Transactions on the Built Environment vol 40 © 1999 WIT Press, www.witpress.com, ISSN 1743-3509

Comparison of nearshore wind-wave measurements and model results in the development of a coupled wind-wave, hydrodynamic and sediment transport model for estimating coastal zone erosion

E. Juntura, (1) H. Ylinen, (2) M. Virtanen (2)
(1) VTT Communities and Infrastructure, Water Engineering and Ecotechnology, P.O. Box 19042, FIN-90571 Oulu, Finland. EMail: Esa.Juntura@vtt.fi
(2) Environmental Impact Assessment Centre of Finland (EIA) Ltd, Tekniikantie 21B, FIN-02150 Espoo, Finland. EMail: Hannu.Ylinen@eia.fi

Abstract

This study is a part of a project to develop a connected sediment transport, wind-wave and 2D hydrodynamic model to estimate coastal erosion. The wind-wave model was adapted from SWAN-nearshore wave model. As a preliminary work, wind-wave model results were compared with nearshore wave height measurements from two sites in Finnish coast of the Baltic Sea. More comprehensive results of the development project will be published in near future.

1 Introduction

Different processes shaping coastal zones have been studied with the help of numerical models since the invention of electronic computers. Separate models for wind-waves, erosion and hydrodynamics have been developed since the 1940's. Different groups in several countries in Europe (for example Delft

Hydraulics, Danish Hydraulic Institute) have developed coupled wind-wave and erosion models during the last couple of decades.

Advanced separate models exist for modelling the wave climate, hydrodynamics and sediment transport on the coastal zone. The aim this development project was to develop a coupled wind-wave hydrodynamic and sediment transport model for estimating coastal zone erosion. This study handles the background of the project and the comparison of the wave height measurements with the wind-wave model results.

Participant organizations of the development project had significant experience with 2D and 3D-hydrodynamic models (Koponen et al.[1]) and some experience in wind-wave and erosion modelling (Virtanen et al.[2], Juntura, Koponen, Alasaarela[3]). After a small project where separate models were used for erosion prediction (Juntura et al.[4]) it was seen that a coupled model approach could be more useful and practical in the future. A decision was made to use the existing advanced 2D-hydrodynamical models developed within the research group and couple an existing wind-wave model to it. The erosion model was chosen to model horizontal sediment fluxes by 1D vertical advection - diffusion equation with mixing length turbulence model.

Of the existing wind-wave models the SWAN model developed in Technical University of Delft, Netherlands by the SWAN team including R. C. Ris, L. Holthuijsen, N. Booij, I. Haagsma and A. Kieftenburg, was chosen for it's versatility and free source code. SWAN has been thoroughly presented by Ris[5].

2 Material and methods

The model results have to be compared with real world conditions to assess the model capability to predict them. To accomplish this long-term fixed measurements and mobile wave height measurements were made in two areas in the coasts of Northern and Southern Finland. Wave direction could not be measured with these single-sensor instruments.

The fixed measurements were made using stand-alone pressure measurement station GWMS-2001 developed and manufactured by GWMS Engineering, Kuopio, Finland. The fixed station sent hourly measurements automatically by GSM mobile communications link. Data was collected each hour for 4 minutes at 10Hz frequency and then transmitted via GSM to monitoring computer at VTT in Oulu. The pressure measurements were converted to wave heights using method developed by Nielsen[6]. The long-term measurement sites and periods are displayed in Table 1.

Table 1. Long-term measurement sites and periods

Site	Depth at deployment	Start of measurements	End of measurements
Marjaniemi, Hailuoto Island, Bothnian Bay, Northern Baltic	1 m	June 18 1998 12:00	July 17 1998 10:00
Kauppakari, Ruissalo, Turku Archipelago	1 m	September 24 1998 17:00	October 17 1998 17:00

Marjaniemi site was situated on a beach south of Marjaniemi harbour with a slope of 1/100 and open fetch of over 100 km to southwestern direction. Depth was 1m at deployment. Distance from the shoreline was about 100 meters.

Kauppakari site was situated in a more closed environment about 1km southeast of Ruissalo Island in the Turku archipelago. Slope of the beach was 1/10 and maximum open fetch was approximately 1 km northwest. Depth of the measurement site was 1m at the deployment. Distance from the shoreline was approximately 10 meters.

