Supplementary material

Dominant hydro-climatic drivers of water temperature, salinity and flow variability for the large-scale system of Baltic coastal wetlands

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Part A: Model validation for the FVCOM simulations

The Baltic Sea model is constructed using FVCOM (Finite-Volume, primitive equation Community Ocean Model). The model is based on the primitive equations of momentum to simulate free-surface water motion and uses the Mellor and Yamada level 2.5 (MY-2.5) turbulent closure model [1] to calculate turbulence [2]. The model uses triangular mesh in the horizontal (Figure S1) and sigma layers in the vertical dimension, which can better fit the complicated coastlines and bathymetry. The mesh has a horizontal resolution of 10km, divided into 20 uniform sigma layers in the vertical dimension.

Forcing data, including wind and heat flux (short wave heat flux and net heat flux) from the atmosphere, river runoff from the landscape, water elevation and salt influx from the open sea boundary, are used to drive the model. Scalars, such as depth and time series data of heat flux, are interpolated on to each node of the triangular grid, while vector data such as wind are interpolated on to each centroid of the triangular grid. The Baltic Sea is a shallow water body with an average depth of around 54 meters. However, it's bathymetry varies significantly and changes sharply from several meters along the coastlines to more than 400 meters at the deepest sections. In our model, bathymetry is smoothed with 4 iterations such that nearshore nodes with depth smaller than 10 m are smoothed to be 10 m; this is done to avoid divergence and computational artefacts, for instance, unrealistic overheating of the shallower sections of the sea. The open boundary is set at Skanör (blue boundary line in main Figure 1a), for which time series data are available for water elevation at Skanör Station. Time series data of water salinity and temperature at different depths from Station BY1 are used for the open boundary.

The validation of the model is done with the year 2005 as it is hydrologically a normal year according to HELCOM total flux into the Baltic Sea. The 13 largest rivers are taken into account, based on the data availability and major discharge contributions of these rivers of that year, which are consistency with the long-term observations [3,4]. Those discharges account for around 65% of total river runoff into the present Baltic Sea simulation domain.

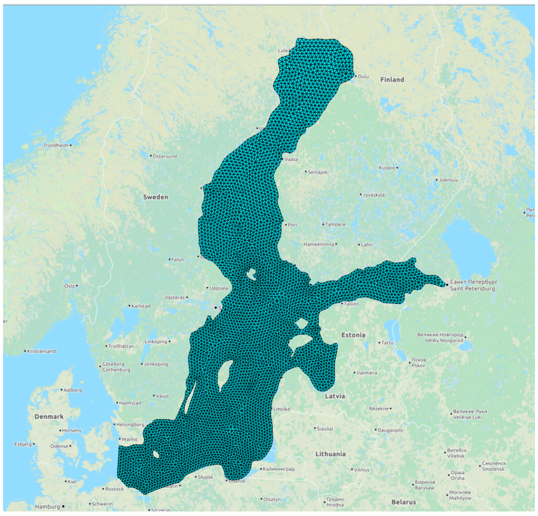

Figure S1. Triangular mesh of Baltic Sea

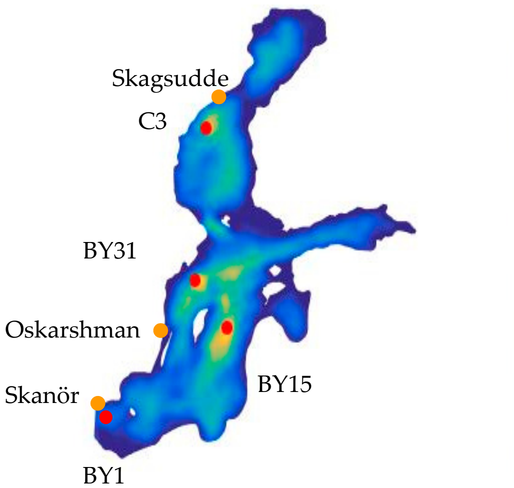

Figure S2. Bathymetry and observation stations in the Baltic Sea

The model is validated against the observed data of temperature and salinity over time and depth, and water level time series, and further compared with flow field results from previous research [5,6]. Simulation results are compared with the observed data of temperature and salinity at stations C3, By31 and By15 shown in Figure S2. Comparison at By15 station is shown up to the depth of 300 meters, which is the depth in the model after interpolation with the implemented horizontal resolution and bathymetry smoothing.

