

Longshore realignment of shore-parallel sand-bars at Wanganui, New Zealand

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Abstract

The disconnection and realignment of shore-parallel nearshore sand-bars in the longshore direction is a recently identified morphological behaviour which is referred to as bar switching. This phenomenon has been observed in data from multi-bar coasts in The Netherlands, in North Carolina on the east coast of the USA, and on the west coast of the New Zealand North Island.

This paper identifies the characteristics of bar switching along a 6 km stretch of coast at Wanganui, New Zealand. Analysis of a 6.3 yr record of image-based morphological data identified nine periods or episodes of bar switching. Switching occurred within transition zones which had longshore lengths between 500 and 1000 m. Episodes occurred throughout the study period at intervals ranging from 0 to 64 weeks (mean = 25 weeks). Episode duration ranged from 8 to 27 weeks (mean = 14 weeks). Episodes tended to occur sequentially at centres located 2000–3000 and 4400–5200 m from the nearby Wanganui River mouth which marks the southeastern boundary of the study area. Two types of switching episodes were identified. Shoreward propagating episodes originate in the outer surf zone and the location of switching then moves landward. By contrast, stationary episodes begin and remain within the mid-surf zone. Episodes of bar switching are characterised by strong longshore currents, peak significant wave height values that are usually greater than the 1% exceedence level (3.2 m), and significant wave heights above the 5% exceedence level (2.6 m) for at least 4.5% of the switching period. While high-energy conditions are necessary for bar switching to occur, such energy levels do not always result in this type of morphological behaviour. Antecedent morphology and other hydrodynamic factors may also play important roles in the morphodynamics of bar switching. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Sand-bar; Multi-bar; Surf zone; Nearshore; Morphodynamics; Bar switching

1. Introduction

Nearshore sand-bars are found on many of the world's sand-dominated coasts and are significant features for the following reasons. The volume of sand contained within the bars may be important in terms of the nearshore sediment budget. Bars provide

a natural barrier to shoreline erosion by dissipating incident wave energy during storm conditions. Sand-bars may be very dynamic, particularly during higher energy conditions and they affect most surf zone processes. Recently, a new type of sand-bar behaviour has been identified on some multi-barred coasts. This involves shore-parallel bars becoming discontinuous and the landward bars on one side of the discontinuity realigning and joining the seaward bars on the other side (Shand and Bailey, 1999). This non-linear

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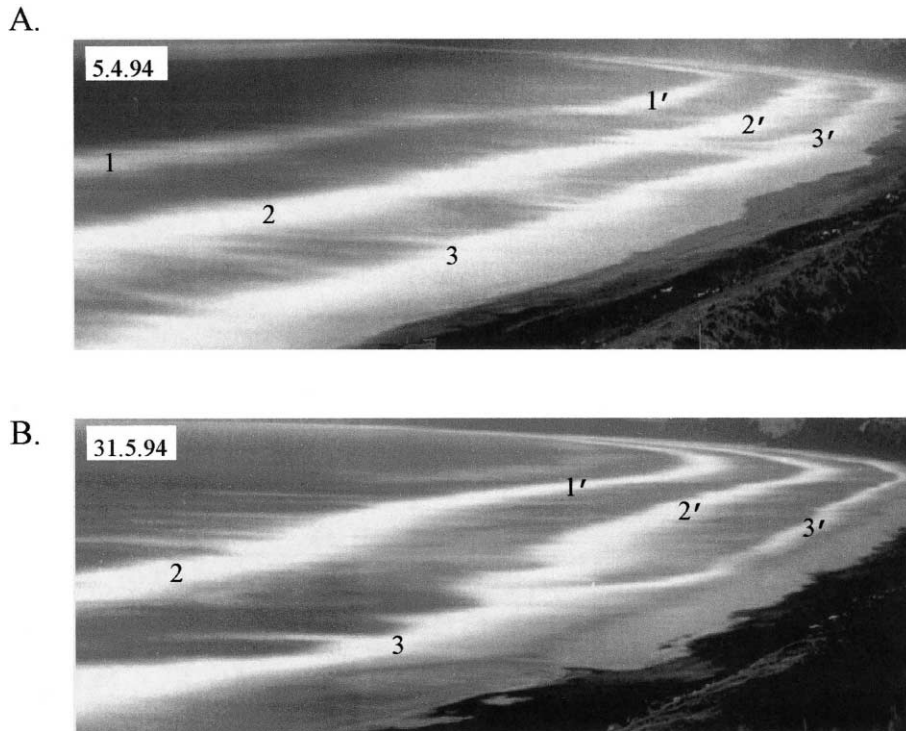


Fig. 1. An example of bar switching within the Wanganui study area. These time-exposure images were obtained using techniques described in Section 3. The high intensity bands signal bar-crests. In the foreground these bars have been marked 1–3 and in the distance as 1'–3'. In (B), bar 2 near the observer has realigned with bar 1', and bar 3 is realigning with bar 2'.

behaviour is henceforth referred to as bar switching. As noted below, bar switching has recently been recognised on other multi-bar coasts for which long-term data-sets are available. Bar switching may therefore be a common type of morphological behaviour, and will need to be well understood if comprehensive surf zone modelling is to be achieved in the future.

An illustration of bar switching is given in Fig. 1. The high intensity bands parallel to the coastline result from breaking waves; these areas broadly define topographic highs such as sand-bars. This technique is discussed later in Section 3. In this example, the switching involves the bar marked 2 in the foreground realigning with bar 1' in the distance, and bar 3 in the foreground is about to realign with bar 2'. This episode of switching is illustrated later in greater detail.

Wijnberg and Wolf (1994) first described such bar behaviour along the Holland coast. Using empirical eigenfunction analysis of bathymetric data, they found

that the underlying cycles of net offshore bar migration¹ which characterise meso-scale bar behaviour along that coast, became out-of-phase in the longshore direction. The region linking two such parts of the bar system was referred to as the transition area. These authors provided data showing the bars in each part making alternating attachments across the transition area. Bar switching, as defined above, therefore occurred within this transition area or transition zone.

Examples of bar switching at two locations on the west coast of the New Zealand North Island have recently been published by Donohoe (1998) and

¹ Net offshore bar migration refers to the systematic offshore migration of sand-bars on multi-bar coasts; see Shand and Bailey (1999) for a review. Briefly, a bar is formed (generated) near the shoreline and then migrates seaward across the surf zone to finally flatten out (degenerate) in the outer surf zone. This process takes several years to complete.

