GENERATION AND MIGRATION OF NEARSHORE BARS UNDER NON- TO MACROTIDAL CONDITIONS

Leo C. van Rijn[1], Gerben Ruessink[2], Bart T. Grasmeijer[3]

Abstract: This paper presents the effect of tidal range on bar generation and migration based on a process-based morphodynamic model. The model was run over an initially plane sloping bed (1:50); the wave climate was schematized into a storm period of 11 days (wave height $H_s \sim 2 - 3$ m), followed by a fair-weather period of 40 days ($H_s \sim 1$ m). The tidal range TR was varied between 0 and 8 m. The model predicted the formation of a subtidal multiple bar system for TR < 4 m, with bar spacing $O(10^1\text{-}10^2$ m) and bar height $O(10^{-1}\text{-}10^0$ m). Bars were predicted to migrate offshore (onshore) during the storm (fair-weather) period. Under macro-tidal conditions (TR > 4 m) an intertidal ridge-and runnel-like system was formed with similar bar spacing, but smaller bar heights than modeled for the subtidal bar systems under non- to mesotidal conditions (TR < 4 m). The predicted bar characteristics agree reasonably well (at least, qualitatively) with those observed under natural conditions.

INTRODUCTION

Bars are among the most common, yet least understood morphological features in many sandy nearshore areas. They are important for their role of wave energy dissipation during storms and actually form the first line of coastal defense. This suggests that their presence has significant implications for beach and dune stability. Furthermore, bars contain significant amounts of sand and are therefore of importance to coastal sediment budget studies.

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The number of bars in a cross-shore profile as well as bar characteristics, such as height, width and volume, appear to be influenced by profile steepness and geometry, grain size and sediment availability, wave climate and tidal range (Van Rijn, 1998a). The relationship between these factors and nearshore bars is, however, not fully understood. The present work mainly focuses on the way tidal range may influence bar behavior, expressed in terms of generation and migration, and bar height. This influence is mainly related to horizontal shifts of different hydrodynamical zones, like zones with non-breaking shoaling waves, breaking waves, swash, or even the dry beach, over the profile. Obviously, this migration becomes more pronounced with an increase in tidal range, which further implies that stationarity in hydrodynamical conditions is reduced and that a specific cross-shore position in a large tidal environment may experience more hydrodynamical zones that in a setting with a small tidal range. With a process-based morphodynamic model this paper aims to contribute to the understanding of bar behavior under non- to macro-tidal situations. Bar generation mechanisms have been reviewed extensively in Ruessink (1998) and Van Rijn (1998a). Herein, the dominant mechanisms are considered to be the wave asymmetry and undertow, inducing onshore and offshore directed sediment transport, respectively. This paper presents a review of existing literature on natural bar behavior under different tidal ranges, a description and validation of the applied model, the model results and comparison to natural bar behavior and is finalized by an outline of future research and a summary of the main conclusions.

NATURAL BAR BEHAVIOR

Non-tidal Conditions (Tidal Range TR ≈ 0 m)

Examples of barred coasts under non-tidal conditions have been presented by, for instance, Aagaard (1988; Zealand, Denmark), Osborne and Greenwood (1992; Nottawasaga Bay, Lake Huron, Canada; see Figure 1) and Pruszak et al. (1997; Lubiatowo, Baltic Sea coast, Poland). All these authors showed profiles with slopes β of 1:50 to 1:100, containing multi-bar systems. The number of bars varied from 2

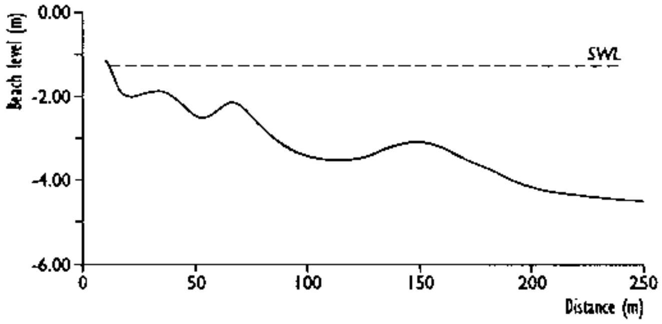

Fig. 1. Cross-shore bed profile for non-tidal conditions (1988; Nottawasaga Bay, Canada; TR ≈ 0 m; $\beta \approx$ 1:75). Reprinted from Marine Geology, 106, Osborne and Greenwood, Frequency-dependent cross-shore suspended sediment transport. 2. A barred shoreface, 25-51, © (1992), with permission from Elsevier Science.

to 5. The height of the bars is typically in the order of a few decimeters to about 1 m, where height is defined as the elevation difference between the crest and the trough shoreward of it. The cross-shore spacing between the bars is in the order of $10^1 - 10^2$ m and generally increases in the offshore direction (see Figure 1). Aagaard (1988) reported that the migration of the subtidal bars was well related to the offshore energy level, with offshore migration during high-energy events and shoreward bar displacement under low-energy conditions. During the offshore migration the bar-trough morphology became more accentuated.

Micro-tidal Conditions (TR ≈ 1 m)

One of the best studied barred environments in a micro-tidal setting is probably Duck, North Carolina, USA, where the Army Corps of Engineers has performed surveys of the nearshore area on a biweekly to monthly basis since 1981. The Duck bar system is in essence a double bar system with a generally well developed inner bar (height in the order of a few decimeters to 1 m) and a subtle outer bar (Figure 2). The inner bar is known to migrate offshore and become better developed during breaking conditions, while low-energy conditions are associated with onshore bar migration and a more subdued bar-trough morphology (e.g., Plant and Holman 1997, Gallagher et al. 1998). The outer bar may move onshore during prolonged periods of low-energetic swell, followed by its complete disappearance (Larson and Kraus, 1994). On the interannual time scale, a cyclic bar behavior has been observed (Lippmann et al., 1993). The disappearance of an outer bar is followed by a rapid offshore migration of an inner bar (which thus becomes the new outer bar), associated with the generation of a new inner bar near the shore. The cycle period seems to be in the order of 7 years. The modeling of bar behavior on the interannual time scale is beyond the scope of the present paper.

