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Decadal changes in the Baltic Sea wave heights

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ABSTRACT

The analysis of decadal changes to the average and extreme wave properties in the Baltic Sea is performed based on the wave hindcast for the entire Baltic Sea 1970–2007 using the wave model WAM and adjusted geostrophic winds under the assumption of no ice cover. The overall wave activity in the entire basin has limited variations over the 38 years of simulations. The local wave properties reveal strong decadal-scale signal in many parts of this water body. Its amplitude is up to 15% of the long-term average value of the significant wave height. The typical time interval between episodes of high or low annual average significant wave height is 10–12 years. The analogous interval between episodes of high and low 99%-iles of wave heights is about 5 years. Changes to the wave properties in different sea areas may be completely different in different decades. The overall maximum in the simulated annual mean significant wave height has drifted from an area between Gotland and Öland in the 1970s to the northern Baltic Proper at the turn of the millennium.

1. Introduction

The Baltic Sea (Leppäranta and Myrberg, 2009) is a challenging area for wave scientists. A combination of its relatively small size (that virtually excludes the presence of long-period remote swells), extremely complex geometry and high variability in the wind fields naturally leads to widespread variability in the wave fields in both time and space. The global wave data sets such as the KNMI/ERA-40 Wave Atlas (with a resolutions of $1.5° \times 1.5°$) (Sterl and Caires, 2005) give only very generalised picture of the Baltic Sea wave properties. The frequent presence of ice in its northern part not only complicates visual observations, instrumental measurements and numerical simulations but also renders several commonly used properties of wave statistics essentially meaningless (Kahma et al., 2003; Tuomi et al., 2011). Wave propagation over a number of relatively shallow areas often leads to refraction-driven wave energy concentration in some areas (Soomere, 2003, 2005). On top of that, specific wave generation conditions under so-called slanting fetch frequently occur in some sub-basins (Pettersson et al., 2010) and convergent storm wind patterns may give rise to uncommonly ordered wave patterns or unusually severe seas (Soomere et al., 2008) that both may affect wave statistics in certain regions.

In this light, it is not unexpected that the existing wave studies reflect a number of mismatches between trends and decadal changes to wave properties at selected sites. For example, the wave intensity (interpreted here as the average significant height over all available measurements over a certain time interval, in this paper usually over a year) rapidly increased at both eastern and western coasts of the northern Baltic Proper in the 1980s and 1990s and decreased radically since the mid-1990s (Broman et al., 2006; Zaitseva-Pärnaste et al., 2009). This quantity behaved completely differently at the Lithuanian coast where it had a deep minimum in the 1990s (Zaitseva-Pärnaste et al., 2011).

These variations were poorly represented in both the Baltic-wide numerical hindcasts (Soomere and Räämet, 2011b) and local wave climate reconstructions (Suursaar and Kullas, 2009). The most remarkable feature is that the temporal course of wave heights in the northern Baltic Sea generally does not follow a gradual increase in the (annual mean) wind speed in this basin (Räämet and Soomere, 2011). There is, however, increasing evidence that such mismatches may be an intrinsic part of rich spatio-temporal patterns in the Baltic Sea wave fields (Soomere and Räämet, 2011b), which are simply not resolved by the existing wave observation network.

The spatial distributions of long-term average wave properties are basically similar in all reconstructions. In essence, these distributions reflect the well-known anisotropy of the Baltic Sea wind fields: the highest waves generally occur in the south-western (SW) and north-eastern (NE) parts of the Baltic Proper and in the eastern Sea of Bothnia (Schmager et al., 2008). The overall maxima of wave heights, however, are located in quite different domains in simulations for different time intervals and/or using different wind information (Jönsson et al., 2003; Räämet and Soomere, 2010; Tuomi et al., 2011). This feature may reflect the rich pattern in formal trends in both average and extreme wave properties in the Baltic (Soomere and Räämet, 2011b). Although such trends may lead to shifts of the locations of certain maxima in time, they cannot continue forever and apparently mimic a certain phase of more complicated patterns of changes.

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The temporal course of the observed wave properties (Zaitseva-Pärnaste et al., 2009; 2011) and changes to the storminess (Bärring and von Storch, 2004) signify the presence of extensive decadal variations but very limited, if at all, long-term changes (BACC, 2008). There is evidence about an increase in the wind speed both in higher atmosphere and at the surface level in some regions of the Baltic Sea during the latter decades (Lehmann et al., 2011; Pryor and Barthelmie, 2003; Pryor et al., 2005). The overall wave intensity in the Baltic Sea (reconstructed using adjusted geostrophic winds) has very limited changes since the 1970s (Räämet and Soomere, 2011). A sensible conjecture, therefore, is that part of the above-described features reflect certain cyclic (eventually decadal-scale) variations in the wind and wave patterns.

In this paper, we make an attempt to reveal spatial patterns of changes to the basic wave properties in the Baltic Sea at a decadal scale. The analysis is based on the numerical hindcast for 1970–2007 (Räämet and Soomere, 2010) using adjusted geostrophic winds. We start with a description of the wave model, driving wind fields and general patterns of changes in Section 2. Spatial patterns of changes during single decades are examined in Section 3. Section 4 contains an analysis of resulting changes in the spatial maps of the average wave intensity and the threshold for the 1% of the highest waves.