The validation results of water salinity are shown in Figure S3. As shown in the figure, the simulated salinity in depth and time series are in good accordance with observed data at three stations. It shows that the model succeeds in simulating the stratification of the sea water, which is an important dynamic character of saline water. The decrease pattern from the open boundary into the inner sea is also captured, as shown by the salinity of the three stations in different locations.

Figure S4 shows the simulated water temperature in depth and time series in comparison with observed data, which are in good accordance. The simulation results show clear seasonal patterns of the sea and successfully reproduce the important yearly thermal cycle.

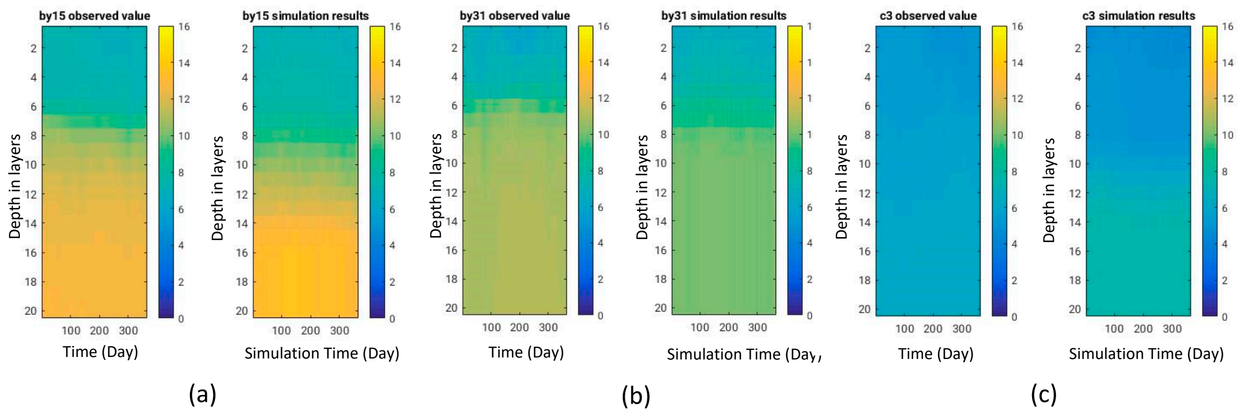

Figure S3. Comparison between the observed and simulated salinity profiles in time series. (a) Station By15. (b) Station By31. (c) Station C3.

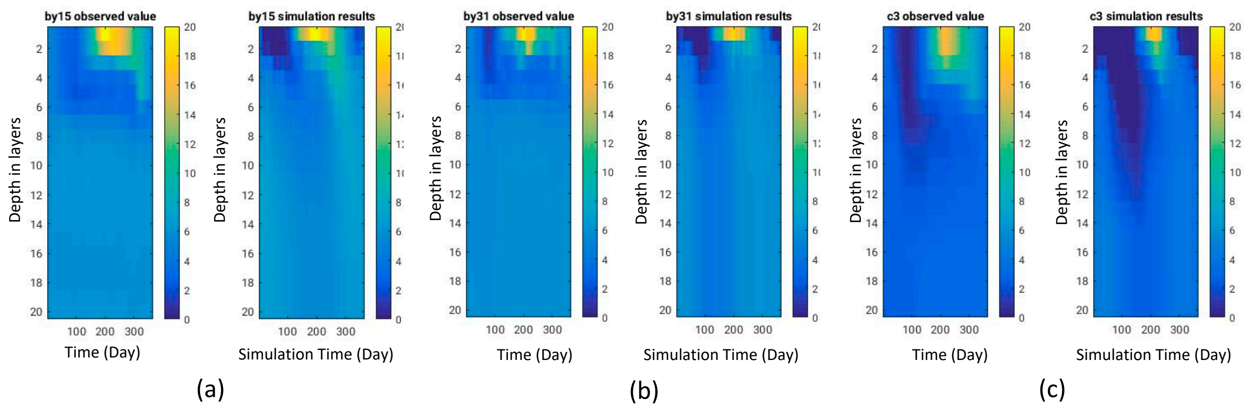

Figure S4. Comparison between the observed and simulated temperature profiles in time series. (a) Station By15. (b) Station By31. (c) Station C3.

Validation is also done against water level to ensure the water mass balance of the model. As shown in Figure S5, the simulated water levels at both the Oskarshamn station and the Skagsudde station (Figure S2) are in good accordance with the observed values, indicating that the water budget is well represented by the model.