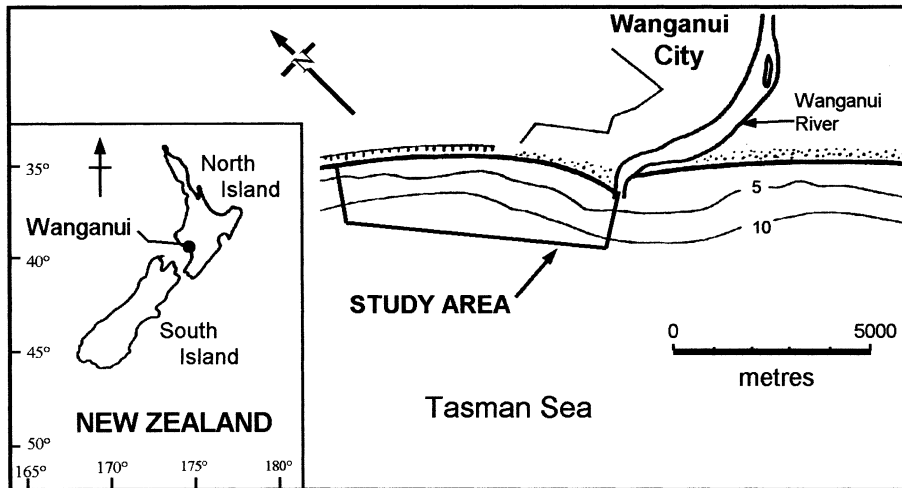


Fig. 2. Location map of the study area. Depth contours are in metres below chart datum where chart datum is 1.8 m below MSL.

Shand and Bailey (1999). These authors used video and photographically based imaging techniques, respectively, to derive their morphological data. Near Auckland, Donohoe (1998) identified a bar realignment at Muriwai Beach. Further south at Wanganui, Shand and Bailey (1999) described a set of interrelated switchings and analysed the associated cross-shore bar migration to show how the bar behaviour differed on each side of the transition zone.

Other published examples of apparent bar switching are shown in Ruessink and Kroon (1994) at Terschelling Island in the Netherlands, Lippmann et al. (1993) and Plant et al. (1999) at Duck in North Carolina, and Carter (1986) on the Magilligan coast of Northern Ireland.

Existing conceptual surf zone models such as two-dimensional storm/fairweather or bar/berm models (Komar, 1976), or more comprehensive three-dimensional beach-state or morphodynamic models (Wright and Short, 1984; Short and Aagaard, 1993), do not accommodate bar switching. For some coasts these models will need to be modified to incorporate this newly identified type of bar behaviour. The purpose of the present paper is to identify the spatial and temporal characteristics of bar switching on the Wanganui coast. Incident energy conditions associated with the switching are also described because high energy is likely to be an important driving force for bar switching given the well established positive

relationship between energy and sediment transport on barred coasts (Larsen and Kraus, 1992; Ruessink, 1998).

2. The study site

The study site covers 6 km of coast to the northwest of the Wanganui River mouth (Fig. 2). This coast is tectonically active with uplift rates of approximately 0.25 mm/yr at the shoreline and subsidence occurring further offshore (Pillans, 1983). The Wanganui River is 305 km long and has a catchment area of 7120 km² (Tonkin and Taylor, 1978). River mouth jetties were constructed between 1884 and 1940 (Gibb, 1962), and the shoreline response has been to prograde by approximately 700 m near the entrance and 100 m at the northwestern end of the study area (Smith and Ovenden, 1998). Observations made over the past decade indicate that the shoreline has prograded a further 10 m during that period. The accretion is superimposed upon a regional erosion trend of 0.2–0.6 m/yr (Johnston, 1985). The bathymetry depicted in Fig. 2 shows the ebb-tide delta of the Wanganui River extending across the eastern part of the study area.

The time-averaged nearshore width ranges from 425 m near the river mouth to 625 m in the northwestern part of the study area (Shand, 2000). The nearshore

region is defined by the intersect of the mean profile and spring low tide level, and, to seaward, where vertical change in the profile bundle becomes approximately constant. The average cross-shore slope flattens with increasing distance from the river and has values ranging from 0.0094 near the entrance to 0.0082 in the northwest (Shand, 2000). The nearshore is characterised by fine sand with the mean size of samples ranging from 2 to 3 phi (Shand, 2000).

Two to three sand-bars occur in the cross-shore direction closer to the rivermouth, while two to four bars occur in the northwest of the study area. Bar behaviour is characterised by net offshore migration with the average time interval between bar formation and bar disappearance, i.e. the life cycle of a bar, being 3.5 yr (Shand and Bailey, 1999; Shand, 2000).

Daily wave height data during the 3439 day study period (see Section 3) were collected using the 'stake and horizon' method described by Patterson and Blair (1983) and Horikawa (1988). While these data may deviate from instrument-based measurement, they do provide an accurate record of relative wave height (Patterson, 1985). A limitation of our data-set will be its tendency to underestimate peak values for higher energy events as only one or two measurements were made on most days. Nonetheless, these data should enable any qualitative pattern between wave energy and switching to be identified relatively easily, as storm events capable of moving the large amounts of sediment required for bar switching, normally have a duration exceeding one day. The resulting mean significant wave height was 1.4 m, and the 5% exceedence value was 2.6 m. These values compare closely with the deepwater wave climate statistics of 1.3 and 2.5 m, respectively. The wave period was measured by counting the number of waves breaking over a 2 min interval; the resulting mean wave period was 10.3 s. Spectral analysis of deep water sea-level data (265 days) carried out by Patterson (1992), showed that both sea and swell populations usually co-exist, with approximately 75% of the wave energy occurring at sea wave frequencies. Directional wave studies found 35% of waves had a shore-normal approach, 43% approached from the west and 22% from the east (McLean and Burgess, 1969).

The mean spring and neap tide ranges at the study site are 2.4 and 0.8 m, respectively (Ministry of Transport, 1989).

Long-term wind data from Wanganui Airport (5 km to the east) reveals a mean speed of 5.3 m/s and a 5% exceedence value of 12.4 m/s. Correlation analysis of process data (158 days) collected by the authors during 1994, indicated that wind speed was strongly associated with wave height ($p \ll 0.01$, where p is the probability of an association having arisen by chance alone). The dominant wind approach direction for the airport data was 290° which makes an angle of $\sim 30^\circ$ with the shoreline. Sixty percent of the long-term wind data had a northwesterly component, 25% a southeasterly component, and during the remaining 15% calm conditions prevailed.

