Supplementary Materials

Steric sea level estimation:

We used two datasets for steric sea level estimations, is-situ observations and a physical reanalysis model. Both datasets are provided by the Copernicus Marine Environment Monitoring Service (CMEMS). The in-situ data are collected by the SMHI (Swedish Meteorological and Hydrological Institute) and the reanalysis model is produced by the Baltic Monitoring and Forecasting Centre (BAL MFC). The Gibbs SeaWater (GSW) oceanographic toolbox of TEOS-10 (McDougall and Barker, 2011) is used to estimate the steric sea level of each station or grid point.

1. Steric estimation at the observation stations: Among available subsurface observation stations in the Baltic Sea, we chose three stations for steric sea level estimation according to two criteria. The first criterion was the location of the stations (measurements) since the stations are not uniformly spread in the basin. Due to the salinity difference in the north and southern parts of the basin, ideally, the stations located regularly along the latitude could yield a more accurate representation of the density related changes. However, the lack of such stations in the Gulf of Bothnia and the Gulf of Finland during the study period confines the dataset to the southern half of the basin (the Baltic Proper). We also avoided the stations close to Danish Strait due to constant water exchange with the North Sea. The temporal continuity of the time series was the second factor considered; for instance, while BY29 was at a higher latitude than the selected stations, large data gaps barred it from the dataset. These criteria, finally, narrow down the stations to three stations, BY10, BY15, and BY20 (Figure 1). It is worth mentioning that there are three Argo floats in the basin (Siiriä et al., 2019), however, their operation periods (since 2011) are not suitable for this study.

Depth interval, in which the salinity and temperature profiles are collected, differs from one epoch to the other at all stations. The salinity and temperature profiles are interpolated to five-meter intervals for every epoch. The Baltic Sea contains 92% of the total water volume down to the depth of 100 m. Therefore, the reference depth is set to 100m at all three stations. Integrating the density variations with an identical weight for each layer will bias the steric sea level estimations due to the fact that the upper layers contain a larger volume of the basin water than the deeper layers. In other words, this will give the density variation of a basin which has a constant depth of 100 m throughout the basin, hence overestimation of the actual density change. Furthermore, density variations in deeper layers are of low frequency signals compared with the upper layers. Thus, giving the same weight to deeper levels can exaggerate the role of these low frequency signals. To solve this, the density variation at each depth is weighted by the area of the Baltic Sea in that depth. For weighting, we used the bathymetry model of the basin, developed by the Leibniz Institute for Baltic Sea Research (Seifert et al., 2001) and accessible through https://www.io-warnemuende.de/topography-of-the-baltic-sea.html. The first layer is weighted the highest and the deeper layers are weighted in descending manner according to their areas. The measurement collection is not temporally regular for stations (e.g., once in a month) so a monthly mean is estimated by averaging steric changes in a month. There are months with no profiles at all stations as can be seen in Figure S1. Finally, the monthly time series are averaged for all stations to represent the steric sea level variations of the Baltic Sea.

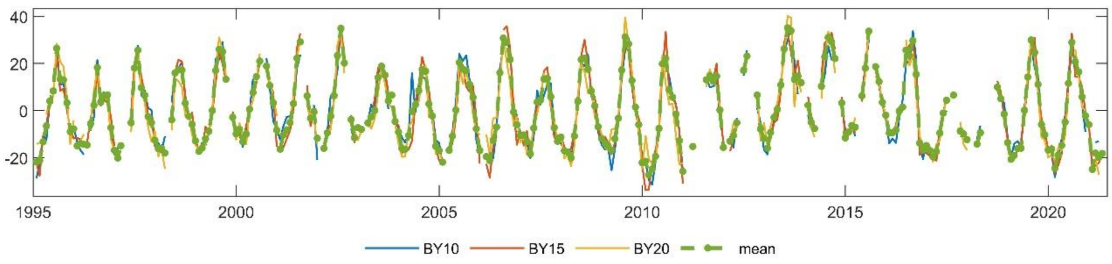

Figure S1 Estimated steric sea levels at three observations stations located in the Baltic Proper. The unit is mm.

2. Steric estimation by reanalysis model: The reanalysis model used in this study is BALTICSEA_REANALYSIS_PHY_003_01, estimated by the ice-ocean model NEMO-Nordic and LSEIK data assimilation. It is provided in 4 km × 4 km resolution in 56 depth levels for the basin. The dataset covers 1993 to 202 and it is offered in three temporal resolutions, hourly, daily, and monthly. We used monthly data set in this study. Further detail regarding the model and product can be found in Axell (2019).

