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Comparing a 41-year model hindcast with decades of wave measurements from the Baltic Sea

Jan-Victor Björkqvist [a,*], Ingvar Lukas [b], Victor Alari [c], Gerbrant Ph. van Vledder [d], Sander Hulst [b], Heidi Pettersson [a], Arno Behrens [e], Aarne Männik [c,f,g]

[a] Finnish Meteorological Institute, Marine Research, P.O. Box 503, FI-00101 Helsinki, Finland
[b] BMT ARGOSS, Spacelab 45, Amersfoort, 3824 MR, The Netherlands
[c] Tallinn University of Technology, Department of Marine Systems, Akadeemia tee 15a, 12611, Tallinn, Estonia
[d] Delft University of Technology, P.O. Box 2048, 2600 GA, Delft, The Netherlands
[e] Helmholtz-Zentrum Geesthacht, Max-Planck Strasse 1, 21502 Geesthacht, Germany
[f] Estonian Environment Agency, Mustamäe tee 33, 10616 Tallinn, Estonia
[g] University of Tartu, Ülikooli 18, 50090 Tartu, Estonia

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ABSTRACT

We present ice-free and ice-included statistics for the Baltic Sea using a wave hindcast validated against data from 13 wave measurement sites. In the hindcast 84% of wave events with a significant wave height over 7 m occurred between November and January. The effect of the ice cover is largest in the Bay of Bothnia, where the mean significant wave height is reduced by 30% when the ice time is included in the statistics. The difference between these two statistics are less than 0.05 m below a latitude of 59.5°. The seasonal ice cover also causes measurement gaps by forcing an early recovery of the instruments. Including the time not captured by the wave buoy can affect the estimates for the significant wave height by roughly 20%. The impact below the 99th percentiles are still under 5%. The significant wave height is modelled accurately even close to the shore, but the highest peak periods are underestimated in a narrow bay. Sensitivity test show that this underestimation is most likely caused by an excessive refraction towards the shore. Reconsidering the role of the spatial resolution and the physical processes affecting the low-frequency waves is suggested as a possible solution.

1. Introduction

Knowledge of the sea state is essential for diverse engineering, oceanographic and climatological purposes. Model simulations covering multiple spatial and temporal scales are a common method for acquiring the spatio-temporal characteristics of wave parameters. The well known KNMI/ERA-40 global wave atlas (Sterl and Caires, 2005) satisfactorily describes the wave climate of the World Ocean and has also been used to calculate exceedance values for significant wave height. It is, however, not intended to resolve regional wave climates, such as the Baltic Sea climate.

The Baltic Sea is a semi-enclosed body of water ranging from 9°–30° E to 53°–66° N and it is characterised by a seasonal ice cover. It has several topographically and geographically defined sub-basins with a combined area of 435,000 km and a longest possible fetch of about 700 km (Fig. 1). While the mean water depth is only 55 m the maximum depth reaches 459 m. The Baltic Sea has heavy marine traffic (HELCOM, 2010), but wave data is also in demand for coastal planning purposes (e.g. Kahma et al., 2016).

The wave climate of the Baltic Sea has been assessed using both instrumental wave measurements (e.g. Kahma et al., 2003; Pettersson and Jönsson, 2005; Broman et al., 2006) and model hindcasts (e.g. Jönsson et al., 2003; Räämet and Soomere, 2010; Tuomi et al., 2011). Both approaches have their limitations. The measurements can be lacking in terms of spatial coverage, especially since almost no instrumental wave measurements exist from the central and eastern Baltic Proper. There are also no wave measurements from the Gulf of Riga, except for short measurement campaigns (Suursaar et al., 2012). In the eastern Baltic Sea region there are no continuous instrumental wave measurements either, but only visual estimates made by observers onshore (Soomere, 2013). These observations, however, do not represent open sea conditions and are lacking homogeneity in time. Only one long

* Corresponding author.
E-mail address: jan-victor.bjorkqvist@fmi.fi (J.-V. Björkqvist).

