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Application of Two Coastal Profile Evolution Models to Lubiatowo, Poland and La Barrosa, Spain

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Abstract

Two contrasting coastal profile models are applied to three bathymetries including a uniform gradient beach and natural profiles (multi-barred and multi-stepped) obtained from Lubiatowo, Poland and La Barrosa, Spain. The first model, developed at the Institute of Hydro-Engineering of the Polish Academy of Science (IBW PAN) (Poland), couples a quasi-3D model for nearshore hydrodynamics with a quasi-phase resolving sediment transport model which considers transport in the bed load, contact load and outer layers. The second model (PLYMPROF), developed at the University of Plymouth (UK), couples a relatively simple wave transformation model with a new abstracted description of cross-shore sediment transport beneath waves.

A variety of model simulations are described, including simple runs with uniform wave forcing (up to 50 days in duration using PLYMPROF) and runs with parameterized wave forcing (wave height and wave period in deep water) for periods with one or two storm events (6–11 days total duration). Both models coped well with the different initial profiles and with uniform and time-varying wave conditions. The results of the simulations suggest that onshore-directed sediment transport in the shoaling and outer surf zones is dominant for the cases considered. Compared to the IBW PAN model, the PLYMPROF model results (using coefficients from a separate study of bar evolution at Duck, USA) show larger offshore-directed transport in the inner surf zone associated with return flow, with the overall sediment transport pattern located considerably closer to the shore. Alteration of a single coefficient in the PLYMPROF model shifts the predicted transport pattern seawards, but also results in enhanced offshore-directed transport.

Despite differences in predicted cross-shore sediment transport the two models produced surprisingly similar trends in overall profile evolution suggesting that feedback between existing bathymetry and the sediment transport pattern may exert a major control on profile development. Results also suggested that bar migration patterns cannot be simply related to the occurrence or absence of storm conditions, but rather depend more subtly on the exact placement of wave breaking locations in relation to existing bars. Incorporation of tidal water level variations for La Barrosa produced small changes in model predictions, with tidal migration of the sediment flux pattern suppressing the development of bar morphology in line with the form of the observed profile.

Key words: beach, coastal profile model, hydrodynamics, sediment transport

1. Introduction

This paper describes a contribution to the EC-funded project HUMOR (Human Interaction with Large-Scale Coastal Morphological Evolution) that took place between February 2001 and January 2004 under the leadership of the Grupo de Puertos y Costas at the University of Granada, Spain. The project involved 12 research institutes and universities from across Europe working collaboratively to develop reliable assessment and forecasting techniques to better understand, model and predict the physical and geomorphological processes governing medium and long-term natural changes in the coastal zone, including the impact of anthropogenic activities. One component of the project was to develop, extend and improve analysis and predictive tools (such as the models presented in this paper) for a wide range of coastal morphological phenomena, with these tools then being applied to a 'single cell' consisting of the coastline between Sancti-Petri and Tarifa in south-west Spain.

The use of mathematical models to explore the behaviour of natural systems such as coastlines and coastal morphological features is a long established procedure. It allows controlled experimentation into the response of the system to various forcing scenarios with rapid assessment of changes that occur in nature over longer timescales, relatively low cost and analysis of the sensitivity of predicted changes to variations in input parameters. The construction of such models involves the use of many assumptions and approximations, the accuracy of which may be limited by the level of understanding of the system being considered and the ability to develop robust computational systems. Within the field of coastal science and engineering, an ability to predict changes in the morphology of beach profiles has been an important goal for many years and attempts to produce useful models have followed a number of different approaches.

The simplest beach profile models are based on the concept of an equilibrium profile which suggests that the profile always adapts towards a preferred shape (such as an exponential or power law form) that depends upon the input wave conditions (e.g. Dean 1977). Such models have some use in determining the basic underlying form of a beach profile, but do not attempt to represent the detailed morphology of beaches that is often observed in nature (e.g. systems of sand bars) and, in particular, assume that the profile has sufficient time to respond to the wave conditions even though these (and other factors such as tidal water levels) are continuously varying. In practice, the morphological response time of beaches is likely to be considerably longer than the timescale associated with changes in the forcing conditions (e.g. Plant et al 2001, O'Hare and Huntley 2006) and so the likelihood of equilibrium beach profiles occurring in nature seems low.

Whilst equilibrium beach profile models ignore most detailed knowledge of the processes operating in the nearshore zone, 'process-based' models attempt to incorporate as much of this detail as possible. Most models of this kind exhibit a common structure consisting of sub-models that represent relevant hydrodynamics (such as nearshore waves, wave-driven currents and tides), associated sediment transport processes (including bed load and suspended load transport and sheet flow) and the resulting pattern of sediment movement and morphological evolution. The resultant beach profile is then used in combination with the appropriate hydrodynamic forcing to derive new estimates of sediment transport rates so that the overall model incorporates feedback between the various elements of the morphological system. In principle, the construction of such a model appears to be a simple task of determining the best possible theoretical description (i.e. containing the most accurate physics) of each component of the system and putting these components together within a suitable mathematical framework. However, in practice, although understanding of key processes has grown enormously in recent years, there is still great uncertainty about regarding how best to represent processes and even about which processes are important. This uncertainty is largely a result of the relative paucity of observations due to the extreme difficulty of making appropriate measurements, but also potentially arises because of the inherent complexity (e.g. randomness) of the systems being considered. In a recent assessment of six 'state-of-the-art' process-based cross-shore profile models van Rijn et al (2003) concluded that such models are still in their infancy and can best be useful as qualitative tools for comparison of one management solution against another. For short term (storm) time scales, it was found that this type of model could simulate the offshore migration of outer bars reasonably well, but failed to accurately simulate changes in the beach zone. Onshore migration of bars in post-storm periods could also be simulated but only when near-bed orbital velocities and variable bed roughness were represented in a sufficiently accurate manner. Over longer (seasonal) time scales, four of the six models considered were "unable to produce meaningful results" and the remaining two models could only simulate offshore migration of outer bars after sufficient tuning of model coefficients with measured profiles, with prediction of changes in the inner bar and beach zones remaining poor. Even more complex models, for example phase-resolving models that solve Boussinesq-type equations (Rakha et al 1997) or models that include the effects of storage, advection and settling of sediment within the surf zone (Kobayashi and Johnson 2001) have shown some promise in reproducing accretional conditions observed in short (several hours) laboratory experiments, but the use of such models for prediction of the longer-term evolution of nearshore profiles is prohibitively time consuming and prediction errors are likely to accumulate as the beach profile evolves (Kobayashi and Johnson 2001). Recently, Henderson et al (2004) report the use of a wave-resolving eddy-diffusive model of water and suspended sediment motion in the bottom boundary layer to simulate erosion and accretion on a natural beach, the successful prediction of two bar migration events (one shoreward, one seaward) and failure to predict a third (seaward) bar migration event (with events lasting up to five days in duration). However, their model was forced with detailed measurements of nearbed velocities across the profile concerned and so the model cannot be considered as a realistic tool for predicting evolution of a nearshore profile from a knowledge of offshore wave conditions, even for the short timescales considered.

An alternative approach to modelling the evolution of nearshore profiles over longer timescales involves what may be described as 'parametric' (or 'abstracted') models. Such models seek to retain only the essential detail of important processes. For example, the empirical model for bar migration suggested by Plant et al (1999) parameterizes the general tendency for sand bars to move towards the wave breakpoint and was able to explain 80% of the long-term variability of bar crest locations at Duck, USA for the period 1981–1996. Models of this kind generally only provide information on one aspect of the system being considered (bar location in the example given) and so have limited utility for assessing the overall profile behaviour. In other cases (e.g. Plant et al 2001, Masselink 2004, Plant et al 2004, Marino-Tapia et al submitted) a parametric model of cross-shore sediment transport has been combined with a simple model for wave transformation to produce a morphological model with similar structure to typical process-based models (but with much of the model physics replaced by a measurement-based parameterization). Such models have shown considerable promise for simulating profile development over medium-long time scales. For example, Plant et al (2004) report significant prediction skill for prediction periods between 3 and 17 days at Duck, USA provided that model parameters were adjusted in response to changing forcing conditions, Masselink (2004) describes model simulations with real wave forcing for a one year period that show good qualitative agreement with observations of multiple intertidal bars, and Marino-Tapia et al (submitted) produce excellent agreement with observed bar crest locations (again at Duck, USA) over a 77 day model simulation forced with actual offshore wave conditions.

In summary, cross-shore profile models exist in a variety of forms, ranging from simple equilibrium models, through parametric models which incorporate measurement-based descriptions of the pattern of cross-shore sediment transport that is observed to occur on many natural beaches, to more complex process-based models (even wave resolving models) which seek to include the most detailed descriptions of as many relevant physical processes as practicable. Although the more detailed modelling approaches show some promise on short timescales, at present parametric models appear to offer the best approach for assessing possible changes in the form of nearshore profiles over medium (weeks) and long (month-years) timescales

The objective of this contribution is to provide an outline of two contrasting cross-shore profile models that were developed and/or utilized within the HUMOR project and to discuss simulations performed with these models for a uniform gradient beach, a barred beach at Lubiatowo, Poland and the beach at La Barrosa within the HUMOR project 'single cell' (the latter containing a series of step-like bars). The first model, developed by researchers at the Institute of Hydro-Engineering of the Polish Academy of Science (IBW PAN model), couples a detailed quasi-3D model for nearshore hydrodynamics with a quasi-phase resolving sediment transport model whereas the second model, developed at the University of Plymouth (PLYMPROF model), combines a relatively simple wave transformation model with a new abstracted description of cross-shore sediment transport beneath waves. The simulations for the two field sites have been carried out with only minimal or no information to compare with model outputs and so the emphasis is on exploring the capabilities of the two models for application to real scenarios and attempting to gain insights into the kinds of morphological change that could be expected to occur in various forcing scenarios and the key processes that operate in each case.

In Section 2, a brief outline of the two cross-shore profile models is given. Information on the two field sites for which model simulations have been completed is provided in Section 3 and the results of these simulations and those with an initially uniform gradient profile are presented and discussed in Section 4. Finally, Section 5 describes the conclusions of the study.

2. Outline of the Cross-Shore Profile Models

2.1. The IBW PAN Model

The IBW PAN cross-shore profile model has been developed over a period of time by various researchers at the Institute. In particular, hydrodynamic aspects come from the modelling framework developed by Szmytkiewicz (2002) (also Szmytkiewicz 1995), while the sediment transport model was developed by Kaczmarek and Ostrowski (2002) based on earlier works (Kaczmarek and Ostrowski 1992, 1996) and amended by Ostrowski (2002). A very brief overview of the model is provided here and the reader is referred to the above sources for full details of the model equations and solution techniques.

