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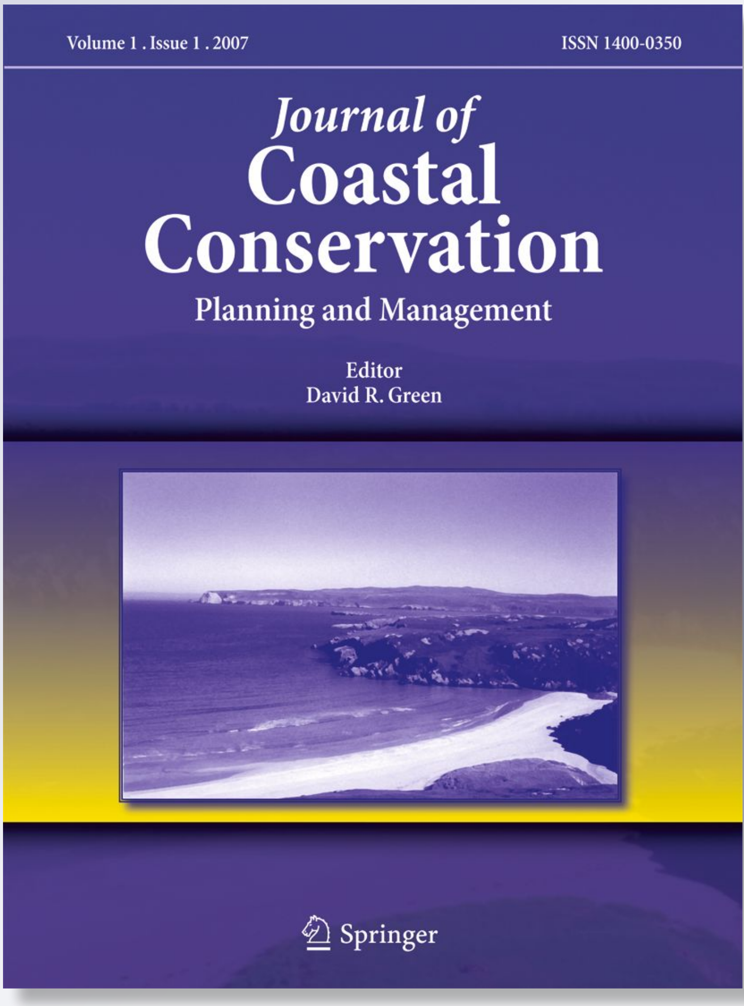

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Abstract In this paper, a cross-shore profile evolution model, Uniform Beach Sediment Transport-Time-Averaged Cross-Shore (UNIBEST-TC), is used. The model was developed at WL/Delft hydraulic laboratory in the Netherlands. The model is used to predict wave height in a barred beach (Egmond site, The Netherlands) and the results show that there is a good agreement between the measured and predicted values by the model. In the present study, Morlet wavelet is used to distinguish the breaking waves; it is integrated over frequency to provide the temporal variation of localized total energy. The study shows that the local peaks of the energy densities correspond to the events of wave breaking in the predicted–wave time series. Furthermore, the wave energy distribution shows a tendency to decrease in the off-shore direction of the inner bar.

Keywords Morlet wavelet · Wavelet power spectrum · Wave breaking · Barred beach

Introduction

Prediction of wave height variations in barred beaches has a great importance in analyzing the phenomenon of bar migration. A cross-shore profile evolution model, Uniform Beach Sediment Transport-Time-Averaged Cross-Shore (UNIBEST-TC), is used in the present study to predict wave height variations across the measured profiles in barred beach (Elsayed 2006). The model was developed at WL/Delft hydraulic laboratory in the Netherlands.

