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The Coastal Studies Unit and Development of the Australian Beach Models

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ABSTRACT

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The Australian coast provides an ideal laboratory in which to undertake beach research on a continental scale. The 30 000 km of open coast surrounds an entire continent that ranges from tropical to temperate latitudes (9-43°S); with tides ranging from <0.5 to 12 m; average breaker wave height from <0.5 m to ~3 m; beach sediment from fine to medium sand, half of which is carbonate; and many of the ~12 000 beach systems are embayed. Commencing in the mid-1970s this laboratory was utilized by members of the Coastal Studies Unit (CSU) leading to the development of beach models that encompass the full range of beach types and states that incorporate every Australian beach and most global beaches. This paper will review the development of these models, based initially on beach research on the micro-tidal, wave-dominated southeast coast; then expanding into both the higher wave energy environments of southern Australia and the higher tide range environments of northern Australia; culminating with an assessment of every beach system around the coast. The end result was the wave-dominated, tide-modified and tide-dominated beach models.

ADDITIONAL INDEX WORDS: *beach, surf zone, beach models*

INTRODUCTION

Australia has one of the world's great national coastlines as well as that of an entire continent. Its coastline is renown for its sheer size – 30 000 to 60 000 km depending on how it is measured; its latitudinal range (9-43°S); its full range of orientations, exposing it from very low to the world's highest waves; its full range of tides from micro to mega; and its climatic diversity from tropical to temperate and from humid to arid. When you put all these together, combined with a robust coastal flora, extensive climatically-controlled coral-algal reefs, mangroves, seagrasses, beachrock and aeolianites, and a diverse and generally ancient coastal geology you have the making of an interesting coast, half of which consists of sandy beaches.

The coast can be viewed from a range of perspectives. From a geological perspective it is generally an ancient, denuded and flat continent, the oldest, flattest and driest (after Antarctica) on the planet. At the coast it consists of a western-central coast composed of ancient cratons, while successive accretionary fold belts formed the eastern third. Buckling around the coast since the Cretaceous formed a series of more recent sedimentary basins three of which contain Australia's longest beaches. More broadly however, the geology dominates the coast producing thousands of generally short, headland bound-beaches (average length = 1.37 km). The geological stability of the largely passive margin coast has also left a legacy of successive highstand coastal deposits that reach back to the Pliocene and can extend hundreds of kilometers inland. Tropical-arid though humid climates dominate the north, while temperate-arid through humid dominate the south, both having profound effects on coastal sediments, diagenesis and ecology, including the extensive areas of beachrock and dunerock. The surrounding ocean climates deliver the world's largest, longest and most persistent waves to the southern half of the continent, while more benign trade and monsoonal winds produce more moderate waves across the north. These same winds build some of the most extensive and largest coastal dune systems in the world. The coastal vegetation has adapted to the climatic conditions and robust sand stablizing species thrive in even the harshest environment resulting in primarily vegetation-controlled coastal dune systems. Finally, the marine ecology is manifest in coral-algal reefs ringing the northern coast, together with the world's third largest mangrove systems, and the world's most extensive tropical and temperate seagrass meadows, the latter of which has profound impacts on the southern coast and its beaches. The geology, ecology and climates combine to supply the coast with generally mature polycyclic quartz sand along the more humid north and east coasts, while shelf and nearshore marine carbonate sands dominate the south and west coasts.

This paper reviews how this coast was utilized as a natural laboratory to investigate the impact of variable waves, tides and sediment, together with geological control, to influence the type of beaches that formed around the coast. These investigations in

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turn lead to the development of the wave-dominated (WD) beach model (Wright and Short, 1984), the tide-modified (TM) beach model (Masselink and Short, 1993) and finally the tide-dominated (TD) model (Short, 2006), as well as the impact of geological inheritance and embaymentisation on these beach systems (Short and Masselink, 1999; Short 2010a).