The hydrodynamic model of Szmytkiewicz (2002) is a quasi three-dimensional model that assumes mutually parallel isobaths and enables the computation of depth-variable velocities for the longshore current and the return flow (undertow). Wave transformation over the variable bathymetry utilizes the approach of Battjes and Jansen (1978) in which it is assumed that waves are random and that their heights can be described by a Rayleigh distribution across the entire coastal zone. The lag between wave breaking and the appearance of currents (the 'roller' effect) is represented in the equations of momentum and energy by a rotating roller of water located on the crest of the breaking wave. Wave energy lost during breaking is initially transferred to the roller before subsequent transfer into the water column to produce mean flows. Energy dissipation due to bottom friction is assumed to be negligibly small.

Wave-driven steady currents are computed under the following assumptions (based mainly on numerous field observations of waves and currents in the surf zone):

- isobaths are approximately parallel to the shoreline,
- shear stresses in the water column can be determined according to the Boussinesq hypothesis,
- water flow velocities due to circulations in the open sea are negligibly small in relation to the orbital velocities of the waves,
- variability of the return flow in the direction of wave propagation is smaller than its variability over depth,
- there is a fully developed roller just in front of the breaking wave crest.

Szmytkiewicz (2002) follows the approach of Longuet-Higgins and Stewart (1964) in which the momentum equation in the cross-shore direction, integrated over the water depth and wave period, describes the equilibrium between the gradient of the radiation stress and the spatial change of the free-surface slope (resulting from set-down and set-up). However, at particular water depths, these two components of the momentum equation do not balance each other, which results in a mean current through the water column. This offshore-directed flow is further enhanced by the need to balance the onshore transmission of water between the wave crest and trough levels related to wave-drift and roller-induced flow. Szmytkiewicz (2002) obtains the vertical distribution of the mean flow by solving the time-averaged (over the wave period) momentum equation incorporating all of the effects mentioned above. The solutions obtained have quite a different character in front of and behind the wave breaker location which has important consequences in the modelling of the wave-current boundary layer and sediment transport.

Once the hydrodynamics across the nearshore profile have been calculated, an attempt can be made to model the sediment transport driven by the influence of waves and currents close to the bed. The approach used, which is based on the work of Kaczmarek and Ostrowski (2002), is highly detailed and can be regarded as being quasi-phase-resolving. Within this approach, the description of the wave-induced near-bed velocity is obtained from one of two theories for asymmetric waves (Stokes or cnoidal) dependent on the regime of wave motion determined from the ratio L/h and the Ursell parameter $U = H/h(L/h)^2$ (where H = wave height, L = wave length, h = water depth). The near-bed wave-induced velocities are combined with the mean flows already calculated and the equations for the wave-current boundary layer are solved to yield time-dependent bed shear stresses and sediment transport rates. Instantaneous sediment transport rates are then integrated over the wave period to obtain the net sediment transport rate.

The boundary layer model makes use of Stokes' approximations unless the ratio $L/h > 8$ (generally accompanied by high Ursell numbers, $U > 20$), in which case cnoidal wave theory is used (Ostrowski 2002). The appropriate free-stream velocity (Stokes or cnoidal) is used in the mometum integral model of the bed shear stress (following Fredsøe 1984) and sediment transport rates calculated with the three-layer model of Kaczmarek and Ostrowski (2002). This model comprises a bedload layer (below the theoretical bed level) and two layers of suspended material – the contact load layer (near-bed suspension of sediment) and the outer layer (suspension in the water column). In the contact load layer, time-dependent vertical distributions of flow velocity and sediment concentration are obtained following the approach of Deigaard (1993). The solutions in the above-mentioned layers are combined to give the instantaneous sediment transport rate (from which the net transport rate is obtained by integrating over the wave period). For the outer layer, determination of the time-dependent sediment concentration has proved difficult and so a simpler approach is adopted in which the net sediment transport rate is obtained by integrating the product of the time-averaged horizontal velocity and sediment concentration (obtained using the formulation of Ribberink and Al-Salem (1994)) over the appropriate part of the water column.

It should be noted that in this model, the balance or imbalance between wave asymmetry and return flow can lead to various types of resultant flow and sediment flux with sediment typically moving seawards due to undertow inside the surf zone and shorewards further offshore, due to wave asymmetry. In the transitional region sediment may move in the direction of wave advance close to the bed (in the contact layer), but seawards further away from the seabed, due to return flow. The overall result is a location close to the wave breakpoint at which sediment fluxes converge and the possibility of the formation of a sand bar if the wave breakpoint remains in one location for long enough.

Once the cross-shore distribution of onshore-offshore sediment transport is precisely calculated by use of the modelling system described in the paragraphs above, changes in bed level across an initial profile can be determined from the equation of sediment continuity perpendicular to the shore:

$$\frac{\partial h\,(x,t)}{\partial t} = \frac{1}{1-n}\frac{\partial Q\,(x,t)}{\partial x}, \tag{1}$$

in which Q denotes the sediment transport rate (m^2/s) in the cross-shore direction, n is the bed porosity ($\sim$0.4) and x and t represent the cross-shore location and time respectively. Equation (1) is solved using a modified Lax scheme. This introduces a kind of smoothing of the updated bed profile which helps to neutralize any inaccuracies of the sediment transport calculations which result in unrealistic bed changes (or numerical instabilities).

2.2. The PLYMPROF Model

The PLYMPROF model provides a model for the evolution of cross-shore beach profiles over timescales of weeks/months. The model, which was developed within the framework of the HUMOR project, is built around two key components, namely a standard wave transformation model and a new abstracted model for the resultant cross-shore sediment transport which is designed to capture the key elements of cross-shore sediment transport in a robust manner without lengthy and complex computation.

The model incorporates three standard wave transformation models, namely the models of Thornton and Guza (1983), Lippmann et al (1996) and Ruessink et al (2003). In each case, a simple forward-difference scheme is used to derive wave height values inside the model domain working sequentially shorewards from the wave height at the offshore boundary of the model domain (obtained from the deep water value H_{rms} using linear wave theory and assuming zero dissipation to this point). The methods of Lippmann et al (1996) and Ruessink et al (2003) both require the use of an iterative procedure to compute the wave height at each model grid point and thus require significantly more computational effort than the method of Thornton and Guza (1983). Consequently, the latter model is generally used (all results from the PLYMPROF model presented in this paper use this model).

A key parameter in the various wave models is the breaker index γ. This parameter is commonly taken as the ratio of the wave height to water depth in the inner part of the surf zone, and in the wave models it determines (along with the wave height, wave period and water depth) the local energy dissipation that occurs (energy dissipation and breaker index are inversely related). Parameterizations for the breaker index reported in the literature vary significantly, but in all cases γ is calculated from a combination of the local wavenumber, water depth and beach slope (not necessarily all three). For example, using field measurements, Sallenger and Holman (1985) suggested a linear dependence of γ on beach slope only ($\gamma = 3.2\tan\beta + 0.3$) whereas Raubenheimer et al (1996) and Sénéchal et al (2001) obtain a more complex dependence on beach slope, wavenumber and water depth, but with different coefficients, e.g. (Raubenheimer et al 1996):

$$\gamma = 0.19 + 1.05\frac{\tan\beta}{kh}.$$

However, there is no clear consensus on the exact form for an expression for γ and many modelling studies simply assume that γ takes a constant value reflecting the fact that in the saturated part of the inner surf zone the ratio of wave height to water depth is typically constant. In a recent study, Ruessink et al (2003) used inverse modelling to find the optimum form for γ over barred beach profiles using the wave model of Battjes and Jansen (1978). They obtained an expression for γ that differs significantly from those obtained from direct field measurement in that γ is found to be a function of the product kh rather than $1/kh$, namely:

$$\gamma = 0.76kh + 0.29.$$

It is notable that this form produces γ values that decrease in shallower water, thereby producing relatively larger values of wave energy dissipation close to the shoreline and over offshore sand bars than would be obtained from a field-based parameterization for γ. However, there is no dependence of γ on the local beach slope.

In general, and for all model simulations presented in this paper, γ is represented by a function which combines the dependence on the product kh and the beach slope $\tan\beta$ found in field-based parameterizations with the linear dependence on kh found via inverse modelling by Ruessink et al (2003), as follows:

$$\gamma = \gamma_C \left(1 + \gamma_S \frac{\tan\beta}{kh}\right) kh, \tag{2}$$

in which γ_C and γ_S are constants which scale the overall value of γ obtained and determine the relative importance of the value of the local slope respectively. Note that with $\gamma_C = 0.19$ and $\gamma_S = 5.53$, the inner bracket retains the form suggested by Raubenheimer et al (1996) whereas for $\gamma_C = 0.76$ the form suggested by Ruessink et al (2003) is obtained if $\gamma_S = 0.38/\tan\beta$. Although seemingly arbitrary, the custom form for γ represented by equation (2) was found to produce wave height distributions that agreed well with those of the (calibrated) model of Ruessink et al (2003) for a variety of linear and exponential beach profiles, and is within the variation of functional forms for γ that is reported in the literature. When used within the Thornton and Guza (1983) wave transformation model and combined with the sediment transport model described later, it was the only form that produced generally robust performance in the overall morphological model. Values of γ were computed using local values of water depth, wavenumber and bed slope and then at each model grid point the value of γ used in the wave transformation and sediment transport models was the average of the locally-calculated γ values over a given distance (usually one local wave length) offshore of that point. This lag-averaging procedure helped to prevent the growth of numerical instabilities in the modelled profile by smoothing out variations in γ due to small-scale local variations in the bed slope and wave parameters.

The PLYMPROF model utilizes a new abstracted model for cross-shore sediment transport which has its basis in the work of Plant et al (2001). In this model, the cross-shore sediment flux due to bedload transport (Q_B) is given by the product of two terms, one representing the overall magnitude of the sediment transport (q) and related to the local wave height and water depth, and the other representing the cross-shore shape of the bed load transport and including terms for wave-driven transport (r, the sediment flux shape function) and slope-driven transport ($r_0 \tan\beta$). In addition, a multiplier (Q_M typically O(10)) is incorporated to account for the enhancement of sediment fluxes when suspended load transport is taken into account (assuming that variations of the suspended load and bed load transports have the same cross-shore shape), i.e.

$$Q = \frac{1}{\rho_s} Q_M (r_0 \tan\beta + r), \tag{3}$$

in which ρ_s is the sediment density (the inclusion of which ensures that the sediment flux is expressed as a volume, rather than mass, transport rate).

Following the procedure outlined by Plant et al (2001), the sediment flux magnitude term is obtained from the local root-mean-square wave height (H_{rms}) and water depth (h) using the following expression:

$$q = \frac{C_f \rho_s}{(\rho_s - \rho)} \frac{1}{16\sqrt{2}} \frac{\rho\sqrt{g}}{\tan\phi} \left(\frac{H_{rms}^3}{h^{3/2}} \right),$$

in which C_f is a drag coefficient O(10^{-3}), within the range of values suggested by field measurements (e.g. Church and Thornton 1993), ρ is the water density, ρ_s is the sediment density and ϕ is the angle of repose for the sediment (default values were 0.001, 1030 kgm^{-3}, 2500 kgm^{-3} and 30° respectively). This expression differs from that found in Plant et al (2001) due to the correction of errors in the analysis of the original paper as described by O'Hare and Huntley (2006).

