A 40-YEAR HIGH-RESOLUTION WIND AND WAVE HINDCAST FOR THE SOUTHERN NORTH SEA

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1. INTRODUCTION

The planing of sustainable development and of economic activities in the marine environment requires long term information about the prevailing environmental conditions. For the design of marine and coastal protection structures detailed knowledge on local wave conditions is an essential prerequisite. To estimate the risk which emerges from local wave conditions knowledge on both, the wave climatology and the extreme events is necessary.

Direct observations of sufficient length are not always available at the place of interest. Furthermore, observations are usually distributed irregularly in space and time. Therefore, there have been a number of studies in the recent past that tried to use numerical wave models to provide hindcasts of the past wave conditions. For example, one of the more prominent attempts to reconstruct the wave and storm climate over a longer period was provided by the WASA Group (WASA 1998). The objective here was to prove or disprove hypotheses of a worsening storm and wave climate in the Northeast North Atlantic. The changes in the wave climate were assessed using a state-of-the-art wave model driven by wind analyses over a period of 40 years (1955-1994) (Günther et al. 1998).

The WASA data set has proven to be extremely useful and was requested frequently, often being the only source of information available for wave climate studies at many places along the European Coast. However, there was increasing awareness that the spatial and temporal resolution of this data set was too coarse for many applications, especially in coastal areas and that the atmospheric forcing suffered from a lack of inhomogeneities along the reconstruction period (Günther et al. 1998). Therefore, based on the experience made within the WASA, the European project HIPOCAS (Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe) (Soares et al. 2002) was set-up to reduce several of these shortcomings, in particular to use more homogeneous wind fields and to increase the spatial and temporal resolution of the wave hindcast.

Although HIPOCAS is focused on providing high-resolution wind, wave and storm surge hindcasts as well as climatologies for a variety of European Coastal Areas we here concentrate on the results obtained for the Southern North Sea so far. For a more detailed overview on the coastal areas studied under the HIPOCAS project we refer to Soares et al. (2002). In section 2 we briefly describe the methodology and the models applied for the Southern North Sea. Preliminary results are presented in section 3. A summary and preliminary conclusions are provided in section 4.

2. METHODS AND GENERAL APPROACH

One objective of HIPOCAS is to provide a reasonable reconstruction of the wave conditions and the wave climate over the past decades for the European Coastal Areas. For the Southern North Sea we therefore have adopted the following approach:

2.1 Atmospheric forcing

High-quality wind fields are an essential prerequisite for the production of reliable wave hindcasts. While the wind fields used in WASA still suffered from some inhomogeneities (see for example Günther et al. 1998) that may have had impacts on the quality of the wave hindcast, recently wind data from the global reanalyzes projects (Kalnay et al. 1996, Gibson et al. 1996) have become available. These wind fields are generally believed to be much more homogeneous than previous products, as they have been produced by global atmospheric circulation models that were used for reanalyzing existing observational data back in time for some decades using a frozen state-of-the-art data assimilation system together with an enhanced observational data base that additionally comprises observations that were not available in real time. So far, the NCEP reanalysis (Kalnay et al. 1996) represents the longest available reanalyzed data set (1948 until now).

The NCEP reanalysis has a spatial resolution of about 200 km, and the data are provided every 6 hours. While this resolution appears to be sufficient for a variety of studies, it remains too coarse for providing sufficiently resolved wind fields that may be used for wave studies in coastal areas. Therefore, in HIPOCAS a regional atmosphere model (RAM) was set-up that was driven by the NCEP reanalyzes at its lateral boundaries (Feser et al. 2001). The RAM was applied at a spatial resolution of about 50 × 50 km and the modeled wind fields were stored every hour. This way the spatial resolution was increased by a factor of about 16 and the temporal resolution by a factor of 6 compared to the driving NCEP reanalysis. The model was integrated for the entire NCEP reanalysis period.

Several integration domains covering different parts of the Europe have been set-up and integrated. For a complete listing we refer to Soares et al. (2002). For the wave simulations in the Southern North Sea described here, we have used data from an integration that covered Europe, the entire North Sea, the Baltic Sea and large parts of the North Atlantic. This domain together with the RAM integration is described in detail in Feser et al. (2001) and von Storch et al. (2000).

2.2 Hydrodynamical Modeling

The wind fields provided by the 40-year RAM integration (section. 2.1) have been used in cooperation with the Coastal Division of the Federal Waterways Engineering and Research Institute (BAW) to drive a storm-surge model for the North Sea. The objective of this simulations was twofold: First, we were interested in a comprehensive and *consistent* wind, wave and surge data set for the Southern North Sea. Second, we expected an impact of the water level variations caused by tides and surges on the modeled wave heights because of the relative shallow water depth of the Southern North Sea. The magnitude of this effect is illustrated in Figure 1 for the platform K13-Alpha where the water depth is about 27m. Here the effect was found to be in the order of 1-3% of the modeled wave height. It increases with decreasing water depth.