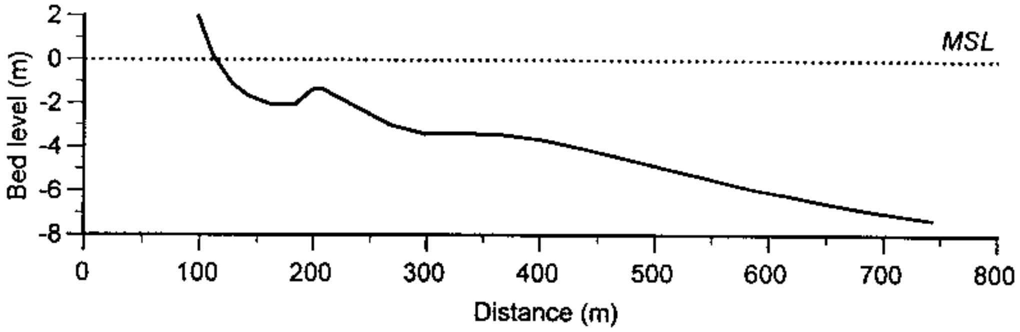

Fig. 2. Cross-shore bed profile for micro-tidal conditions (12 Dec. 1997; Duck, USA; TR ≈ 1 m; β ≈ 1:50).

Meso-tidal Conditions (TR ≈ 2 m)

Barred beaches under meso-tidal conditions have been reported from the Dutch coast, where an annual sounding of the nearshore zone has been carried out by the Dutch Public Works Department since the mid 1960s. Multiple bar systems are present on slopes with β < ~1:50, an example of which is shown in Figure 3. The bar

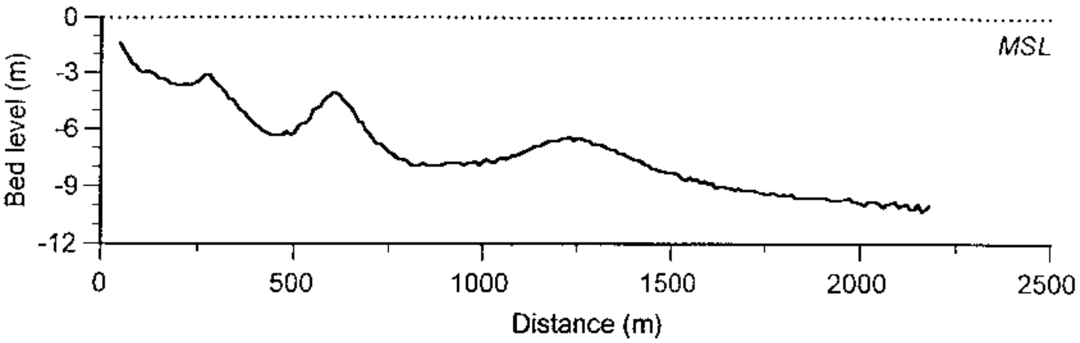

Fig. 3. Cross-shore bed profile for meso-tidal conditions (1988; Terschelling, the Netherlands; TR ≈ 2 m; β ≈ 1:200).

spacing is $O(10^1 - 10^2$ m) and increases in the offshore direction (Figure 3). The bar height is typically less than about 2 m and increases in the offshore direction, before it finally reduces to a few decimeters in the outer surf zone (Ruessink and Kroon, 1994). Minor or no bars are present for surf zone slopes steeper than 1:50 - 1:25 (Van Rijn, 1998a).

As the Dutch data set consists of annual sounding, not much is known about the response of individual bars to storms and fair-weather periods. On the interannual scale, however, similar cyclic behavior as described for the Duck bar system (see previous subparagraph) has been observed (e.g., Ruessink and Kroon, 1994).

Macro-tidal Conditions (TR > ≈4 m)

As also noted for smaller TR settings, the overall profile slope is an important factor whether a barred or non-barred system develops under macro-tidal conditions. Profiles with β < ≈ 1:75 are generally devoid of any bar-like features (Short 1991, Wright et al. 1982). Similarly, bar systems are also lacking or only poorly developed on ultra-dissipative beaches (β > ≈ 1:200), see for instance Short (1991). In the intermediate β range ridge-and-runnel system can be observed. Examples include the work presented by King and Williams (1949; Blackpool, United Kingdom; TR ≈ 7.5 m; see Figure 4), Mulrennan (1992; East coast of Ireland; TR ≈ 4 m) and Short (1991; various Irish, British and Australian sites; TR ranging between 3 and 7.5 m). The ridges are generally found between Mean Sea Level and the Mean Low Water (see Figure 4); their number may amount to approximately 2 to 5. The cross-shore

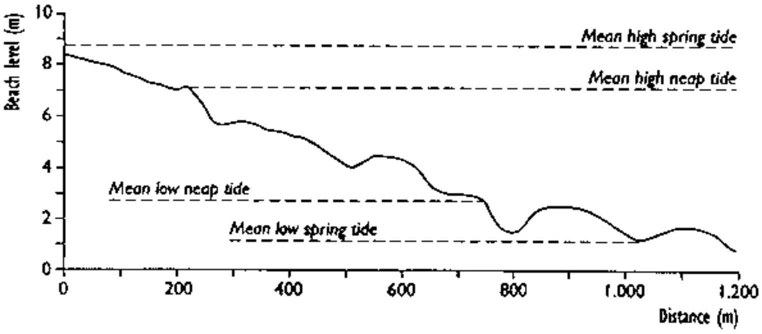

Fig. 4. Cross-shore bed profile for macro-tidal conditions (Blackpool, United Kingdom; TR ≈ 7.5 m; β ≈ 1:150). Source: King and Williams, 1949.

ridge spacing is in the order of $10^1 - 10^2$ m, generally increasing in the offshore direction (Short, 1991). The height of the ridges is about 0.5 – 1.5 m. Mulrennan (1992) observed that that the ridge-and-runnel system was best developed during low- to moderate wave energy conditions, during which the ridges migrated in the onshore direction. In contrast, storm conditions could totally destroy the barred morphology.