In the original formulation of Plant et al (2001), the two terms that make up the sediment flux shape function are given as $r_0 = -2.25$ assuming that positive transport is directed onshore and the local bed slope (tanβ) is positive for a seawards facing slope, and:

$$r = r_1 \left(\frac{y}{y_C} \right)^p \left[1 - \frac{y}{y_C} \right],$$

in which r_1 and p are constants, $y = H_{rms}/h$ and y_C is a critical value of y which scales with the maximum "saturated" value of H_{rms}/h (i.e. the breaker index γ). Plant et al (2001) use values of $r_1 = 0.5$, $p = 1, 2, 3$ and $y_C = 0.3$ giving a sediment flux shape function with a parabolic form that simulates onshore-directed sediment transport for small values of y/y_C (in the wave shoaling region and outer part of the surf zone) and offshore-directed transport for $y/y_C > 1$ (in the inner part of the surf zone). The model does not incorporate onshore-directed sediment transport in the swash zone and thus predicts continuous shoreline erosion, limiting its usefulness within a model for long-term profile evolution.

In the PLYMPROF model, the slope-driven component of the cross-shore sediment flux shape function is calculated in an identical way to Plant et al (2001) (although the value of r_0 can be adjusted by the user), but the wave-driven component in equation (3) is described by a simple sinusoidal expression:

$$r = 0.125 \sin(\pi X_t) \left| \cos\left(\frac{2\pi X_t}{3}\right) - 1 \right|^S, \tag{4}$$

with the 'transport X' parameter (X_t) given by:

$$X_t = c\left(\frac{H_{rms}/h}{\gamma}\right)^p,$$

in which c and p are user-defined coefficients. These expressions give rise to a wave-driven component for the cross-shore sediment flux shape function that simulates onshore-directed transport for $X_t < 1$ (shoaling wave region and outer surf zone), offshore-directed transport for $1 < X_t < 2$ (undertow-dominated inner surf zone) and onshore-directed transport for $X_t > 2$ (swash zone). Note that in this formulation X_t plays an equivalent role to the ratio y/y_C in the original formulation of Plant et al (2001) and is the key parameter that maps the wave-driven component of the sediment flux shape function into real space. The factor 0.125 in equation (4) is present to ensure that the maximum onshore-directed transport is of the same magnitude as that obtained from the original formulation of Plant et al (2001) and the second term allows adjustment of the relative magnitudes of the peak onshore-directed transport in the shoaling wave region and the peak offshore-directed transport inside the surf zone. The relative sizes of the two peaks in the sediment transport shape function are determined by the value of the power S, with the ratio of the magnitude of the offshore-directed surf zone peak to that of the onshore-directed shoaling zone peak being equal to 4^S.

As the shoreline is approached in the model, the value of X_t generally increases (unless wave re-formation after breaking occurs) and so the wave-driven cross-shore sediment transport shifts from onshore-directed shoaling wave transport, to offshore-directed surf zone transport, to onshore-directed swash zone transport in a smooth and logical fashion. However, as the shoreline is approached and wave height estimates become unreliable, the values of X_t and the sediment flux magnitude (q) are obtained using a special matching procedure. This procedure is applied from a point on the profile defined as the first offshore location at which X_t reaches a critical value (usually 2) to the location of the still-water shoreline or run-up limit and ensures that X_t and its cross-shore spatial gradient (and q and its gradient) are continuous at the matching point. Values of X_t and q shorewards of the matching point depend only on the offshore location and reach values of 2.5 and zero respectively at the still-water shoreline or run-up limit (note that $X_t = 2.5$ represents a location where the onshore-directed swash zone component of the wave-driven cross-shore sediment flux shape function reaches a maximum). Extension of the active zone of the nearshore above the still-water shoreline due to wave run-up is normally included in a simple way by calculating the location of the run-up limit assuming that the vertical extent of the run-up is $0.7H_0$ (Guza and Thornton 1982). An additional correction factor (a cosine taper between the matching point and the run-up limit) is applied to the sediment flux magnitude q if its value increases towards the shore at the matching point.

The unmodified sediment transport model predicts finite sediment fluxes at all locations with finite wave height and water depth and consequently predicts small onshore sediment transport at the offshore boundary of the model domain. To ensure sediment continuity and remove unwanted boundary values, a closure scheme is used that reduces the sediment flux magnitude to zero at a critical water depth (h_C). Sediment flux magnitudes across the entire model domain are multiplied by an adjustment factor:

$$1 - \left[\frac{h}{h_C}\right]^4,$$

where the power 4 (default value) is selected so that the sediment flux magnitude is reduced by $\sim$6% at a depth of $0.5h_C$ and by 32% at a depth oh $0.75h_C$. The default value of h_C is selected as 20 m.

As with the IBW PAN model, water depths are updated every timestep from the gradient of the cross-shore sediment flux using the sediment conservation equation (Eq. 1). In order to reduce any tendency for the model to exhibit numerical instability, five-point linear smoothing is applied to the cross-shore sediment flux, gradient of the cross-shore sediment flux and total bed change from the start of the simulation at each timestep. In addition, values of the breaker index γ are calculated using the lag-averaging procedure outlined previously.

3. Outline of Field Sites

3.1. Lubiatowo, Poland

Lubiatowo is situated on the Polish Baltic Sea coast. Data for this area were obtained from the Coastal Research Station run by IBW PAN at Lubiatowo.

The beach profile at Lubiatowo for 16 September 2001 (refer to Fig. 5) shows a series of four pronounced longshore sandbars with spacings that increase away from the shore (bar crests are located at approximately 120 m, 260 m, 450 m and 780 m). The first bar had a crest to trough height of $\sim$1 m while the height of the outer bars was 2–3 m. The underlying gradient of the profile was approximately 0.02 over the first 300 m offshore, reducing to 0.002 further offshore. The typical grain size of the sediment present was $D_{50} = 220\ \mu$m.

For the present study, wave information for the region was available in the form of a time series of deep water wave height (H_{rms}) and peak period

(T_P) calculated from data obtained from a wave-rider buoy during the period September–October 2001. Of particular interest was the period from 16–27 September 2001 during which two distinct short storms occurred for which wave approach was approximately shore-normal (refer to Fig. 4). Water level variations due to tides were considered negligible, as the Baltic is a typical non-tidal sea.

3.2. La Barrosa, Spain

La Barrosa beach is located on the south-west coast of Spain close to the Gulf of Cadiz facing the Atlantic Ocean. The region has seen considerable human development in the coastal margin over recent years including nourishment of the beach. Data for this area were obtained from the University of Granada, Spain.

A limited number of beach profiles were available and from these a typical profile was selected representing conditions towards the end of the summer period in 2001. The profile is characterized by a series of step-like bars (refer to Fig. 7) having cross-shore length scales that increase away from the shoreline. These bars had no, or minimal, troughs (regions with a shorewards-facing slope inside the bar crest). The underlying beach gradient close to the shore (within 1000 m) was approximately 0.009. Beaches in the region are composed of fine-medium sand (D_{50} = 250 μm) consisting of 85–95% quartz and 5–15% calcium carbonate. In 1993–94 and 1997 the beach was nourished with ~450,000 m^3 and 30,000 m^3 of material with D_{50} = 290 μm and 300 μm (slightly coarser than the naturally occurring sediment) respectively.

Wave information for the region was available from three nearby hindcasting points for the period 1996–2003. The information derives from a third generation spectral wave numerical model (WAM) which includes wave growth due to wind, refraction, dissipation due to bottom friction and breaking and non-linear interactions between different wave components. Solutions were derived with a finite difference method on a grid with spatial resolution of 0.25° using input data consisting of the time-varying wind field at 10 m height from a numerical model (HIRLAM) run every six hours with 0.5° spatial resolution at the Instituo Nacional de Meteorologiá in Spain.

The region has a mesotidal range with medium neap to spring variation (1.2–3.3 m tidal range). Tidal data for the region came from an ultrasonic tide gauge at Bonanza (Mareógrafo de Bonanza) at the mouth of the Guadalquivir River just north of the Gulf of Cadiz. Data was recorded over the period 1992–2001 and revealed that the amplitudes of the two most important constituents were 0.94 m (M2) and 0.33 m (S2).

4. Discussion of Model Simulations

4.1. Linear Beach Profile

As an initial test of the two profile models, runs were completed for a seabed profile having an initial linear slope of gradient 0.01 (see Fig. 1). Computations were carried out with assumed values of the deep water wave height $H_{rms} = 1.5$ m and peak period $T_P = 6.5$ s.

In the IBW PAN model the median grain diameter was set as $D_{50} = 220$ μm with settling velocity $w_s = 0.026$ m/s and relative density $\rho_s/\rho = 2.65$. The spatial resolution was set as 10 m and the model timestep was 4 hours. Model results after the first time step are presented in Fig. 1 and suggest that the velocity of the return flow increases slowly towards the shore reaching only a few centimetres per second prior to wave breaking, whereas wave asymmetry produces a distinct increase in all three sediment transport components. Inshore of the wave breakpoint, the return flow increases rapidly (up to 0.5 m/s close to the shore) and starts to influence the bottom boundary layer. This causes great local variability in the net sediment transport rates with the wave breaking point being a location of sediment convergence. Closer to shore, the wave motion restores after breaking, becoming increasingly asymmetrical due to the decreased depth and this effect dominates over the return flow to produce onshore-directed sediment fluxes. At the shoreline the waves collapse and the increased return flow results in an offshore-directed sediment flux. Perhaps surprisingly, the IBW PAN model simulations for the uniform gradient profile suggest that transport is predominantly onshore resulting in no erosion of the beach face. Bed height changes after 5 days of simulation show the formation of a very localized bar-like feature (only around 50 m in extent) at the point of sediment transport convergence that forms due to the sudden interruption of the predicted onshore-directed sediment transport due to shoaling waves that occurs when the waves break.

