Wave hindcast and climate change scenario simulations for the North Sea and the Baltic Sea

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1. Introduction

An appropriate planning of coastal and offshore applications needs the knowledge of various aspects of the wave climate. Statistics of past, present and future wave climate are essential to support the design process of several marine tasks. To ensure a good skill of this wave information long and homogeneous data sets are needed for past conditions and a large ensemble of future wave realizations is necessary to assess the range and uncertainty of possible future wave climate.

To fulfill the issues of long consistent time series either observations or model simulations based on reanalyses can be used. Observations which are scare in time often cover only short periods or are not always homogeneous. Simulations have the advantage of being highly resolved in time and space but are limited to the availability of global reanalysis data and the reliability of the used models. The investigation of future wave climate conditions is limited to model simulations and has to rely on the quality of the involved models. A large ensemble including various models (global and regional atmosphere and wave models) and their combinations is needed to account for possible model uncertainties. Further, several emission scenarios accounting for possible future global economy and realizations with different initial conditions or perturbations of the model physics are important to take into account the internal climate variability.

Here, a hindcast simulation based on a global reanalysis and a set of climate change scenarios for future wave conditions are presented for the North Sea and the Baltic Sea. Beside these wave datasets, similar model data from regional atmosphere, ocean and water level simulations are stored in a database referred to as *coastDat* and are available online (more information at http://www.coastdat.de).

In the following a brief description of the principal model and experimental setup is given and a few results for past and possible future wave conditions are shown. Finally, some applications of the wave data concerning coastal and offshore issues are shortly metioned. A more detailed description of meteo-marine simulations and their applications in the North Sea are given in Weisse et al. (2009).

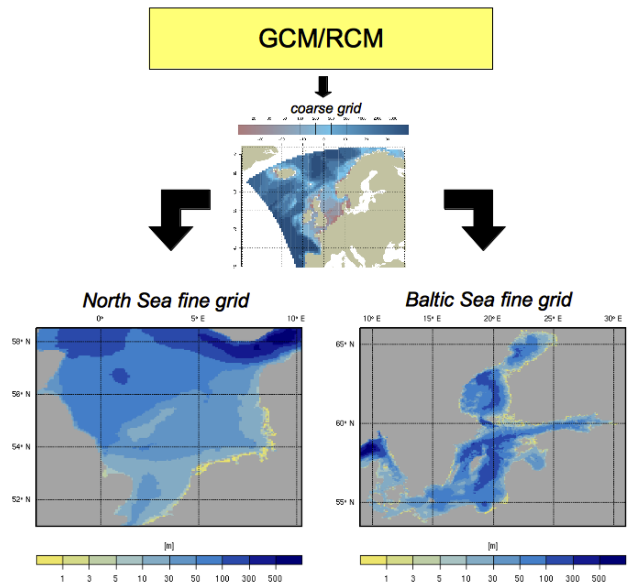

Fig. 1. Principle model chain used in the presented experiments. Model domain and topography of the coarse grid and the fine grid for the North Sea and the Baltic Sea.

2. Model and experimental setup

For all experiments the third generation wave model WAM (WAMDI-Group 1988) is used in a nested version. The coarse grid simulations (approx. 50 km x 50 km) covering the Northeast Atlantic allocate the wave spectra at the boundaries of the fine grid simulations for the North Sea and the Baltic Sea with a spatial resolution of about 5 km x 5 km (Figure 1). All wave experiments are forced with surface wind fields generated by a combination of a general circulation model (GCM) and a regional atmosphere model (RCM). For the hindcast simulation the National Centers for Environmental Prediction - National Center for Atmosphere Research (NCEP-NCAR) global reanaly-

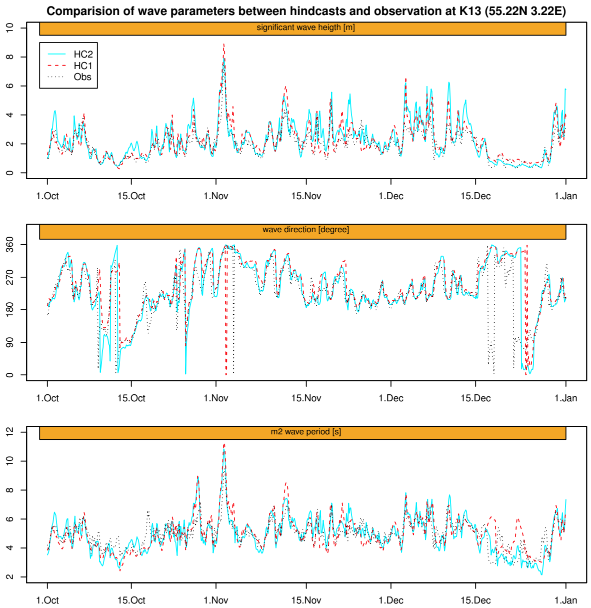

FIG. 2. Comparison of significant wave height (top), wave direction (middle) and m2-wave period (bottom) for 3-hourly data between HC2 (cyan), HC1 (red) and observations (black) for a period from the 1st of October to the 31st of December, 2006.