The simulations of the tides and storm surges in the North Sea have been performed at the BAW using their finite element high-resolution hydrodynamical model TELEMAC2D. This model is used routinely by some German coastal authorities and has a resolution of a view kilometers in the Northern North Sea which increases towards the German Bight were it finally reaches a few hundred meters. The model domain comprises the entire North Sea. External surges have been taken into account by assimilating water level observations at Ab-

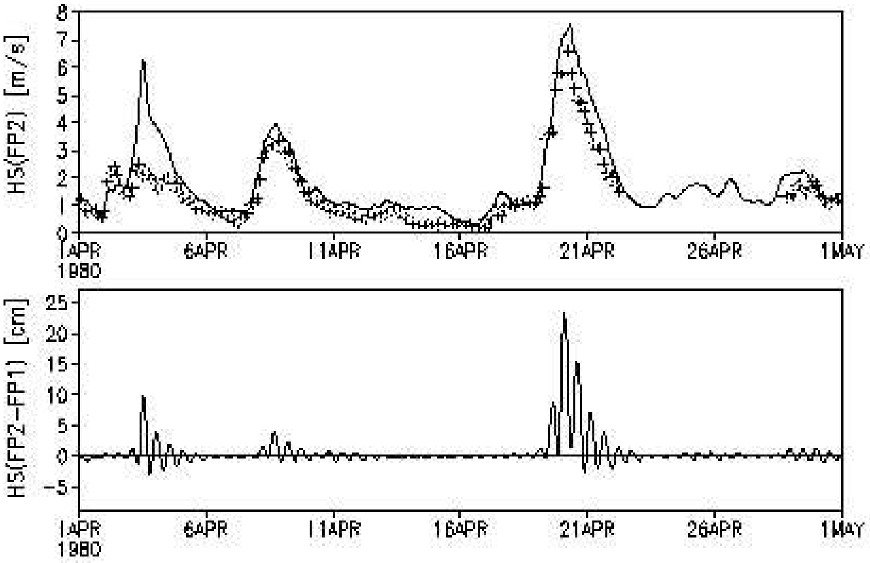

Figure 1: Difference in simulated significant wave height in cm between two wave model simulations (bottom). In the first simulation (FP2) time dependent water levels caused by tides and surges have been accounted for while in the second simulation (FP1) a constant water depth was used. Results are shown at platform K13-Alpha (53.22°N, 3.22°E). For comparison modeled (solid) and observed (crosses) wave heights are shown additionally (top).

erdeen. The simulation has recently been completed and data are analyzed right now. Initial analysis showed that reasonable reconstructions of the water levels along the German coast have been obtained this way (Pluess pers. comm. 2002).

2.3 Wave Modeling

The hourly wind fields and the hourly water levels described above have been used to force the wave model WAM (WAMDI 1988) for the period from 1958 until now. The model was set-up as a nested system with a coarse grid covering the entire North Sea and large parts of the Northeast North Atlantic at a spatial resolution of 0.75° longitude × 0.5° latitude and a fine grid nested within the coarse grid. The domain of the fine grid covers the North Sea between 51°N and 56°N, and between -3°W and 10.5°E at a spatial resolution of roughly 5 × 5 km. Compared to the WASA simulations the frequency grid was extended by two more frequencies in the high frequency domain.

For the coarse grid monthly varying ice fields as described in Günther et al. (1998) have been accounted for. The full model output (including all spectra) of this simulation has been stored every three hours. It has been used subsequently to force the fine grid simulation at the lateral boundaries. For the fine grid simulation, the wave model WAM was modified such that time varying water levels can be taken into account and the full model output including all spectra was stored hourly.

3. RESULTS

Since the simulations described above have finished only recently, we are only able to present preliminary results here.

