Near coastal wave modelling in the German Bight and Wadden Sea

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Abstract

Within the framework of the project COSYNA (Coastal Observing System for Northern and Arctic Seas) nested modelling systems are used for estimating pre-operational reliable now- and short-term forecasts of ocean state variables concerning ocean waves, hydrodynamics and suspended matter in the North Sea and German Bight. Ongoing developments of a coupled wave-current system, will improve the modelling results in coastal areas like the Wadden Sea and estuaries. First results, obtained with a one-way coupled system illustrate the effect of current and/or water level changes on wave parameters and spectra. The results are verified with available observations from wave rider buoys and indicate an improvement of the wave modelling results in areas highly influenced by the tide.

1. Introduction

The Coastal Observation System for Northern and Arctic Seas (COSYNA) coordinated by the Helmholtz-Zentrum Geesthacht (HZG) is a pre-operational system joining observations and numerical models. Observations consist of in-situ measurements from fixed (piles and buoys) and mobile platforms (FerryBox) as well as of remotely sensed data from shore by HF-radar and from space by satellite. The forecasting suite includes nested wave (WAM, Komen at al. (1994)) and 3-D hydrodynamic models (the General Estuarine Transport Model (GETM), Burchard and Bolding (2002)) running in a data-assimilation mode.

In line with the philosophy of COSYNA is the revision of wave model WAM. The basic physics and numerics are kept in the new release WAM 4.5.3. The source function integration scheme of Hersbach and Janssen (1999) and the reformulated wave model dissipation source function (Bidlot et al., 2005), later reviewed by Bidlot et al. (2007) and Janssen (2008), are incorporated. Depth induced wave breaking (Battjes & Janssen, 1978) has been included as an additional source function. Depth and/or current fields can be in-stationary. Grid points can fall dry and refraction due to spatially varying current and depth is accounted for. These modifications will improve the wave modelling results in coastal areas like the Wadden Sea – an area highly influenced by the tide.

2. Model setup

The North-Sea model has a spatial resolution of 3nm. Boundary values and the forcing wind fields are provided by the German Weather Service hourly. Within it the German Bight model is nested with a spatial resolution of 1km. Both models use a directional resolution of 15^0 and 30 frequencies, with equidistant relative resolution between 0.04 and 0.66. The wave model system with a constant water depth and without currents runs in a pre-operational set-up twice a day and provides forecast for 24 hours. All model results are saved hourly for further analysis.

Figure 1 presents the bathymetries of the North Sea and German Bight models. Additionally, the locations of two buoys used for validation are shown. The buoy 'Elbe' close to the river Elbe estuary is maintained by Federal Maritime and Hydrographic Agency (BSH) and buoy 'Hoernum Tief' in the Wadden Sea by HZG. Both buoys are directional Datawell wave riders. Table 1 gives details of the buoy positions and depths.

For July 2011 the German Bight model was run with additional forcing due to water level variations and currents using the same boundary values from the North Sea model as the pre-operational model. The forcing data are hourly available from the GETM model.