BACKGROUND

The Australian coast, and particularly its beaches, received very little scientific attention until the beginning of the 20th C with reports on a series of damaging storms. In the next few decades there were individuals working on rock platforms (Jutson, Edwards) and sea level (Fairbridge) but it was not until, the 1960-70s, that scientists like Jennings, Davies and Bird began publishing systematic studies of parts of the coast and coastal systems, including the first classification of the coast (see Thom, 1984a and Thom and Short, 2006 for reviews). The first detailed investigation of beach morphodynamics was by McKenzie (1956) who described the various rip current systems on the Sydney coast. The catalyst for the so-called 'Australian' school of beach research can be traced back to the 1960s when at the University of Sydney under the supervision of Professor T Langford-Smith a number of honours and graduate students including B G Thom, L D Wright and A D Short, began more systematic coastal and beach investigations. All three went on to complete Ph.D.s on coastal topics at Louisiana State University (LSU). Here they were introduced to the more holistic approach to studying the world's coastal systems developed at LSU's Coastal Studies Institute (CSI) by people like R J Russell, W McIntire and J Coleman, and transferred to the beach environment by C J Sonu (Sonu, 1973; Short and Jackson, 2010). By the mid-1970s all three were back at the University of Sydney, with Thom, Wright and Langford-Smith establishing the Coastal Studies Unit (CSU) in the Department of Geography, in 1976, in part a second generation to the LSU-CSI. At the same time Wright and Thom (1977) wrote the seminal paper on coastal morphodynamics, providing a blueprint for what was to follow, later updated by Cowell and Thom (1994).

Over the next 30 years the CSU undertook coastal research covering the entire Australian coast. In the process its members developed the wave-dominated beach model (Wright and Short, 1984), followed by the tide-modified model (Masselink and Short, 1993), and finally the full spectrum of beaches also including the tide-dominated and rock/reef-affected states (Short, 2006). In addition its members conducted wide-ranging research into rip currents (Short, 1985; Brander, 1999; Brander and Short, 2000); Quaternary coastal evolution (Thom, 1984b; Roy and Thom, 1981); the relationship between waves-beaches and dunes (Short and Hesp, 1982; Hesp, 1984); foredune morphodynamics (Hesp 1988); estuarine evolution and classification (Roy, 1984; Nichol, 1991; Lessa and Masselink, 1996); beach stratigraphy (Short, 1984b); beach groundwater and swash dynamics (Turner, 1993; Hughes, 1992); beach hazards and safety (Short and Hogan, 1994; Brander 2010); shoreface morphodynamics and sedimentation (Roy, *et al.*, 1997; Cowell, *et al*., 1995); beach rotation (Short, *et al.*, 1995; Short and Trembanis, 2005); the role of embaymentisation and geological inheritance on beaches (Short and Masselink, 1999); the impact of the 9000 km long temperate coastal carbonate factory on the adjoining coast, beaches and dunes (Short, 2002, 2013); and finally, all 11,761 open coast mainland beaches and 2261 barrier systems were investigated as to their beach type-state and hazards and barrier type, size and stability (Short, 2006, 2010b). This paper will briefly review the development of the three beach models: wave-dominated, tide-modified and tide-dominated.

CSU: 1976-1082

The CSU's first six-years were to be an exciting, humorous, at times adventurous, but very productive phase. It was an era that firmly established the CSU and its reputation in beach research, as well as establishing its field-oriented approach to coastal research and the so-called 'Australian school' of coastal geomorphology and morphodynamics. At the helm was L D Wright. His approach to research was to gather a team of reliable assistants and students, inspire them with his (then) pipe-puffing ideas, and lead them into the field to literally battle with the surf. In the field Wright often came off second best and in hospital, but the data flowed as did the papers. A D Short arrived at CSU in November 1977, when he replaced B G Thom who had taken up a position at the UNSW Faculty of Military Studies (Duntroon). The first field experiments took place during 1976 and 1977 on two of Sydney reflective beaches: Jibbon and Pearl; and in 1977 on the NSW south coast at the reflective Bracken (Mckenzie) beach, followed by work on the nearby rip-dominated Bengello beach (originally called Moruya) (Figure 1) and Sydney's Palm Beach. The aim of these experiments was to document and record the morphodynamic character of each 'type' beach, including its morphology, wave and current transformation across the surf zone and eulerian and lagrangian surf zone circulation, the latter using CSU members as rip-floaters.