Summary

Table 1 presents a summary of the information on the type bar system in the surf zone in relation to the tidal range and the overall (linear) bed slope of the inner surf zone. Based on the tidal range, a distinction can be made between non- to meso-tidal conditions on the one hand and macro-tidal on the other. In the former group subtidal single to multi-bar system can be found, depending on β. In multiple bar systems the cross-shore spacing is in the order of $10^1 - 10^2$ m with, in general, an increasing spacing with distance offshore. Bar height is typically less than 2 m, although larger values have been observed (e.g., Figure 3). In macrotidal settings ridge-and-runnel features are present on intertidal beaches having slopes in the range 1:75 – 1:200. The ridge spacing and height is comparable to the numbers given for subtidal multi-bar systems in environments with a smaller tidal setting.

Table 1. Type of bar systems in the surf zone for sandy coasts (Van Rijn, 1998a)

Tidal range (TR)	Surf zone slope β	Bar system
< 3 – 4 m (non, micro and meso tidal)	• < 1:50	• Multiple subtidal bars
	• 1:25 – 1:50	• Single subtidal bar
	• > 1:25	• No bar
> 3- 4 m (macrotidal)	• < 1:200	• No bars or poorly developed ridge and runnel system
	• 1:75 - 1:200	• Ridge and runnel system on intertidal beach
	• > 1:75	• No bar

MODELED BAR BEHAVIOR

Model Description

The propagation, transformation (shoaling) and breaking of individual waves are described by a probabilistic model. The individual waves shoal until an empirical criterion for breaking is satisfied. Wave height decay due to bottom friction and breaking is modeled by using an energy dissipation method. Wave-induced set-up and set-down and breaking-associated longshore and cross-shore currents are also modeled (Van Rijn and Wijnberg, 1996). The near-bed orbital velocities of the high-frequency waves (low-frequency effects are neglected) are described by the modified Isobe-method (Grasmeijer and Van Rijn, 1998). The depth-averaged return current (U_r) under the wave trough of each individual wave (summation over wave classes) is derived from linear mass transport and the water depth (h_t) under the trough. Streaming in the wave boundary layer due to viscous and turbulent diffusion of fluid momentum is taken into account. The streaming (u_b) in the wave boundary layer is of the order of 5% of the peak orbital velocity and generally onshore-directed in deeper water (symmetric waves).

The sand transport rate is determined for each wave (or wave class), based on the computed wave height, depth-averaged cross-shore and longshore velocities, orbital velocities, friction factors and sediment parameters (Van Rijn, 1993). The net (averaged over the wave period) total sediment transport is obtained as the sum of the net bed load (q_b) and net suspended load (q_s) transport rates. The net bed-load transport rate is obtained by time-averaging (over the wave period) of the instantaneous transport rate using a formula-type of approach.

The net suspended load transport is obtained as the sum ($q_s = q_{s,c} + q_{s,w}$) of the current-related and the wave-related transport components. The current-related suspended load transport ($q_{s,c}$) is defined as the transport of sediment particles by the time-averaged (mean) current velocities (longshore currents, undertow currents). The wave-related suspended sediment transport ($q_{s,w}$) is defined as the transport of sediment particles by the oscillating fluid components (cross-shore orbital motion). The oscillatory or wave-related suspended load transport ($q_{s,w}$) has been implemented in the model, using the approach given by Houwman and Ruessink (1996). Computation of the wave-related and current-related suspended load transport components requires information of the time-averaged current velocity profile and sediment concentration profile.

The current velocity profile is represented as a two-layer system to account for the wave effects in the near-bed layer. The convection-diffusion equation is applied to compute the equilibrium time-averaged sediment concentration profile for current-related and wave-related mixing. A recent improvement of the sand transport model is a better representation of the effect of breaking waves on the sand concentration profile, based on re-analysis of large scale flume and field data (not yet reported). The effect of the local cross-shore bed slope on the transport rate is taken into account. The sediment transport model can be operated in the single fraction mode or in the multi fraction mode. In the multi-fraction mode the bed material is divided in a number of size fractions. The sand transport rate of each size fraction is then computed using an existing single fraction method (replacing the mean diameter of the bed material by the mean diameter of each fraction) with a correction factor to account for the non-uniformity effects (Van Rijn, 1997). In the present study the model was used in the single fraction mode. Bed level changes are computed from the depth-integrated sediment balance. Details of the model (CROSMOR) are described by Van Rijn (1993, 1997, 1998a, b).