In the PLYMPROF model, coefficients were initially set to values that were similar to those that had previously been found to represent well the bar migration pattern at Duck, USA over a 77 day period. In particular, $c = 1.2$, $p = 1.6$, $S = 1$, $Q_M = 15$ and $r_0 = 1.25$ with $\gamma_C = 0.95$ and $\gamma_s = 5.53$ (the latter values retaining the same relative importance of kh and $\tan\beta$ as determined by Raubenheimer et al (1996) in the bracketed term of Eq. (2), but producing wave transformation patterns closely resembling those obtained with the calibrated model of Ruessink et al (2003)). The spatial resolution was set at 1m and the model timestep was 15 minutes. Model results after one day and after five days are presented in Fig. 2. It is evident from these results that initially waves start to break around 500 m from the shoreline (somewhat closer to shore than predicted with the IBW PAN model). The model predicts weak offshore-directed sediment transport well offshore of the wave breakpoint (due to the dominance of down-slope transport in this region). Through the outer part of the surf zone sediment transport is

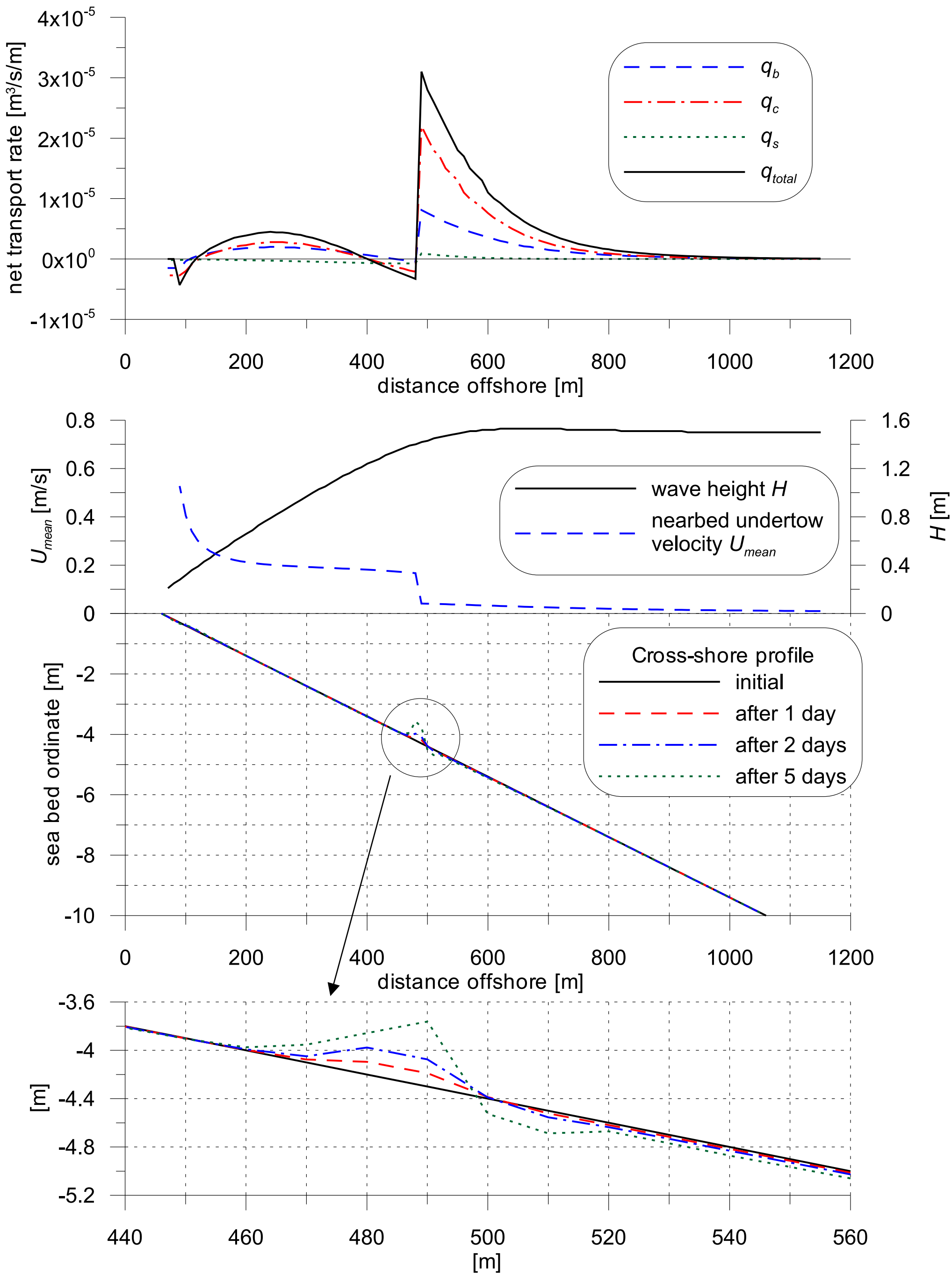

Fig. 1. Modelled net sediment transport rate (top: q_b = bed load, q_c = contact load, q_s = suspended load, q_{total} = total rate), wave height transformation and near-bed mean velocity (middle) and short-term profile evolution (middle and bottom) for an initially uniform sloped profile ($\tan\beta$ = 0.01) IBW PAN model

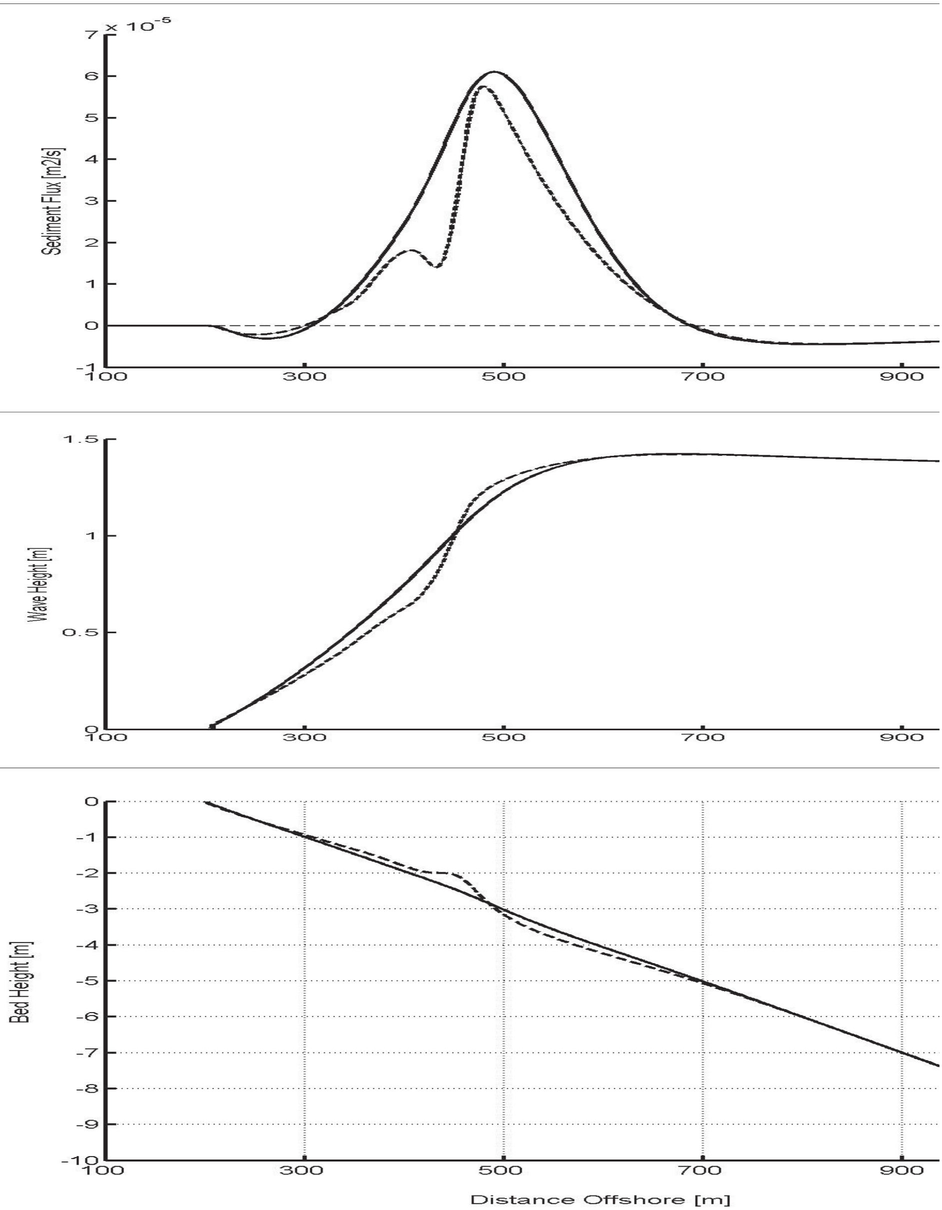

Fig. 2. Modelled sediment flux (top), wave height transformation (middle) and short-term profile evolution (bottom) for an initially uniform sloped profile ($\tan\beta = 0.01$) PLYMPROF model with $c = 1.2$ (bottom graph: solid line = results at end of day 1; dashed line = results at end of day 5)

mainly onshore directed and only becomes offshore directed (and is then only weak) around 100 m from the shoreline. The magnitude of the sediment flux and dominance of onshore-directed sediment transport is in line with the results of the IBW PAN model, but the sediment convergence point and resulting position of bar formation is located some way shorewards of the location predicted by the IBW PAN model ($\sim$250 m from the shoreline in comparison to $\sim$420 m). With the PLYMPROF model, the location of sediment convergence (and hence bar formation) can readily be shifted seawards by increasing the value of c. For example, a second PLYMPROF model run performed with $c = 2$ (other parameters unchanged) predicted that the offshore-directed sediment transport inside the surf zone is much stronger (because it occurs closer to the wave breakpoint where sediment flux magnitudes are maximum) and the profile rapidly evolves a series of multiple bars with the location of the outer bar crest after 5 days occurring at $\sim$410 m from the shoreline (similar to the IBW PAN model). The model predicts that waves break on each bar and subsequently reform before breaking again on the next bar. The longer-term evolution of these two model runs is illustrated further in Fig. 3 which shows the time evolution of the change in bed height during the simulations over a period of 50 days. In the first case (Fig. 3a), with $c = 1.2$, the bar quickly migrates to an equilibrium position with an inner bar forming approximately 80 m further inshore due to the reformation of waves which break on the outer bar and the occurrence of a secondary sediment flux convergence. The behaviour of the second run (Fig. 3b) is more complex, with a series of multiple bars forming and progressively migrating offshore. The outer bar appears to reach a maximum offshore position ($\sim$450–500 m from the shoreline) before decaying in amplitude, migrating slightly onshore and merging with the next bar inshore. The system apparently reaches a dynamic equilibrium with one complete cycle lasting approximately thirteen days. The prediction of different multiple bar fields and the existence of a dynamic equilibrium with particular parameter settings is certainly intriguing, but highlights the fact that uncertainty in the determination of appropriate values for coefficients in the abstracted sediment transport model used in the PLYMPROF model represents a potentially serious drawback of the approach. However, these runs also demonstrate the potential usefulness of the PLYMPROF model for exploring long-term behaviour of nearshore profiles (the model has been run without the occurrence of instabilities or long-term drift of the predicted profile for several decades for the case of Duck, USA using parameterised wave forcing that incorporates seasonal variations in wave climate).

