

## Review of MS „Salinity dynamics of the Baltic Sea“ by Andreas Lehmann et al.

Submitted to Earth System Dynamics esd-2021-15

### General comments

The MS presents an interesting review of recent advances in Baltic Sea physical oceanography, from the viewpoint how different physical processes affect the variability of salinity. The review goes beyond the traditional focus on Major Baltic Inflows and their reflections in different deep basins, up to the Gotland Deep. The MS considers also salinity variations and key processes behind them in the more river-influenced sub-basins (Gulf of Finland, Gulf of Riga, Gulf of Bothnia, lagoons), variations in mean salinity, and specific features like effect of salinity-dependent temperature of minimum density. Regarding external influences, recent findings of atmospheric forcing and of terrestrial freshwater flux are reviewed. Response of salinity depends on the circulation and stratification that are analyzed as well. Possible impact of global sea level rise on Baltic salinity is discussed. Finally, Baltic-specific effects of varying salinity on marine ecosystem (lateral advection of deep oxygen-rich water, salinity-dependent cod spawning volume and other fisheries issues) are considered.

The MS refers to the earlier studies within two phases of the Assessment of Climate Change for the Baltic Sea Basin (BACC I and BACC II) and some other review publications. As a good start for the updated review, earlier findings concerning salinity dynamics have been summarized in a well-readable compact form. The MS contributes to the Baltic Earth program activity of Assessment Reports (BEAR) summarizing the studies conducted around the Baltic Earth strategic research challenge under the same name as the title of MS.

The MS is comprehensive and well written. It could be endorsed for publication with some technical corrections only. Still I give below some specific comments for consideration by the authors, suggesting how the MS might be improved.

### Specific comments on sub-chapters

Well-written sub-chapter 3. Atmospheric forcing driving the salinity dynamics of the Baltic Sea contains an ambiguity regarding LVCs and MBIs. They are treated here in combination (LVCs/MBIs), earlier they have been mentioned separately. Their detailed explanation comes later in sub-chapter 4.1, but until that, readers (especially students) are left without any short guidance what they have in common and what are the differences. Even a forward citation to 4.1 could help.

If said the above, I found that 4.1. Large Volume Changes and Major Baltic Inflows lacks condensed explanations for the recently introduced terms like revised MBI and LVC in reference to traditional MBI. I think the wider marine research community could be interested to read such information in the review paper.

Lines 199-201 contain the statement “There are also smaller inflows of barotropic origin. These occur during all seasons having a low variability between the years. Such inflows bring about 30 % of the entire salt transport to the Baltic Sea”. It could be interesting to know on what depth levels the waters from smaller inflows occur and how much the earlier findings agree with the more recent results. For example, Meier and Kauker (2003) and Meier (2005) estimated that east from the Gotland transport of more saline waters incoming from the Bornholm Basin is concentrated on about 100 m depth, just below the halocline but clearly above the bottom layers.

In 4.2. The cold intermediate layer there is a statement “colder and slightly saltier water, which has its origin from the upper layer of the Bornholm Basin, advects to the east and forms the core of the CIL”(L229-230). To my knowledge, Bornholm basin as the origin of CIL (without specifying the region) is an interesting hypothesis and should be presented in a milder form, like “It has been proposed...”. For example, CIL is formed also in the Gulf of Finland, about 1000 km away from the Bornholm Basin. It is not easy to understand, how this water is directly advected from the remote area.

6.1. Development of the mean salinity. The approach of volume-average salinity is an appropriate indicator for ongoing and projected changes. It might be reminded for the wider marine research audience, how much of the volume and area fraction cover the deep quasi-stagnant regions with depth more than 150 m, which are quite often put on the focus in the point measurements.

6.2.1. The specific role of precipitation and river runoff. In the nice overview, surface salinity response to seasonal maximum of river discharge during spring could be outlined as well. For example, lines 370-372 say about the Gulf of Finland “Salinity maximum/minimum usually occurs in the deep/surface layer in summer, when the seasonal thermocline restricts vertical mixing, and westerly winds are not that dominant.” Seasonal course of freshwater supply is ignored in this discussion.