Model Validation

Within the framework of the European Large Installations Plan (LIP) a program of detailed measurements of hydrodynamics and sand transport and morphology along a sloping cross-shore profile has been carried out in the large-scale Deltaflume of Delft Hydraulics (Arcilla et al., 1994). Herein, the data of test LIP1A has been used to validate the model. This test consists of irregular waves over a cross-shore profile without a dune at the shore. The offshore wave height is $H_{1/3} = 0.9$ m, $T_p = 5$ s, water depth at $x = 0$ m is 4.1 m, sand of $d_{50} = 0.0002$ m, temperature = 15 °C, salinity

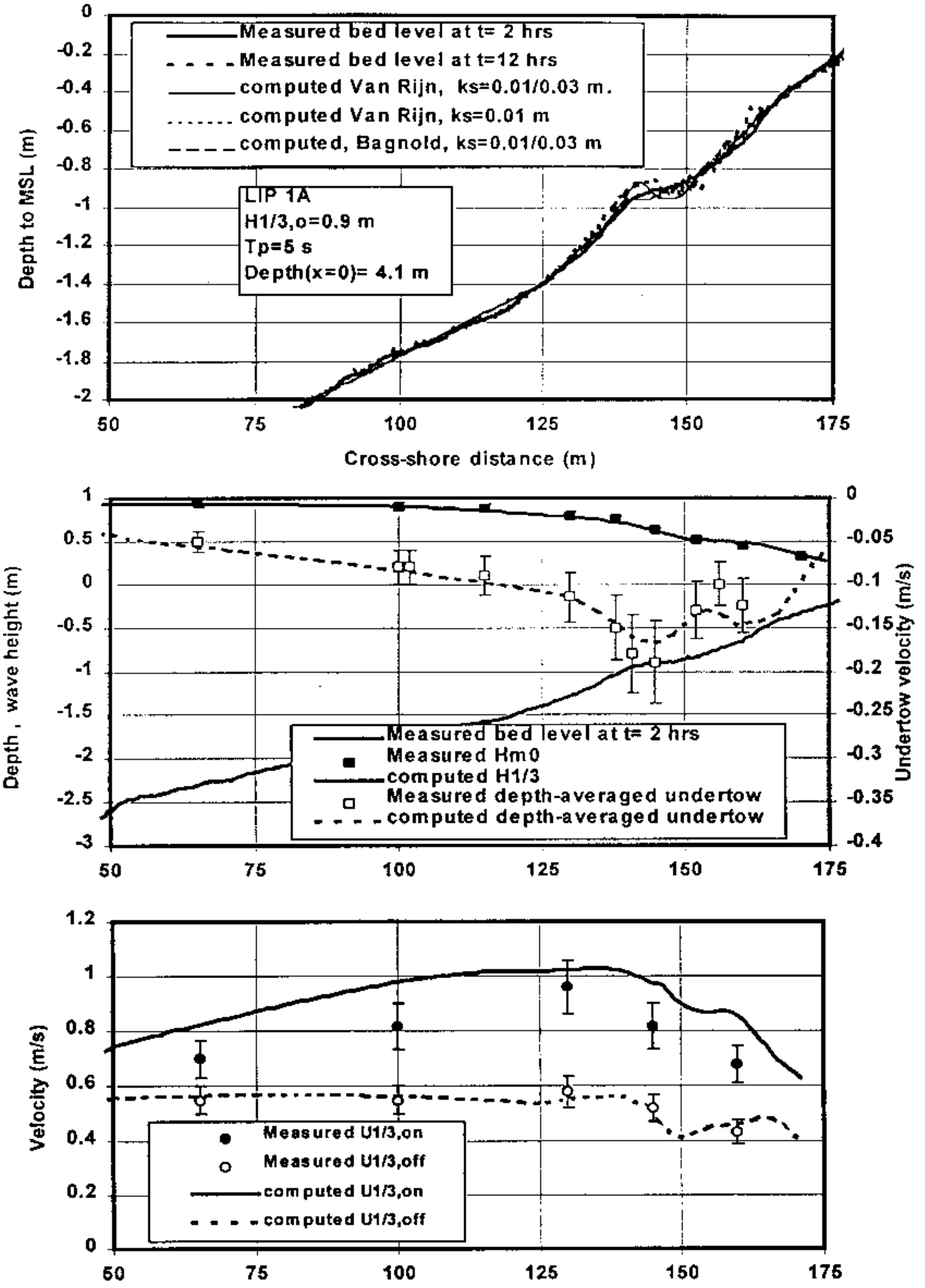

Fig. 5 Computed and measured results of LIP1A-test. *Top*: Bed level evolution; *middle*: Wave height and undertow along profile; *bottom*: Peak onshore and offshore orbital velocities (near bed)

= 0 ‰ (fresh water). The wave spectrum was represented by 10 wave classes. The bed roughness was estimated to be 0.03 m between x = 145 and 155 m (bar trough) and 0.01 m for $x < 140$ m and $x > 160$ m. Linear interpolation was used to determine the bed roughness at intermediate locations. The calibration coefficient of the high frequency suspended transport was set to the standard value of 0.2.

Computed and measured results are given in Figure 5. The computed significant wave heights ($H_{1/3}$) are within 10% of the measured values (H_{m0}) in all stations. The computed values of the undertow (depth-integrated velocity below wave trough level) agree reasonably well with the measured values (error bars indicate variations of velocity over depth). The computed and measured undertow values are maximum above the developing breaker bar at x = 140 m. The computed significant peak onshore orbital velocity (modified Isobe-method, see Grasmeijer and Van Rijn, 1998) is about 10% to 20% too large compared to the measurements. However, the computed peak offshore orbital velocity compares favorably with the measured values. The bar development is reasonably well simulated, when the effective bed roughness is varied along the profile (larger bed roughness in the bar trough between x = 145 and 155 m). A constant bed roughness of 0.01 m does not result in sufficient bar development. To see the effect of another transport formula, the Bagnold formula was implemented. The application of the Bagnold sand transport formula and variable bed roughness does not result in sufficient bar development. The Bagnold model always yields onshore-directed transport for this case. The Van Rijn model produces offshore-directed transport between x = 140 and 145 m.

Model Application

The model has been applied to study the generation and migration of bars over an initially plane sloping bed in conditions with and without tidal water level variations. The tidal range has been varied between 0 (no tide) and 8 m (macro-tide). The model parameters and input data are given in Table 2. The wave climate was schematized to a storm period with H_s = 2 and 3 m, followed by a fair-weather period with H_s = 1 m. Based on sensitivity computations, the number of wave classes to represent the wave spectrum of each wave condition was set to 8.