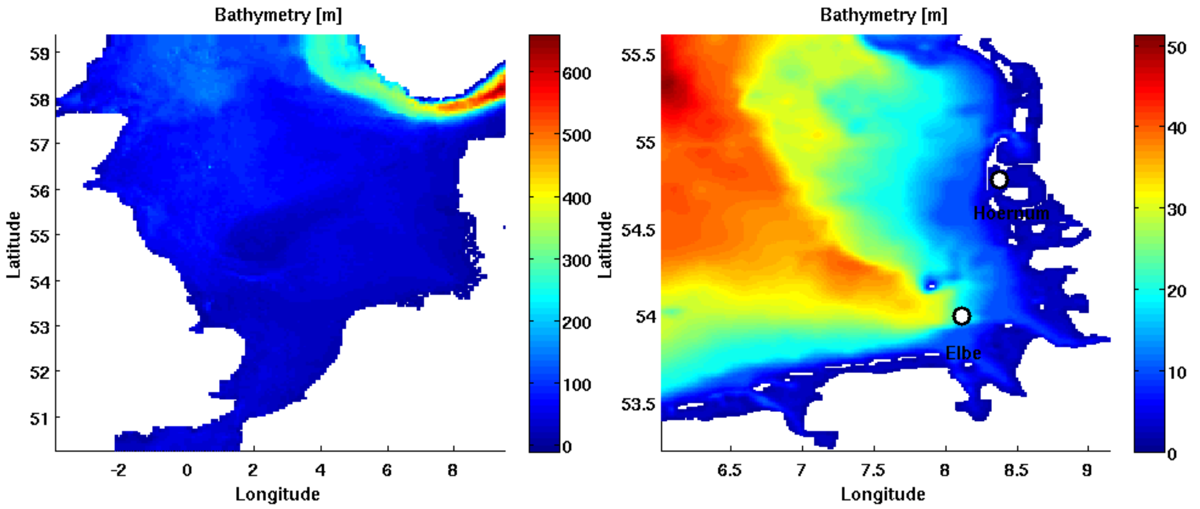

Fig. 1: Bathymetry in the North Sea and German Bight as used in the model. The positions of wave rider buoys used for the validation is indicated, too.

Table 1: Buoys used for validations.

Name	Latitude ^{0}N	Longitude ^{0}E	Mean water depth (m)	Tide range (m)
Elbe	53.997	8.1105	20.9	2.5
Hoernum Tief	54.775	8.3800	3.7	1.0

3. Results

To quantify the impact of in-stationary currents/water depth hydrodynamic forcing on the wave model results the standard deviation (STD) between both runs of the significant wave height (hs) and the mean period (tm1) are shown in Figure 2. The data are the one month average, normalized by the mean values from the run without hydrodynamic forcing. For the calculation of the STD the data pairs are only taken into account, if the grid point is wet in both results.

In the open North Sea nearly no difference is found. Significant differences are near the coast and in the Wadden Sea, where currents and water levels change rapidly under the influence of the tide. In these areas the STD of hs goes up to 30%, mainly due to the changes in water depth. The STD of tm1 is about 10-15%. In particular in the South-East of the German Bight, where the main rivers Elbe and Weser are entering, the impact on tm1 period reaches far more off-shore than the impact found in the wave heights hs.

Interesting to notice are a few relative small areas where the STD of tm1 reaches values up to 30%. These areas are characterized by strong currents (up to 1.5m/s) often parallel or anti-parallel to the waves coursing a large Doppler Shift. A detailed analysis of the large SDT in the entrance of the Jade lagoon (8.25^0E, 53.5^0N water depth 6±1m) reveals that hs and tm1 increase heavily during southerly wind (local wave growth, longer effective fetch) and opposing currents (wave blocking and Doppler Shift).

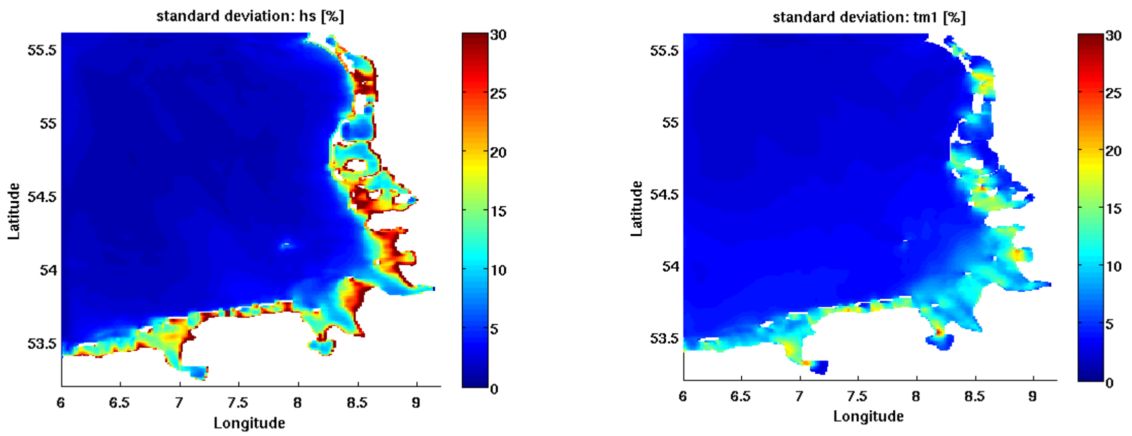

Fig. 2: Impact of in-stationary currents/water depth in the German Bight: standard deviation of significant wave height (hs, left) and mean period (tm1, right). Averaged values for one month (July 2011).