4.2. Lubiatowo, Poland

In order to test the ability of the models to predict beach profile evolution during a period of changing wave conditions, model runs were carried out using an initial profile obtained at Lubiatowo (Poland) on 16 September 2005 with an

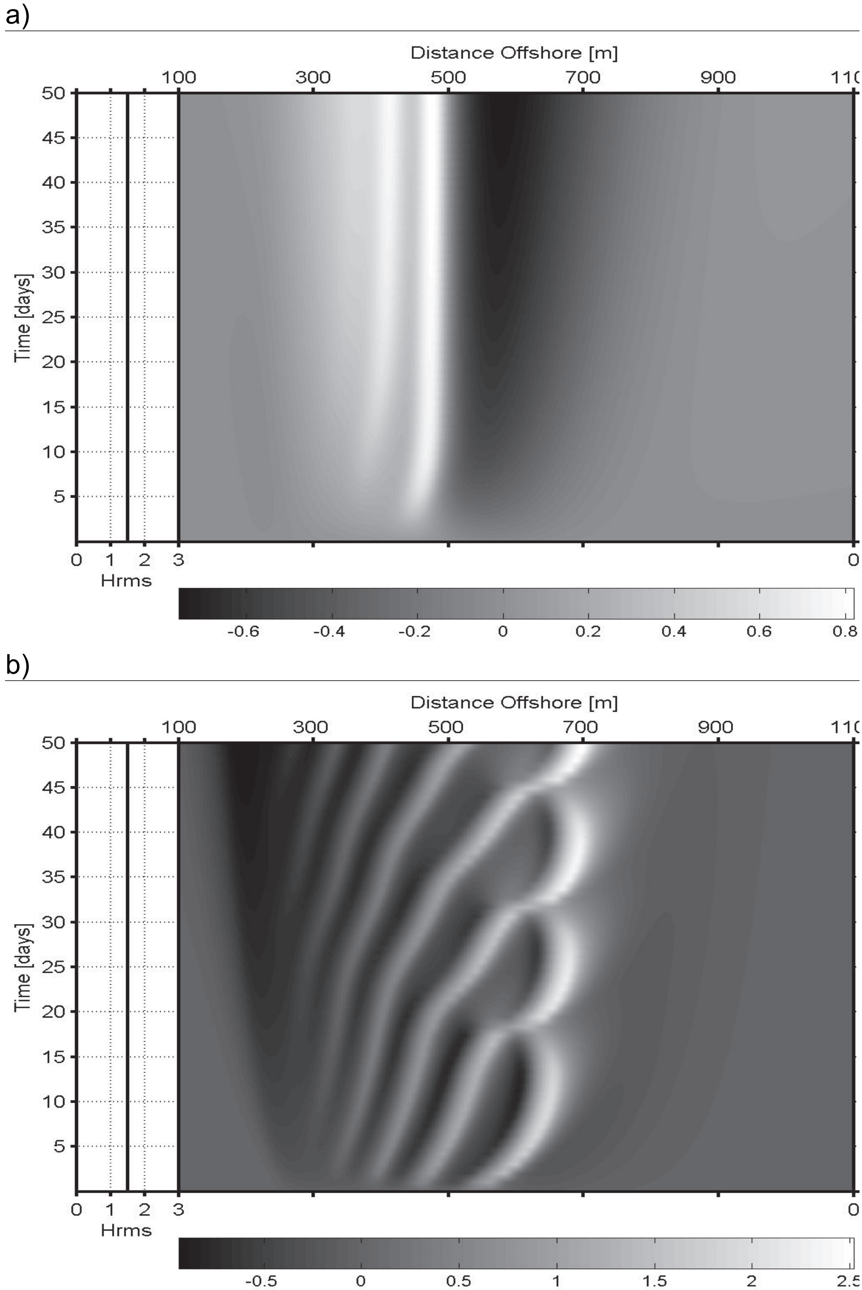

Fig. 3. Modelled medium-term (50 day) profile evolution (shown as variation in bed height [m] from start of run: dark = erosion, light = accretion) for an initially uniform sloped profile ($\tan\beta = 0.01$), a) PLYMPROF model with $c = 1.2$, b) PLYMPROF model with $c = 2.0$. Left/right panels show wave height/period of forcing time series

appropriately sampled, or parameterized wave forcing time series. For the IBW PAN model the wave time series segment was represented by pairs of values (H_{rms} and T_P) at four hourly intervals (the model timestep). For the PLYMPROF model the wave time series segment was divided into periods of calm conditions during which the wave height and period were assumed to be constant and intervening periods of storm conditions in which both the wave height and period increased linearly from their preceding calm values to a peak value at mid-storm before returning linearly to the appropriate values for the succeeding calm period (the time interval between successive pairs of H_{rms} and T_P values was 15 minutes throughout the modelled time series). These two different representations of the wave forcing were selected as being the simplest way to drive the two models given their different spatial resolutions and timesteps and are shown together in Fig. 4.

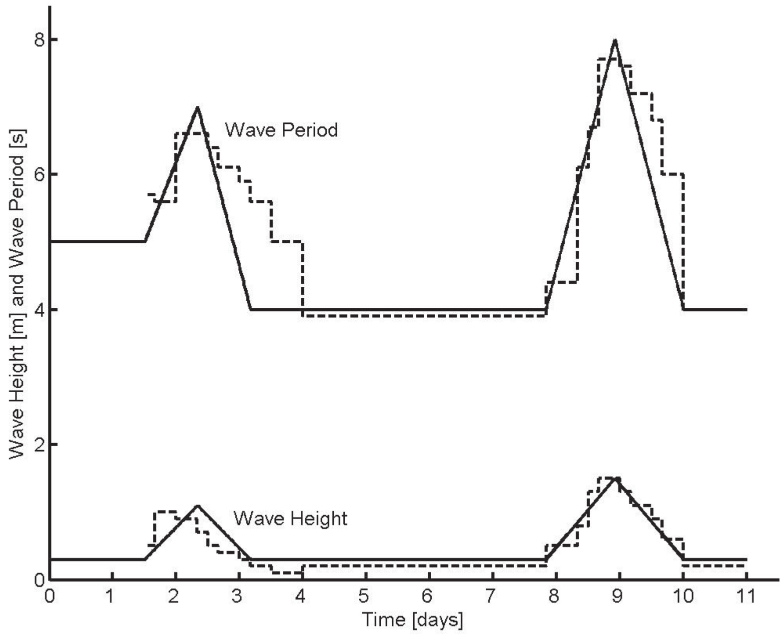

Fig. 4. Wave forcing time series (H_{rms} and T_P) for the Lubiatowo model simulations (solid line = PLYMPROF model; dashed line = IBW PAN model)

Results from the IBW PAN model (with spatial resolution 10 m and timestep 4 hours) are presented in Fig. 5 which shows the net sediment transport rates at the peak of the second storm (H_{rms} = 1.5 m, T_P = 7.7 s) and the initial and final sea bed profiles. Sediment transport during the peak storm conditions is predicted to be strongly onshore-directed over the two outer bars on the profile and

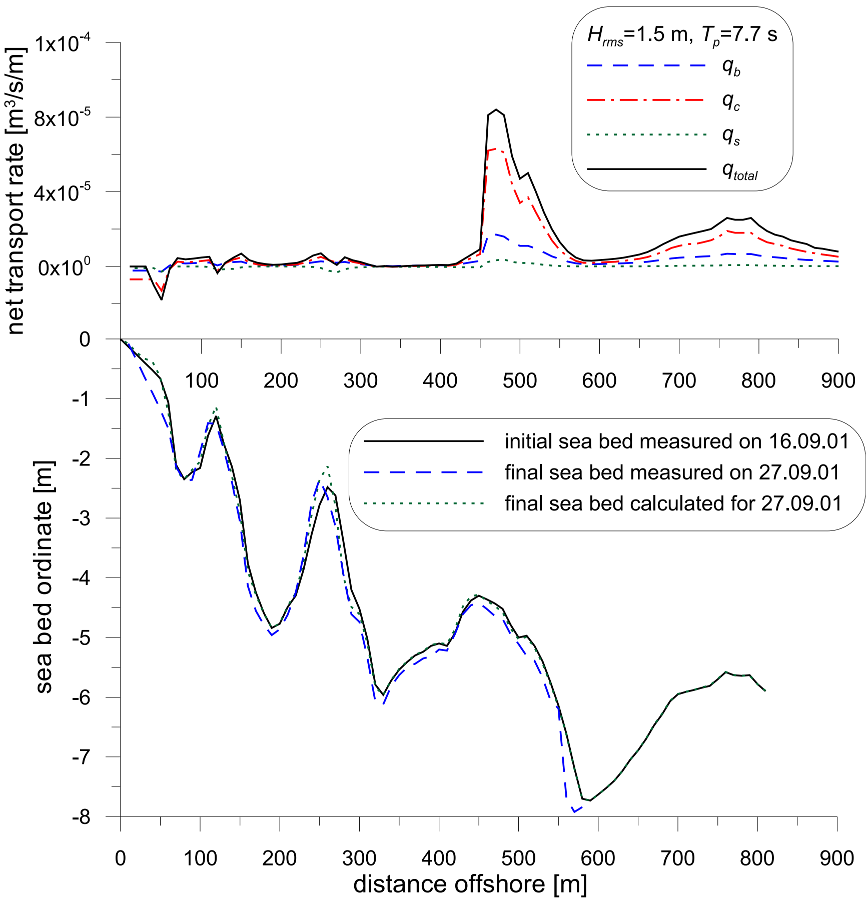

Fig. 5. Modelled sediment flux at the storm peak (top) and overall profile evolution (bottom) for the Lubiatowo simulation (see text for full details) IBW PAN model

near-zero (mainly onshore-directed) over the two inner bars. The model predicts no significant region of offshore-directed sediment transport due to return flow (a similar result is also obtained in the later simulations for La Barrosa) suggesting that the bars may migrate onshore even under relatively severe offshore wave conditions (a situation frequently encountered during field investigations at CRS Lubiatowo). Over the whole period of the model simulation distinct changes in the sea bed elevation are only predicted to occur at the second bar with the bar migrating shorewards a short distance (~20 m). This change is in reasonable agreement with field data although the latter also show changes across the entire beach profile including substantial erosion near the shoreline, weak onshore migration of the first bar and erosion and weak onshore migration of the third bar. It should be noted that the model results for high waves suggest significant changes in net sand transport at the third bar, but due to the short duration of these conditions only very small changes in the seabed profile occur in this region. It should also be borne in mind that profile changes due to processes occurring in the longshore direction are not accounted for by the model.