Model results are given in the following.

Non-tidal Conditions (TR = 0 m)

Figure 6 shows the bed evolution for non-tidal conditions. The results in terms of bar development can be summarized as:

- generation of three bars by storm waves; outer bar with height of about 2 m and length of about 100 m; middle bar with height of about 1.5 m and length of about 60 m; inner bar with height of about 1 m and length of about 30 m;
- offshore migration of the three bars by storm waves;
- onshore migration and flattening of the outer bar and slight growth of the middle bar by fair-weather waves (H_s = 1 m);
- slight growth of the inner bar by fair-weather waves;
- generation of beach berm during fair-weather period.

Table 2. Input data and model parameters

Input data and model parameters	Values
• Wave climate	H_s = 2 m, T_p = 7 s, during 10 days H_s = 3 m, T_p = 8 s, during 1 day H_s = 1 m, T_p = 6 s, during 40 days
• Wave angle to coast normal	30 degrees
• Tidal range	0, 1, 2, 4, 8 m
• Tidal period	12 hours
• Tidal velocity (longshore)	0 m/s
• Bed profile (initial, t = 0)	Slope of 1:200 for bed level < -5 m Slope of 1:50 for –5 < bed level < 0 m Slope of 1:30 for bed level > 0 m
• Bed roughness; $k_{s,w}$; $k_{s,c}$	0.01; 0.01 m
• Sand size; d_{50}; d_{90}	0.25; 0.5 mm
• Transport factor	0.5
• High-frequency susp. transport factor	0.2
• Porosity factor of bed	0.4
• Water temperature; Salinity	15 °C; 30 ‰

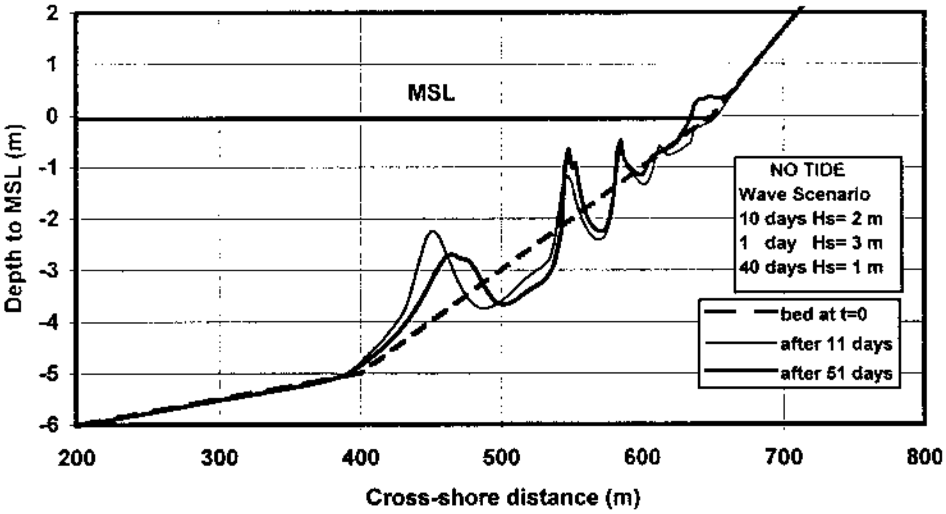

Fig. 6 Bar development for non-tidal conditions and wave climate: 10 days H_s = 2 m, 1 day H_s = 3 m and 40 days H_s = 1 m

To study the bar migration by storm waves (H_s = 2 m) in more detail, additional bar profiles are shown in Figure 7. Sand transport rates at t = 10 days and corresponding bed level changes over a time step of 1 hour are also shown in Figure 7. Focussing on the outer bar, it can be observed that:

- the sand transport rate is maximum (offshore-directed due dominant effect of undertow) at the bar crest (x = 478 m);
- the sand transport is onshore-directed (due to dominant effect of wave asymmetry) on the seaward slope of the bar (up to x = 468 m);
- the sand transport is offshore-directed on the seaward and landward slopes of the bar between x = 468 and 482 m (around the crest);

- the sand transport is onshore-directed in the landward trough beyond $x = 482$ m;
- the sand transport pattern results in deposition (maximum about 0.05 m/hr) on the seaward slope and erosion (maximum about 0.05 m/hr) on the landward slope; thus there is a convergence point on the seaward slope and a divergence point on the landward slope of the outer bar, which results in offshore migration;
- similar processes occur on the middle and inner bars;
- the time scale of bar development in the inner surf zone is of the order of 3 to 5 storm days, resulting in a bar with a height of about 1 m and a base length of approximately 30 m;
- the time scale of bar development in the outer surf zone is of the order of 10 storm days, resulting in a bar with a height of about 2 m and a base length of about 100 m.

