THE IMPACT OF VARIABLE DEPTH AND CURRENTS ON WAVE DEVELOPMENT

H. Günther, G. Gayer and W. Rosenthal

GKSS Research Center Geesthacht
Institute for Coastal Research
Geesthacht, Germany

1 INTRODUCTION

In coastal areas detailed knowledge of the surface wave field is very important for the understanding of hydrodynamic and transport processes. The interaction of waves with the bottom and current is one of the keys to understand and predict developments in coastal seas.

Substantial progress has been made in the recent years in predicting ocean surface gravity waves. The third generation WAM model, Komen et al. (1994) has demonstrated its excellent performance on global and regional scales, which are the deep-water ocean and the shallow shelf sea areas. However, difficulties have been found in the coastal zone. The space and time scales in these areas are normally too small to allow the non-linear interactions to control the energy balance. The growth and decay of waves is dominated by the input energy from the atmosphere and by enhanced dissipation of wave energy in the water column and at the sea floor. In particular the dissipation in the water column by turbulent diffusion, Rosenthal (1989), which is not included in most coastal wave models, has been identified as a key process to explain the self-similar spectral shape, Günther and Rosenthal (1995).

In this paper a brief description of the K-model is presented followed by examples of model applications in the tidal area of the Waddensea and around Helgoland to demonstrate the impact of changing currents and water depth on the wave development. In these situations the propagation effects (shoaling and refraction) are balanced by the source functions and especially by the wave dissipation of wave energy.

2 WAVE MODEL

The K-model is a discreet spectral wave model solving the action density balance equation in wave number space, Schneggenburger et al. (2000) and Schneggenburger et al. (1998). It was developed for small-scale (typical grid resolution from 50 m up to a few 100 m) applications with non-stationary currents and water depths. Restricted to the essential physical processes in such environments, the model includes in the source functions the energy input (modified Snyder source term and Phillips source term), energy dissipation (turbulent diffusion) and energy dissipation by bottom friction. The source and sink terms are balanced by the propagation terms, which include refraction and shoaling.

The model is forced by wind fields (at 10 m height, typically every hour) and current and water level fields (typically every 20 minutes). At land boundaries of the model area free outflow of energy is assumed. At the open sea boundaries wave spectra have to be used. For the following examples these spectra are taken out of a North Sea model runs with a coarse resolution of 30 km with an input frequency of 1 hour.

Previously published in Proceedings of 11th International Biennial Conference on Physics of Estuaries and Coastal Seas (PECS'02) Hamburg, Germany, September 17-20, 2002

3 APPLICATIONS

In the following two applications of the model are discussed. In 3.1 the impact of sea floor changes on waves and currents in a Waddensea area to the southwest of the Elbe river estuary is investigated. In 3.2 a study of the Helgoland area to quantify the impact of variable water depth and/or currents on the wave development and propagation is presented.

3.1 WADDENSEA

To estimate the impact of topographical changes on the wave and current climate in a Waddensea area in the southern North Sea, we examined the results of the spectral wave model and a hydro-dynamical model for different storms and for a 20 days period of moderate weather conditions. Two bathymetries were used, one representing the actual condition and a worst case scenario of dredging sand in an area of approximately 6 km^2 increasing the water depth by 2 m from 10 m to 12 m at once.

The model results are compared to find the area of changes and the places where major changes occur. During a north-westerly storm in January 1994 the biggest differences (after dredging – before dredging) are found to be approximately 20 cm in significant wave height (see figure 1, white areas are land or dry flats. White lines show the 0 and 10 m water depth contours giving an indication of the bathymetry with tidal channels and adjacent flats). The waves at the boundary of the model area had a height of about 6 m during the peak of the storm.