The first measurements in Hailuoto ended prematurely as the measurement mast fell over in hard conditions. For further measurements in Ruissalo a more robust tripod base was constructed for the equipment. The dates and numbers of mobile measurements made are shown in Table 2.

Table 2. Dates of mobile measurements

Site	Date of measurements	Number of measurements
Hailuoto Island, Bothnian Bay, Northern Baltic	June 17, 1998	3
	July 2, 1998	2
Ruissalo, Turku archipelago	September 22-23,1998	13

Mobile measurements were made in the shoreline area to assess the wave damping on the shore. Measurement system consisted of a capacitive water level meter and portable computer with logger software. Measurement frequency was 4 Hz.

Measurements were also made in the nearshore area in Ruissalo within vegetation to have comparison data for including the processes involving vegetation in the model. Vegetation consisted of a thick *phragmites* growth. Wave height was measured in a rapid succession at two depths in a beach near vegetation and at two depths inside vegetation zone. Due to lack of time the data set was thus quite small.

For future flow velocity comparisons with the model results and real world conditions, acoustic doppler current velocity measurements were made from aboard R/V Aurelia of the Archipelago Sea Research Institute of the University of Turku during the Ruissalo measurement excursion.

3 Measurement results

The significant wave heights H_{sign} were chosen to be the first variable to be used in the comparison of model and measurement results. Significant wave heights H_{sign} were calculated from the wave height measurements using standard deviation method, where

$$H_{sign} = 4*\sigma. \tag{1}$$

In equation (1) σ is the standard deviation of the wave height measurements.

3.1 Long-term measurements

During June 1998 the winds at Bothnian Bay were very light and consequently significant wave height rarely exceeded 0.1 meters. The results of Hailuoto measurements are displayed in Figure 1.

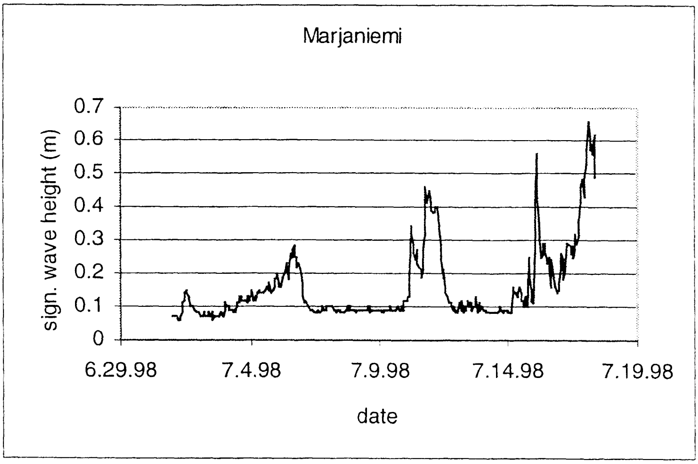

Figure 1. Measurement results from the July 1998 Hailuoto measurements.

Some periods with stronger wind are visible from the wave height measurements. The analysis of results was concentrated on these strongest wind periods.

The September 1998 measurement period in Kauppakari was also dominated by light winds and significant wave height was mostly below 0.1 meters. The results of Kauppakari measurements are displayed in Figure 2.

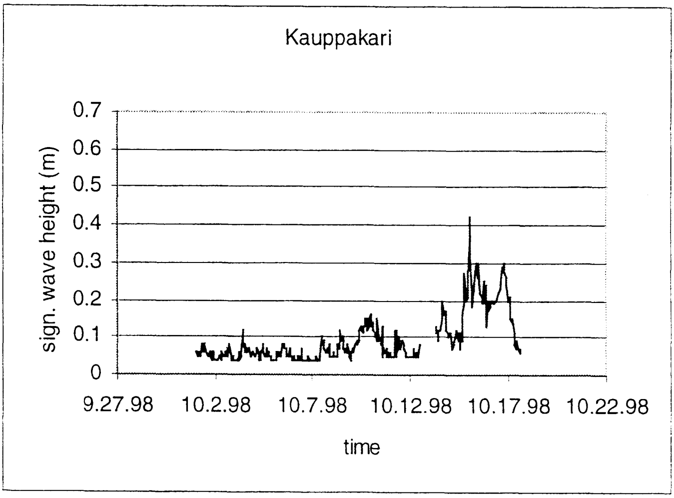

Figure 2. Measurement results from the October 1998 Ruissalo measurements. Some data is missing because of interruption in communications.