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Beach behaviour usually is expressed by the temporal position of the high water line (HW), low water line (LW) or dune foot line (DF), but spatial beach variations due to alongshore migrational features such as sand waves, crescentic bars, rip channels, etc.… can also be observed. Temporal and spatial variations of the shoreline are closely related and often are manifestations of the same phenomena. Temporal variations generally show a mean component (time-averaged trend) and a fluctuating component (variability). The mean component can be a linear trend (erosion or accretion), but most often it is a long-term oscillation cycle (erosion followed by accretion or vice versa) and generally is of the order of 1 m/year for straight coasts. Near inlets these mean (trend) values may be somewhat larger (up to 10 m/year) due to the interaction of the beach with large scale bars and flats detaching from or attaching to the coast (bar–channel interaction). The temporal variability of the shoreline is of the order of 10 m for straight coasts up to 100 m/year for inlet coasts (Van Rijn 1998; Van Rijn et al. 2003). Temporal beach variability of straight coasts on the seasonal time scale is most closely related to seasonal variations in wave conditions (storm–fair weather cycle, storm intensity) and the local breaker bar configuration. The typical beach-bar behaviour on the time scale of the system during the winter season and onshore migration and beach recovery during the summer season (low waves). Seasonal variation resulting in so called winter and summer profiles is a general characteristic of nearshore morphological behaviour, but the degree of seasonality varies widely (Van Rijn et al. 2003). Along Pacific coasts the nearshore bars often disappear during the summer period (bar welding to beach); along many other coasts the nearshore bars are permanent features. The knowledge of the seasonal variability of nearshore bars has increased considerably during recent years due to the use of video remote sensing techniques (Lippmann et al. 1993; Van Enckevort 2001).

Breaking waves play an important role in the exchange of mass, momentum, and energy (Agrawal et al. 1992) and gases (Wallace and Wirick 1992) between the atmosphere and the ocean. Radar reflectivity is used extensively in both laboratory and field investigations of wave breaking (Banner and Peregrine 1993).

In barred beaches, wave breaking has a great effect in bar migration as the dissipation of energy is enormous. The main goals of the present study are the following:

- To validate the UNIBEST-TC wave model by comparing model results with the measured data in the Egmond site in the Netherlands.
- To use wavelet to analyze wave breaking and examine the energy level variations in the barred beach of Egmond site in the Netherlands.

Collected data

The field site in Egmond is a coastal area of about 1 km along shore and about 1 km offshore. It is situated south of the village of Egmond aan Zee in the Netherlands (see Fig. 1). Longshore differences in the offshore wave climate are small because of the relative uniform orientation of this stretch of the Dutch coast. The wave climate is dominated by wind waves related to low-pressure areas moving from west (Atlantic) to east (European Continent). The tidal range near Egmond varies between 1.2 m (neap tide) and 2.1 m (spring tide). At the site, the flood tide has a duration of 4 to 5 h and the ebb tide of 7 to 8 h. The horizontal tide runs ahead of the vertical tide by about 30 to 45 min. The semidiurnal tide induces asymmetrical long-shore currents, which may reach values of 0.6 to 1.0 m/s. The data set (all measured data) for the event of 30 April 1998 to 5 May 1998 was available as an Excel file prepared by Delft Hydraulics within the COAST3D project (Elsayed 2006; Van Rijn et al. 2003).

The instruments used during the COAST3D campaigns are:

- electromagnetic velocity meters;
- acoustic Doppler velocity meters ADV and ASTM;
- acoustic Doppler current velocity profiler ADCP.

For wave height measurements, water level fluctuations have been measured by various pressure sensors.

The University of Caen (tripod-arrangement) has used Paroscientific 2100-A pressure sensors. The precision of this instrument is 0.015% i.e. 1 cm for a maximum range of 0–70 m (0–100 psi). The resolution is 0.0015% (0.1 cm).

The pressure sensor of Univ. of Cean (Van Rijn, et al. 2000) used on the S4 system has a precision of ±0.15% of the full scale (±10 cm for range of 0 to 70 m). The resolution is 4 mm.

The atmospheric pressure influence was eliminated (Univ. of Caen) by fitting a linear function between the atmospheric pressure and the height recorded by the pressure sensors above water. After compensation, residual errors (difference between the corrected height measured by the pressure sensor above water and the theoretical value that should be zero) of up to ±5 cm were observed during the main experiment at the Teignmouth site 1999. This value may be considered as a realistic order of magnitude for the accuracy of this compensation process. It nevertheless depends on the number of readings of the atmospheric pressure during the measurement period.

The pressure transducers used by the University of Utrecht have the following characteristics: ± 0.25% of measured value; linear calibration curve (correlation coefficient >0.99). The instrument offset is determined in the laboratory prior to deployment and taken into account by the calibration curve. Afterwards, barometric (air) pressure (measured in the field every 10 min), is taken into account (accurate to ±1 cm).

The measurements for wave propagation model (wave height, wave direction and wave period) are used in the present study and Fig. 2 gives the schematic layout of instruments for the experiment within COAST3D project.