sis (Kalnay and Coauthors 1996) is taken as input for a spectral nudging RCM simulation with the COSMO-CLM regional model to generate highly resolved surface wind fields (Geyer 2013). The simulation period range from 1948 until present. The future climate change wave simulations presented here use the wind fields from a combination of the global model ECHAM5/MPI-OM (Röckner et al. 2003) and the regional model COSMO-CLM (Hollweg et al. 2008) with two different emission scenarios (A1B and B1) and two initial conditions from the global simulations. These transient wave simulations consider observed greenhouse gas concentration from 1960 to 2000 and concentrations based on the mentioned emission scenarios from 2001 to 2100.

3. Hindcast simulation

Compared to the hindcast simulation from Weisse and Günther (2007) (hereafter HC1) the new simulation (hereafter HC2) starts earlier (1948) and will continue in time as new regionalized wind fields are available. Additionally, HC1 covers the whole North Sea instead of the North Sea south of 56° N in HC1. This allows for an analysis of the wave climate in the whole North Sea over a longer period (more than 60 years). Before using the data extensively, the HC2 data are compared with data from HC1 and observations.

Figure 2 shows a comparison for the significant wave height, wave direction and m2-period of the two hindcasts with observations at the platform K13 (53.22°N, 3.22°E) in the southern North Sea for a 3-month-period in 2006. Note a severe storm event with wave heights of more than 8m at the 1st of November. There is a good agreement between both hindcast simulations and the observations during this event. However, for a period at the first half of December both hindcasts overestimate the wave height of the observation, whereas the simulated wave direction and wave period are closer to the observations. Beside these differences the comparison show an overall good agreement between the observations and the two hindcast simulations. This gives confidence that the new hindcast simulation will be as useful as HC1 to analyze the wave climate over the last 60 years in the North Sea. However, before using the data for other applications (see section 5) a more detailed comparison will be done.

4. Climate change simulations

For estimating future climate change more than one realization of the future climate is needed to incorporate various sources of uncertainty. This uncertainty originates from unknown future emissions, models and internal variability of the climate system. Transient regional wave simulations for the North Sea and the Baltic Sea based on two emission scenarios and two initial conditions with one model combination are investigated, ending up with four realizations of the future climate and two reference climates according to the two initial conditions of the GCM. Here, the focus is on the common changes in the wave climate of the four realizations towards the end of the 21st century (2071-2100) compared to the period 1961-1990. It is assumed that all four realizations are equally likely and instead of an ensemble mean of the four realizations the common change signal is presented. The common change signal shows the lowest common change in all four realizations and thus gives some confidence in the range of future climate change.

However, this comparison can only be a part of a wider comparison with already existing future wave simulations (e.g. Debernard et al. (2002), Debernard and Røed (2008), Grabemann and Weisse (2008), Lowe et al. (2009), Winter de et al. (2012)) and with upcoming simulations. This next step could be realized in a more systematic way by many scientific groups, as suggested by the COWCLIP initiative (Hemer et al. (2012), Hemer et al. (2013)).

a. North Sea

The North Sea is a semi-enclosed sea open in the north to the Northeast Atlantic. Therefore the wave climate is not only influenced by waves generated within the North Sea but also by the possible larger fetch and swell entering

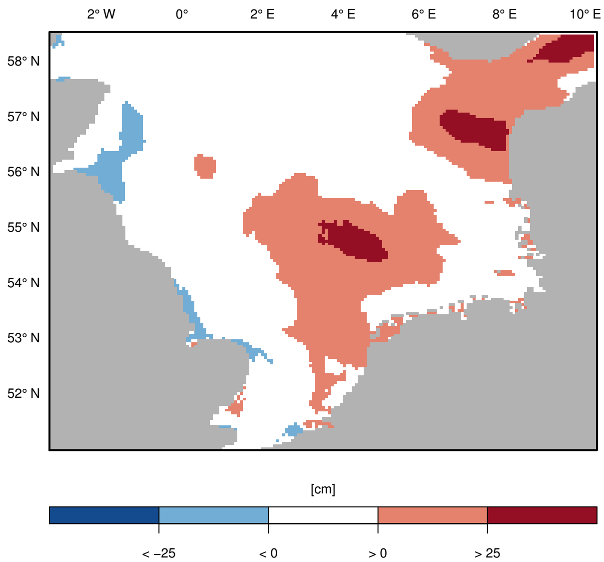

FIG. 3. Common changes in all four realizations with at least the same change of the yearly maximum significant wave height in [cm] for the period 2071–2100 compared to 1961–1990 in the North Sea. White areas indicate areas where the four realizations do not show the same sign of change.

