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MODELLING ACCRETION AT NHA TRANG BEACH, VIETNAM

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Abstract

The process-based morphodynamic model XBeach was used to simulate observed beach accretion during a field experiment at Nha Trang beach, Vietnam. The field experiment began at the end of an erosive swell event. Immediately following this event, rapid accretion of the beach was observed, forming two berms at different elevations on the beach face. After testing a number of model parameters and process implementations, XBeach was able to reproduce these berm formations using 'optimal' settings. These settings are related to correcting the magnitude and direction of sediment transport, groundwater infiltration and exfiltration, and resolving short-wave interactions in the swash zone. This case study shows the ability of the model to simulate onshore transport processes and swash zone dynamics and provides a foundation for further model testing and application.

Key words: morphodynamics, swash zone, beach accretion, numerical modelling, XBeach

1. Introduction

Given the significant value of beaches to human development and the global economy, it is important to understand not only the impact of storms on beaches, but also process by which they recover. Cycles of erosion and accretion occur naturally and have been well-documented in numerous studies. Empirical research has definitively shown that beaches erode at accelerated rates when the incident wave energy is above a certain equilibrium threshold, and that they will slowly accrete under less energetic conditions (Yates, et al., 2009). Interactions between the beach and corresponding features such as sub-tidal bars can also be described in a similar fashion (van de Lageweg et al., 2012; Blossier et al., 2016). While these studies advance our understanding of large-scale beach dynamics – that which occurs in the order of several years and over several kilometers – the complex interactions of small-scale processes remain enigmatic.

Processed-based morphodynamic models have been exceptionally useful in advancing our understanding of small-scale process interactions and have shown good skill in predicting beach erosion due to storms (de Winter et al., 2015). Open-source models, such as XBeach (Roelvink et al., 2009), have become adept at simulating wave propagation and beach morphodynamics, including implementations for processes such as infragravity wave runup, dune avalanching, and breaching. XBeach has been successfully used to simulate, inter alia, dune erosion, barrier overwash and wave propagation over fringing reefs (van Thiel de Vries, 2009; McCall et al., 2010; van Dongeren et al., 2013). However, compared to the number of studies which use XBeach for modelling extreme events and erosion, few actually investigate beach recovery and accretive processes (van Rooijen et al., 2013; Pender and Karunarathna, 2013). It is usually more difficult to predict beach recovery and onshore sediment transport as it requires accounting for additional processes. It is crucial, nonetheless, to understand the accretion process and thereby include the relevant physics in the model.

Onshore sediment transport is strongly influenced by the non-linear shape of incident short-waves in the surf zone (Elgar et al., 2001). This wave shape, characterized by its asymmetry (vertically) and skewness (horizontally), causes strong onshore accelerations at the wave front and increases the magnitude of onshore velocities under the wave crest relative to the longer trough, respectively. Non-linear wave

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effects will gradually transport sediment from the nearshore and surf zone toward the base of the swash zone. At this point, the complex dynamics of the swash zone allows the beach to build upward. Within the swash zone, sheet flow transport is dominant as the water depth is very small and flow velocities are very large. Wave-wave interactions during up- and down-rush increase turbulence and sediment suspension, influenced by the superposition of short wave bores and infragravity wave runup. Groundwater infiltration at the upper reach of the swash enhances sediment deposition, while exfiltration at the base of the swash increases the capacity for sediment to be mobilized. It is therefore important to represent these all of these processes in morphodynamic models in order to simulate accretion (Bahktyar et al., 2009).

In this work, the XBeach model is used to reproduce observed erosion and accretion at Nha Trang beach, Vietnam, measured during a field experiment in December 2015. The model has implemented the above-mentioned physical processes required to simulate beach accretion. Details of the study site and field experiment at Nha Trang beach is presented in Section 2 following. A brief description of the XBeach model and of the various implementations are presented in the Section 3, along with information about the model setup. Results of the model validation are presented in Section 4 and discussed in Section 5, with an outlook for future work.