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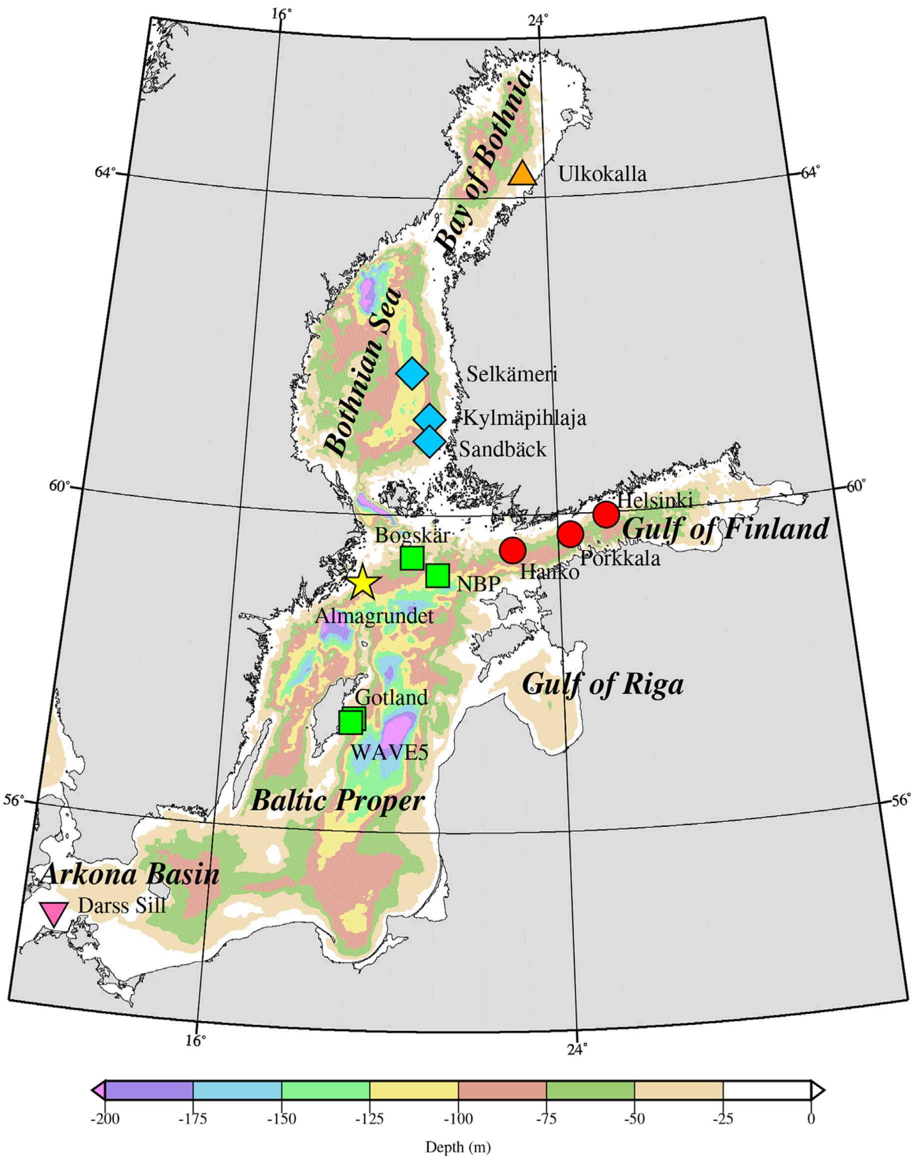

Fig. 1. The location of the available wave observations. The symbols indicate the grouping used in certain parts of the validation, whereas the colour scale describes the bathymetric data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

instrumental time series spanning several decades can be found for the southern Baltic Sea region (Soomere et al., 2012). The majority of instrumental observations in the Baltic Sea are made with wave buoys. Because of the seasonal ice-cover wave buoy measurements seldom cover the entire ice-free period, since the devices have to be removed in advance to avoid damage by freezing. This adds one more factor to take into account when considering the representability of measurements.

Model hindcasts are able to provide spatial information about the wave field, but the resolutions used in previous studies (∼6–11 km) might not replicate all its features with sufficient accuracy. Near shore conditions in particular are still a big challenge for wave models (Tuomi et al., 2014; Björkqvist et al., 2017). Not all hindcast studies include the ice-cover (Jönsson et al., 2003; Räämet and Soomere, 2010), while other studies have even used daily updated ice-charts (Tuomi et al., 2011). The quality of the wind forcing is also a limiting factor, and the resolution used in different studies has varied from 9 km (Tuomi et al., 2011) to 111 km (Räämet and Soomere, 2010). The hindcast lengths for the whole Baltic Sea ranges from 1 year (Jönsson et al., 2003) to 43 years (Cielikiewicz and Papliska-Swerpel, 2008). Recently, Siewert et al. (2015) hindcast the western Baltic Sea wave fields with a 52-year simulation.

The aim of this paper is to use a new high-resolution (∼1.85 km) simulation to present more accurate long-term (41 years) wave statistics for the Baltic Sea. Together with several extensive observational data sets from three different institutes, we are also able to study the similarities and differences between the wave statistics when estimating return values based on measured and modelled time series of different lengths. We will focus especially on the limitations a seasonally ice-covered sea impose on the measurements by quantifying the impact of the resulting measurement gaps. Caires and Sterl (2005) limited the ERA-40 data set so that it would always match the wave buoy measurements, thus not quantifying the statistics lost by the gaps. They also completely excluded years with gaps longer than one month. This approach is too strict in the Baltic Sea area, which has an ice cover that can last several months per year.

The paper is structured as follows. In Section 2 we introduce the wave model set-up, the atmospheric forcing and the wind and wave measurements used in this study. Section 3 presents an extensive validation of the wave model results covering all the different sub-basins of the Baltic Sea, except for the Gulf of Riga. The wave statistics from the model hindcast are presented in Section 4, while the difference in determining wave height and wave period exceedance values from both the measurements and the hindcast is explored in Section 5. Conclusions are formulated in Section 6.