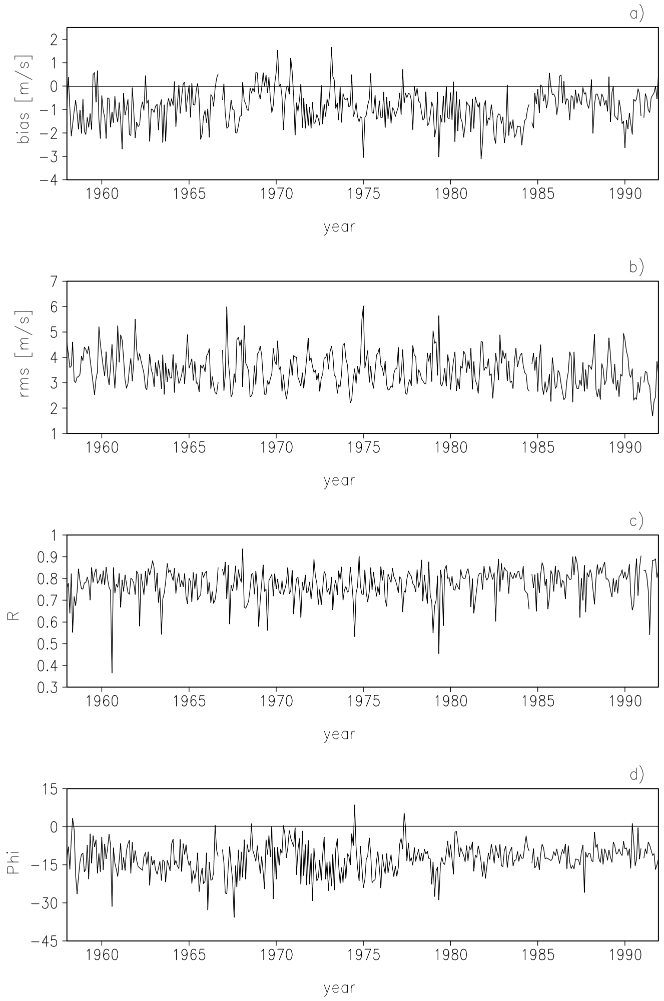

Figure 2: Monthly bias (a), root-mean-square error (b), magnitude (c) and veering angle (d) of the complex correlation between the observed and the modeled wind at Ocean Weather Ship Mike for the period 1958-1991.

We used the complex correlation ρ (Kundu 1976) between the observed $U_t^{\text{obs}} = u_t^{\text{obs}} + \mathrm{i}v_t^{\text{obs}}$ and the modeled wind field $U_t^{\text{mod}} = u_t^{\text{mod}} + \mathrm{i}v_t^{\text{mod}}$ to assess the quality of the numerical wind hindcast

$$\rho = \frac{\mathcal{E}(U_t^{\text{obs}}, U_t^{\text{mod}^*})}{\sigma_{U_t^{\text{obs}}}\sigma_{U_t^{\text{mod}}}}. \tag{1}$$

Here U denotes the complex representation of the two dimensional wind field at 10 m height, u and v are the zonal and the meridional wind component respectively, t is time, $\mathrm{i} = \sqrt{-1}$, and the indices “obs” and “mod” denote the winds taken from observation or simulation. $\mathcal{E}$ denotes the expectation operator, $*$ the complex conjugate, $\sigma_{U_t^{\text{obs}}}$ is defined as $\sigma^2_{U_t^{\text{obs}}} = \mathcal{E}(U_t^{\text{obs}}, U_t^{\text{obs}^*})$ and $\sigma^2_{U_t^{\text{mod}}}$ is defined similarly. The correlation $\rho = \rho_{Re} + \mathrm{i}\rho_{Im}$ can be written in polar coordinates as

$$\rho = R\exp(\mathrm{i}\phi) \tag{2}$$

where the length R represents a measure of the overall magnitude of the correlation and the phase angle ϕ is a measure of the average relative angular displacement (veering) between a pair of two dimensional vector time