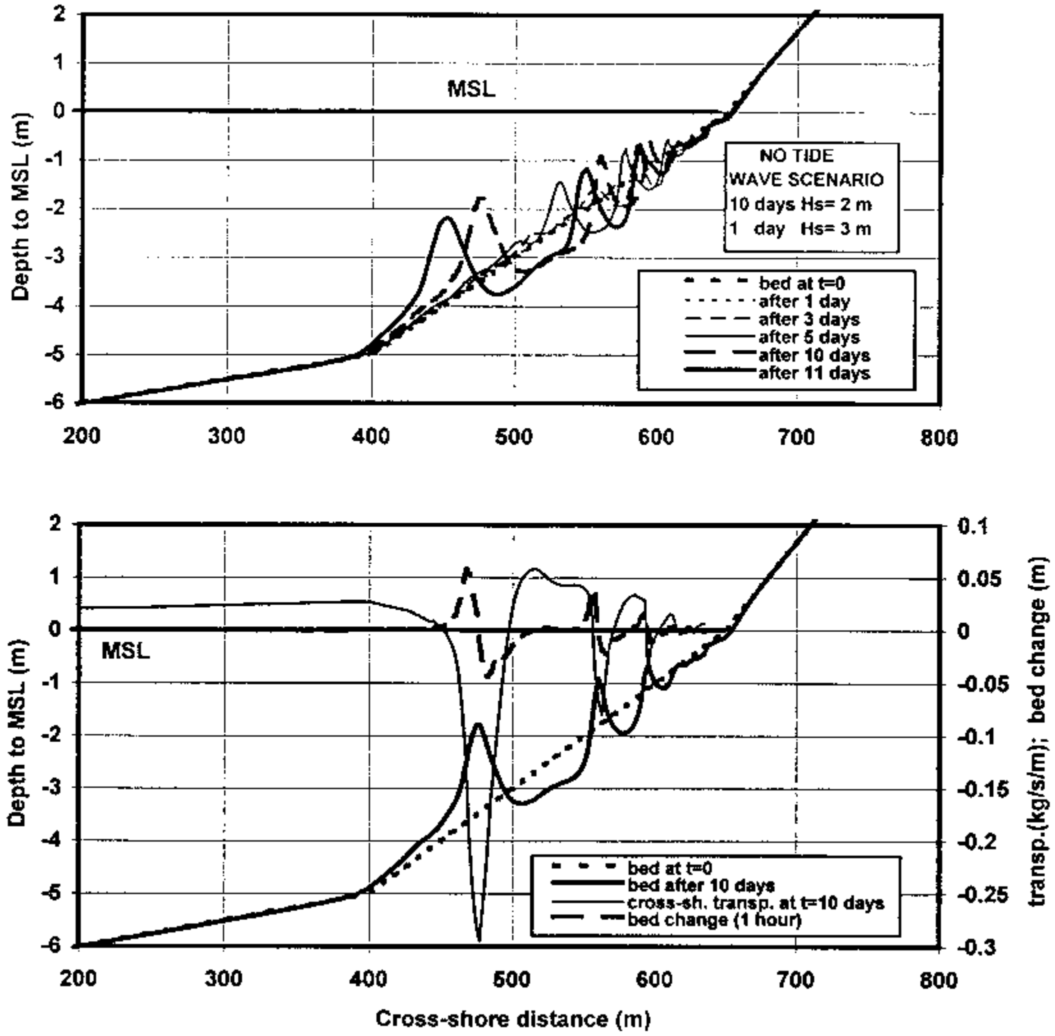

Fig. 7 *Top*: Bar development for non-tidal conditions with storm waves: 10 days H_s = 2 m and 1 day H_s = 3 m; *bottom*: sand transport rates and bed level changes (over 1 hour) at t = 10 days.

Figure 8 shows more detailed bar profiles for fair-weather conditions with $H_s = 1$ m; sand transport rates and bed level changes (over 2 hours) for $t = 10$ days and $t = 50$ days are also shown in Figure 8. The results are:

- bar development in the initial phase (10 to 20 days) shows generation of two minor bars and slow offshore migration of the bars similar to that for storm waves (sand transport is alternately onshore and offshore-directed);
- after about 50 days the outer bar becomes stable, the sand transport rate along the outer bar is approximately constant and sand is just passed along the outer bar to the inner bar where deposition takes place on the seaward slope of it; sand is eroded on the landward slope of the inner bar and carried to the shore to form a swash bar and berm on the beach (sand transport is dominantly onshore-directed along the profile).

The profile development for tidal ranges of 1, 2, 4 and 8 m is given in Figure 9. The main results are summarized hereafter.

Micro-tidal Conditions (TR = 1 m)

- generation and offshore migration of two major storm bars and one minor storm bar in the inner surf zone; erosion of the beach;
- flattening and onshore migration of the outer bar; slight flattening of the middle bar;
- growth and seaward migration of the inner bar with its crest just above the low water line by fair-weather waves; deposition on the beach;
- tidal water level variations of 1 m do not greatly affect the bar development in the outer and middle surf zone. There is a weak tendency for a reduction in bar height and for a merging of the middle and inner bar.

Meso-tidal Conditions (TR = 2 m)

- generation and offshore migration of two storm bars seaward of the low water line; erosion of the beach and generation of a bar on the intertidal beach;
- flattening and onshore migration of the outer bar by fair-weather waves;
- growth and slight seaward migration of the middle bar (height of about 2 m, length of about 80 m) with its crest just above the low water line by fair-weather waves;
- growth and onshore migration of the intertidal bar; deposition on the beach;
- tidal water level variations of 2 m result in flatter outer bar and larger middle bar.

Macro-tidal Conditions (TR = 4 m)

- generation of two minor storm bars in the intertidal zone; erosion of the upper beach; the bed in the zone seaward of the low water line remains relatively flat;
- generation of one major bar (height of 2 m, length of 60 m) near the mean water line in the intertidal zone by fair-weather waves; generation of a minor terrace just above the low water line;
- tidal water level variations of 4 m result in bar generation in the intertidal zone and in a relatively flat seabed below the low water line.