The model results are validated against measurements of the two buoys 'Hoernum Tief' and ‘Elbe’ (cf. Figure 1 and Table 1). Figures 3 and 5 show the comparisons of the wave parameters together with the forcing data at the sites buoys 'Hoernum Tief' and ‘Elbe’, respectively. Figures 4 and 6 present time series of wave energy density spectra both sites. The comparison statistics of the full month are given in Table 2.

Table 2: Statistics of the validation. Additionally to mean and standard deviation the coefficients of a linear regression are given.

	'Elbe'				'Hoernum Tief'			
	hs [m]		tm1 [s]		hs [m]		tm1 [s]	
mean meas.	1.10		4.36		0.33		2.43	
	WAM	WAM c/wl	WAM	WAM c/wl	WAM	WAM c/wl	WAM	WAM c/wl
bias	0.004	-0.025	0.245	0.174	-0.073	-0.120	0.326	0.150
std	0.164	0.171	0.439	0.397	0.117	0.136	0.350	0.293
slope	1.051	1.085	0.982	1.026	0.779	0.835	0.322	0.574
intercept	-0.061	-0.068	-0.169	-0.285	0.146	0.174	1.323	0.886

At the buoy ‘Elbe’ (Figure 3), which is located in a water depth of about 21m and in relative open sea, two different wind regimes occurred. From July 1^{st} to 5^{th} the wind direction is nearly constant from North-West. The wind speeds are increasing from 7,7m/s to a maximum of 15m/s at the 3rd and than decreasing to lit winds. After July 5th of July the winds are moderate (less than 10m/s) with changing direction. The variations of depth and currents are quite regular and not influenced by the wind during the whole period shown.

The measured significant wave height and the wave direction are generally in good agreement with any of the two model runs. In the wave periods a clear tidal signal can be seen in the model taking varying currents into account as well as in the measurements. Consequently the STD between measured and model tm1 period decreases form 0.439s to 0.397s and the bias (model-measurement) from 0.245 to 0.174. The bias and STD of the hs are small in both runs but is marginal increasing with currents and water level changes.

The frequency wave spectra from the buoy and the two runs are shown in Figure 4 for the first 5 days in July during the strong winds event. As in the time series the measurements and the model run with hydrodynamic forcing are in good agreement. The tidal currents are mainly affecting the tail of the spectra, whereas the energy around the peak is not much different in all three panels of the figure.

The measurement site 'Hoernum Tief' (Figure 5) is located in the Wadden Sea of the Hoernum bight in a tidal channel. The bight is connected to the North Sea by a tidal inlet, allowing only south-westerly waves to reach the buoy location. The mean water depth is about 3.7m. The depth change by tide is about ±0.5m, but an additional surge of about 1.0m was happening at the 23rd of July originating from the westerly winds of 14m/s. The currents are always less than 0.5m/s.

Nearly all measured waves shown in Figure 5 are generated in side of the bight. The wave heights follow the wind speeds and the wind and wave directions are very close in both model runs. The tidal variations are observed in the measured wave heights but are much weaker in the model run with hydrodynamic forcing, which is nearly in agreement with the run without hydrodynamic forcing. The wave heights in both runs do not show the lower wave height during ebb tide, resulting in always a positive bias. In contrast to wave heights the wave periods tm1 clearly reproduce the measured values when hydrodynamic forcing is used. The reason for this model performance may be the missing feed back of waves into the hydrodynamic model and the relative coarse resolution of 1km for the area of the Hoernum bight.

The wave spectra at the buoy 'Hoernum Tief' (Figure 6) confirm the findings from the parameter time series. The tidal variations are present in the measurement and the model spectra with hydrodynamic forcing. The variations already present in the run without hydrodynamic forcing are probably caused by wind speed and direction changes and indicate the very fast response of the wave field to the local winds for short fetches. Generally, the measured spectra are more peaked in the frequency domain. The observed strong variations in time indicate that the hourly hydrodynamic forcing is not sufficient.

3. Summary

The impact of changing water levels and currents on the WAM wave model was analysed in the German Bight. The WAM model was run twice in the same set-up, from which one was forced by changing water levels and currents field, taken from a hydrodynamic model which was applied on the same grid.