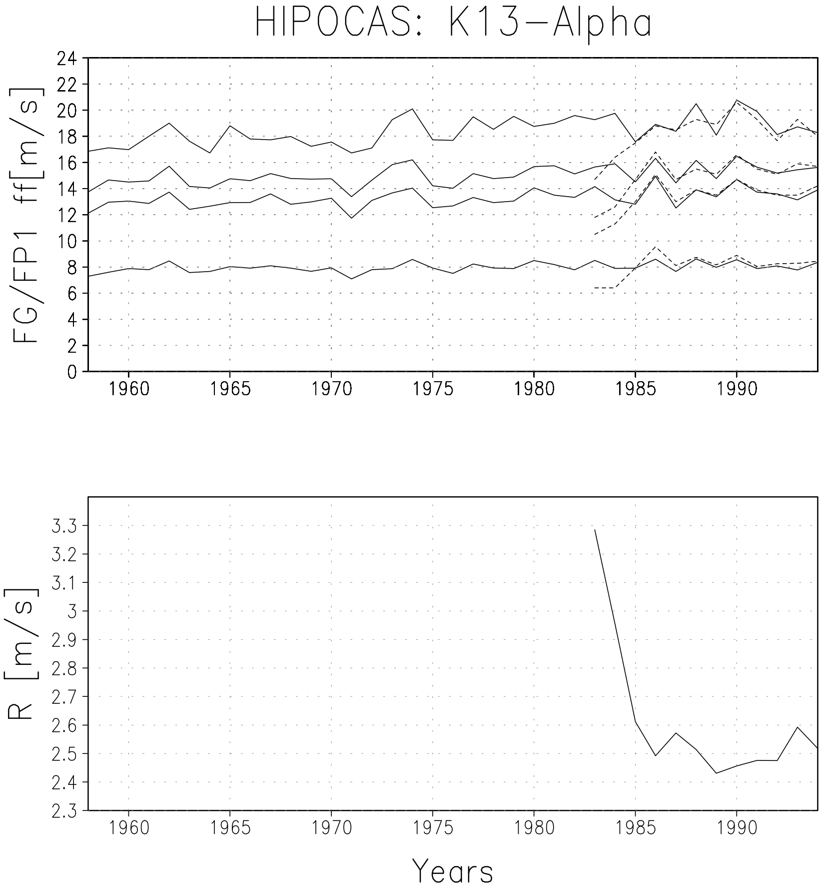

Figure 3: Simulated and observed annual wind speed quantiles (top, in ms^{-1}) at the platform K13-Alpha in the Southern North Sea, and annual root-mean-square errors of wind speed (bottom panel, in ms^{-1}). In the upper panel, the annual 99%, 95%, 90% and 50% percentiles (from top to bottom) are given, with the solid line representing the simulations and the dashed line the observed data.

series (cf. Kundu 1976).

Monthly complex correlations between the observed and the modeled winds at 10 m height at Ocean Weather Ship Mike (66.0°N, 2.0°E) are shown in Figure 2. In general the complex correlations indicate a good agreement between the observations and the simulation. For the entire period from 1958 until 1991 the magnitude of the complex correlation is in the order of 0.8. The relative angular displacement between the observations and the simulations is about 10° to 15° throughout the simulation period with slightly smaller variability at the end of the simulation. Additionally, monthly biases and root-mean-square errors are shown in Figure 2. It can be obtained that on average the simulation underestimates the observations by 1 ms^{-1} or so. However, the bias is rather sensitive on how the observations have been reduced to 10 m height. The monthly root-mean-square error is in the order of 3 to 4 ms^{-1} with a slight tendency towards smaller values at the end of the simulation period.

Figure 3 shows observed and modeled annual wind speed percentiles at K13-Alpha together with the annual root-mean-square error. After about 1985 there is a very good agreement between the observed and the modeled percentiles even for the very high percentiles. The root-mean-square error is rather high around about 1982 and decreases strongly until 1985. It then remains at about 2.5 ms^{-1} for the rest of the simulation period.