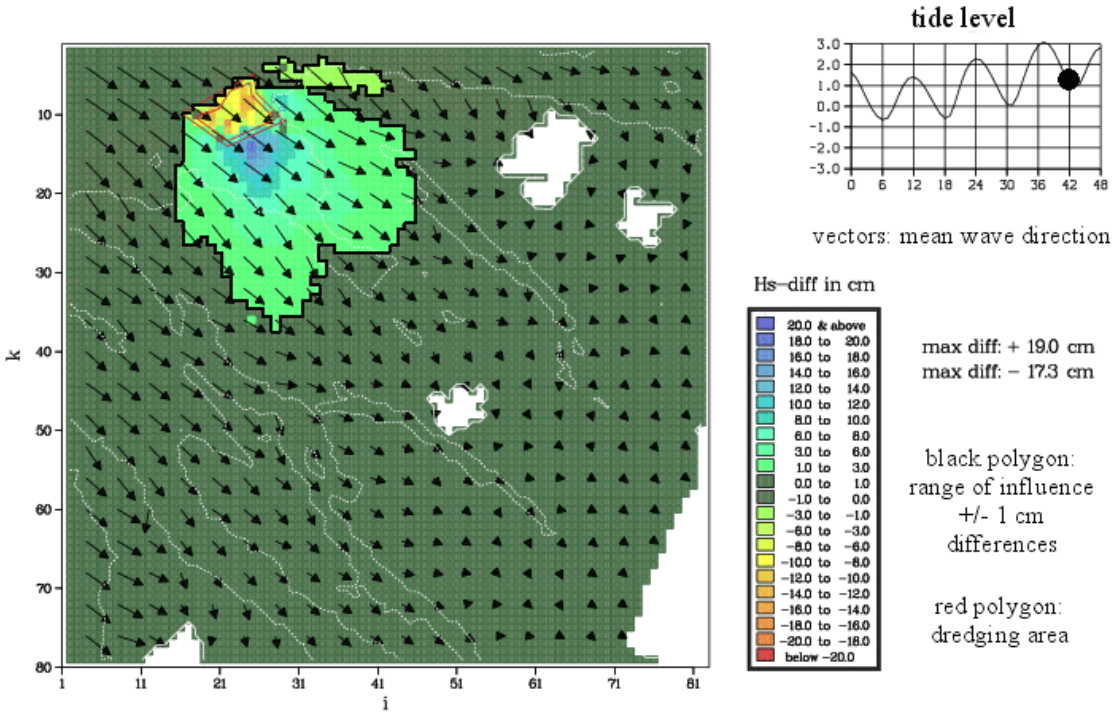

Figure 1: Differences of significant wave height (after dredging – before dredging) 1994 01 28 18:00.

Only in a spatially limited area at and in the vicinity of the dredging site the wave climate is changed noticeably due to differences in shoaling and energy dissipation. Currents are altered only slightly after dredging.

3.2 Helgoland

We investigated the influence of variable current and water level fields on the results of the spectral wave model near the North Sea island Helgoland. This area is characterized by strong water depth gradients (from 50 m – 0 m over a distance of 5 km) especially to the southwest from the island. Two model runs were performed, one with unchanged initial bathymetry, another one taking spatial and temporal water level and current variations into account.

During a storm in October 1998 with wind speeds up to 24 m/s – the wave model calculated a significant wave height of 5.5 m on a coarse North Sea grid at the nearest grid point to the fine grid area of interest (50 m resolution) – the waves approached the island from a direction of 290 degrees. Above the slope the wave heights increased to a maximum of 6.5 m due to refraction and shoaling effects.

Performing the second model run with time series of current and water level variations the shoaling and refraction of waves changed significantly. At high tide shortly after the storm peak a difference plot of significant wave heights shows especially off the western coast 2 stripes of high differences (see figure 2). In front of the coast positive differences of up to 1.5 m can be observed which can be explained with greater water depths and reduced energy dissipation. Further to the west negative differences of up to 1.5 m show that due to greater water depths the shoaling of waves locally is reduced. The shoaling now takes place in front of the coast, adding there to the high positive differences.