Results from the PLYMPROF model for the same segment of wave forcing and with the same coefficients as the initial uniform gradient simulation described previously are presented in Fig. 6. The results are similar to those obtained with the IBW PAN model in that the dominant net sediment transport is onshore with only small patches of relatively weak offshore-directed transport which are generally attributable to dominance of downslope transport on the seawards flank of the bars rather than return flow (at the peak storm conditions, X_t only exceeds 1, and therefore wave-driven sediment transport is offshore directed, at a point around 150 m from the shoreline). Unlike the results from the IBW PAN model, the strongest transport occurs over the second rather than the third bar during the peak storm conditions. The model predicts slight erosion close to the shoreline (in line with the field data) and shorewards movement of material from the first and second bar crests into the corresponding bar troughs (but not shorewards migration of the bar crests). Only minimal profile change is predicted to occur on the two outer bars (similar to the IBW PAN model). Unlike the model simulations with an initially uniform profile described in the previous section, increasing the value of the coefficient c (to $c = 2$) makes only a small difference to the resulting profile evolution with very minor changes in the vicinity of the outer three bars, erosion near the shoreline and weak offshore migration of the innermost bar being predicted over the entire run (in general disagreement with the changes revealed by the field data). During the peak of the second storm, net sediment transport was predicted to be strong and offshore-directed over the first and second bar crests suggesting that the minimal profile change predicted over the second bar results from the cancellation of onshore sediment transport during calm wave conditions and this offshore-directed transport in storm conditions.

Despite obvious differences in the output of the two models for the barred profile at Lubiatowo, particularly in terms of the sediment transport pattern, the resulting profile evolution predicted by the two models does not differ substantially. This may be attributable to the relatively low energy conditions and short period (11 days) over which profile changes are predicted. However, it is also possible that when significant morphological features (such as the Lubiatowo bars) are present, feedback between the bathymetry and wave and sediment transport patterns, rather than the detail of the sediment transport pattern itself, becomes the dominant control on the profile change. This suggestion receives some support from the similarity of profile response that occurs for the PLYMPROF model simulations completed with different values for the coefficient c.

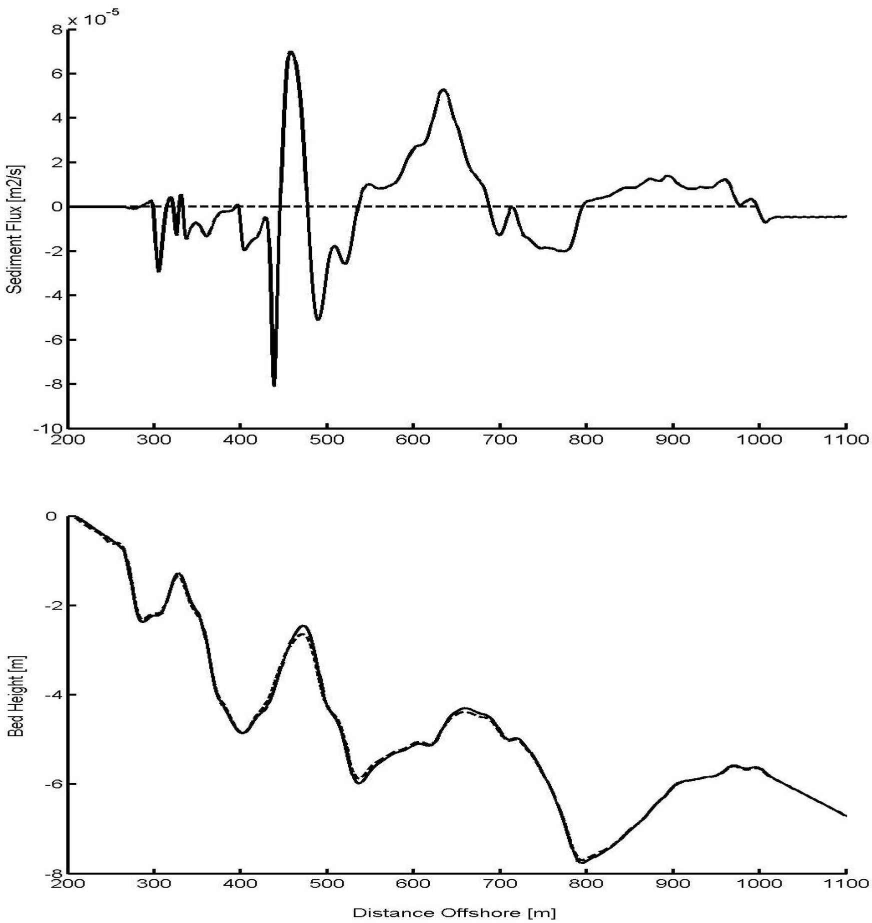

Fig. 6. Modelled sediment flux at the storm peak (top) and overall profile evolution (bottom) for the Lubiatowo simulation (see text for full details) PLYMPROF model with $c = 1.2$ (bottom graph: solid line = initial profile; dashed line = profile at end of simulation)

4.3. La Barrosa, Spain

Both models were applied to the case of La Barrosa, Spain, as part of the effort within Workpackage 6 of the HUMOR project. This Workpackage entailed application of the various models that had been developed or enhanced within the project to relevant areas within a 'single cell' along the coast of south-west Spain from Sancti-Petri to Tarifa. For the purposes of cross-shore profile modelling the beach at La Barrosa was chosen as a useful test site, this area having undergone considerable human development in recent years including renourishment of the beach in 1993–94 and 1997 as previously described. Only limited bathymetric information was available with no accompanying measurements of wave transformation or sediment transport and so this case represents a test of the application of the models to a region with only sparse existing information. Hind-cast wave conditions were available and these were used to identify a small number of relevant test conditions. In general the wave information provided suggests that the local wave climate at La Barrosa is dominated by swell waves (as might be expected from its exposed location facing the Atlantic Ocean) with period exceeding 10 s. Shorter waves generated by local winds occur frequently, but are generally relatively low.

For the IBW PAN model, results are presented here from two exemplary cases for uniform wind and swell waves (see Figs. 7 and 8 respectively). In the case of wind waves, the model was run for deep water waves with $H_{rms} = 0.5$ m and $T_P = 6$ s for total simulation lengths of 24 hours and with $D_{50} = 230\ \mu$m. For the swell wave case, the simulation was shortened to 6 hours and the input wave conditions were $H_{rms} = 1.6$ m and $T_P = 10$ s. In both cases the influence of the tide was ignored. The results presented in Figs. 7 and 8 clearly show that breaker location occurs at distinctly different locations for each type of wave input (at ~5 m depth for the longer/higher/swell waves and ~1.5 m depth for the shorter/lower/wind waves). The net sediment transport patterns predicted for the two wave types show a similar cross-shore shape with transport magnitudes ~4 times bigger for the swell waves, but the location of sediment convergence associated with wave breaking shifts from being close to the inner 'bar' (~150 m offshore) for the wind waves to the region of the second 'bar' (~600 m offshore) for the swell waves suggesting that the two types of waves act quite separately in building one or other of the bars. In the case of wind waves the *inner* bar is predicted to migrate onshore slightly over a 24 hour period whereas for swell waves there is slight onshore migration of the *outer* bar over the 6 hour duration of the model simulation.

Fig. 9 shows results from initial tests with the PLYMPROF model for the two uniform wave cases described above. In these simulations the model coefficients were identical to those used for the other PLYMPROF model simulations presented in this paper with $c = 1.2$ (spatial resolution = 1 m, timestep = 15 minutes). In line with the results already presented for other profiles the predicted patterns of net sediment transport are shifted shorewards in comparison to those predicted by the IBW PAN model, with wind waves producing only weak (mainly onshore) sediment transport with convergence at a point ~50 m from the shoreline and swell waves producing much stronger sediment transport (again ~4 times larger than for the wind waves for the onshore component in the outer surf zone) with significant offshore-directed transport in the inner surf zone and a convergence point ~190 m offshore. In the case of the wind waves, the predicted profile evolution over the 24 hour duration of the model simulation shows slight onshore migration of the inner bar, whereas for the swell waves the model predicts slight offshore migration of the inner bar and onshore migration/infilling of

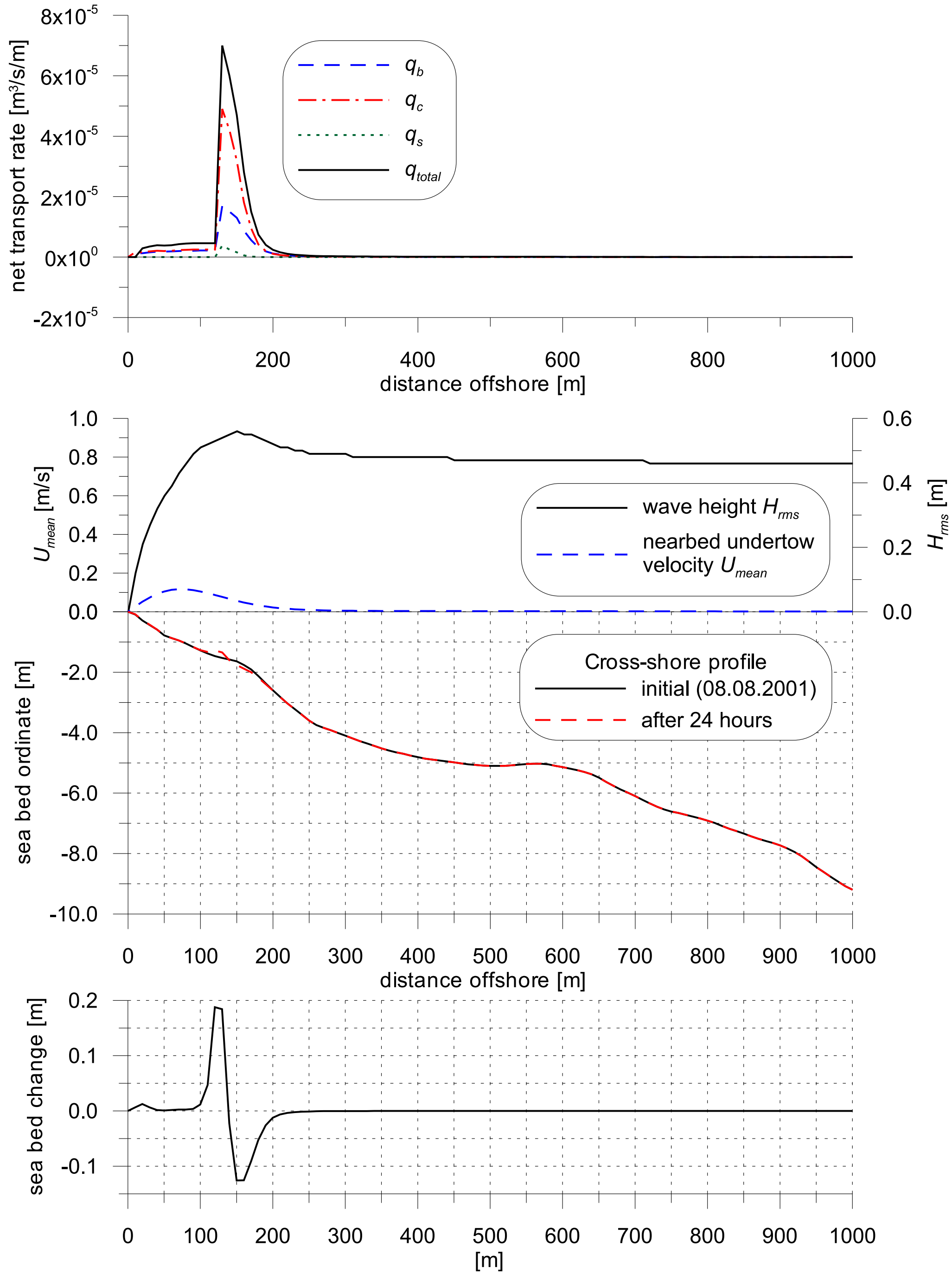

Fig. 7. Model results for wind wave simulation (H_{rms} = 0.5 m, T_P = 6 s) for La Barrosa IBW PAN model. Top panel: net sediment transport rate; upper middle panel: wave height transformation and mean nearbed velocity; lower middle panel: initial bed profile; bottom panel: change in bed height over 24 hours

