freshwater content in the North Atlantic Ocean 1955–2006. Geophysical Research Letters, 34(16).

Von Schuckmann, K., Gaillard, F., Traon, P.-Y.L., 2009. Global hydrographic variability patterns during 2003-2008, Journal of Geophysical Research: Oceans 114(9),C09007.

Watelet, S., Skagseth, Ø., Lien, V.S., (...), Ivshin, V., Beckers, J.-M., 2020. A volumetric census of the Barents Sea in a changing climate, Earth System Science Data 12(4), pp. 2447-2457.

Figure 2. It would be nice to have in the figure a reminder of what are BOB, BOS etc. Same for Figure 4.

We have added the abbreviations into the figure captions. AT - Kattegat, SBP - Southern Baltic Proper, NBP - Northern Baltic Proper, BOS - Bothnian Sea, BOB - Bay of Bothnia, GOF - Gulf of Finland, GOR, Gulf of Riga.