Methodology

UNIBEST-TC model

UNIBEST-TC model consists of a combination of several sub-models. Wave propagation model is applied in the present study. According to the given wave climate and the bottom profile the wave sub-model then calculates the cros-shore distribution of root mean square wave heights, wave set-up, wave angle, the energy dissipation and all other necessary input data for the other sub-models. The wave propagation model calculates the wave energy decay along a cross-shore ray including the effects of shoaling, refraction and energy dissipation. The model consists of three first order differential equations as follows;

- The time averaged wave energy balance (Battjes and Janssen 1978):

$$\frac{\partial}{\partial x}\left[EC_g \cos\theta\right] = -D_w - D_f \quad (1)$$

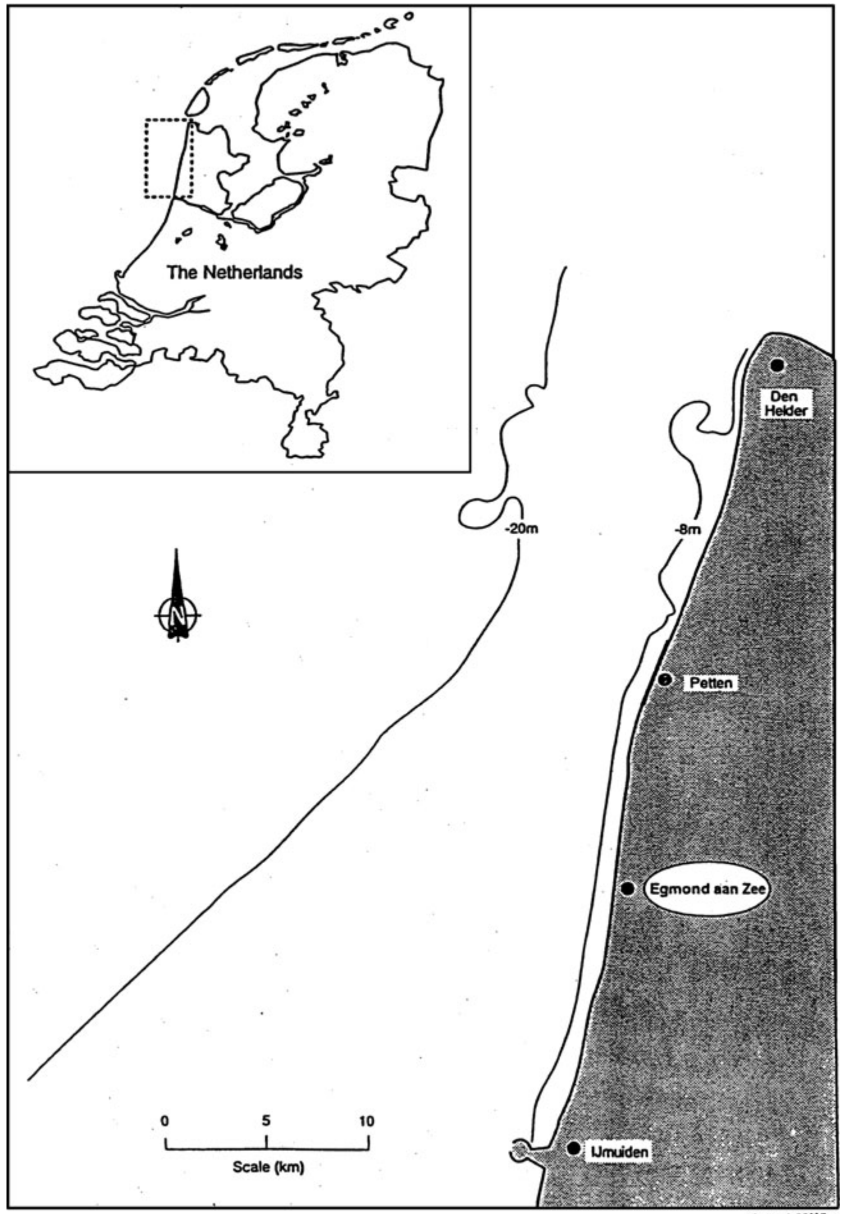

Fig. 1 Map of site for 2.5 D experiment

Where;

- E Wave energy (J/m^2)
- C_g Wave group velocity (m/sec)
- D_w Dissipation of wave energy due to wave breaking (J/m^2)
- D_f Dissipation of wave energy due to bottom friction (J/m^2)
- θ Wave approach angle