Inner surf zone longshore current data collected during the 158 day process study, had a median value of 0.26 m/s and a maximum value of 0.83 m/s. In this study, measurements were made at a single location some 1500 m northwest of the river mouth and these data were obtained by timing floats released into the inner surf zone. Longshore current was positively associated with wave height, wave direction, and the longshore wind component, with $p \ll 0.01$ in each case. Tidal currents account for $\sim 23\%$ of the total longshore flow (Bell, 1990, 1991). Littoral drift reflects the longshore energy regime with NW to SE estimates ranging from 300,000 to 600,000 m³/yr and SE to NW estimates ranging from 60,000 to 280,000 m³/yr (Shand, 2000).

The mean annual flow of the Wanganui River is 224 m³/s, the mean annual flood flow is 2221 m³/y, and the annual bedload yield (gravel plus sand) is approximately 114 ktons (Tonkin and Taylor, 1978). However, the southeast-trending process conditions described above, together with mineralogical evidence (Fleming, 1953), indicate that most of the rivers' sediment load is deposited south of the study area.

3. Methods

The morphological data used in this study were derived from a 6.3 yr record of photographs taken between August 1991 and November 1997. Field sampling was carried out at approximately fortnightly intervals with closer sampling (1–5 days) at times of rapid morphological change. These sampling rates enabled morphological change to be confidently tracked within a sequence of images.

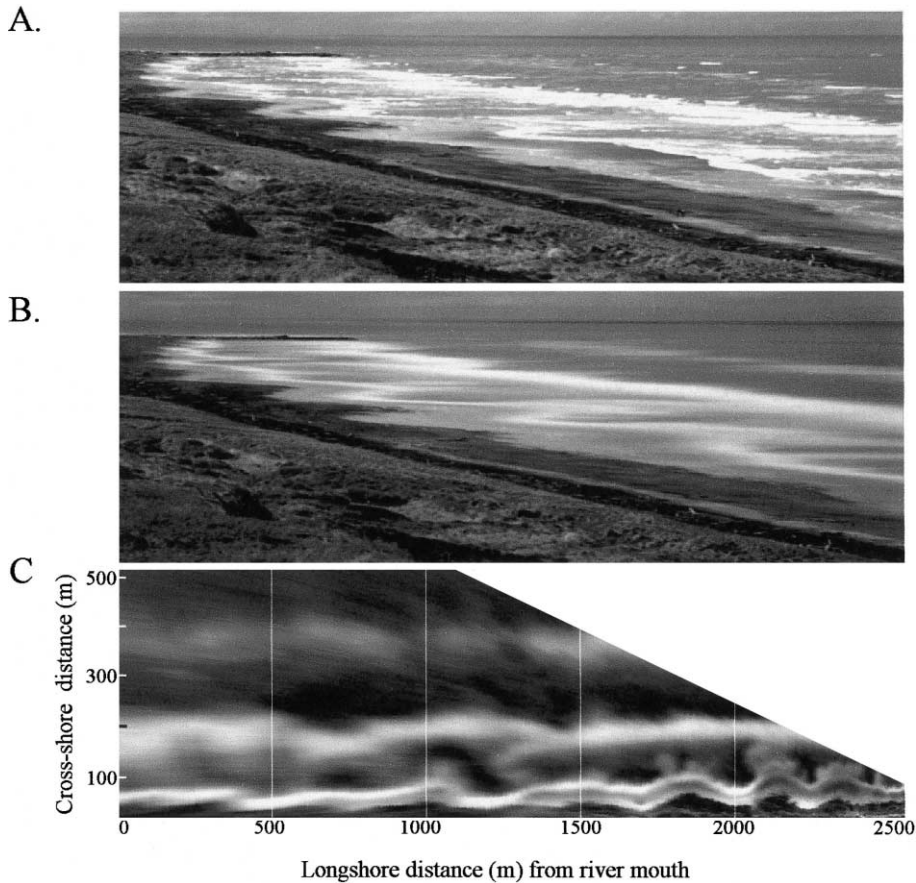


Fig. 3. Examples of an instantaneous (1/125th s) photograph (A) and corresponding time-exposure photograph (B) showing the southeastern section of the study area. The river mouth jetties are evident in the distance. (B) has been rectified and straightened to make the image in (C).

The camera was located on a cliff-top mid-way along the study area. This site is ~ 3200 m from the river mouth, ~ 130 m landward of the foredune toe and ~ 42 m above mean sea-level. A panorama of eight photographs was required to give full coverage of the study area. The four central photographs within the panorama were taken with a 55 mm focal length lens, whilst the end shots were taken with a 135 mm telephoto lens.

Each photograph was exposed for 4 min to minimise tidal change during a panoramic sampling and to provide a relatively stable representation of the breaking wave pattern. Such images are referred to as time-exposures. These images provide an analogue for surf zone morphology because elevated topography such as sand-bars are characterised by locations

of higher intensity resulting from wave breaking which is depth-dependent. Examples of an instantaneous (1/250th s) photograph and the corresponding time-exposure photograph of the eastern end of the study area are shown in Fig. 3A and B, respectively. Time-exposure photographic images are equivalent to the video-based time-exposure images produced by the Argus system which is described in Holman (1995).

Field sampling was carried out during lower tide levels and higher wave conditions to maximise the likelihood of waves breaking on all bar-crests. Furthermore, by limiting sampling (photography) to these conditions, the influence of different wave heights and tide levels on break-point location were minimised; this is described in detail by Shand (2000).

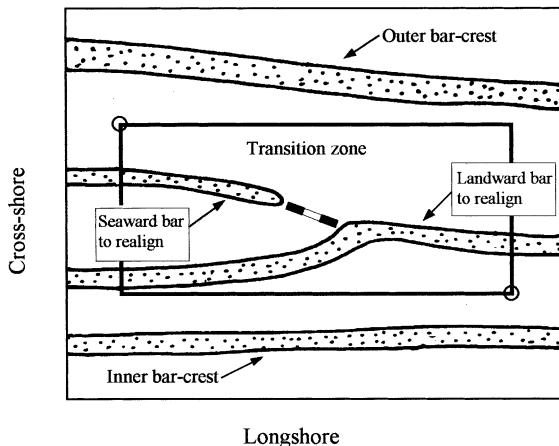


Fig. 4. A schematic illustration of the method used in this study to locate transition zone boundaries. The dashed line shows where realignment is about to occur, and the transition zone within which this realignment occurs is defined by the rectangle. Points represented by the circles at the upper left and lower right corners, delineate the rectangle. The means by which these two points are located is described in the text.