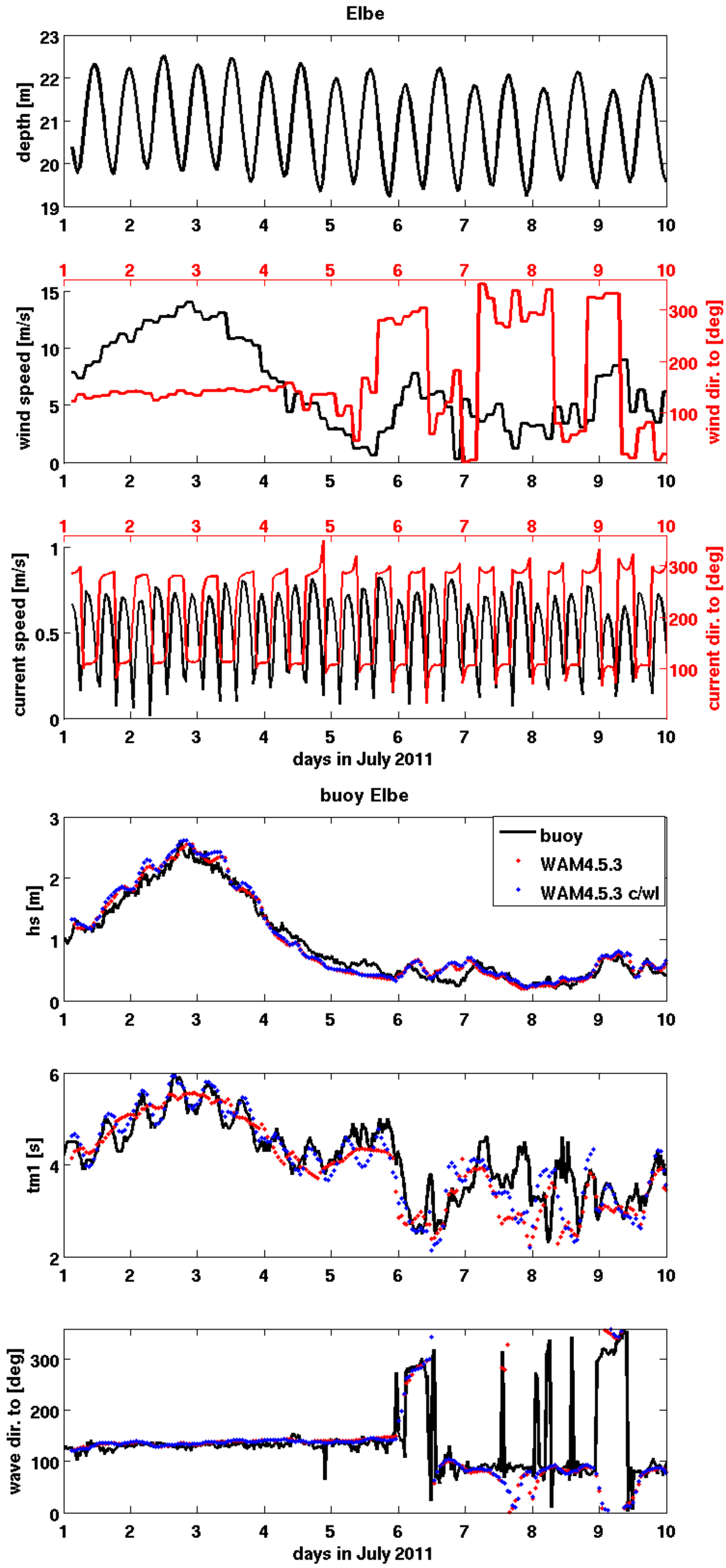

Fig. 3: Comparison of measured and computed values of hs, tm1 period and wave direction at the buoy 'Elbe'. On the top panels the model driving forces – wind, surface elevations and currents are shown.