- The balance equation for energy contained in surface rollers in breaking waves (Nairn et al. 1990)

$$\frac{\partial}{\partial x}[2E_r C\cos\theta] = D_w - Diss \tag{2}$$

Where;

- E_r Roller energy representing the amount of kinetic energy in the roller
- Diss Dissipation of roller energy=2bg E_r/C (J/m^2)
- b The slope of the face of the wave(−)
- C Phase velocity of waves

- Horizontal momentum balance from which the mean water level set-up is computed through:

$$\frac{\partial\eta}{\partial x} = -\frac{1}{\rho g h}\frac{\partial S_{xx}}{\partial x} \tag{3}$$

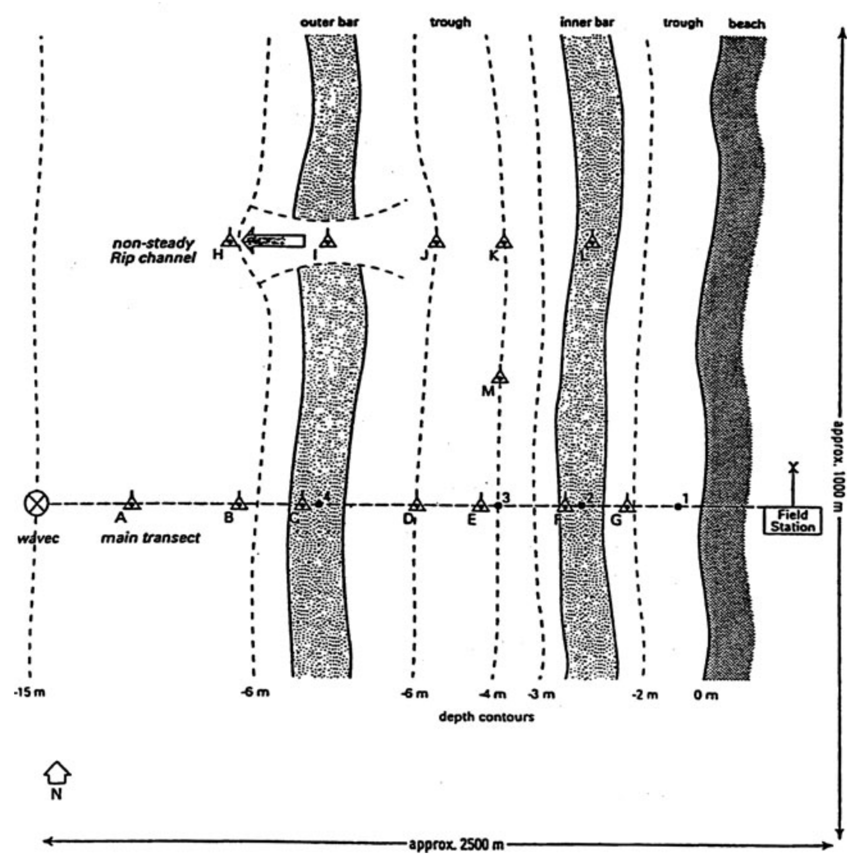

Fig. 2 Schematic layout of instruments for 2.5 D experiment

Where;

η	water surface elevation above MSL (m)
S_{xx}	Radiation stress in the cross-shore direction.
h	water depth

Continuous wavelet analysis

The continuous wavelet transform $W(a, \tau)$ of a function h (t), is defined as:

$$W(a,\tau) = \int_{-\infty}^{+\infty} h(t)\psi^{*}{}_{a,\tau}(t)dt \qquad (4)$$

where a and τ are scale and time variables respectively, and $\Psi_{a,\tau}$ represents the wavelet family generated by continuous translations and dilations of the mother wavelet $\Psi(t)$. These translations and dilations are obtained by

$$\psi_{a,\tau} = \frac{1}{\sqrt{a}}\psi\left(\frac{t-\tau}{a}\right) \qquad (5)$$

Following Torrence and Compo (1998) and Addison (2002), the complex Morlet wavelet (Morlet 1981) to be implemented in this study is defined as:

$$\psi(t) = \Pi^{-1/4}e^{iw_o t}e^{\frac{-t^2}{2}} \qquad (6)$$

In this definition, wo is defined as a mathematical parameter required to satisfy the admissibility condition in the mathematical wavelet theory (Farge 1992).