In the 1970s off-the-shelf equipment did not exist and the first pressure sensors and ducted-current meters were constructed in-house, using a CSI design. This equipment was attached to home-made concrete 'pods' with legs designed to hold the equipment on the seabed, and hardwired back to shore to a Tektronix 4051 minicomputer with a RAM of 13 kb and to ink chart recorders (to show the instruments were recording). It had to be housed in an air-conditioned camper-van to prevent overheating. This was supplemented in 1978 with a Mr Floppy z80 micro-computer running CPM operating system, it had twin diskette drives and a then massive 48 kb RAM. This pre-dated the IBM PC, considered by many to be first PC, by three years. It had just enough memory to run a FFT on 20 minutes of field data, using home-made software. There was also a 16 channel multiplexing data logger constructed for connecting up to the 4051, which controlled the data logging via the software. This rate was about 0.25 sec for a single instrument and more than a second for all 16 channels.

Many problems were encountered starting in the surf zone (Figure 2) with the pods moving, summersaulting and/or being buried, the current meters clogging, and the wires tangling or breaking; while on the beach the chart recorders would run out of ink and the computer mal-function, run out of memory or overheat.

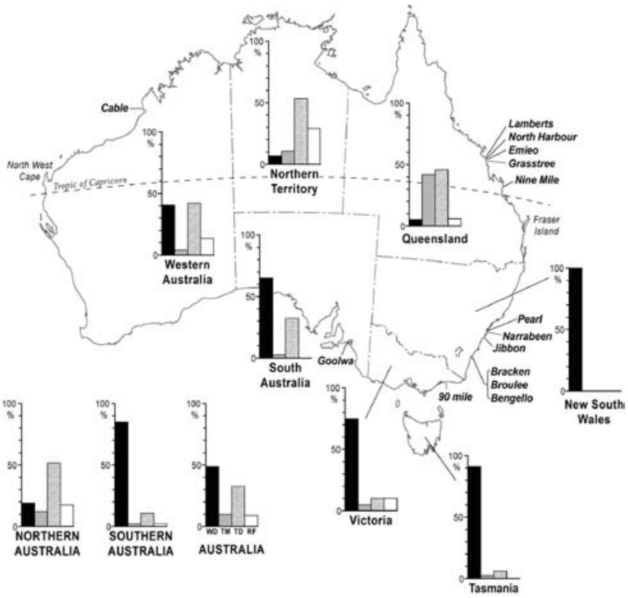

Figure 1. Map of Australia showing the distribution of beach types by state, region and continent, as well as site of the major field studies. WD=wave-dominated, TM=tide-modified, TD=tide-dominated, RF=rock/reef flats.

Figure 2. Deploying field equipment in the dissipative Goolwa surf zone, 1980. The aerial holds pressure sensors and current meters and indicates location in deeper water.

Buoyed with the success of these initial field experiments and boosted by an US Office of Naval Research (ONR) grant in 1980 it was decided to take on the high-energy southern Australian coast, at a site scouted by Short in 1978, Goolwa beach, South Australia (Figure 1). This beach is exposed to the full force of the Southern Ocean with wave averaging 2.5-3 m. It is a 500 m wide, fully dissipative double bar system. The team camped in the sand dunes and ran a successful though very tiring and hazardous field experiment in the very energetic inner surf zone (Wright at al., 1982d; Figure 2) with outer breaker waves averaging 3-4 m thoughout the experiment. It was then decided we needed to look into the impact of high tides on the beaches and after much discussion and pouring over maps and phone calls to local people, Cable Beach in Broome, north Western Australia was chosen, with its 10 m tides. In November the nine-member team left Sydney on the 5500 km, 10-day drive to Broome, camping along the way and at Cable Beach, an adventure in itself. This was to be another successful field experiment (Wright *et al.*, 1982a).

The final ONR funded experiment took place in 1981 at Eastern Beach (Ninety Mile Beach) on Victoria's wild Bass Strait coast. The long storm driven beach is a classic bar-trough system. The CSU team instrumented the swash zone out through the 3 m deep trough to bar and and with the help of a local fishing boat onto the shoreface (Wright at al., 1982b). It was the final major experiment involving Don Wright who left for the Virginia Institute of Marine Science (VIMS) in 1982. However by that time the CSU team had covered all the main wave-dominated beach types (R, TBR, RBB, LBT, D) as well as the tide-modified ultradissipative (UD) Cable beach (Table 1).