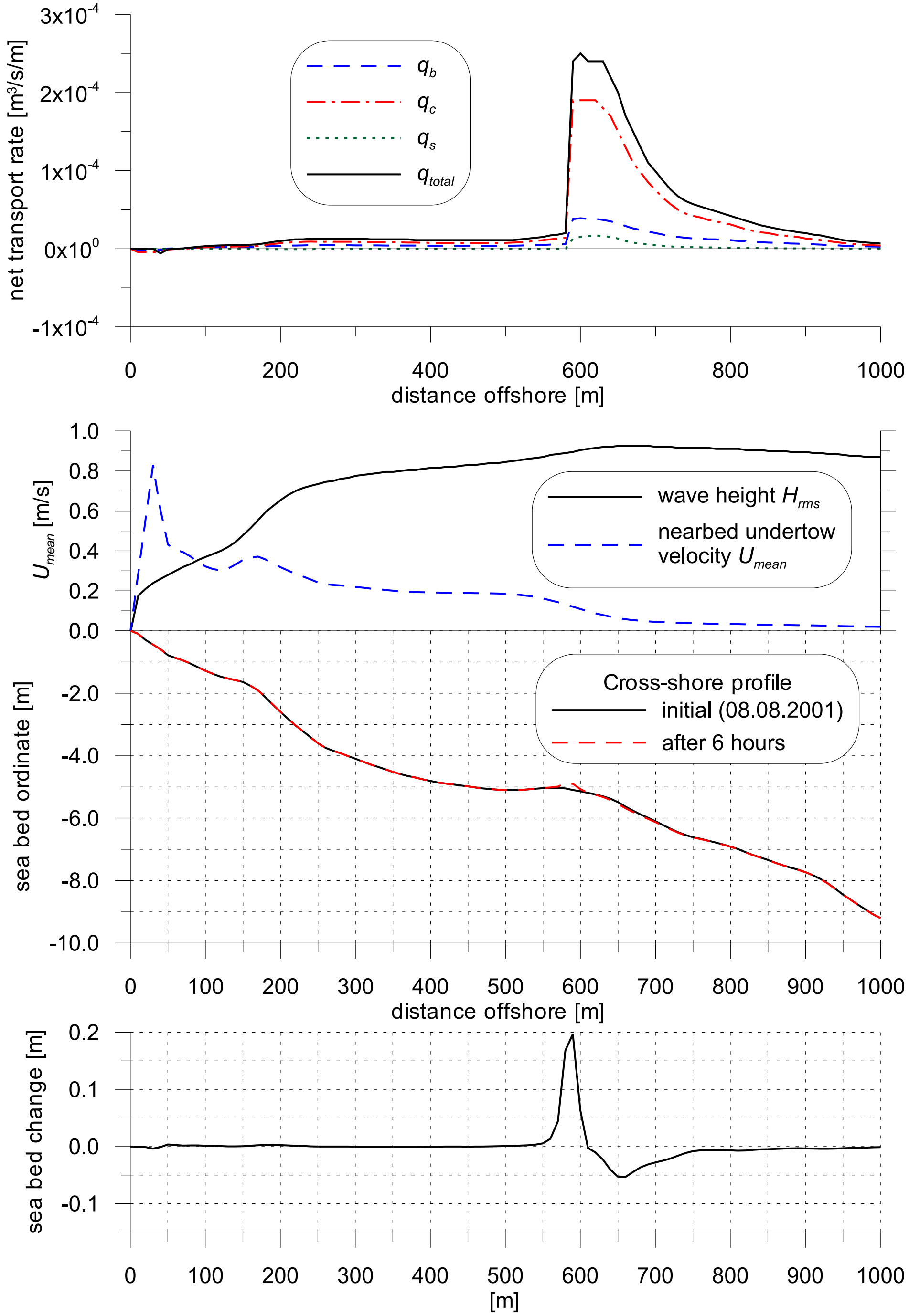

Fig. 8. Model results for swell wave simulation (H_{rms} = 1.6 m, T_P = 10 s) for La Barrosa IBW PAN model. Top panel: net sediment transport rate; upper middle panel: wave height transformation and mean nearbed velocity; lower middle panel: initial bed profile; bottom panel: change in bed height over 6 hours

the second bar (generally similar to the results from the IBW PAN model despite the differences in the predicted cross-shore sediment transport pattern).

Making the same modification to the value of the coefficient c as before (i.e. $c = 2$) produced locations of transport convergence at ~140 m and ~570 m for the wind and swell waves respectively, bringing them into line with the locations predicted by the IBW PAN model (for the swell waves there is also a strong convergence point at ~240 m from the shore). However, for the wind waves there is now strong offshore-directed transport inshore of the inner bar with the resulting profile evolution of 24 hours showing a distinct growth of the inner bar and the initial formation of a small new inner bar ~60 m inshore of the original inner bar (different from the IBW PAN model predictions). In the swell wave case there is now weak offshore-directed transport on the second bar and stronger offshore-directed transport on the seaward face of the inner bar which results in very small growth and offshore migration of the second bar and removal of material from the seaward face of the inner bar over the 6 hour duration of the model simulation (again different from the IBW PAN model predictions).

Despite uncertainty over the appropriate values of coefficients, further simulations were completed with the PLYMPROF model (with $c = 1.2$) to explore the possible profile response at La Barrosa to two important types of storm events identified by workers at the University of Granada. These events are designated as an 'intermediate' storm in which waves with period 7 s increase in height linearly from a background level of $H_{rms} = 2$ m over a 12 hour period to a peak storm height of 6 m before returning linearly to the background level 12 hours later and a 'large' storm in which waves with initial period 18 s and height 2 m increase in height linearly over a 12 hour period to 6 m (with an accompanying decrease in period to 7 s), and then remain at the storm level for 2 days before returning linearly to the initial wave conditions over a 12 hour period. In both cases the total duration of the event was 6 days with the storm event being positioned at the centre of the forcing time series.

Results from the two types of storm event (still ignoring tidal water level variations) are shown in Fig. 10. For the intermediate storm event the model predicts growth and offshore migration of the inner bar together with simultaneous decay and weak onshore movement of the outer bar, whereas for the large storm event, the profile evolution shows significant offshore migration of the inner bar and weak growth of the second bar. Interestingly, the region of accretion shifts shorewards during the storm conditions due to the reduction in wave period (from 18 s to 7 s) that accompanies the higher waves and shifts the wave breakpoint (and resulting sediment transport pattern) onshore. These simulations reveal how an existing sand bar may migrate offshore if storm waves result in convergent sediment transport seawards of the bar, but will migrate onshore if the transport convergence is shorewards of the bar crest (e.g. in less energetic storm conditions or when waves have a shorter period). Notwithstanding the uncertainty in

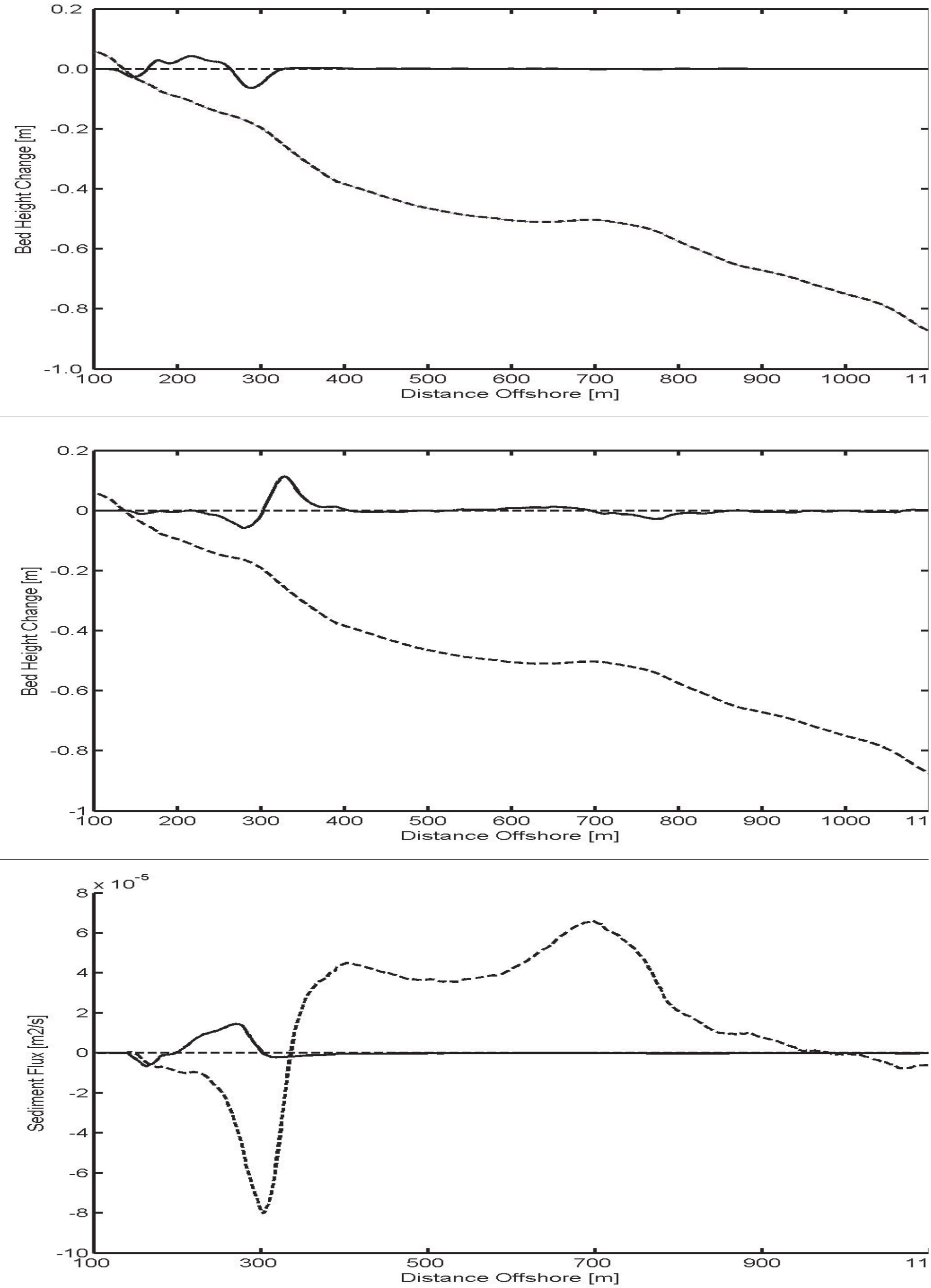

Fig. 9. Model results for wind wave and swell wave simulations for La Barrosa PLYMPROF Model with $c = 1.2$. Top panel: initial profile and change in bed height over 24 hours for wind wave case ($H_{rms} = 0.5$ m, $T_P = 6$ s); middle panel: initial profile and change in bed height over 6 hours for swell wave case ($H_{rms} = 1.6$ m, $T_P = 10$ s); bottom panel: net sediment flux after 1.5 hours (solid line = wind wave case, dashed line = swell wave case)