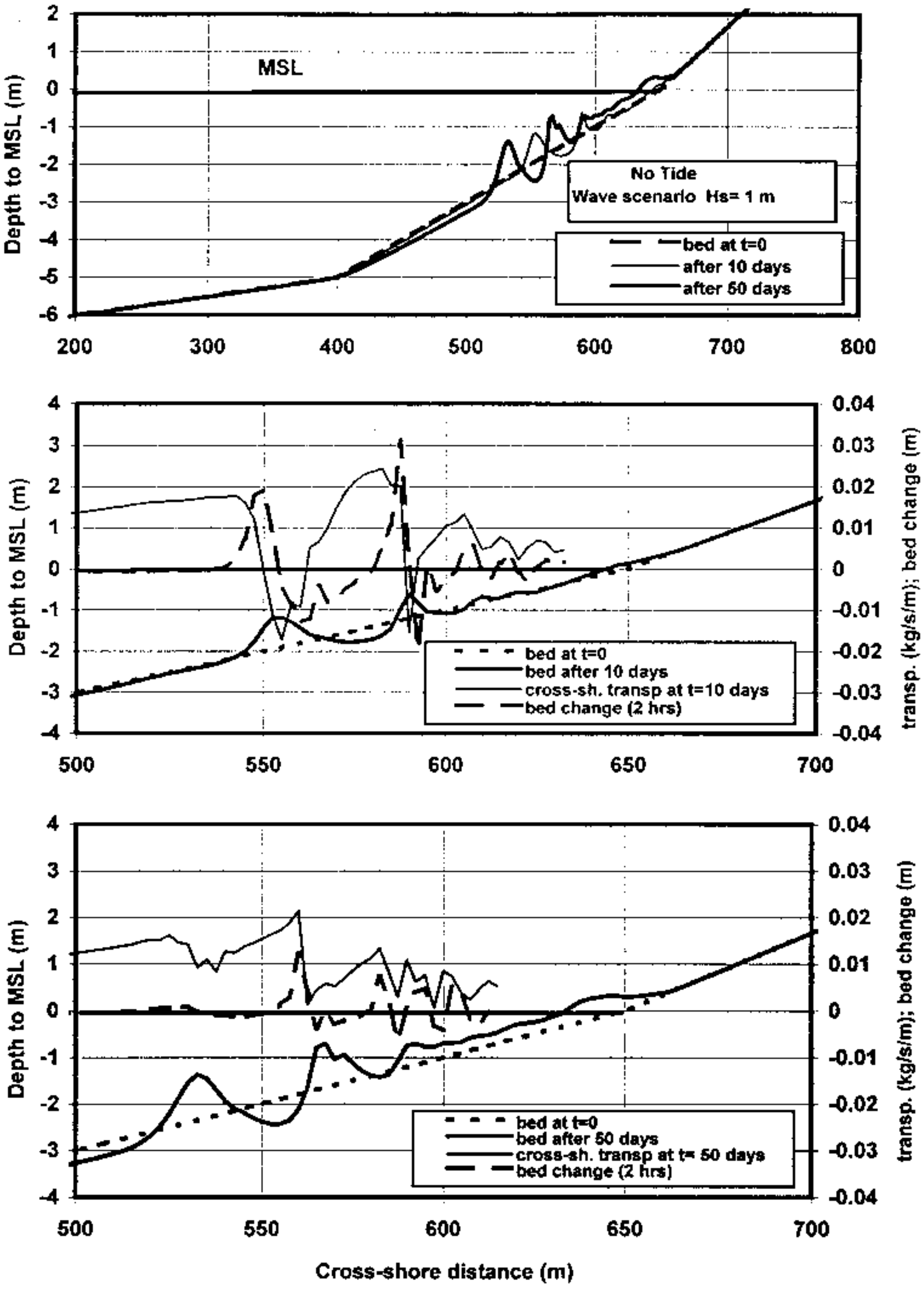

Fig. 8 *Top*: Bar development for non-tidal conditions with fair-weather waves: 50 days H_s = 1 m; *middle*: sand transport rates and bed level changes (over 2 hours) at t = 10 days; *bottom*: sand transport rates and bed level changes (over 2 hours) at t = 50 days.