Table 1. *List of major CSU field experiments/sites and publications.*

Year	Location	Beach state[1]	Publications
Wave-dominated (WD):			
1976	Narrabeen	R-LBT	Short 1979a, b
1976	Jibbon	R	Wright *et al.* 1979
1976	Pearl	R	Wright *et al.* 1979
1977	Bracken	R	Wright *et al.* 1979, 1982c
1977	N Broulee	LTT-TBR	Wright *et al.* 1979
1977	Bengello-Moruya	TBR	McLean and Thom, 1975 Chappell and Wright, 1978 Wright *et al.*, 1979; Thom and Hall, 1991
1980	Goolwa	D	Wright *et al.*, 1982c,1982d
1980	Palm Beach	TBR	Wright *et al.*,1982c
1981	Eastern	RBB-LBT	Wright *et al.*, 1982b, 1986
Tide-modified (TM):			
1980	Cable	UD	Wright *et al.*, 1982a, 1982e
1992	Nine Mile	R+LTR	Masselink and Short, 1993; Turner 1993
1992	Lamberts Nth Harbour	R+LTT R+LTT	Masselink and Short, 1993; Turner, 1993
1992	central Qld	TM	Masselink and Short, 1993
1997	Muriwai, NZ	R+LTR	Brander and Short, 2000
Tide-dominated (TD):			
1988-2001	Australia-wide	WD-TM-TD	Short, 2006

[1] R=reflective; LTT= low tide terrace; TBR = transverse bar and rip; RBB = rhythmic bar; LBT = longshore bar and trough; D =dissipative; R+LTT = R+low tide terrace; R+LTR = R+low tide rips; UD = ultradissipative

While all these experiments were successful in undertaking the first morphodynamic experiments across a range of representative beach types and states, because of their limited time span, they could not record longer term (days-weeks-months) beach change and in particular transformation between beach states. However three complementary projects already in train were able to provide this information. In the early 1970s I Eliot monitored rip currents and bar behavior at Durras Beach (Eliot, 1973); while in 1972 R McLean and B G Thom commenced monthly cross-shore beach profiles of Bengello beach (McLean and Thom, 1975); then in 1976 Short commenced monthly surveys of Narrabeen beach in addition to 18 months of daily beach monitoring when the wave-surf conditions and the location of all bars, channels, rips, berms, cusps, etc. were recorded. The latter two surveys continue to this day, though the Narrabeen surveys have been complemented by DGPS, video camera, Lidar, and UAV surveys (Harley *et al.*, 2015), and recently contributed to the circum-Pacific wave-beach study (Barnard *et al.*, 2015). Based on the repetitive surveys, beach observations, photographs and sketches, three papers emerged illustrating the sequential changes in wave-dominated beach state. Short (1979a, b) developed the full range of accretionary and erosional sequences, while Wright *et al.* (1979) presented a similar range of accretionary states together with their morphodynamic signatures. These papers laid the foundations for the first wave-dominated (WD) beach model.

CSU: POST 1982

The wave-dominated 'Beach Model'

The two complementary models mentioned above were then merged and incorporated with the results of the wide-ranging field experiments into the beach model presented by Wright and Short (1984). This model was quickly and widely adopted, and now forms the basis of the wave-dominated beach model.

However it was not without some scrutiny. Lippman and Holman (1990) found " *The bar types defined in the classification scheme … are unique and encompass the range of possible morphologies from fully dissipative to fully reflective. The model is similar to the previous classification scheme of Wright and Short [1984], although derived in a different, independent manner*." Their independent " … *scheme is consistent with previous work and, in particular, compares well with the most highly evolved classification model of Wright and Short [1984]."* While more recently Masselink *et al.* (2015) found "... *the most comprehensive and rigorous longitudinal study of beach types so far by Scott et al. (2011), including almost one hundred wave-dominated, tide-affected and geologically-controlled beach settings in the UK, confirmed the general validity of the Wright and Short (1984) model."*

The robustness of the model and its wide applicability is due to the simplicity of beach systems, a simplicity that was observed across a range of wave-dominated Australian beaches. Beaches require just four variables, which can be reduced to three in micro-tidal environments, that is, wave height (H_b), wave period (T) and sediment size (W_s). By observing how changes in the full range of wave height (H_b<0.5 to 3.5 m), period (<5 to 15+s) and sediment size (fine to coarse sand) affected beach morphodynamics and associated beach state the six WD beach states, their characteristics and morphodynamic signature were identified (D, LBT, RBB, TBR, LTT, R) around the southern Australian coast. Further, they could be quantified using the dimensionless fall velocity (Ω) (Gourlay 1968) where $\Omega = H_b/W_sT$ (Wright and Short, 1984).