Moreover, the yearly average flow field (Figure S6) is shown to have reproduced the flow field of Baltic Sea and captured the main currents when further compared with the simulation results from previous research of 10-year (1986–1995) averaged barotropic circulation by Lehmann et al. [5] and the annual mean transport for 1981 to 2004 by Meier [6]. The comparison demonstrates the ability of our model to simulate the dynamic process in the entire sea.

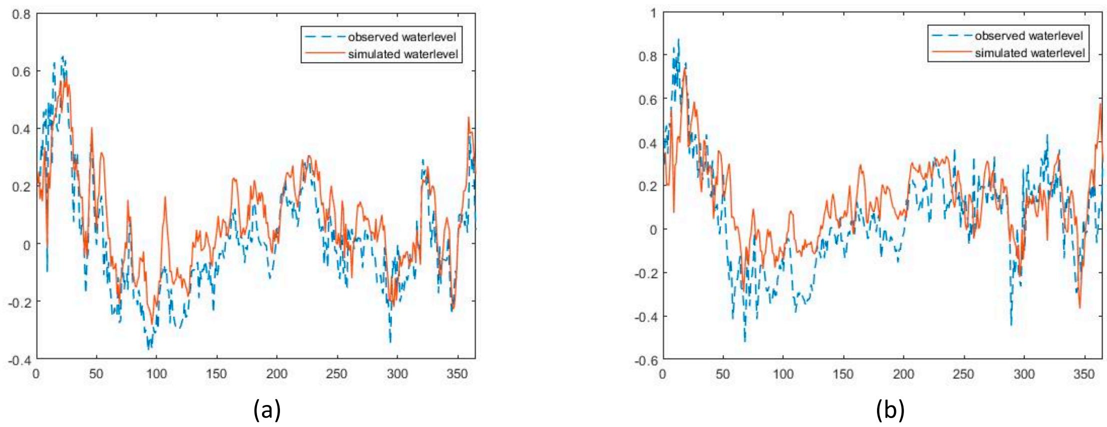

Figure S5. Comparison between the observed and simulated water level. (a) Station Oskarshamn. (b) Station Skagsudde.

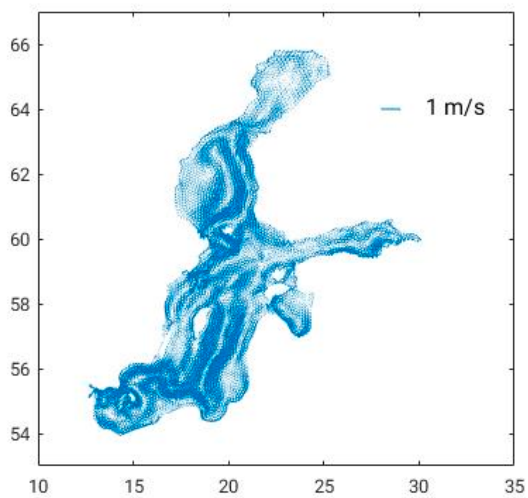

Figure S6. Simulation results of the vertical average flow field.

Part B: Hydro-climatic settings of the Baltic Sea model

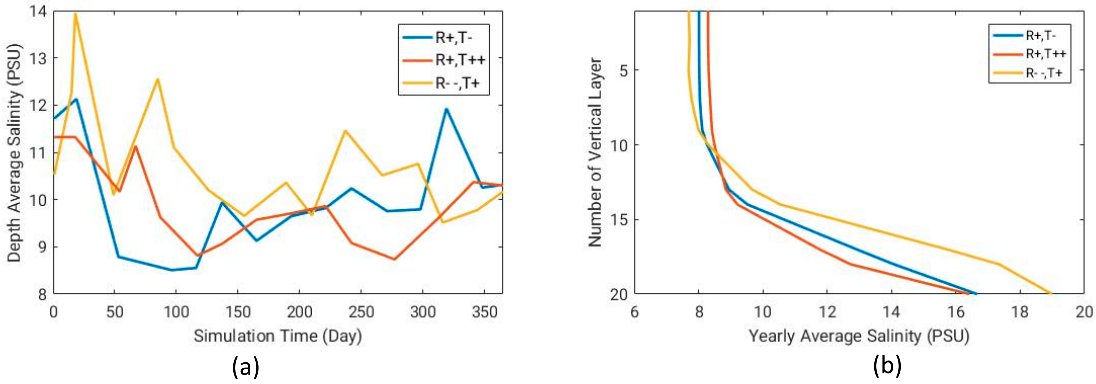

Figure S7. Salinity at the open boundary. (a) Vertically average salinity time series over the year. (b) Mean salinity profile for the simulation cases "R+,T-"; "R+,T++" and "R--,T+".