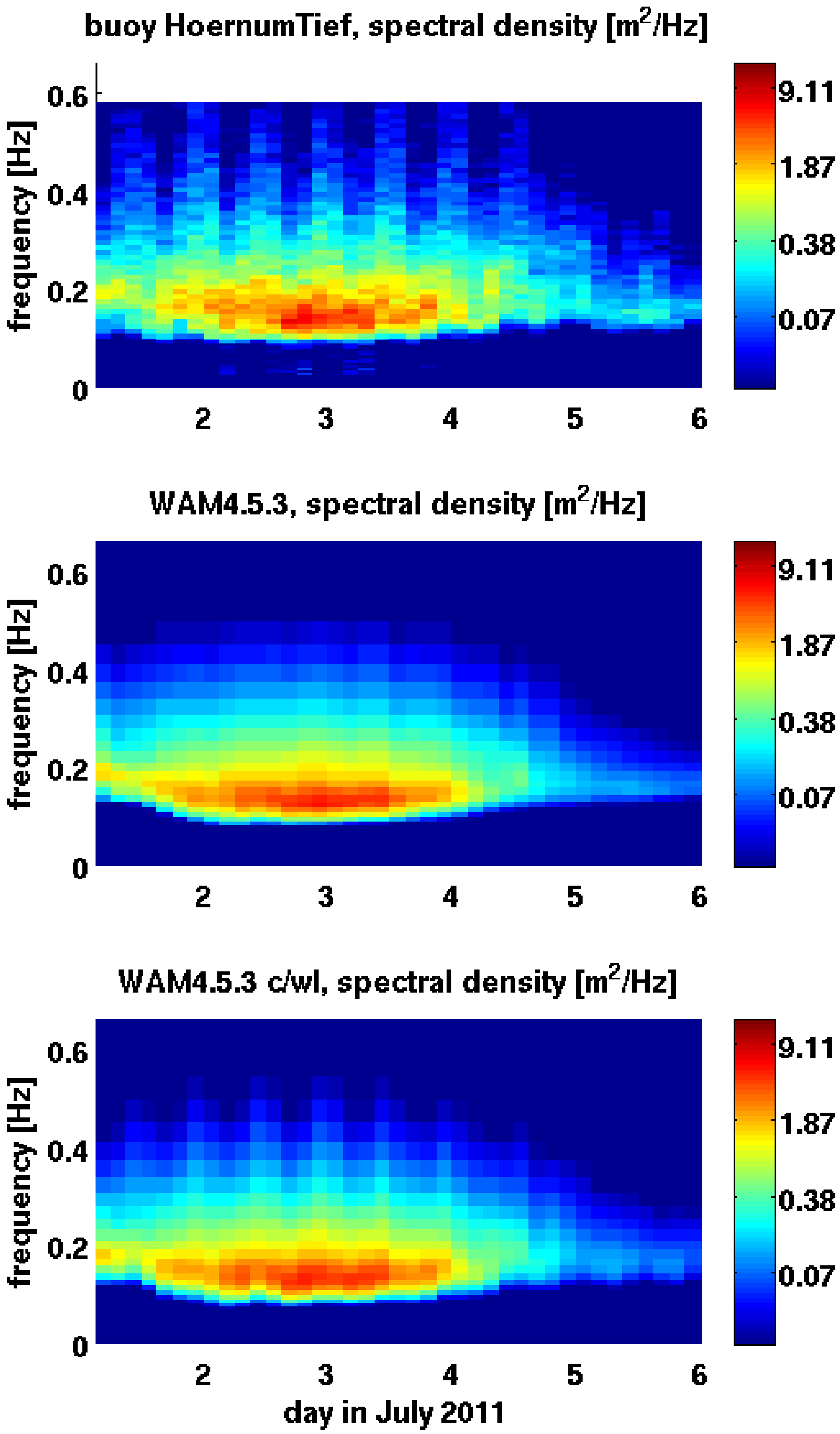

Fig. 4: Comparison of measured (top) and computed values of the spectral energy density at the buoy 'Elbe'.