The landwardmost intensity maxima usually relates to wave breaking over a step feature observed to occur where the landwardmost trough joins the foreshore; we refer to this as the low tide step. Sand-bars have been defined by positive residuals from a smooth curve fitted to the cross-shore profile (e.g. Holman and Bowen 1982; Larsen and Kraus, 1992; Kroon, 1994). Under this definition the low tide step is a sand-bar and it will be considered as such for this study.

Digital image processing was used to rectify each photograph to ground co-ordinates and then to merge this output with adjacent images. This combined output image was subsequently transformed to straighten the coastline, thereby facilitating viewing and analysis. These procedures have been described by Bailey and Shand (1993, 1996). Fig. 3C shows the rectified and straightened output image corresponding to the time-exposure photograph in Fig. 3B. The cross-shore resolution of bar-crest data from output images is estimated at ± 20 m, while the longshore resolution varies between ± 1 m opposite the camera to approximately ± 100 m at the ends of the study area (Shand, 2000).

Data used for analysis in the present study were selected from the data-base of rectified images after

taking the following considerations into account. During an episode, several months could pass with little change to the morphological configuration; this situation is illustrated later in the paper. To minimise the analysis of repetitious configurations, samples at monthly intervals were selected. However, as significant configuration change could occur within several days, smaller intervals were used for such periods.

The method used in this study to identify transition zone boundaries is illustrated in Fig. 4. The two circles denote points which define the rectangle marking the transition zone boundaries. The seaward cross-shore limit was defined by the mid point between the seawardmost bar-crest (intensity maximum) undergoing switching and the adjacent offshore bar (intensity maximum). The landward transition zone boundary was the mid point between the landwardmost bar undergoing switching and the adjacent inner bar. The low tide step was used as the most landward bar in the switching process. The longshore boundaries of the transition zone were where bar morphology appeared to have been unaffected by the realignment process. Identification of the boundaries was assisted by zooming onto the relevant section of rectified image, applying colour enhancement, and overlaying a $50 \text{ m} \times 50 \text{ m}$ grid. The accuracy of visually locating the cross-shore and longshore transition zone boundaries is estimated at ± 10 and ± 50 m, respectively.

The data resolution limitations and the errors in locating the transition zone boundaries, are not sufficient to affect significantly the results and conclusions described later in this study.

Bar switching was deemed to have begun when the usually distinct intensity minimum representing a longshore trough between adjacent bars, was not evident. The switching was considered to have finished when a distinct trough was apparent between bars involved in the realignment.

The high energy events, i.e. storms, which are expected to occur at times of bar switching, may be characterised by parameters representing wave intensity, duration and frequency. When the wave field has been sampled at hourly intervals, parameters such as those described in Kroon (1994) and Lee et al. (1998) may be used. However, in the present study only one or two daily samples were available, so alternative parameters were used. The first was the maximum

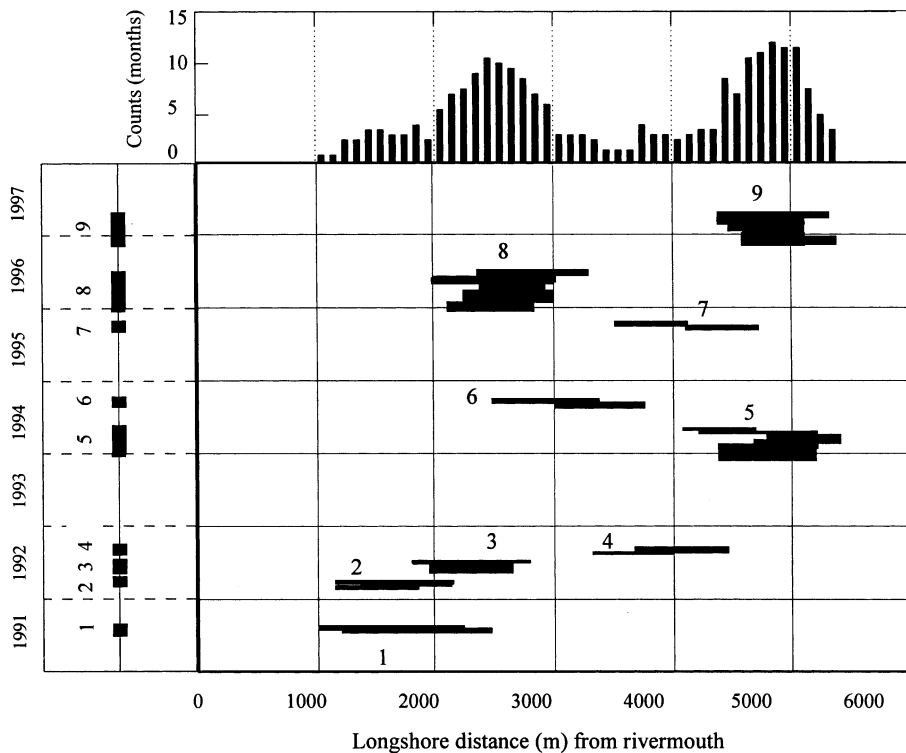


Fig. 5. Longshore distribution of 33 transition zones defining nine chronologically numbered episodes of bar switching at the Wanganui study site between 1991 and 1997. The time-line for the episodes is shown on the left of the figure, and a histogram of the number of months transition zones occurred at each longshore location is depicted along the top of the figure.

(peak) wave height for each period of bar switching (or non-bar switching). The second was a cumulative time-based high energy parameter consisting of the number of days that wave height was greater than the 5% exceedence level (2.6 m) during an interval of bar switching (or non-bar switching) normalised by the total number of days within the interval. The 5% level was used as all episodes experienced wave heights above that value.