Also in the Kauppakari case the main interest was in the periods of strongest winds near the end of observations.

3.2 Mobile measurements

In the mobile measurements the main interest was in the effects of vegetation. These results are shown in Table 3 and Figure 3.

Table 3. Mobile measurements near Ruissalo.

meas. no.	site	date and time	depth (m)	series in Figure 5	*phragmites*, distance from open water	H(sign) (m)
1	Kuuvannokka	9.22.98 11:58	1			0.16
2	Saaronniemi	9.22.98 13:46	0.7			0.11
3	Kauppakari	9.22.98 15:02	0.9			0.11
4	Kauppakari	9.22.98 15:17	0.3			0.18
5	Kallanpää	9.22.98 16:23	0.9	no phragmites		0.18
6	Kallanpää	9.22.98 16:30	0.4	no phragmites		0.17
7	Kallanpää	9.22.98 16:40	0.7	phragmites	10 m	0.16
8	Kallanpää	9.22.98 16:45	0.9	phragmites	7m	0.23
9	Kallanpää	9.23.98 15:39	0.5	no phragmites/2		0.18
10	Kallanpää	9.23.98 15:46	0.3	no phragmites/2		0.10
11	Kallanpää	9.23.98 15:53	0.5	phragmites/2	20m	0.14
12	Kallanpää 2	9.23.98 16:48	0.8	no phragmites/3		0.19
13	Kallanpää 2	9.23.98 16:52	0.8	phragmites/3	3.5m	0.22

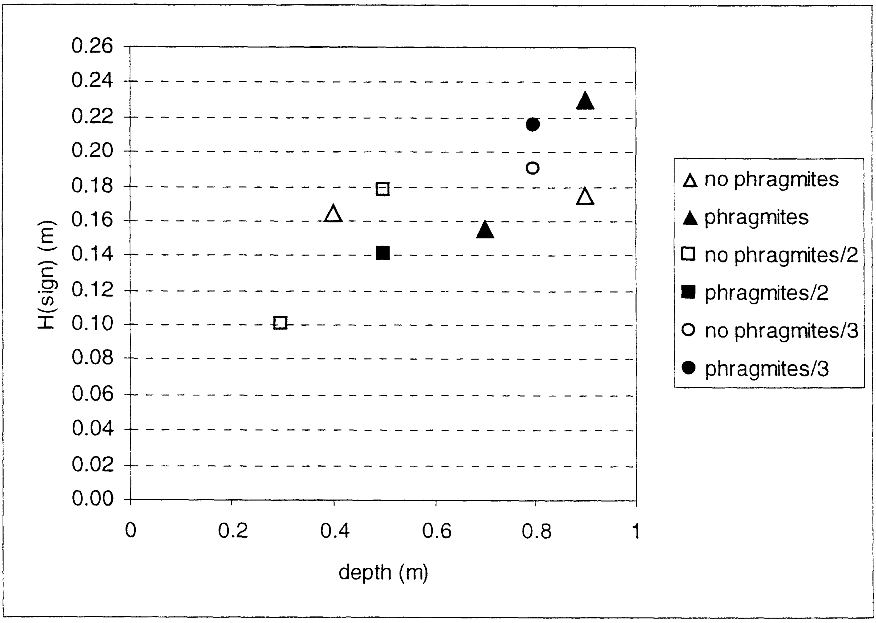

Figure 3. Measurements in sites with vegetation and without vegetation.

Near the border of the vegetation zone (within 0 - 8 m) the wave height seems at first to be somewhat amplified whereas further within vegetation (at 10 - 20 m) attenuation is clear. This indicates a need for further measurements.

4 Wind-wave model results

SWAN-wind-wave model was preliminarily tested in this study by making two steady-state runs corresponding to real-world conditions in two cases. Two grids were generated with 50-meter grid resolution. Kauppakari grid contained a 4500m x 5000m area around measurement site, including the most important fetch area. Kauppakari grid was based on digitized depth maps.
Marjaniemi grid was a more abstract one, only describing a beach with a slope of 1/100 with dimensions of 5000m x 5000 m. The Marjaniemi grid also included only the area closest to the shoreline and left out the greatest fetch area of over 100 km to southwest. This gives the possibility to assess the effect of possibly missing fetch areas on the results in the final applications of the complete model.
The simulation conditions were chosen based on the extreme wave height measurements and available wind measurement results from the direction of most open fetch during measurement periods.