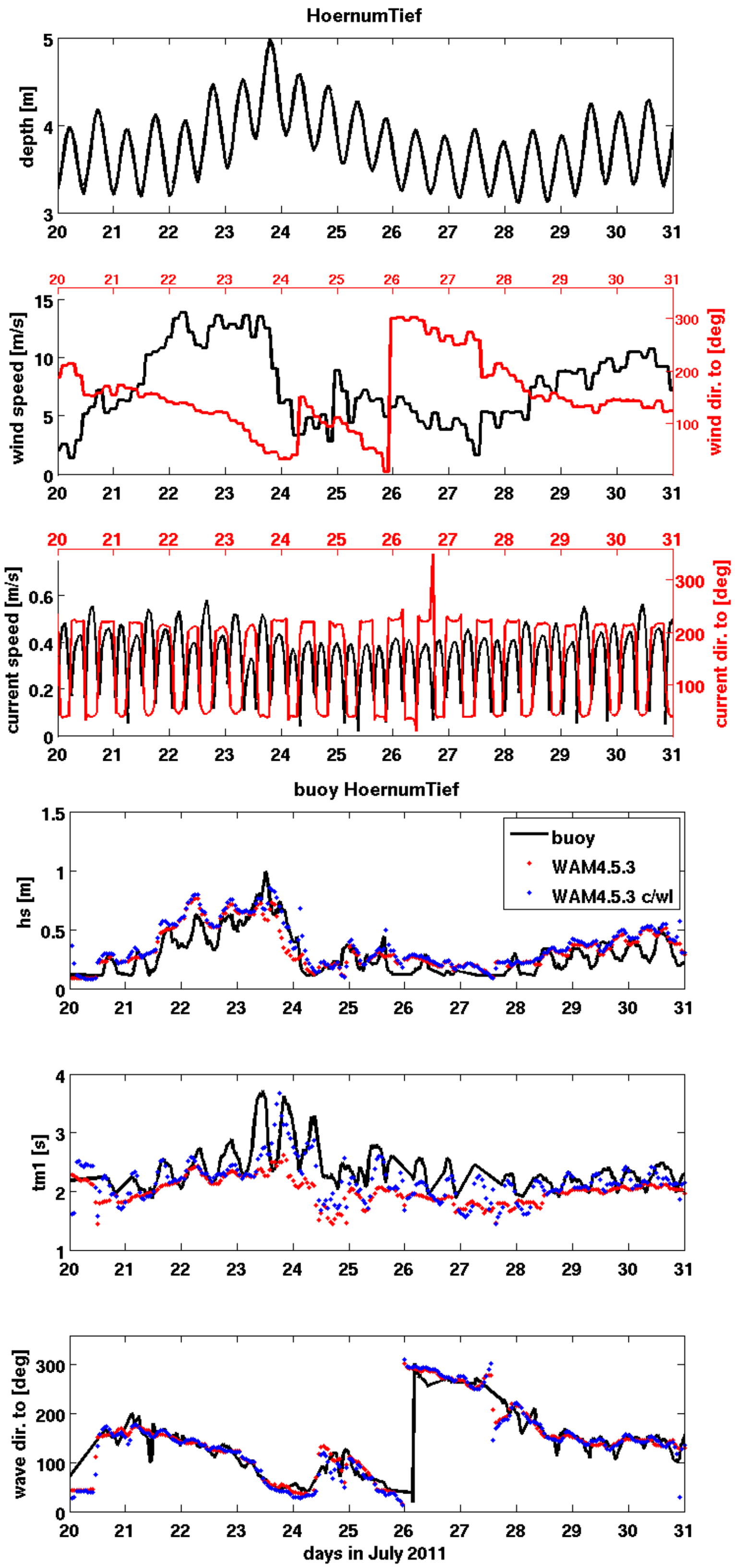

Fig. 5: Comparison of measured and computed values of hs, tm1 period and wave direction at the buoys 'Hoernum Tief'. On the top panels the model driving forces – wind, water level variations and currents are shown.