4. Results

4.1. Temporal characteristics

Nine separate periods of bar switching were identified within the study area. A period of bar switching consisted of a set of interrelated bar realignments and is referred to as an episode of bar switching. The nine episodes have been plotted and chronologically

numbered on the time-line in Fig. 5. Duration for the episodes of bar switching ranged from 8 to 27 weeks with a mean of 14 weeks. Episodes occurred throughout the study with a mean spacing of 25 weeks. However, the episodes occurred somewhat irregularly, with the spacing ranging between zero and 64 weeks.

4.2. Spatial characteristics

4.2.1. Longshore

The longshore location of the set of transition zones associated with each episode of bar switching is plotted against time in Fig. 5. Longshore length dimensions of these transition zones ranged from 500 to 1000 m with a mean of 760 m. Longshore movement in transition zone location during episodes of switching is evident in Fig. 5. Sixty percent of the net displacements were from the northwest to the southeast. The maximum movement of the centre of

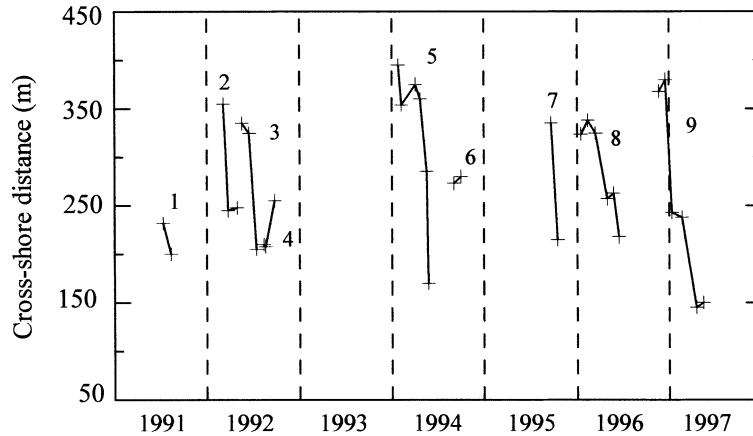


Fig. 6. Time-series depicting cross-shore locations of centre of mass of transition zones associated with each episode of bar switching. The episodes have been chronologically numbered.

mass of the transition zones between the beginning and end of each episode was 625 m, the minimum movement was 25 m and the mean was 315 m. The rates of change in location of the transition zones ranged between 1 and 305 m/month with a mean of 115 m/month.

A histogram of the number of months that transition zones occurred at different longshore locations is

shown at the top of Fig. 5. The centre of mass of each transition zone was used for this analysis. The result shows a bimodal distribution with frequency peaks between 2000 and 3000 m alongshore (from the river mouth) and between 4400 and 5200 m alongshore. Switching occurred approximately 12% of the time at these locations. At least one episode of switching occurred at each location between 1000 and 5400 m; however, switching was absent at each end of the study area.

The results in Fig. 5 also show that the longshore location of the nine episodes of bar switching tended to alternate between the two frequency distribution centres. This longshore alternation was disrupted during the period 1992 through 1993 when no switching occurred. This time interval was characterised by lower wave energy levels and will be considered further in Section 4.3 which examines process conditions experienced during the study period.

4.2.2. Cross-shore

The cross-shore location of transition zones associated with each episode of bar switching are depicted in Fig. 6. These results show that most episodes of bar switching (episodes 2, 3, 5, 7, 8 and 9) began in the seaward portion of the outer surf zone, and the transition zone location subsequently shifted shoreward. The remaining episodes (1, 4 and 6) began closer to shore and their subsequent transition zones remained in approximately the same place. These results are more clearly depicted in Fig. 7. The start

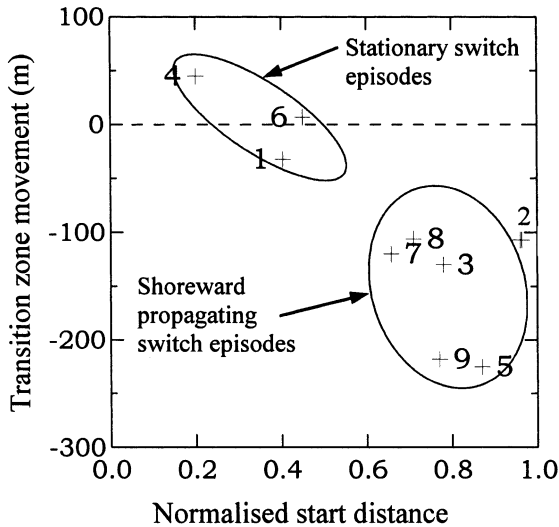


Fig. 7. Bivariate plot for cross-shore start distance and cross-shore transition zone movement for each of the nine episodes of bar switching. Start distances have been normalised with respect to surf zone width. Positive transition zone movements are directed seaward. The partitioning is based on 95% confidence ellipses.

locations have been normalised with respect to the distance between the landward and seaward protruberances on the time-averaged profile, as most of the nearshore sand-bars occurred within this region (Shand, 2000). These distances increase with increasing distance from the rivermouth in a similar manner to the change in nearshore width described earlier. The two groups of switching episodes are henceforth referred to as shoreward propagating episodes and stationary episodes.

Examples of morphological configuration sequences which clearly depict landward propagating and stationary episodes of bar switching are shown by the images in Fig. 8A (episode 5) and B (episode 6), respectively. The shoreward propagating episode consists of three separate bar realignments, while the stationary episode consists of a single realignment.

It is further noted that switching episode 1 may not be a stationary type for the following reasons. The first available data showing longshore morphological variation were a set of echo-sounding profiles sampled in July 1991. It is possible that the episode began prior to this. If this was the case, then the landward movement of the observed transition zones suggest that this episode may have originated further seaward. Episode 1 may therefore be a shoreward propagating type, rather than a stationary type, and it will be reclassified as such for this study.

Re-analysis of the earlier bar switching characteristics in light of these two types of realignment, show that the two stationary switch episodes (4 and 6) had lower durations (8 weeks) than the shoreward propagating episodes, which ranged up to 27 weeks.

4.3. Process characteristics

The maximum wave height that occurred between each set of morphological surveys is depicted in Fig. 9A, and the maximum (peak) wave height which occurred during (and between) each episode of bar switching is depicted in Fig. 9B. Seven of the nine episodes experienced a peak wave height value greater than the 1% exceedence level (3.2 m). The remaining two episodes experienced peak values greater than the 5% exceedence level; these episodes (4 and 6) were of the stationary type. By comparison, only 4 of the 10 non-switching intervals experienced peak values greater than the 1% level. For the

six remaining periods of non-switching, three experienced a peak wave height greater than the 5% level, two had a peak value less than the 5% level and in one case there was no interval between episodes. It is noteworthy that the highest peak value (3.7 m) occurred during a period of non-switching.