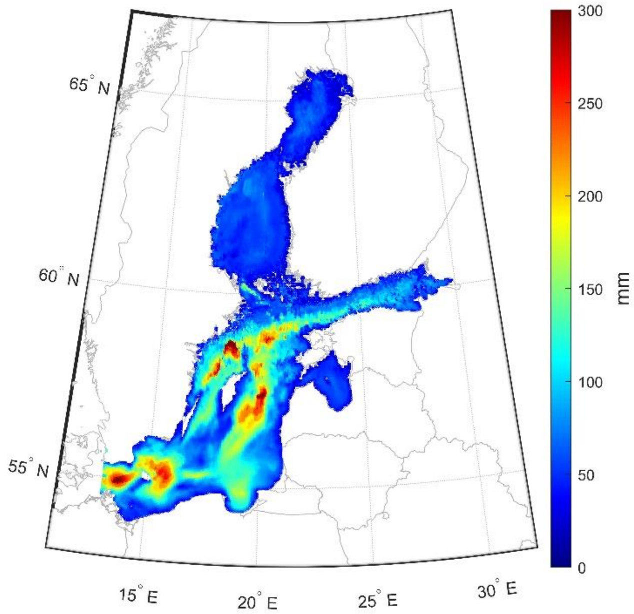

Figure S2 The amplitude of steric sea level across the Baltic Sea estimated by the reanalysis model. The amplitude is estimated by subtracting the maximum of the time series from the minimum for each grid point.

We estimated the steric sea level variation in each grid point. Figure S2 shows the amplitudes of the steric sea level in each grid point. The amplitude is estimated by subtracting the minimum value of the time series from the maximum. The average of the steric sea level estimated by the reanalysis model is compared to the that of the in-situ observations in Figure S3. The steric sea level estimated by the reanalysis model is smoother than that of the observations but shows in-phase changes. The low frequency variations are similar in both time series. These arguments show that the methodology used to estimate the steric from observations are reliable enough to be used in the budget study.

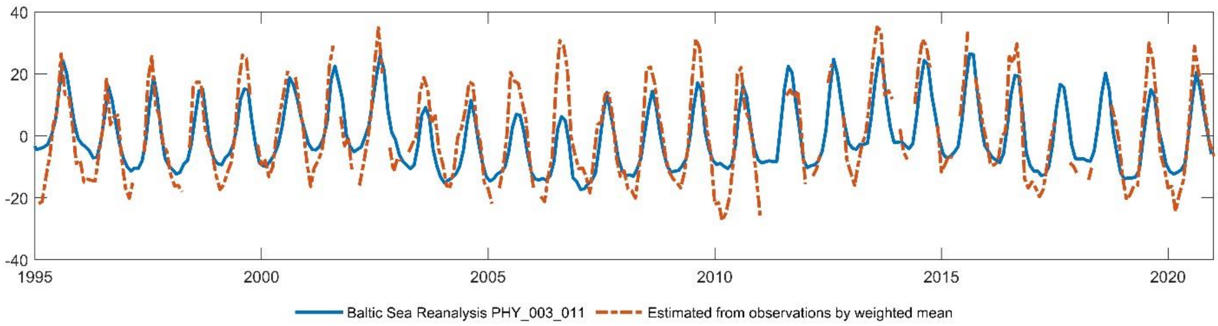

Figure S3 Comparison of the steric sea levels estimated by observations (Figure S1) and the average of the reanalysis model (Figure S2). The unit is mm.

Reference:

Axell, L. (2019). Product User Manual of Baltic Sea Physical Reanalysis Product BALTICSEA_REANALYSIS_PHY_003_011. issue 2.0, Tech. Rep., Copernicus Marine Environment Monitoring Service, https://catalogue. marine. copernicus. eu/documents/PUM/CMEMS-BAL-PUM-003-011. pdf (last access: 30 October 2019), 2019. a, b, c, d.

Mcdougall, T.J., and Barker, P.M. (2011). Getting started with TEOS-10 and the Gibbs Seawater (GSW) oceanographic toolbox. Scor/Iapso WG 127, 1-28.

Seifert, T., Tauber, F., and Kayser, B. (Year). "A high resolution spherical grid topography of the Baltic Sea–revised edition", in: Proceedings of the Baltic Sea Science Congress, Stockholm), 25-29.

Siiriä, S., Roiha, P., Tuomi, L., Purokoski, T., Haavisto, N., and Alenius, P. (2019). Applying area-locked, shallow water Argo floats in Baltic Sea monitoring. Journal of Operational Oceanography 12, 58-72.