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Ocean Science Discussions

Interactive comment on "Long-term spatial variations in the Baltic Sea wave fields" *by* T. Soomere and A. Räämet

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It is our pleasure to thank the referees for their professional and friendly comments that highlighted some shortages in the presentation and served as a valuable help to improve the manuscript.

As suggested by both Referees, we have extended the discussion of the connection of the quality of the geostrophic wind fields (in terms of their temporal and spatial resolution) with the underestimation of the long-term significant wave height in our hindcast results. In order to maximally avoid distortions of the results owing to non-physical manipulations of the forcing data, we did not perform any interpolation in time. The wind properties were set constant during the relevant 3 or 6 h time intervals starting from the measurement instant (e.g., the 6 hour wind at 12:00 was considered as valid from

12:00 to 18:00). This approach does not affect the long-term statistics but may result in a delay of the properties of the modelled wave fields compared with their measured values. An important reason for doing so is to avoid the uncertainty connected with the interpolation of wind direction. The procedure of its spatial approximation has a clear physical interpretation and the relevant errors are explicit. On the contrary, temporal changes in the wind direction may have much more complicated spatio-temporal patterns in the Baltic Sea basin (Tomson and Hansen, 2000; Soomere, 2001).

A major theme raised by Referee #1 is the potential impact of ice cover on the results of the hindcast. As this topic is especially important for many regions of the Baltic Sea, we have included the relevant discussion into the last section of the manuscript.

The frequent presence of sea ice is a major challenge for the adequate representation of the Baltic Sea wave fields. There is no commonly accepted way of presenting wave climate for seasonally ice-covered seas (Kahma et al., 2003) and several characteristics of wave climate are simply meaningless in such conditions. Our basic wish is to identify the changes to the wave field in generally accepted terms such as the average significant wave height and the highest percentiles of the wave height. These characteristics are not unambiguous (and even confusing in some context, see Kahma et al., 2003) for seasonally ice-covered areas. To understand the nature and driving forces behind any (recorded or modelled) changes, it is important to quantify, if possible, the impact of each factor shaping the Baltic Sea wave fields. Our paper presents an attempt to specify the role of wind fields in the formation of spatial patterns of changes to waves for the entire Baltic Sea whereas the frequent presence of sea ice is ignored in the wave model.

The use of this approach implies that the established patterns of changes may be unreal in areas that freeze during a large part of the year (such as the Bothnian Bay). The key distortion to instantaneous wave properties in ice-free regions of partially ice-covered basins stems from the potential decrease in the fetch length and from an associated overestimation of the wave heights and periods. Given the predominant wind direction from the SW in the northern Baltic Proper and the typical presence of sea ice in this area, it is very unlikely that the related distortions would qualitatively affect the established patterns in most of the Baltic Proper.

In general, problems connected with wave climate in seasonally ice-covered seas have received very little consideration in international scientific literature but their comprehensive coverage is far beyond the scope of our paper. Ice cover affects wave properties in different ways, not only by completely sheltering some regions from wave energy or by decreasing the effective fetch but also by drastic changes of surface fluxes. For example, in many cases the modelled wind speed may have lower values over the ice covered sea areas than it would have over ice-free sea and changes to wave properties and ice coverage are interrelated in an extremely complicated way. For this reason we have avoided discussion of the effect of ice cover on our results and only brought to the reader the flavour of some potential consequences to coastal processes from joint changes in wave and ice conditions.

The predomination of SW winds in the northern Baltic Proper basically suggests that a large part of the roughest wave conditions are expected to occur in the north-eastern region of this water body. This does not necessarily mean that the maxima of wave periods over all wave conditions would occur in the same place. The probable reason for their locations in the southern Baltic Proper is that this region has a long fetch in several directions (especially in the western and N-NW directions) and frequently receives low-frequency swells generated in remote sea areas. We have added the relevant explanation into the text.

Statistical significance of the changes was calculated in our research in terms of the significance of the correlation of the set of annual values of significant wave height with the relevant trendline. Therefore, a high significance indicates that the time series of the annual wave activity can be represented well by a linear model; equivalently, the variability of the annual mean values is in some sense small compared to the overall course of wave properties. Moreover, even a very high significance in this

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framework does not necessarily indicate a nonzero slope of the trendline. In other words, the existence of a statistically significant increase or decrease in the wave height still remains unclear. An extension of our work towards establishing whether or not the slopes of trendlines are (non)zero is feasible by means of using somewhat more elaborated analysis of the simulated values.

The match of the areas that show high values of the statistical significance and the domains that exhibit substantial positive and negative changes in the wave heights is remarkable indeed. We emphasize this point more clearly in the revised manuscript. As we have no sensible explanation for the reasons of such a match, we did not expand the relevant discussion. This match, however, suggests that the wave regime in these areas has very likely experienced clear changes over the simulation interval.

According to suggestions of Referee #2, we emphasize that the nested version of the model was used in different studies. Also, the remark concerning the applicability of the model in relatively shallow areas of the Baltic Sea is expanded and a reference to a more recent validation of the WAM-based wave forecast (Tuomi, 2008) is added. The basic reason why the model works well in quite shallow areas of the Baltic Sea is that typical wave periods are short. As only very few near-coastal grid points in semi-sheltered bays have the model water depth below 5 m and wave heights >4 m occur with a frequency of less than 1% even on the open sea (Kahma et al., 2003), the option of depth-induced breaking is not used in this study.

We admit that our choice of wind forcing ignores several important factors shaping the wind properties in such a complex basin as the Baltic Sea. Probably the most important distortion of the average properties of the wave statistics stems from ignoring the air stability conditions. This choice is usually not suitable for the analysis of wave properties in single storms that may exhibit quite strong ageostrophic features. We included a discussion of these aspects and a relevant reference (Niros et al., 2002) into Section 3. We definitely agree with Referee #2 that a more detailed analysis, although desirable in order to check the validity of our results, is beyond the scope of the current paper. For easier reading, we also added a short definition of geostrophic winds.

The text has been adjusted to avoid possible ambiguities. For example, it is clearly stated now that in Section 3 the spatial variations of average wave periods are discussed while in Section 4 the long-term changes to wave periods are analysed.

We chose the total change in the wave height over the simulation interval as the basic quantity simply because this dimensional quantity can be easily compared with the values of the long-term wave height. This quantity is equivalent to the slope of the relevant trendline (that is also widely used in climatological studies and frequently expressed in terms of the change in the wave height over a decade). We agree that the variability of the time series of the annual mean values with respect to the trendline is only implicitly discussed in terms of statistical significance of the changes and that a further discussion of this variability is highly desirable in order to further clarify the role of the detected changes. As our wish is to keep the major message of the paper as transparent as possible, we still chose not to considerably expand the manuscript in this direction.

We also highly appreciate minor comments made by both Referees and a discussion of further research by Referee #2. The only item where we have not much to add concerns the established spatial distribution of the regions of steep decrease and an equally steep increase in wave heights in open sea areas. This result is highly intriguing for the authors. We are looking forward to further research into wave modelling towards clarifying its reliability, persistence and background reasons.

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