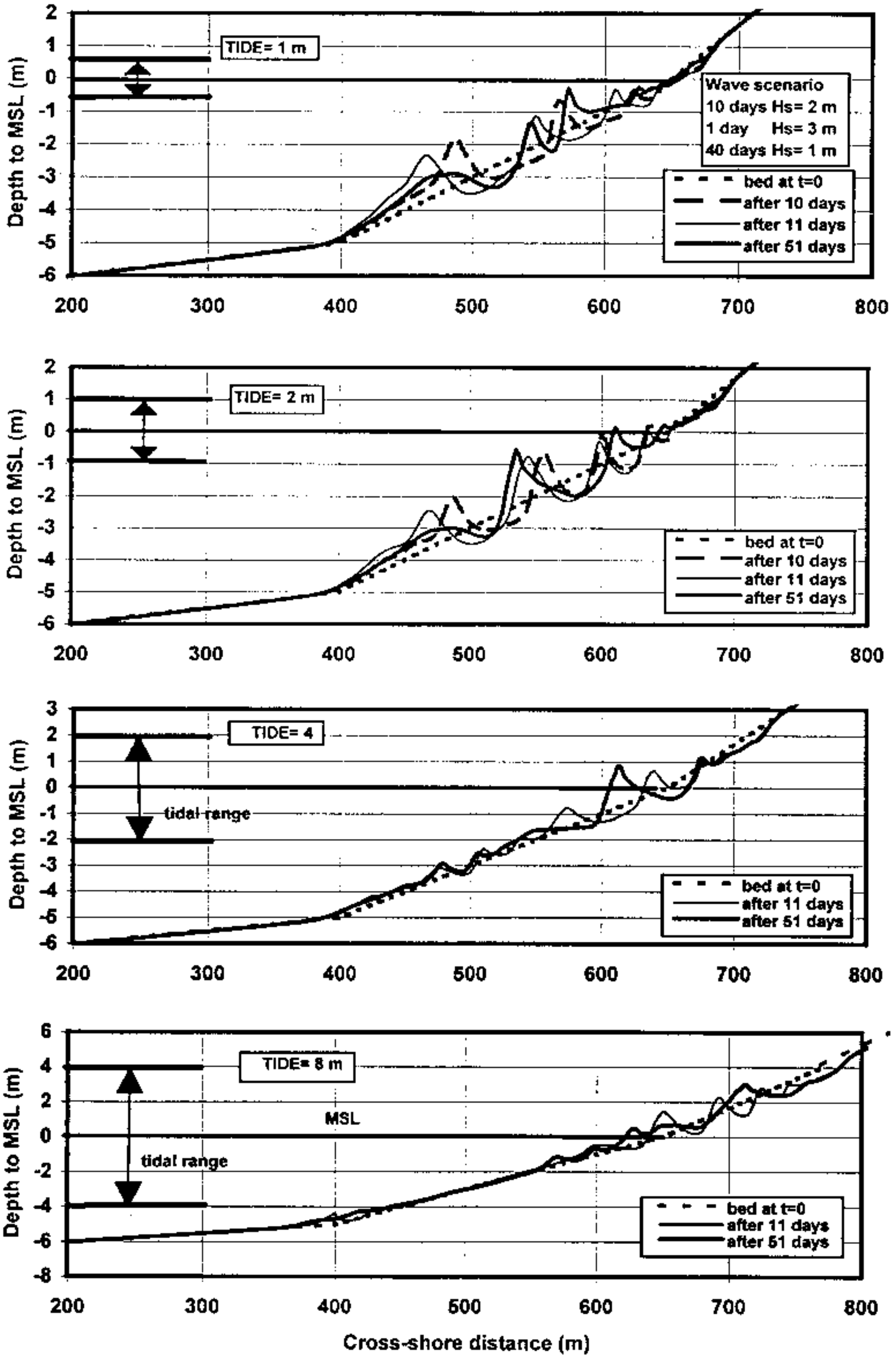

Fig. 9 Bar development for TR = 1, 2, 4 and 8 m

Macro-tidal Conditions (TR = 8 m)

- generation of two minor storm bars in inter-tidal zone between mean and high water lines; erosion of the upper beach; bed in zone seaward of mean water line remains almost flat;
- generation of one minor bar (height of 0.5 m, length of 40 m) just landward of high water line by the fair-weather waves; generation of minor terrace just above mean water line;
- tidal water level variations of 8 m result in relatively flat seabed below the mean water line and some minor bars in the zone between the mean and high water lines.

DISCUSSION

Summarizing our model results, it is fair to say that the response of an initially plane sloping beach to tidal ranges between 0 and 8 m can be categorized into two distinct groups. For TR = 0, 1, and 2 m, the model predicted the generation of a subtidal bar system comprised of 2 to 3 bars, with cross-shore spacing $O(10^1 - 10^2$ m) and height $O(10^{-1} - 10^0$ m). The effect of the tidal range on both the spacing and height is small. In more detail, the outer bar morphology gets more subdued after the fair-weather period with increasing TR, causing the middle bar to grow in height (Figures 6 and 9). For TR = 4 and 8 m no or minor subtidal bar features are predicted. Instead, multiple (2 – 5) bars are formed around Mean Sea Level (= 0 m; see Figure 9). The bar spacing is still in the order of 10-100 m; however, the bar-trough relief is less accentuated than in the TR = 0 - 2 m range. Especially, for TR = 8 m the predicted bar height barely exceeds 0.5 m. Wright et al. (1987) also noted that a more subdued barred morphology is associated with larger tidal ranges. However, their observation was based on neap-spring tidal variations in a micro-tidal setting and not on the TR = 0 – 8 m range applied in this paper.

It is encouraging that a similar division in barred systems was found based on the literature review of natural bar behavior (Table 1). Furthermore, the predicted bar response to changes in wave height (that is, onshore/offshore migration during storms/fair-weather; Figures 7 and 8) is similar to that observed under natural conditions. Nonetheless, our model results have to be considered with care and the reasonable agreement between natural and modeled bar behavior should only be viewed in a qualitative sense. There are still many uncertainties in the adopted model, such as the effect of breaking waves on the sediment transport, the down-slope gravity transport, the high-frequency transport factor (Table 2). Also, it is yet uncertain whether similar results would have been obtained if the wave climate had been schematized differently. Of special concern is the way the sediment transport in depths less than 0.5 m is modeled (see Van Rijn, 1998b). Although the present formulation predicts berm formation under non-tidal conditions following an extended fair-weather period - which is a realistic finding -, the present method is rather crude. Obviously, its effect on the model results increases with TR as the width of the intertidal beach then increases. Future model research therefore has to focus on the improvements of all these model uncertainties. Besides, a model study of the effect of beach slope, grain size and wave climate on bar behavior would definitively be worthwhile.

CONCLUSIONS

Bar generation and migration was investigated with a process-based morphodynamic model, applying it to tidal water level variations of 0 (non-tidal) to 8 m (macro-tidal). The model, CROSMOR (Van Rijn, 1993, 1997, 1998a, b), was run over an initially plane sloping bed ($\beta = 1:50$); the wave climate was schematized into an 11-day storm period ($H_s = 2 - 3$ m), followed by a 40-day fair-weather period ($H_s = 1$ m). For tidal ranges of 0 to 2 m, the model predicts the generation of a subtidal multiple bar system, consisting of 2 to 3 bars. The cross-shore spacing is in the order of 10 to 100 m; the bar height is less than 2 m. Under the storm waves the bars are predicted to move offshore, whereas the fair-weather period results in an onshore bar migration and a flattening out of the outer bar. For larger tidal ranges (macrotidal) the subtidal bar-trough morphology vanishes, but is replaced by an intertidal multiple bar system, consisting of 2 to 4 bars. The bar-trough morphology of these macrotidal systems is much less accentuated than that of subtidal morphology under non- to mesotidal conditions, especially for the 8-m tidal range case.

Future work focuses on the improvement of various model concepts, such as the sediment transport in depths less than 0.5 m and the high-frequency oscillatory transport. Additionally, the effect of beach slope, grain size and wave climate on cross-shore bar behavior will be investigated.

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