Local total energy

An integration of the wavelet transform over time gives energy spectrum, whereas integration of the wavelet transform over frequency provides a temporal variation of the localized total energy (Liu 1993, 1994). The MATLAB code developed by Torrence and Compo (1998) to compute the continuous wavelet transform of the time series of the signal is modified to compute the localized total energy and this approach was carried out successfully by Elsayed (2008) and LIU (1993) .

Results and discussions

Figures 3, 4, 5 and 6 give the predicted wave height at points 1a,1b,1c,1 d as shown in the figures. A close inspection of the figures reveal that there is a very good

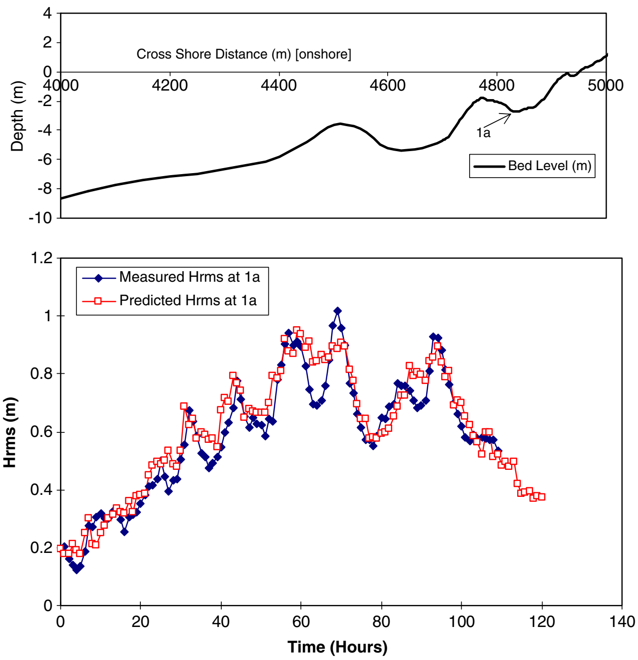

Fig. 3 Measured and predicted wave height at point 1a, Egmond, the Netherlands

agreement between the measured and predicted values by the model for all selected points above the inner bar and these findings agree with our earlier study (Elsayed 2006).

The integration of wavelet transform over frequency gives the temporal variation of the localized energy, as shown in Fig. 7 for point 1a above the inner bar, Fig. 8 for point 1b, Fig. 9 for point 1c, and Fig. 10 for point 1 d