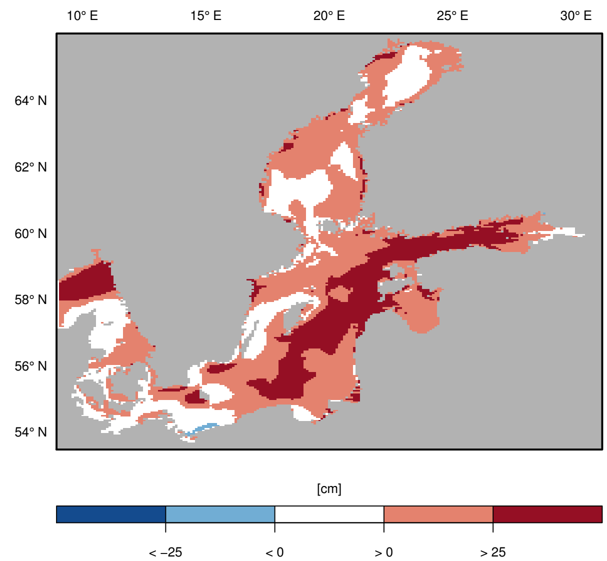

FIG. 4. same as Figure 3, but for the Baltic Sea

from the north which can further influence the internal climate variability.

Figure 3 shows the common signal of the 30–year mean of the yearly maximum significant wave height. The red areas in the southern central and northeastern North Sea indicate that all four realizations show an increase of the 30–year mean of the yearly maximum. An increase of more than 25 cm of the 30–year mean of the yearly maximum in all four realizations is limited to the central North Sea, off the Danish coast and in the Skagerrak.

An increase in a single realizations can exceed the 30–year mean of the yearly maximum of the reference period of more than 1 m (not shown) and can already occur before the end of the 21st century. Beside small areas of a common decrease along the British coast, large white parts indicate that the four realizations do not agree on the sign of a possible future change. This may point to the uncertainty of changes in wave climate in the North Sea. A more detailed description of these four future wave realizations can be found in Groll et al. (2013).

b. Baltic Sea

Compared to the North Sea, the Baltic Sea is an almost enclosed sea apart from the Kattegat in the northwest, and changes in wave climate are only caused by waves generated within the Baltic Sea. Not only changes in the wind fields can have an effect on the wave climate, but also a possible smaller sea ice coverage in the Baltic Sea and thus a change in the fetch.

The common change of the 30–year mean of the yearly maximum (Figure 4) shows large areas of an increase in all four realizations compared to the reference period. Also the increase of more than 25 cm covers larger parts than for the North Sea and range from the southern central Baltic Sea into the Gulf of Finland. Based on these four realizations a change in the wave climate towards higher yearly maximum waves is more likely in the Baltic Sea than in the North Sea. Again a comparison with other studies will give more confidence in the range of possible changes in the wave climate of the Baltic Sea.

5. Applications

The experiments, described here, a new hindcast (HC2) and the future wave climate simulations for the North Sea and Baltic Sea are part of the coastDat database together with the already widely used hindcast HC1 and future simulations by Grabemann and Weisse (2008). This database is already used by third party costumers for various applications. Some of them are shortly mentioned here:

Ship route optimization. Optimization of ship routes for vessels operating on fixed routes in the North Sea by using the simulated conditions from the hindcast simulations can reduce the fuel consumption by about 9%.

Ship design optimization. Analyzing the environmental conditions on the basis of the coastDat data give information to optimize ship design to enhance the safety of the ship; for instance if stabilizer systems are necessary or not in the area in which the ship usually operates.

Planning off-shore wind farms. Wave data from the hindcast are also used in the design phase of a lot of off-shore wind farms in the North Sea to simulate the structural integrity and safety of the construction during severe events. The data also contribute to the planning of the construction phase by calculating weather windows to allow for specific working steps.

Coastal protection. Simulated future wave climate is used as boundary conditions for nearshore models, along with corresponding simulations of the water level to evaluate coastal defense structures (Weisse et al. 2012).

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