Climate change causes among other effects also change in timing of floods and maximum river flows (Blöschl et al., 2017). It could be interesting to find a discussion how it might affect the salinity dynamics and related ecosystem response of the Baltic Sea. Earlier in the MS there are already references on stratifying effects of the “juvenile freshwater” in the Baltic Proper by Eilola and Stigebrandt (1998) and in the Gulf of Riga by Stipa et al. (1999), Liblik et al. (2017) and Skudra and Lips, (2017). Seasonal freshwater fluxes in the Baltic have been evaluated by Hordoir and Meier (2010).

7. The impact of salinity dynamics on the environmental conditions of the marine ecosystem. Presently this sub-chapter considers mainly the issues of ecological dynamics of deep-water, like deep oxygen deficiency and cod spawning volume. “Horohalinicum” critical salinity range of 5-7 g kg<sup>-1</sup> that separates the freshwater and marine species population areas (Vuorinen, 2015), could be iterated as well in this sub-chapter.

## **Technical remarks**

Line 32: Abbreviation BACC is introduced without explanation

Line 36: Abbreviation MBI is introduced without explanation

L50: The sentence “Despite this long research history, there are still gaps in our knowledge of salinity changes, both in space and time” could be reformulated. There will always be knowledge gaps; when some gaps get reasonably clear then other gaps will emerge.

L87: Instead of “more extensive” perhaps “larger”.

L89: “lack of inflows” needs refinement, perhaps “lack of inflows reaching the deepest layers”.

L91-94: “However, despite the abrupt changes in salinity, there was no clear trend for the vertical mean salinity” could need refinement as well. Is it “abrupt changes in deep salinity”. What is the “vertical mean salinity”? If it is total salt amount in a basin divided by the volume of the basin, then it could be named “mean salinity over basin”.

L98: “there should be firstly winds from the east, and after such a period,” it could be nice to read about duration and speed of easterly winds, required for MBI.

L105: “Summer inflows inject higher saline water with higher temperatures and low oxygen content into the halocline” needs refinement. There are occasionally larger baroclinic inflows that reach the bottom layer of the Gotland Deep, bringing warm and low-oxygen water. See <https://helcom.fi/wp-content/uploads/2020/07/BSEFS-Water-exchange-between-the-Baltic-Sea-and-the-North-Sea-and-conditions-in-the-deep-basins-2017.pdf>

L171: “A critical study objective is the transition area”, I think an area is object not objective.

L204-206: “Holtermann et al. (2017) investigated the dynamics of the deep waters and vertical mixing in the central part of the Baltic Sea while Major Baltic Inflows took place; thus, providing new information on dense bottom gravity currents on their way to the deep central Baltic Sea and associated turbulent mixing.”: it could be interesting to read (at least with a few words) what is the essence of the obtained new information.

L207: “Liblik et al. (2018) studied the impact of MBIs downstream from the eastern Gotland Basin to the Gulf of Finland.”: also, what are the main results.

L360: Start of the sentence is not clear.

L391: “The Gulf of Bothnia is mainly separated from the northern Baltic Proper by sills and archipelagos”, why it is separated only mainly, what are then non-main separations? Perhaps the Gulf of Bothnia is connected to the northern Baltic Proper by ...

L520: “Environmental interaction between fish/larvae and salinity dynamics”, interaction is not correct.

Fig. 2. Subdivision 28 (SD 28) must be defined with bounds here and on later figures.

Fig. 4. SD 25 must be defined with bounds.

## References

- Blöschl, G., Hall, J., Parajka, J., Perdigão, R.A., Merz, B., Arheimer, B., Aronica, G.T., Bilibashi, A., Bonacci, O., Borga, M. and Čanjevac, I., 2017. Changing climate shifts timing of European floods. *Science*, 357(6351), pp.588-590.
- Hordoir, R. and Meier, H.M., 2010. Freshwater fluxes in the Baltic Sea: A model study. *Journal of Geophysical Research: Oceans*, 115(C8).
- Meier, H.M., 2005. Modeling the age of Baltic Seawater masses: quantification and steady state sensitivity experiments. *Journal of Geophysical Research: Oceans*, 110(C2).

July 18, 2021