However, as each of these variables can change in both time and space, additional work was required to quantify these spatial and temporal changes in beach character. The daily observations and monthly beach surveys at Narrabeen quantified the changes in beach state through time in response to changing wave height, enabling the transition time between states to be identified both in the accretionary and erosional cycles (Wright at al., 1984). Likewise the role of grain size (beach gradient) and wave period on the number of bars was assessed by Short and Aagaard (1993); the impact of changing wave height and period on both beach state and the spacing of rhythmic features, particularly rip currents was reviewed by Short and Brander, (1999); and the impact of changing sediment size on beach state were observed and quantified by (Short, 1984b; Short 1999). This work provided robust models of both the beach character associated with each beach states, as well as the transformations that occur when H_b, T and W_s change.

Tide-modified beaches

It became apparent early on however, that the wave-dominated model did not directly apply to areas of higher tide range, resulting in the field experiments at the mega-tidal Cable beach in 1980. A second surge of beach experiments in high tide range locations took place in the early 1990s when Short's graduate students Turner, Masselink, Lessa and Brander undertook a series of beach and estuarine experiments in the meso- to macro-tidal central Queensland coast. The experiments took place across a range of tide-modified beaches, barriers and estuaries. These experiments investigated both beach morphodynamics during the tidal cycle, as well as its impact on the beach groundwater and barrier stratigraphy (Masselink and Lessa, 1995; Turner 1993), resulting in the tide-modified beach model of Masselink and Short (1993). This model also introduced the role of spring tide range (TR) into the relative tide range (RTR) parameter where $RTR = TR/H_b$

Now with four variables (H_b, T, W_s and TR) beaches from wave-dominated through tide-modified (TM) environments could be classified.

Tide-dominated beaches

In 1986 Short was invited to assist Surf Life Saving New South Wales (SLNSW) in compiling a database on all NSW beaches, including the hazards associated with each beach system (Short, 1993). When this was finished, he was invited in 1990 by Surf Life Saving Australia (SLSA) to expand the program Australia-wide, as the Australian Beach Safety and Management Program (ABSAMP). Over the next 14 years every beach on the Australian mainland and thirty major islands was inspected and incorporated in an Australia-wide database, in total 10,796 mainland beaches and 965 beaches on 30 islands. In investigating and recording these beaches it soon became apparent that not all fitted the WD or TM models, particularly many of the higher tide range and lower energy beaches across northern Australia. In order to accommodate these beaches, a new series of four tide-dominated (TD) beaches (RTR>10) was developed. These include the Beach + ridged sand flats (B+RSR), B + sand flats, (B+SF) B + tidal sand flats (B+TSF) and B+ tidal mud flats (B+TMF) (Short, 2006), though the latter two may range from sand to mud.

In addition there were a few hundred beaches that did not fit any of the WD, TM and TD models. These were high tide beaches fronted by intertidal rock or coral reef flats. Two more beach states were required to accommodate these beaches: the R + rock flats (R+RF) and R + coral reef flats (R+CF) (Short, 2006). With these additional beach types and states the full range of Australian beaches could be accommodated by four beach types and 15 beach states, six WD, three TM, four TD (Figure 3a) and the two fronted by rocks/reefs (Short and Woodroffe, 2009). But how widely applicable are these models?

As Figure 3 indicates while there are close similarities between the UK and Australian beaches, especially the WD-TM boundary (~3) and the general location of the TM beaches, there are also subtle differences, particularly beyond an RTR of ~10. Whereas the Australia beaches grade into the TD beaches all the way to an RTR of 50, the UK beaches transition into multiple intertidal-barred (MITB), before reaching an RTR of 20 where the transition to tidal flats begins, though these may be what are considered TD beaches in the Australian model. What this indicates is three things: first, the boundaries are porous and not meant to be precise; second, there is room for more field data from other coastal environments to accurately quantify the nature and full range of beach states; and third, one might expect there will be subtle variations between coastal environments, such as the higher energy meso-macro-tidal UK environments, compared to their lower energy Australian meso-macro counterparts. For example, the UK multiple intertidal-barred beach (MITB), is not found on the lower energy TM-TD northern Australian beaches. Clearly more research in other coastal environments is required to achieve the definitive spectrum of beach types and states, as well the processes that control both the bars and ridges on both the MITB and R+RSF beaches.