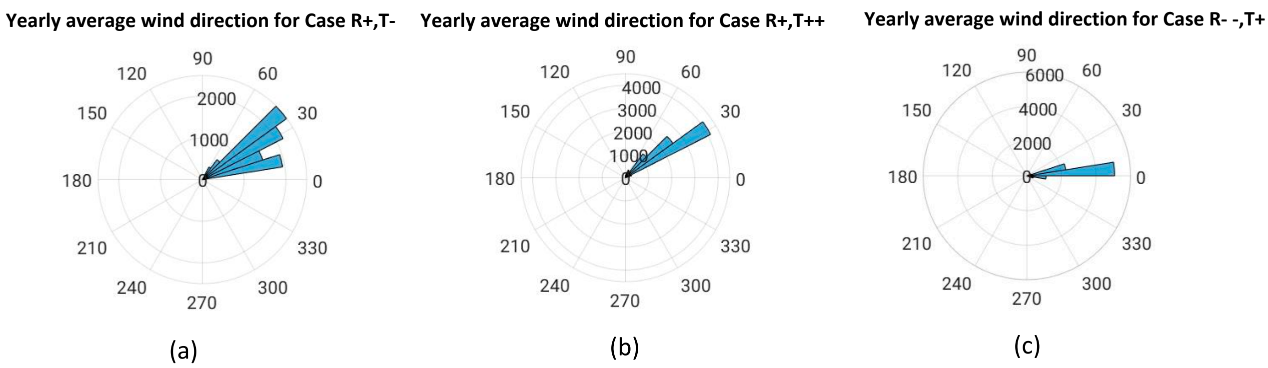

Figure S8. Yearly average wind direction for the simulation cases: (a) "R+,T-", (b) "R+,T++", (c) "R--,T+".

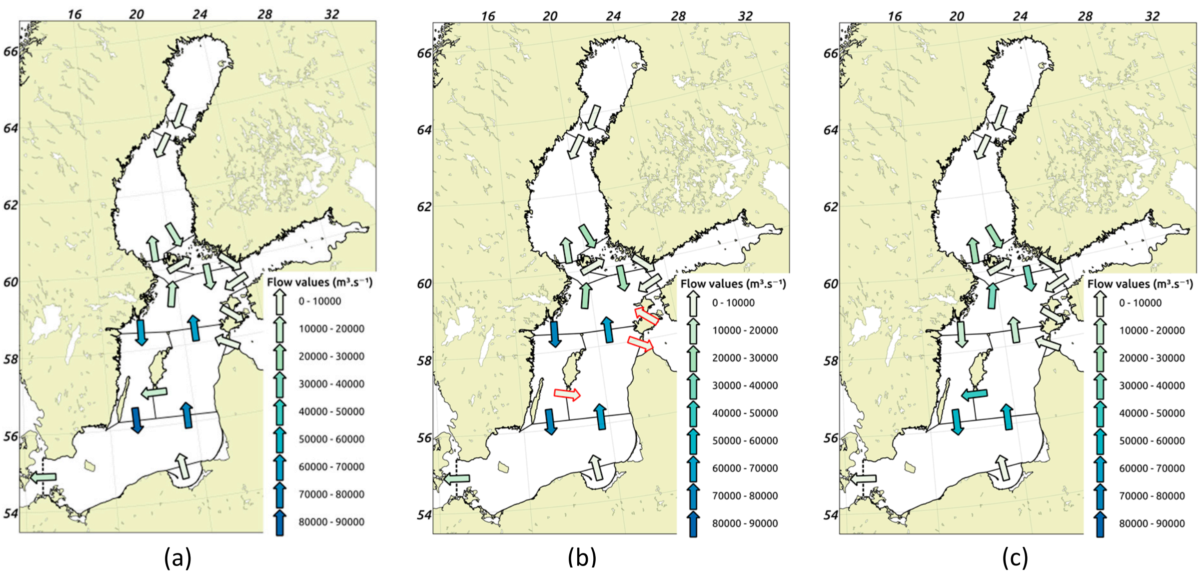

Figure S9. Yearly average flows between marine basins of the Baltic Sea at quasi-steady state (end of simulation period for each case) for the simulation cases: (a) "R+,T-", (b) "R+,T++", (c) "R--,T+".

References

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