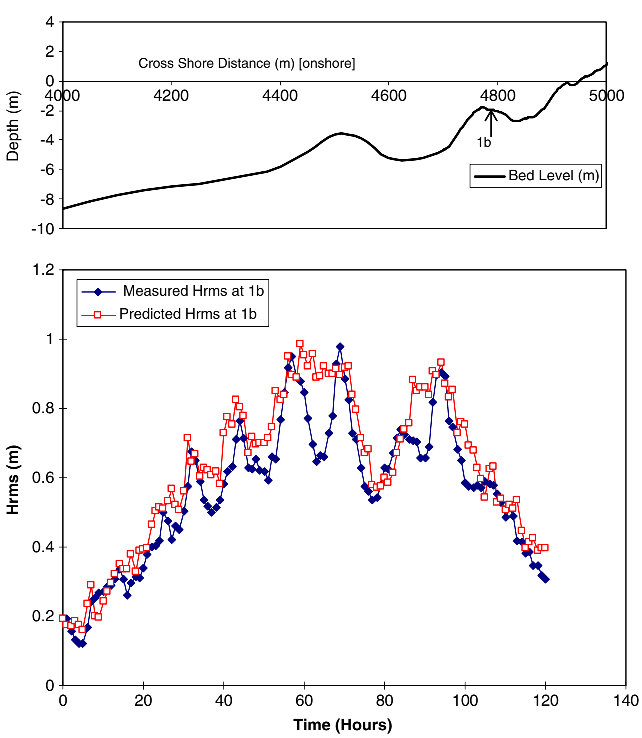

Fig. 4 Measured and predicted wave height at point 1b, Egmond, the Netherlands

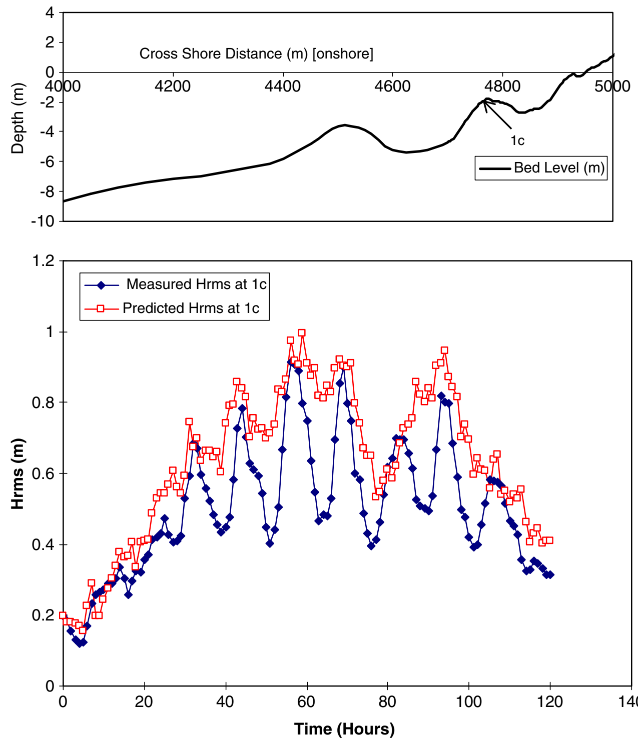

Fig. 5 Measured and predicted wave height at point 1c, Egmond, the Netherlands

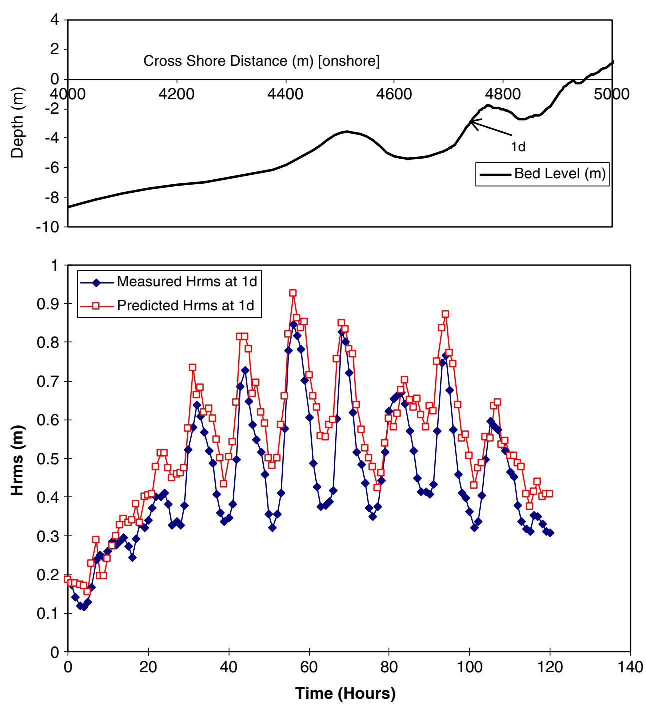

Fig. 6 Measured and predicted wave height at point 1 d, Egmond, the Netherlands

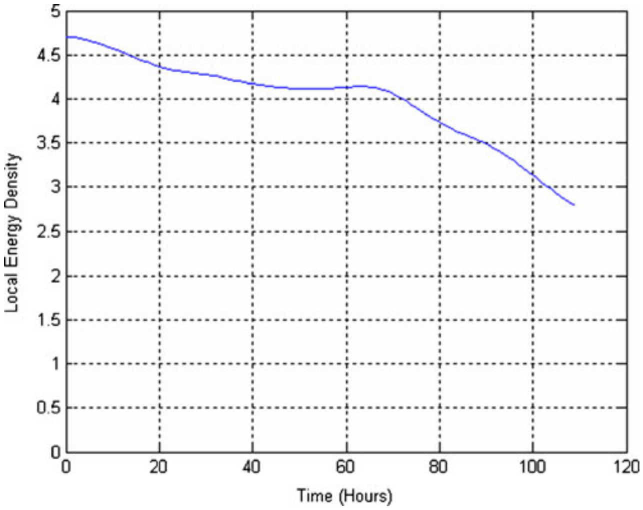

Fig. 7 Temporal variations of localized energy density at point 1a

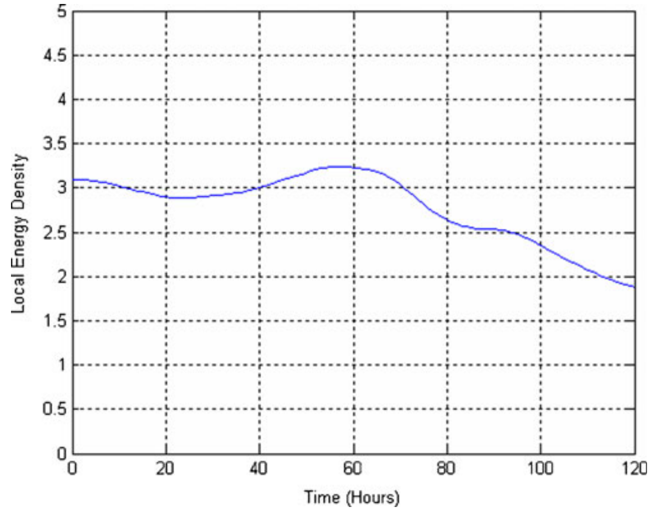

Fig. 9 Temporal variations of localized energy density at point 1c

that are located above the inner bar in Egmond site.. The peaks shown in these plots correspond to the events of wave breaking as found in our earlier study (Elsayed, 2008). Besides these results agree with the findings of Liu (1993).

A close inspection of these plots reveal that the energy dissipation decrease in the off-shore direction of the inner bar.

Conclusions

A cross-shore profile evolution model, Uniform Beach Sediment Transport-Time-Averaged Cross-Shore (UNIBEST-TC) is used in this study to predict the wave height variations