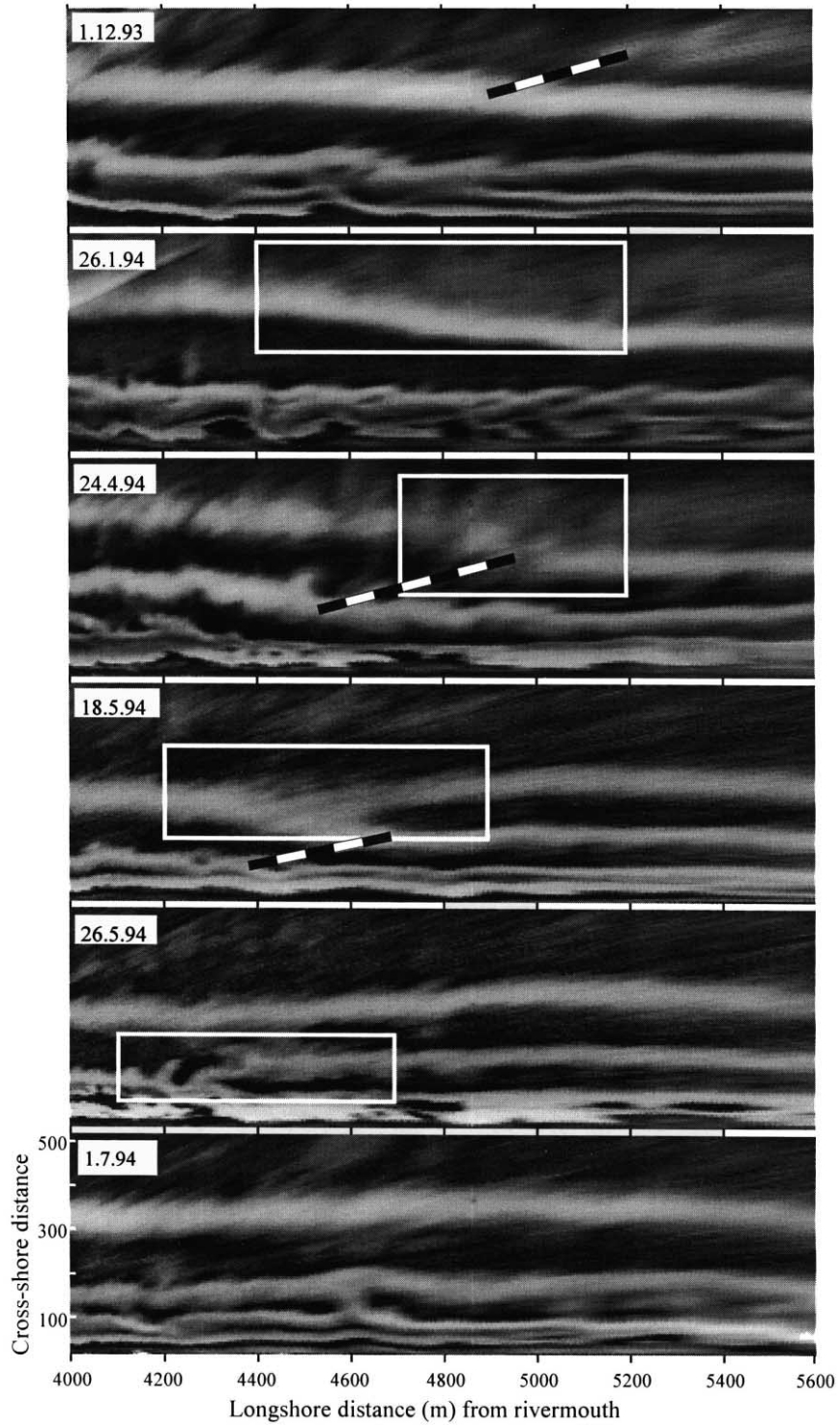
The cumulative time-based high energy parameter values for switching and non-switching intervals are depicted in Fig. 9C. These results show that for all periods of bar switching, wave heights exceeded the 5% level (2.6 m) for at least 4.5% of each time interval. By comparison, only 5 of the 10 periods of non-switching exceeded this cumulative value. However, as with peak wave height, the greatest value for this parameter (0.115) was experienced during a period of non-switching.

5. Discussion

Comparison of the Wanganui bar switching results with those derived from the Holland data presented in Wijnberg and Wolf (1994) and Wijnberg (1995), show that episode durations at Wanganui were shorter (0.15–0.51 yr cf. up to 5 yr), the average longshore length of transition zones were shorter (750 m cf. 2500 m), and the longshore migration rates of transition zones were higher (maximum 306 m/month cf. 92 m/month). These differences may relate to the larger sediment volume contained in bars along the Holland coast, which may in turn be a consequence of higher overall levels of wave energy (see Shand et al., 1999). Empirical eigenfunction weighting diagrams presented in Wijnberg and Wolf (1994) and Wijnberg (1995), suggest that bar switching along the Holland coast tends to occur at preferential locations as is the case at Wanganui (Fig. 5).

The energy parameter results described in Section 4.3, identified possible conditions under which bar switching did (and did not) occur. In particular, bar switching coincided with very high peak wave height values, together with the relatively frequent occurrence of high values throughout the episode. While lower peak and cumulative values often occurred during non-switch intervals, particularly high levels also occurred during such periods. These relationships suggest that while high energy levels are necessary for the occurrence of