The foregoing beach models assume long, straight uninterrupted beaches. However, Australian beaches average only 1.37 km in length, and many of the world's beaches are similar, being curtained, bordered and affected by headlands, rock, reefs and structures. McKenzie (1958) recognized this when he described the headland rips that occur on most of Sydney's embayed beaches. The role of these same headlands in producing megarips was also noted by Short (1985), followed by documentation of the beach rotation occurring within the embayed Narrabeen beach (Short *et al.* 1995). The full range of embayment impacts on beaches was presented in more detail by Short and Masselink (1999) who introduced the embaymentization parameter; and discussed the impact of headlands and structures on beach planform, beach rotation and headland sand bypassing, as well as the impacts of beach structures like groynes, training walls, breakwaters, seawalls. Finally, Short (2010a) examined the role of geological inheritance on Australian beach morphodynamics.

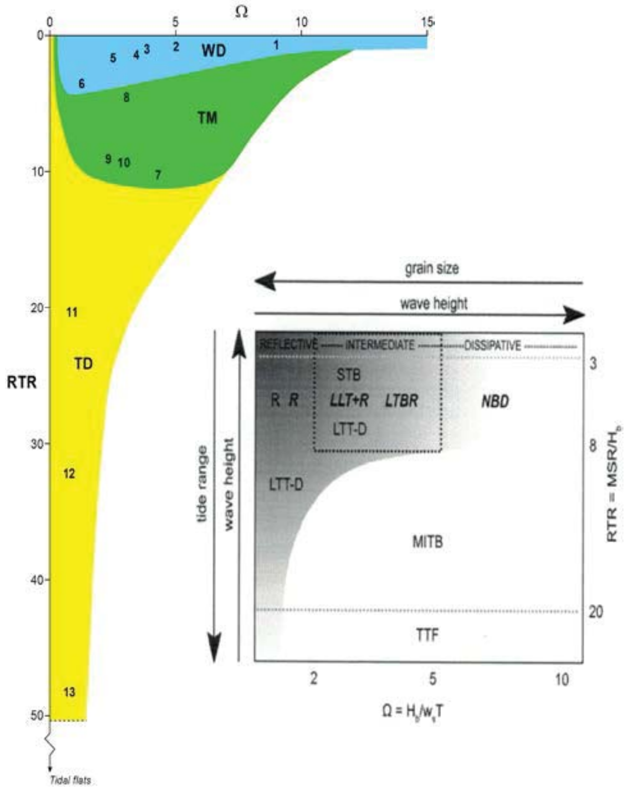

Figure 3. a) Relationship between Ω and RTR in controlling Australian beach type and state (WD=wave-dominated, TM=tide-modified, TD=tide-dominated) (source Short and Jackson, 2013). Numbers refer to the mean location of WD (1-6), TM (7-9) and TD (10-13) beach states; b) similar diagram from Scott *et al.* (2011) based on UK beaches.

SUMMARY AND CONCLUSIONS

The development of the Australian beach models by CSU researchers provided a framework for locating, classifying and understating the morphodynamics of Australian beach systems. Because of the size and variety of beaches around Australia these models have also been widely applied in other coastal locations, including most wave and tidal environments. The excellent work by the Plymouth group (Scott *et al.*, 2011; Masselink, *et al.*, 2015) has added scrutiny and robustness to these models particularly in the energetic and high tide range environments of the United Kingdom, and indicates that more work in other coastal environments is required to verify the full range of beach states.

These beach models and the role of embayments provide a simple framework for identifying and classifying a beach. Using four simple readily obtained variables (H_b, T, W_s and TR) beaches can be fitted into one of the 15 beach states, then by adding the embaymentisation parameter, based on H_b and the beach planform, together with other local inputs, the full morphodynamic character of the beach can be understood. With this knowledge a wide range of generic processes and behavior can be associated to any beach. The models provide a first step in understanding a particular beach. However, detailed site specific field work and monitoring is still required to understand how any particular beach behaves, particularly over time, where other parameters such as extreme events and sediment supply may play a role.

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