above the inner bar of Egmond site in the Netherlands. The results show that there is a very good agreement between the measured and predicted values of wave height by the model and these results agree with our earlier findings (Elsayed 2006) .

In this study, a new technique in analyzing wave breaking is applied through the use of wavelet transform. The use of Fourier transform in the spectrum analysis has shortcomings in neglecting important temporal and localized characteristics of the signal. The integration of wavelet transform over frequency gives the temporal variations of the localized energy that are found to be correlated with the events of wave breaking in the wind–wave time series, and this agrees with Liu (1993, 1994). Furthermore, the wave energy distribution shows a tendency to decrease in the off-shore direction of the inner bar.

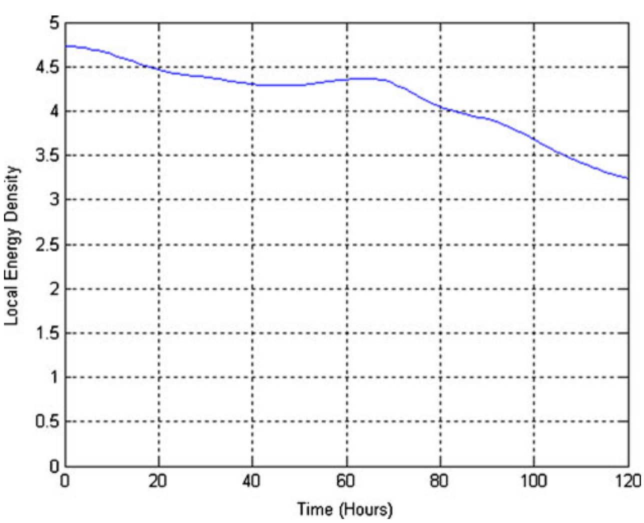

Fig. 8 Temporal variations of localized energy density at point 1b

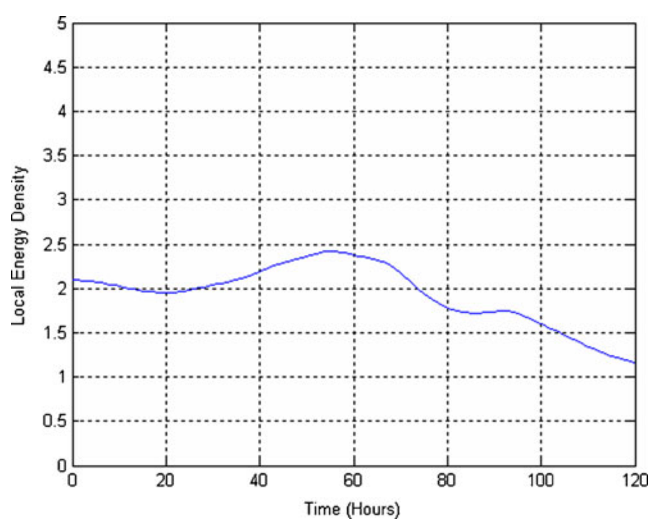

Fig. 10 Temporal variations of localized energy density at point 1 d

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