A. Switch episode 5



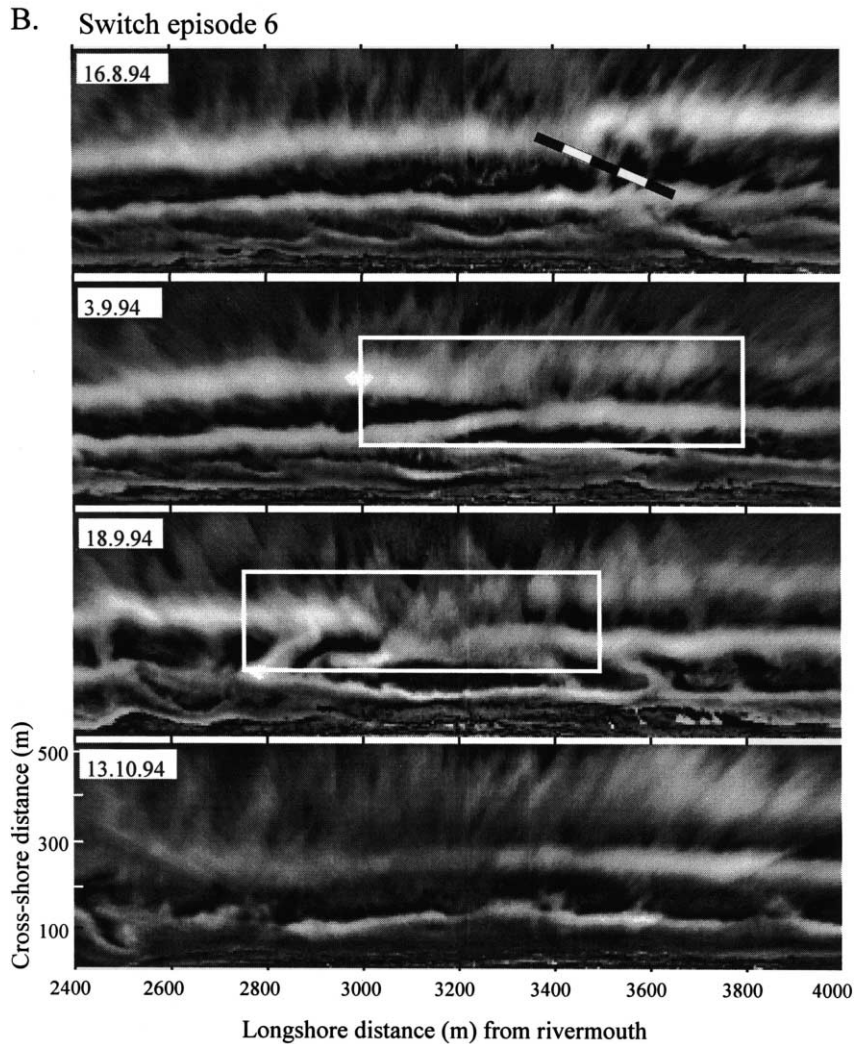


Fig. 8. Configuration sequences depicting an example of a shoreward propagating switch episode (A) and a stationary switch episode (B). The bold dashed lines show where bar switching is about to happen and the rectangles define the transition zones within which bar switching is occurring.

bar switching, high energy levels alone do not necessarily result in switching. Bar switching therefore appears to be forced by high energy acting in combination with factors such as other types of hydrodynamic conditions or antecedent morphology. Other types of hydrodynamic influences are considered later in this section, and support for morphological control has recently been provided by Shand (2000) who showed that longshore variation in the depth and shape of the seawardmost bar in the

vicinity of the transition zone, precedes bar switching.

The highly significant positive correlation between wave height and longshore currents described earlier in Section 2, indicate that strong longshore currents occur during bar switching. In addition, the importance of longshore current for switching morphodynamics is suggested by the similarity between net longshore movement of transition zones (60% toward the southeast and 40% toward the

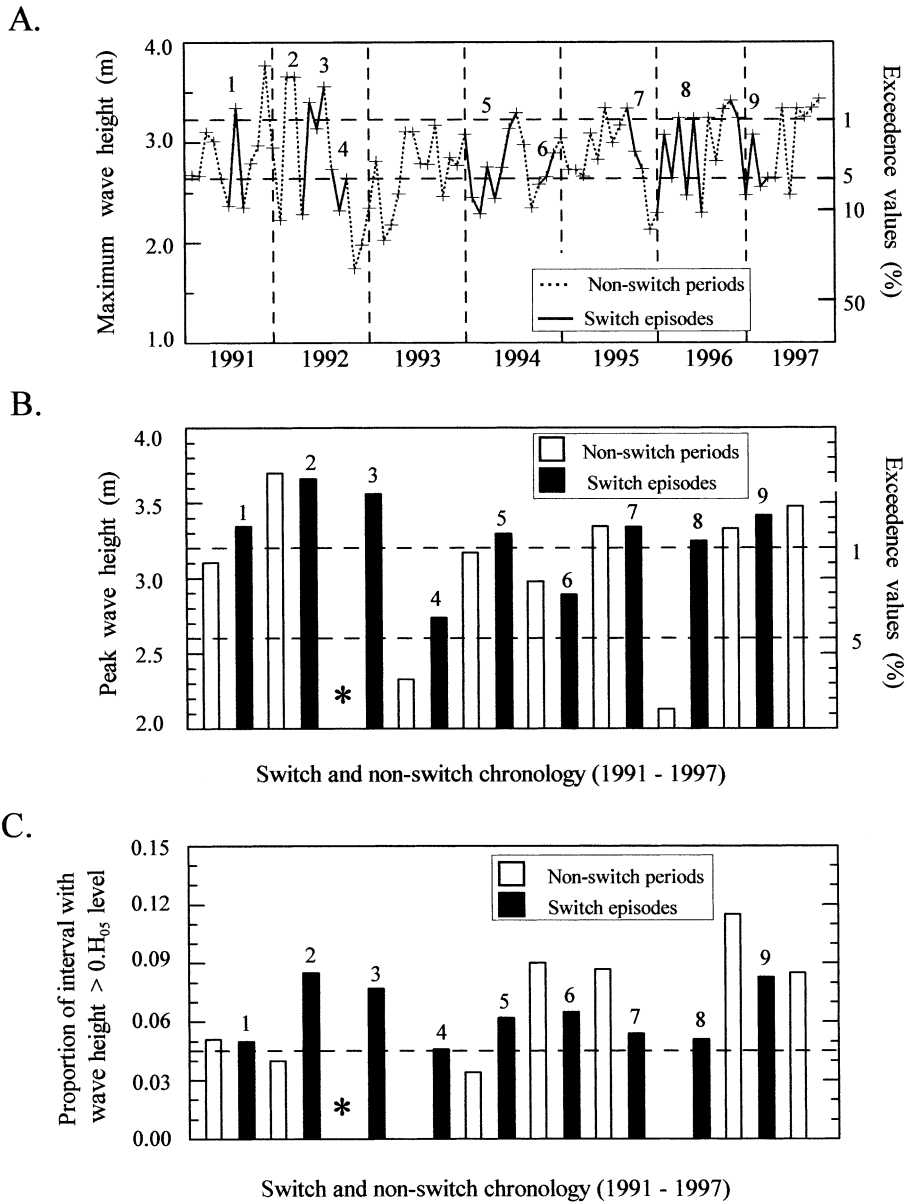


Fig. 9. Maximum significant wave height between each morphological inter-survey period is depicted in A, with the solid lines relating to chronologically numbered episodes of bar switching. Peak wave height for each switching episode, and for the interval between switching episodes, is shown in B. The proportion of each episode of switching, and each period of non-switching, for which wave height was greater than the 5% exceedence level, i.e. $H_{0.05} > 2.6$ m, is depicted in C. The asterisks denote instances where there was no time between successive episodes of switching.

northwest) and the directional wind and wave statistics described in Section 2.

