Ocean Climate Variability over Recent Centuries Explored by Modelling the Baltic Sea

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Abstract

Natural variability and anthropogenic factors both contribute to changes in the ocean climate of the Baltic Sea. Observations over the past century indicate that changes in environmental settings and ocean climate have taken place, attracting considerable media attention and building public awareness of climate and environmental issues related to the Baltic Sea. These changes need to be seen in the context of a longer-term perspective to evaluate whether current conditions lie outside the expected boundaries of natural variability. Using a time-dependent, process-oriented, coupled basin model, this thesis examines the sensitivity of the Baltic Sea water and heat balance, investigating the variability of water temperature, ice cover, river runoff, salinity, and oxygen concentrations over long time scales, in particular, the past 500 years.

Models are influenced by initial conditions over a certain amount of time before the system has spun up and the lateral boundary conditions become dominant. Spin-up experiments demonstrate that the Baltic Sea operates on two time scales: a 33-year time scale for the water balance and a one-year time scale for the heat balance. These time scales are associated with the exchange of salt through a small cross section in the entrance area and with the flux of heat through a large surface area. It was also found that the maximum ice extent is strongly sensitive to the mean winter air temperature. A mean winter air temperature of –6°C produces full ice cover, while a mean temperature of +2°C produces minimal ice cover.

The vertically and horizontally averaged water temperatures display great variability, with both cold and warm periods occurring over the past 500 years. The warmest century was the twentieth century, but on decadal time scales, the 1730s, 1930s, and 1990s were equally warm. The coldest century was the nineteenth century, and the 1690s was the coldest decade since 1500. These temperature variations are also reflected in the maximum ice extent. The Baltic Sea has been at least partly ice covered every winter over the past 500 years, and the winter 2008 ice cover was the smallest ever observed.

River runoff from 1500 to 1995 was reconstructed using atmospheric circulation indices. It was found that river runoff to the northern Baltic Sea and the Gulf of Finland is sensitive to changes in temperature, wind, and the strength of cyclonic activity. Runoff to the southern Baltic Sea, on the other hand, is more sensitive to the strength of cyclonic activity and changes in temperature. Even though there is some variability on annual and decadal time scales, no statistically significant change in the total Baltic Sea river runoff has occurred since 1500.

Reconstructed river runoff was used as forcing to model the variability of the salinity and oxygen concentrations of the Baltic Sea. The salinity was found to have increased since 1500, peaking in the mid nineteenth century. Oxygen concentration is closely related to salinity; conditions were found to have been hypoxic once or twice per century until the mid-twentieth century, when the deep water became constantly hypoxic. This large change in oxygen conditions is probably due to the increase in nutrients released from anthropogenic sources, leading to the eutrophication of the Baltic Sea.

Key words: Baltic Sea, ocean climate, modelling, reconstruction, water temperature, sea ice, river runoff, salinity, oxygen concentration, long-term.

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