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ORIGINAL RESEARCH ARTICLE

Spatial and temporal variability of sea surface temperature in the Baltic Sea based on 32-years (1982—2013) of satellite data☆

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Summary Satellite measurements provide synoptic view of sea surface temperature (SST) and can be used to trace global and regional climate trends. In this study we have examined the multiyear trends and variability of the Baltic Sea SST using 32-years (1982—2013) of satellite data. Our results indicate that there is a statistically significant trend of increasing SST in the entire Baltic Sea, with values ranging from 0.03 to 0.06°C year^{-1}, depending on the location. SSTs averaged over the entire Baltic Sea increase at the rate of 0.05°C year^{-1}. Higher values of SST trend are generally present in the summer months, while trend is not statistically significant in the winter months. The seasonal cycle of SST in the Baltic Sea is characterized by well-defined winter and summer seasons. The average amplitude (16—18°C) of this cycle is significantly larger than in the North Sea waters located at the same latitudes as the Baltic Sea. The analyzed data set also highlights considerable interannual SST variability, which is coherent in different regions of the Baltic Sea and significantly correlated with interannual variability of the air temperature. SST variability in the Baltic Sea in winter can be linked to the North Atlantic Oscillation index.

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1. Introduction

The Baltic Sea (BS) is a semi-enclosed brackish sea located in Northern Europe (Fig. 1). The sea is quite shallow and has an average depth of only 56 m. The hydrography of the BS is strongly influenced by the fact that annually about 480 km^3 of freshwater are added to the Baltic Sea by river runoff and atmospheric input. The river runoff is about one order of magnitude larger than the net atmospheric flux (precipitation minus evaporation, Leppäranta and Myrberg, 2009). Significant influx of freshwater from rivers promotes a permanent two-layer salinity structure in the Baltic Sea with a persistent halocline and an estuarine-like water exchange with the North Sea. Water residence time in the Baltic Sea is about 30 years. Low salinity waters coming out of the Baltic Sea have significant influence on the hydrography of the North and Norwegian Seas (e.g., Leppäranta and Myrberg, 2009). Most of the time, however, there is only limited inflow of dense and salty water to the Baltic Sea from the North Sea (through the Danish Straits, Skagerrak, and Kattegat) because of shallow topography. The intensity of this inflow can sporadically, at irregular intervals of time, increase significantly. Such events, called the Major Inflows depend on weather patterns, which control the sea-level difference between the Baltic and the North Seas (e.g., Gustafsson and Andersson, 2001; Omstedt et al., 2004). The Major Inflows are difficult to predict, but have a vital influence on the state of the Baltic Sea (e.g., Leppäranta and Myrberg, 2009).

Because of its geographical location, the BS region has some arctic characteristics with a pronounced seasonality (Leppäranta and Myrberg, 2009). At irregular intervals of time this region is under the influence of continental or marine climate forcing. In general, the westerly winds dominate, but the atmospheric circulation has a strong annual cycle component, with more intense westerlies during the autumn and winter seasons. The mean near-surface air temperature in the Baltic Sea region is usually several degrees higher than in other geographical regions located at the same latitudes. The reason for this is that atmospheric circulation and the warm North Atlantic Current bring heat to Western Europe (e.g., Bigg, 1996). The transport of warm water masses in the North Atlantic has significant effects on climate even much further north, including the Arctic Ocean (e.g., Beszczynska-Möller et al., 2012; Holliday et al., 2008).

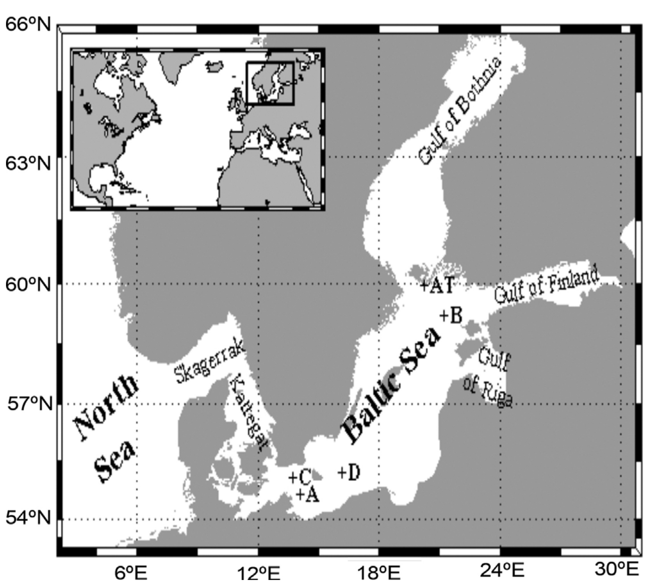

Figure 1 Map showing the geographical location of the Baltic Sea. The letters A and B indicate the positions of the time series data displayed in Fig. 3, the letters C and D show the positions of data sets in Fig. 4, and the AT is for the air temperature data presented in Figs. 7, 9, and 10.

A characteristic feature of the Baltic Sea hydrography is the seasonal surface layer with relatively warm and low salinity water embedded in the upper layer of water. This seasonal layer is formed in the spring due to seasonally increased freshwater input, ice and snow melt, and more efficient solar heating. Optical properties of this water layer are closely linked to river discharge of water with optically active components (dissolved and suspended matter, e.g., Babin et al., 2003; Stramska and Świrgoń, 2014). In deeper parts of the Baltic Sea a permanent halocline persists throughout a year at depth of about 40—80 m. Below it anoxia is common and interrupted only by the Major Inflows of the North Sea water (Leppäranta and Myrberg, 2009). The hydrography of the Baltic Sea is further complicated by the fact that the sea is partially covered by ice in winters. The extent of sea ice in the Baltic Sea varies from year to year. In average winters, the ice-covered region in March includes the Gulf of Bothnia, Gulf of Finland, Gulf of Riga, northern parts of the Baltic Proper, and shallow coastal waters, including those located in the southern part of the sea. In extremely cold winters almost all of the BS can freeze (Leppäranta and Myrberg, 2009). More details about the physical oceanography of the BS can be found in a recent review published by Omstedt et al. (2014).

Scientific efforts undertaken to understand past and present changes in the climate of the Baltic Sea region have been intensified in the past two decades. It has been shown that during the past century the increased frequency of both anticyclonic circulation and westerly winds has resulted in a warmer climate with reduced sea-ice cover. Significant increase in surface air temperatures in the Baltic Sea region has been also documented (e.g., BACC Author Team, 2008; Rutgersson et al., 2014).

In the present paper we have focused on satellite sea surface temperature (SST) data records covering 32-years (1 January, 1982 to 31 December, 2013). Our main goal is to analyze long-term SST trends and their regional and seasonal variations. In addition, our objective is to review characteristic features of the annual SST cycle and patterns of interannual variability. Sea surface temperature is an important oceanographic parameter, linked to many processes that occur in the upper ocean. For example, studies on primary productivity, exchange of energy with the atmosphere, climate change, ocean and weather modeling and forecasting require information about the SST. As a result, SST has been classified as one of the Essential Climate Variables that support the work of the UN Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC, 2007). The information about SST in the Baltic Sea gained through our analysis will contribute to improved understanding of the hydrography and climate trends in this region. Similar analyses of SST in the Baltic Sea published before have been based on significantly shorter time series. For example, Darecki et al. (2008) demonstrated good agreement between in situ and satellite derived SST in