Response of a two-layer estuary to freshwater inflow and wind: a case study of the Baltic Sea

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The Baltic Sea is one of the world's largest brackish-water sea areas, with large horizontal and vertical salinity gradients. The average salinity amounts to about 7.4 ‰ (Meier and Kauker, 2003a). A large net freshwater supply mainly from river discharge of about 15,000 to 16,000 $m^3 s^{-1}$ in combination with the hampered water exchange through the Danish Straits causes this low salinity. Decadal salinity variations are of the order of 1 ‰, and no long-term trend is detectable during 1902-1998 (Fig. 1).

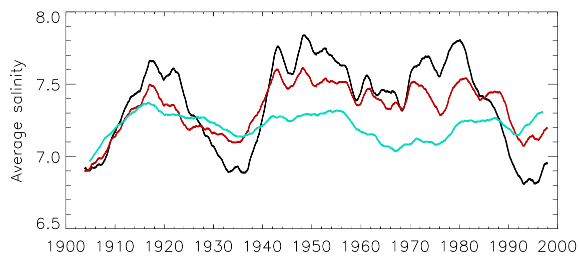

Figure 1: *2-year running mean simulated salinity in the Baltic Sea (in ‰): reference run (black), sensitivity experiment with climatological monthly mean freshwater inflow (red), and sensitivity experiment with climatological monthly mean freshwater inflow and 4-year high-pass-filtered sea level pressure and associated surface winds (blue).*

Hindcast simulations for the period 1902-1998 have been performed using the 3-D coupled ice-ocean model RCO for the Baltic Sea (Meier and Faxén, 2002; Meier et al., 2003). Daily sea level observations at the open boundary in Kattegat, monthly basin-wide discharge data, and reconstructed atmospheric surface data have been used to force RCO. The reconstruction utilizes a statistical model to calculate daily sea level pressure and monthly surface air temperature, dew-point temperature, precipitation, and cloud cover fields (Kauker and Meier, 2003). Sensitivity experiments have been performed to explore the impact of the natural fresh- and saltwater inflow variability on the salinity of the Baltic Sea (Meier and Kauker, 2003a). The decadal variability of the average salinity is explained partly by decadal volume variations of the accumulated freshwater inflow from river runoff and net precipitation and partly by decadal variations of the large-scale sea level pressure over Scandinavia (Fig. 1). During the last century two exceptionally long stagnation periods are found, the 1920s to 1930s and the 1980s to 1990s. During these periods precipitation, runoff and westerly winds were stronger and salt transports into the Baltic were smaller than normal. As the response time scale on freshwater forcing of the Baltic Sea is about 35 years, seasonal and year-to-year changes of the freshwater inflow are too short to affect the average salinity significantly. We found that the impact of river regulation which changes the discharge seasonality is negligible.

As recent results of some regional climate models suggested a significant increase of precipitation in the Baltic catchment area due to anthropogenic climate change, the response of salinity in

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the Baltic Sea to changing freshwater inflow is investigated. Therefore, model simulations with modified river runoff and precipitation for the period 1902-1998 have been performed (Meier and Kauker, 2003b). Thereby, it is assumed that the Kattegat deepwater salinity of about 33 $^o/_{oo}$ will not change regardless of the changed freshwater supply. We found that even for a freshwater supply increased by 100% compared to the period 1902-1998 the Baltic Sea cannot be classified as a freshwater sea. A still pronounced halocline separates the upper and lower layer in the Baltic proper limiting the impact of direct wind mixing to the surface layer. A calculated phase diagram suggests that the relationship between freshwater supply and average salinity of the final steady-state is non-linear (Fig. 2). The results of RCO are in agreement with an analytical

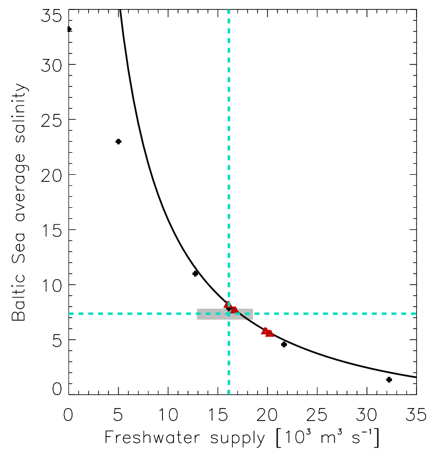

Figure 2: *Steady-state Baltic Sea average salinity as a function of the freshwater supply. The solid line shows analytical results of a steady-state Baltic Sea model. The plus signs denote steady-state RCO results for the period 1969-1998. The red triangles show scenario results based upon changes of freshwater inflow in regional climate models. In addition, the present climate (1902-1998) with a mean salinity of* $7.4\,^o/_{oo}$ *and a mean freshwater inflow of* $16,000\,m^3\,s^{-1}$ *is shown (blue dashed lines). Minimum and maximum values of the 4-year running means indicate the natural variability (shaded area).*

steady-state model which is supposed to work for freshwater changes smaller than 30 % (Meier and Kauker, 2003b). The latter model is applied in 4 scenarios for the average salinity of the Baltic Sea (Fig. 2). The largest increase of the freshwater inflow of 16 % is found in a B2 scenario utilizing data from ECHAM4/OPYC3 of the Max-Planck-Institute for Meteorology in Hamburg, Germany. The corresponding estimated average salinity is about 35 % lower than the present value. Such a large change is outside the range of natural variability of the past century.

References

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