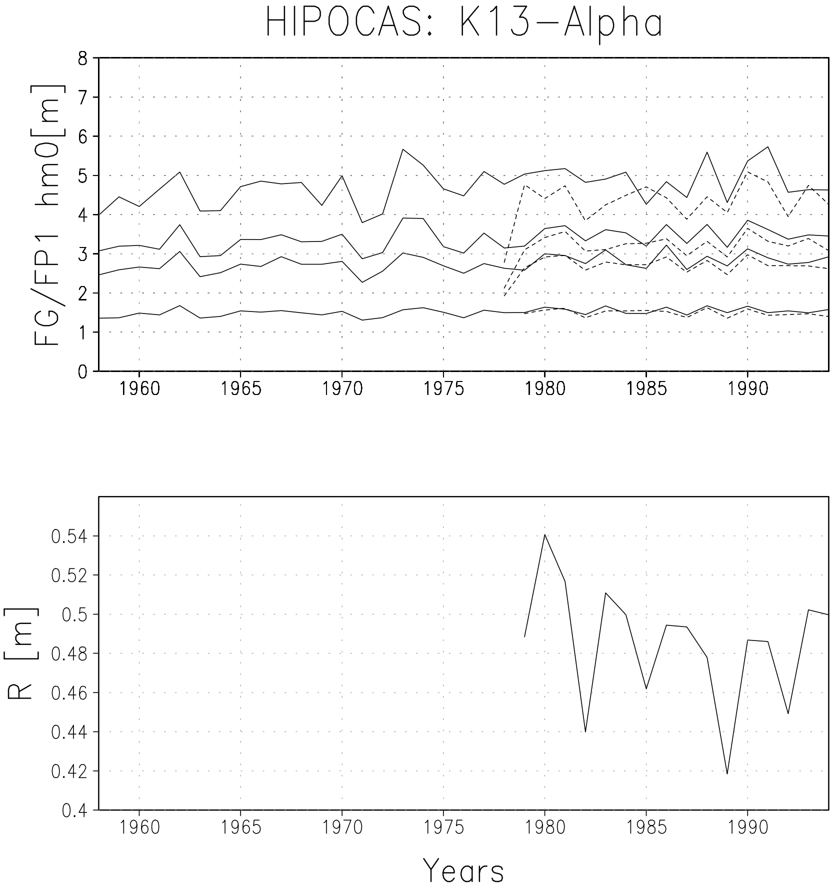

Figure 4: Simulated and observed annual wave height quantiles (top, in m) at the platform K13-Alpha in the Southern North Sea, and annual root-mean-square errors of wave height (bottom panel, in m). In the upper panel, the annual 99%, 95%, 90% and 50% percentiles (from top to bottom) are given, with the solid line representing the simulations and the dashed line the observed data.

A similar analysis for the wave height at K13-Alpha is presented in Figure 4. For the 50% percentile again a very good agreement with the observations can be inferred. For the highest percentiles, however, an overestimation between about 10 and 40 cm can be inferred. This is illustrated also by the root-mean-square error which is in the order of about 45 to 50 cm for the entire period for which observational data have been available. Contrary to the wind speed, the root-mean-square error for the wave height shows no significant decrease between 1982 and 1985 as it was obtained for wind speed (Figure 3). We therefore conclude that the large differences between modeled and observed wind speed in this period are more likely caused by observational problems at the beginning of the recording period than by atmosphere model errors.

Table 1 shows some statistics for wind speed and wave height for three different buoys and platforms for the period 1985 until 1997. For wind speed a reasonable agreement can be obtained. The statistics at Huibertgat are slightly worse than those for K13 and Europlatform since model winds at Schiermonnikoog have been compared with measurements at Huibertgat. For the wave heights the agreement is best for K13 and Europlatform and significantly worse for Schiermonnikoog. The reasons for this are not yet clear and are presently investigated.

Table 1: Observed and simulated mean together with bias, root-mean-square error and correlation between observed and simulated data for wind speed and wave height from the period 1985 until 1997. Shown are the results for K13-Alpha (K13, 53.2°N, 3.2°E), Europlatform (EUR, 52.0°N, 3.3°E), Schiermonnikoog (SON, 53.6°N, 6.2°E), and Huibertgat (HBG, 53.6°N, 6.4°E)

Station	Wind speed					Wave height				
	Mean Obs. $[ms^{-1}]$	Mean Hind. $[ms^{-1}]$	Bias $[ms^{-1}]$	RMS error $[ms^{-1}]$	Corr. Coeff.	Mean Obs. $[m]$	Mean Hind. $[m]$	Bias $[m]$	RMS error $[m]$	Corr. Coeff.
K13	8.14	8.14	0.02	2.52	0.80	1.45	1.55	0.07	0.48	0.87
EUR	7.90	7.52	-0.37	2.30	0.82	1.26	1.21	-0.05	0.40	0.87
SON	N.A.	N.A.	N.A.	N.A.	N.A.	1.26	1.19	-0.07	0.63	0.70
HBG	7.90	7.64	-0.25	3.14	0.66	N.A.	N.A.	N.A.	N.A.	N.A.

4. SUMMARY

Preliminary results from a 40-year high-resolution wind, wave and surge hindcast for the Southern North Sea were presented. This hindcast is embedded in the European project HIPOCAS (Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe) which is focused on high-resolution wind, wave and surge hindcasts for European Coastal Seas (Soares et al. 2002). In this study we limited ourselves on the discussion of wind and waves, excluding the surges so far.

First results from a high-resolution wave model (about 5 × 5 km) for the Southern North Sea using an improved meteorological forcing and taking the effects of tidal water level fluctuations on the waves in shallow waters into account have been shown. The high-resolution wind fields are available hourly and were obtained from a regional atmosphere model driven by the NCEP reanalysis (Feser et al. 2001). Although some limitations seem to exist the wave hindcast appears to be reliable in general. More detailed analysis is presently performed in order to validate the hindcast regionally and to perform an assessment of the hindcast climate.

Acknowledgements. We are grateful to Koos Doekes from Rijkswaterstaat for providing us with the wave data at K13, EUR, and SON. Wind data have been obtained from the KNMI HYDRA project (http://www.knmi.nl/samenw/hydra). This research is supported by the European Union under EVK2-1999-00248 (HIPOCAS).

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