Off Kauppakari, Oct.14, 1998, at 8 pm, southwestern wind 12 m/s resulted in significant wave heights 0.27 m as measured and 0.23 m as modelled. In

Marjaniemi, July 17, 1998, at 3 am., southern winds 10 m/s created 0.56 m significant wave heights from the fetch of 100 km in the sea while only 0.27 m was obtained from the 5 km's fetch in the model.

5 Discussion

The study of the effects of vegetation needs a larger data set to be collected to have more statistical relevance. The expected dissipative effect of vegetation was clear only in the deeper areas of the vegetation zone. Closer to the border the measurements indicate even amplification of significant wave height.

Longer period test runs are needed to complement the single steady state runs. This will help to assess the reliability of long-term simulations.

Kauppakari results show quite close agreement between measurements and model results. Clearly the relatively small enclosed nature of the modelled area gives much better results than in the Marjaniemi case.

In Marjaniemi results it can be clearly seen that long fetches cannot be overlooked in calculations. Measured values are over two times greater than the model results. In future applications it may be necessary to have refined grid in the nearshore area of interest to improve spatial resolution and a coarser grid in the open sea areas to take large fetches into account.

6 Conclusions

In line with the work and results presented here, the wind-wave model has been connected to the water current and erosion models. The current and erosion models are composed by a 2D vertically integrated current model and by a separate 1D model for vertical profiles of currents and sediments ("quasi-3D"). The vertical model uses friction velocity depended bed concentration as a boundary value for an advection-diffusion model with mixing length turbulence. Bed load and Lagrangian drift transport are included. To speed up the computation, wave period averaged sediment fluxes and bottom friction values are pre-calculated for several values of current velocity, wave orbital velocity, wave-current angle, radiation stress, wave period and water depth terms. These values are stored in large look-up tables and interpolated in actual calculation. The methodology used follows closely the one by Fredsøe and Deigaard[7].

Extensive verification with measured data and analytical values, and perhaps inclusion of physical parameters for practical use are needed for further testing of the model systems and for the completion of its development.

Acknowledgements

This research and product development project was funded by the TEKES Finnish Technology Development Centre grant. Numerous people outside the research team contributed to the project, most notably Tapio Suominen from the Southwest Finland Environment Centre and the staff at the Hailuoto Biological Research Station of the University of Oulu. Many thanks go to Mr. Mika Visuri for his invaluable field expertise. Mobile measurement equipment was loaned from the Department of Geography, University of Oulu, Finland.

References

1. Koponen, J., Alasaarela, E., Lehtinen, K., Sarkkula, J. Simbierowicz, P., Vepsä, H. & Virtanen, M., *Modelling the Dynamics of a Large Sea Area.* Publications of the Water and Environment Research Institute 7. National Board of Waters and Environment, Helsinki 1992.

2. Virtanen, M., Koponen, J., Huttula, T. & Alasaarela, E., Approximation of Sedimentation and Erosion in Transport Models, *Proc. of the Nordic Hydrological Conference*, KOHYNO Coordination Committee for Hydrology in Nordic Countries, NHP-Report 22(1), pp. 281-293, 1988.

3. Juntura, E., Koponen, J., Alasaarela, E., Modelling resuspension in the Bothnian Bay, Northern Baltic, *Boreal Environment Research*, **1**, pp. 27-35, 1996.

4. Juntura, E., Ylinen, H., Virtanen, M., Ihme, R., *Study of the Possible Construction Solutions for the Blocking of Siltation of the Keskuskari Harbour (in Finnish)*, Research Reports of VTT Communities and Infrastructure, 401/97, 1997.

5. Ris, R. C., *Spectral Modelling of Wind Waves in Coastal Areas*, Communications on Hydraulic and Geotechnical Engineering, Delft University of Technology, Delft, 1997.

6. Nielsen, P., Analysis of Natural Waves by Local Approximations, *J. of Waterway, Port, Coastal and Ocean Engineering*, Vol. 115, No. 3, pp. 384-396, 1989.

7. Fredsøe, J., Deigaard, R., Mechanics of Coastal Sediment Transport, World Scientific, Singapore, 1992.