The absence of bar switching between 5400 m and the northwestern boundary of the study site, raises

the question of whether bar switching is a local rather than a regional phenomenon. However, morphological configurations consistent with bar switching are evident on aerial photographs taken of

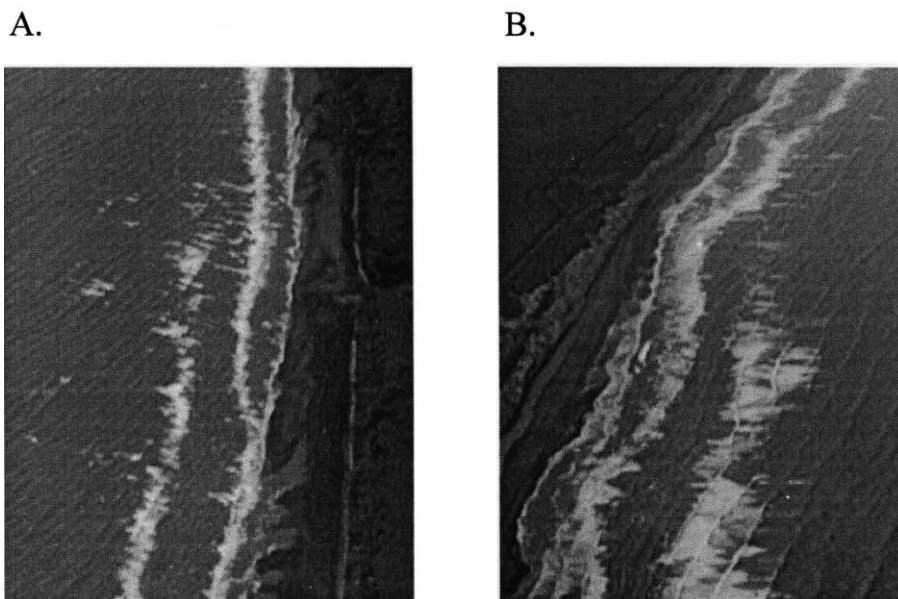


Fig. 10. Examples of morphological configurations from outside the Wanganui study area which are consistent with bar switching. (A) is located approximately 11.5 kms northwest of the Wanganui River mouth, while (B) is approximately 25 km southeast of the river.

the Wanganui coast beyond the study area. Examples of two such configurations located ~ 11.5 km northwest and ~ 25 km southeast of the river mouth are depicted in Fig. 10A and B. It is noted that the northwestern location is a multiple of 2300 m from the river mouth, and this spacing is very similar to that associated with the two preferred locations of bar switching within the study site (2500 and 2400 m, as depicted in Fig. 5).

The apparent existence of bar switching along the Wanganui coast beyond the study area, together with the regularity in the longshore location of switching both at Wanganui and along the coast of Holland, suggest that a regional hydrodynamic control may be important in morphodynamics associated with this phenomenon. Such mechanisms may involve the influence of low frequency standing edge waves, or instabilities in the wave/current field, both of which have been theoretically shown to be capable of generating regularly spaced three-dimensional nearshore morphologies (e.g. see Hino, 1974; Holman and Bowen, 1982; Holman, 1983; Damgaard Christensen et al., 1994). Alternatively, the observed longshore preference in the location of bar switching may result from morphodynamics linked to the

changes in cross-shore slope or bar number, which occur along the ebb delta and adjacent coasts.

While the transition zone analysis identified two apparent populations of bar switching (stationary and shoreward propagating), this is not unequivocal. If an initial seaward switching was undetected because of under-sampling or low image resolution, then the seaward transition zone would also remain undetected, thereby resulting in the spurious identification of stationary switching. Alternatively, the single and multiple bar realignments associated with the examples of stationary and shoreward propagating episodes, respectively (Fig. 8), suggest that the two types of episode may be the product of the same realignment process, with the difference being a function of differing numbers of bars. Nevertheless, the differing levels of three-dimensionality apparent within the antecedent morphologies of Fig. 8A and B, suggests that an underlying difference in morphodynamics may occur between the two types of bar switching. For example, the greater level of 3D morphology associated with the antecedent configuration of stationary switching, may constrain longshore flows, thereby locally enhancing nearshore currents and increasing sediment transport potential. This

process could explain the observed occurrence of lower peak energy levels with stationary switching.

6. Conclusions

This paper has identified the characteristics of nine episodes of bar switching at Wanganui by analysing the transition zones within which bar realignment occurred. Episodes of bar switching happened throughout the study period at an average spacing of 25 weeks. The duration of the episodes ranged from 8 to 27 weeks (mean = 14 weeks). Episodes tended to occur sequentially at centres located 2000–3000 and 4400–5200 m from the river mouth.

The transition zone analysis identified two types of switching episodes. Shoreward propagating episodes originate in the outer surf zone and switching then moves landward. Stationary episodes begin and remain within the mid-surf zone. However, further research is required to determine whether these are fundamentally different types of morphological behaviour.

Episodes of bar switching were characterised by the following process conditions: strong longshore current; peak significant wave height usually exceeding the 1% level (3.2 m); and, significant wave height exceeding the 5% level (2.6 m) for at least 4.5% of the switching period. While these results suggest that very high energy levels are a necessary condition for the occurrence of bar switching, high-energy conditions also prevailed during some of the periods when bar switching did not occur. High energy conditions alone are therefore not sufficient to cause bar switching, and this phenomenon may also be controlled by other hydrodynamic factors and antecedent morphology.

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