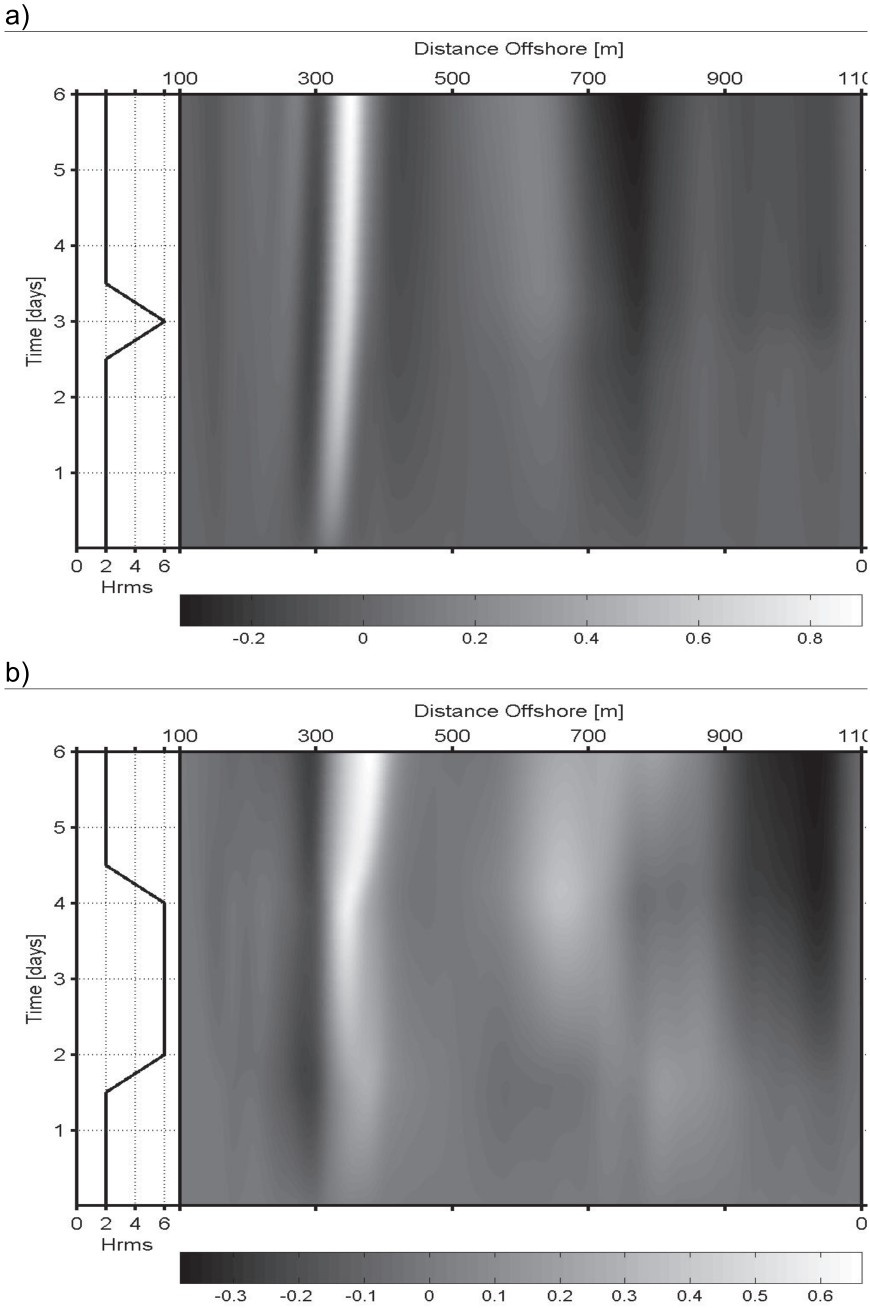

Fig. 10. Modelled profile evolution (shown as variation in bed height [m] from start of run: dark = erosion, light = accretion) for La Barrosa simulations without tidal water level variations (see text for full details) PLYMPROF Model with $c = 1.2$, a) intermediate storm event, b) large storm event. Left/right panels show wave height/period of forcing time series

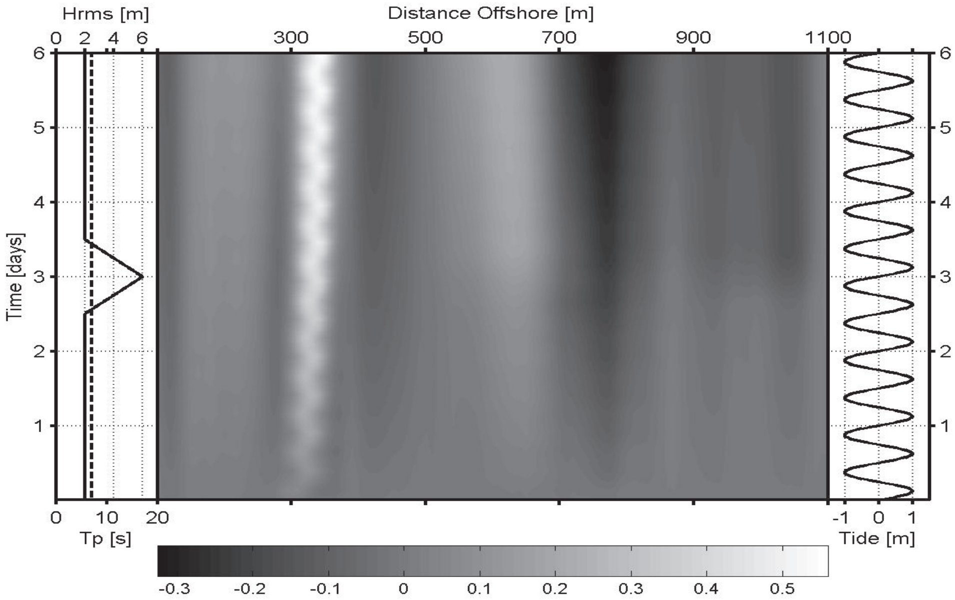

Fig. 11. Modelled profile evolution (shown as variation in bed height [m] from start of run: dark = erosion, light = accretion) for La Barrosa simulations with tidal water level variation included. Wind wave case (H_{rms} = 0.5 m, T_P = 6 s) PLYMPROF Model with c = 1.2. Left panel shows wave height (solid line) and wave period (dashed line) of forcing time series. Right panel shows tidal water level variation of forcing time series

PLYMPROF model coefficients these results demonstrate that the response of a barred profile cannot be evaluated simply, as the development of the profile is highly sensitive to the actual wave conditions (both in terms of height and period) that occur and where locations of breaking and sediment divergence/convergence occur in relation to the pre-existing morphology.

Finally, two further model runs were completed with the PLYMPROF model for the intermediate and large storm events with identical coefficients as the runs described above, but including water level variations due to the tide. In these runs the tide was modelled as a sinusoidal variation in water level with amplitude 1m (approximately equivalent to the range midway between neap and spring conditions). The time evolution of the change in bed height from the start of the run for the intermediate storm event with tide included is shown in Fig. 11. In both cases the differences between the model simulations with and without tides are small, the overall effects of the tide being to cause tidal migration of the pattern of sediment erosion and accretion thereby suppressing the development of bar morphology. For the intermediate storm event case the tidal simulation also shows enhanced levels of accretion close to the shore.

5. Conclusions

In this paper results are presented from the application of two contrasting coastal profile models to three different initial bathymetries (linear, barred and step-like) with uniform and non-uniform wave forcing conditions. The first model (IBW PAN model) incorporates a relatively complex description of wave breaking processes and a highly complex quasi-phase-resolving sediment transport model that makes use of non-linear (Stokes and cnoidal) descriptions of near-bed wave-induced velocities. The second model (PLYMPROF) is much simpler and includes only a basic description of wave breaking processes together with a new abstracted model for cross-shore sediment transport.

In all cases the results from the IBW PAN model tend to show strong onshore-directed sediment transport which rapidly reduces in magnitude at the onset of wave breaking. Inside the surf zone there is generally a much smaller (near zero) onshore-directed flux with minimal offshore-directed sediment flux associated with transport by the return flow. Using default settings that have previously been found to adequately represent morphological change at Duck, USA over a 77 day period, the PLYMPROF model also predicts onshore-directed transport in the shoaling wave and outer surf zone regions, but produces significant offshore-directed sediment fluxes in the inner surf zone. Overall, the sediment transport pattern predicted with the PLYMPROF model using default settings was generally found to occur considerably closer to the shore than with the IBW PAN model, although the resulting patterns of profile change produced by the two models did not appear to be significantly different in cases where direct comparison was possible, perhaps suggesting that feedback between (significant) existing morphology and sediment transport patterns exerts a major control on the morphological development that occurs.

Alteration of a single coefficient in the PLYMPROF model shifted the predicted sediment transport pattern offshore providing a better match in terms of the locations of active regions of the profile with corresponding predictions from the IBW PAN model. However, this shift also resulted in enhanced offshore-directed transport both in terms of its magnitude and horizontal extent, as the region of offshore transport was shifted into the outer surf zone where sediment mobilization is greater. Without further field data it is impossible to ascertain the reliability of the predictions produced by either model, but the possible uncertainty in the values of coefficients used in the PLYMPROF model represents a potentially serious drawback with the simplified modelling approach (although this problem should be alleviated if further model validation can be completed).

Simulations completed for two different types of storm event at La Barrosa revealed that the evolution of existing morphology cannot be simply related to the occurrence or absence of storm conditions, but rather depends upon the detail of the wave forcing and where regions of wave breaking occur in relation to any bar features already present on the profile. Inclusion of tidal water level variations resulted in migration of the pattern of sediment erosion and accretion and suppressed development of bar morphology.

Both models coped well with the three different initial profile configurations and with uniform and time-varying wave conditions though the simplicity (and consequently greater speed) of the PLYMPROF model makes it potentially uniquely suited to exploration of long term phenomena.

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