2. Reconstruction of spatial patterns of changes to wave properties

We use the time series of wave properties computed for 38 years (1970–2007) for the entire Baltic Sea (Fig. 1) with the third-generation spectral wave model WAM (Komen et al., 1994). A regular rectangular grid (11 545 sea points) covers the entire Baltic Sea down to the Danish Straits (the wave energy flux through which was ignored) from 09°36′ to 30°18′E and from 53°57′ to 65°51′N with a resolution of about 3 × 3 nautical miles (Räämet and Soomere, 2010). The wave energy spectrum at each sea point was represented by 24 equally spaced directions. An extended frequency range up to about 2 Hz (wave periods down to 0.5 s) was implemented through using 42 frequencies with an increment of 1.1 to ensure realistic wave growth rates after calm situations (Soomere, 2005).

In general, the WAM model gives good results in the Baltic Sea if the model resolution is appropriate and the wind information is correct (Augustin, 2005; BACC, 2008; Schmager et al., 2008; Soomere et al., 2008; Tuomi et al., 2011; Weisse and von Storch, 2010). The spatial and directional resolution in use is generally thought to be acceptable in the Baltic Proper. It is questionable for smaller sub-basins such as the Gulf of Riga, Gulf of Finland or the Bay of Bothnia. The basic properties of reconstructed wave fields still adequately match the observed ones in the Gulf of Finland and the Darss Sill area (Soomere et al., 2010; Suursaar, 2010; Soomere et al., 2012).

The calculations use two major simplifications. First of all, we employ relatively low-resolution forcing derived from the geostrophic wind using a comparatively simple scheme while several other authors (Jönsson et al., 2003; Schmager et al., 2008; Tuomi et al., 2011) have used somewhat more detailed wind information.

The reliability of simulated changes in the wave properties crucially depends on whether or not the wind information is homogeneous in

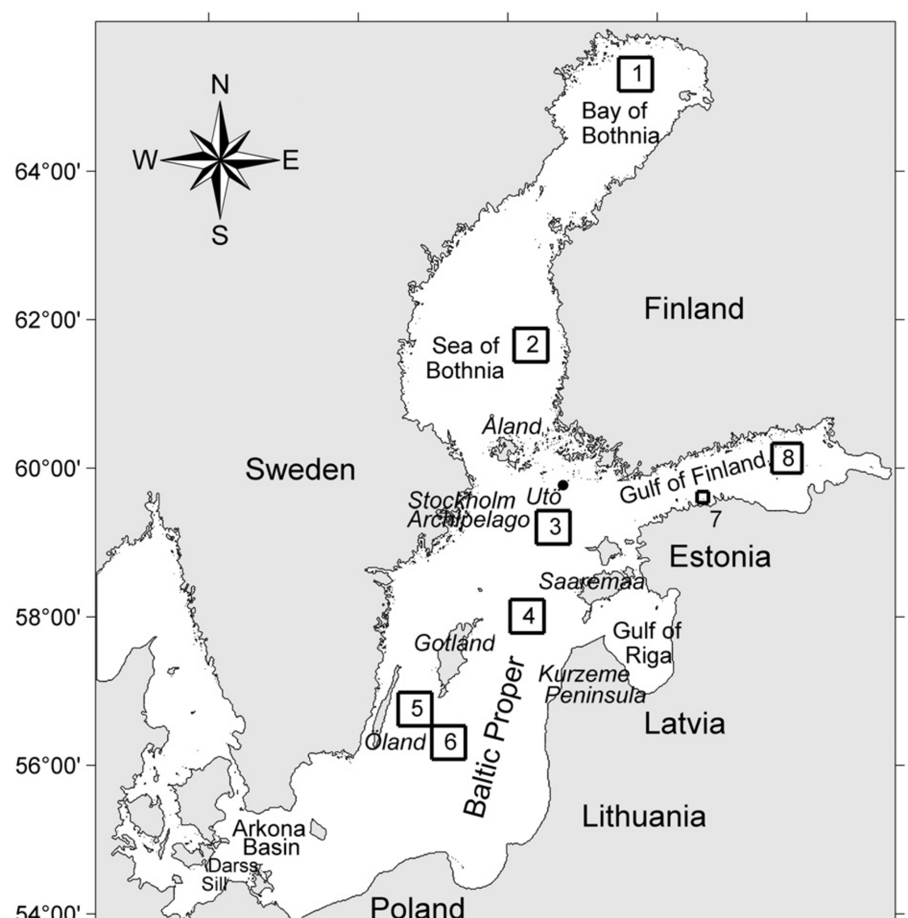

Fig. 1. Scheme of the Baltic Sea and its selected domains: 1 — northern Bay of Bothnia, 2 — eastern Sea of Bothnia, 3 — northern Baltic Proper, 4 — between Gotland and Saaremaa, 5 — between Gotland and Öland, 6 — south of Gotland, 7 — southern Gulf of Finland, 8 — north-eastern Gulf of Finland.

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