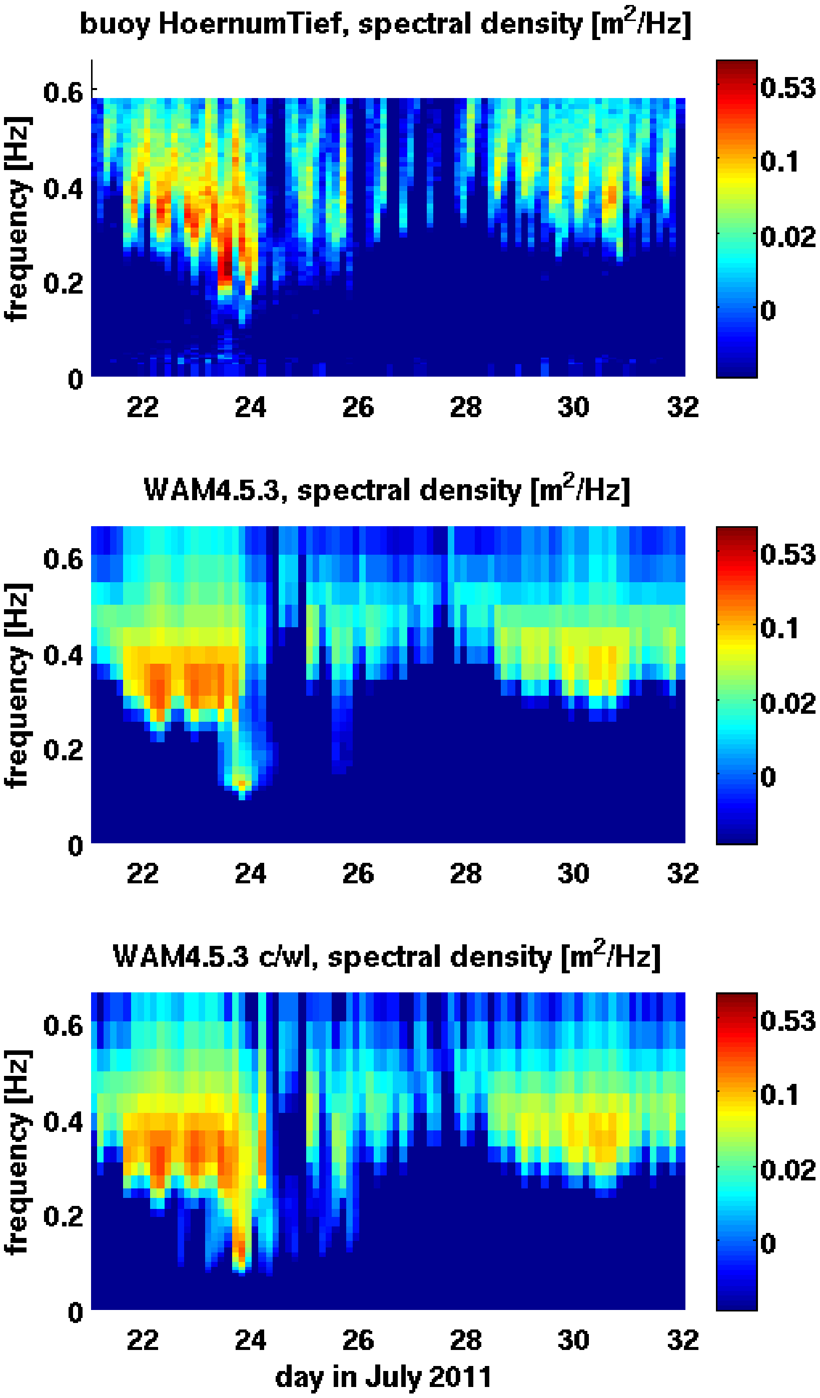

Fig. 6: Comparison of measured and computed values of the spectral energy density at the buoy 'Hoernum Tief'.

The comparison of both model runs revealed that over large areas of the German Bight the impact on wave heights and wave periods is very small. Significant impact was found in shallow water areas close to the coast and on the tidal flats in the Wadden Sea. Here the standard deviation between both run showed standard deviations up to 30% in wave heights and about 10-15% in wave period. The impact on the wave period reaches far more off-shore than on the wave heights and was found in water depth of up to 25m. In tidal inlets, where strong currents, opposing the waves, are present, standard deviations of close to 30% for the wave period were found too.

The validation of the model results with measured data at two sites showed that the wave period measurements were reproduced much better, when the hydrodynamic forcing was applied. The agreement in wave heights is excellent at the site in open waters and the differences between the two model runs are marginal. At the site in a semi-enclosed bight the model did not reproduce the amplitude of wave height variations with the tide, which are present in the measurement. This may be coursed by the coarse resolution (1km) of the model and by the one-way coupling with the hydrodynamic model. Wave directions are in very close agreement with measured data.

In summary, it is concluded that the WAM model can be applied with variable currents and water levels. In a next step wave model will be incorporated in the pre-operation model system in a two-way coupled set-up.

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