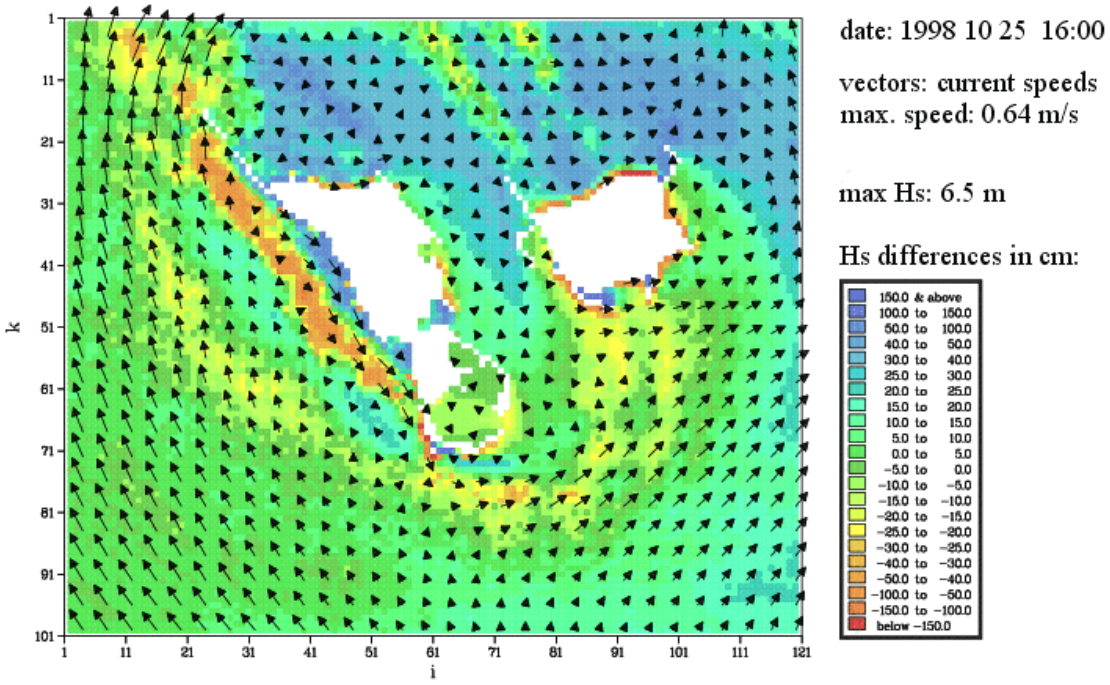

Figure 2: Differences of significant wave height (variable depth/currents – constant fields).

4 CONCLUSIONS

In small-scale coastal applications the influence of water level and current variations cannot be neglected. The example of the coastal area of the island of Helgoland showed that locally the balance effects with shoaling in case of sloping bottom and in the presence of in-stationary water depth and current fields led to high differences in significant wave height fields compared to the scenario with constant bathymetry. In case of the Waddensea

area example changing the bathymetry locally led to much smaller differences due to a reduced bottom slope compared to the Helgoland area.

5 ACKNOWLEDGEMENT

Those studies were done in close co-operation with The Federal Waterways Engineering and Research Institute - Coastal Division (BAW-AK)

6 REFERENCES

Komen, G. J., L. Cavaleri, M. Donelan, K. Hasselmann, S. Hasselmann, P. A. E. M. Janssen, Dynamics and Modelling of Ocean Waves, 1994: Cambridge University Press, Cambridge, UK, ISBN 0 521 43291, 560 pages.

Rosenthal, 1989: W., Deviation of Phillips a-Parameter from Turbulent Diffusion as a Damping Mechanism, In: Radar Scattering from Modulated Wind Waves, Komen, G. J. and W. A. Oast (eds.), Kluwer Academic Publishers.

Günther, H. and W. Rosenthal, 1995: A Wave Model with a Non-linear Dissipation Source Function, in Proceedings of the 4th International Workshop on Wave Hindcasting and Forecasting, October 16-20, 1995, Banff, Alberta, Canada, pp. 138-148.

Schneggenburger, Ch., H. Günther, W. Rosenthal, 2000: Spectral wave modelling with non-linear dissipation: validation and applications in a coastal tidal environment, Elsevier Coastal Engineering, 41, pp 201 – 235.

Schneggenburger, Ch., H. Günther, W. Rosenthal, 1998: Shallow water wave modelling with non-linear dissipation: application to small-scale tidal systems, GKSS 98/E/7.