2. Study Site

2.1 *Site Description*

While field experiments are indispensable for studying coastal dynamics, most study sites are located in developed countries at high-latitude, with beaches in tropical developing countries understudied. As such, Nha Trang beach, in the Khánh Hòa Province of Vietnam (Figure 1), was chosen as the location for observing the dynamics of a storm-impacted tropical beach. The region is a popular tourist destination, with many hotels constructed along the shoreline to take advantage of the beach. The beach is 5.7 km long and forms the western boundary of Nha Trang Bay. The beach forms an embayment bound at the north by the mouth of the Cai River and at the south by a natural headland at the Nha Trang Port. A number of islands are scattered within the bay, the largest of which, Tre Island, is ~3 km offshore and effectively shadows the beach from waves coming from the south and south east.

The northern end of the beach, where the field experiment was conducted, is only exposed to waves coming from the east and north east. It features a narrow low tide terrace ~15 m wide and 0.85m below MSL with a fairly steep 1:8 swash slope. The beach is backed by a seawall 5 m above and 50 m landward of the mean shoreline. Based on a number of sediment samples taken at 26 locations over the length of the beach, the median sediment grain size becomes progressively coarser with increasing distance from the river mouth: ~0.5 mm at the study site in the north and ~1.0 mm at southern end of the beach.

Figure 1. Location of Nha Trang beach (grey box) in the Khánh Hòa Province (red box) of Vietnam (white box). (Source: http://www.maphill.com).

2.2 *Field Experiment*

2.2.1 Experimental Setup

An 8-day field experiment was performed at Nha Trang beach from 27 November to 4 December 2015 within the framework of the COASTVAR project (Almeida et al., 2016). An instrumented cross-shore transect, set up 1 km south of the mouth of the Cai River (12°15.17'N, 109°11.81'E), consisted of four pressure transducers recording at 4 Hz, a LIDAR bed surface profiler, an acoustic Doppler velocimeter and an acoustic Doppler current profiler (ADCP, 1200 kHz, placed at 15 m depth). Topography across a 1 km length of beach was surveyed daily with high-resolution RTK-GPS and drone photogrammetry. Topography measurements were taken out to a depth of 0.6 m. On the final day of the experiment, a single profile was measured out to a depth of 1.5 m. A bathymetric survey conducted in the vicinity of the experimental site measured depths between 3 and 15 m. There was therefore a small gap between the topography and bathymetric datasets that was filled by extrapolating the bed slopes at the edge of each dataset.

The first two days of the experiment coincided with the arrival of swell waves from a northeast monsoon storm which passed over the South China Sea, causing slight erosion of the upper beach. This was followed by four days of calm wave conditions where the beach quickly recovered and displayed accretive cusp patterns of ~20m wavelength. Figure 2a-c shows the wave conditions measured during the field experiment. Peak wave heights 1.45 m with a corresponding mean period of 11.5 s. The mean wave direction during the experiment was 81° with a standard deviation of 7°. As the beach is oriented at 89°, a slight southward-directed long-shore current was experienced at the site.

2.2.2 Description of Observations

Figure 2d shows the along-shore-averaged cross-shore profile of the beach topography measured over a 100 m distance, centered on the instrumented profile. In Figure 2d, beach erosion is shown to occur between 27 and 29 November, with sediment removed from the upper swash and the intertidal terrace. This sediment was visually observed to have been deposited some distance offshore, in an area that was not surveyed with the RTK GPS. The erosion corresponds to a peak in wave height and period (1.5 m and 12 s at the peak, respectively) during the same time. The erosion of the upper beach was enhanced by spring tides (0.75 m), also occurring at the same time.

Following this event, wave conditions gradually become more calm over the remaining period of the field experiment between 30 November and 4 December (0.6 m and 7 s waves, at the lowest). During this time the tidal range also decreased toward neap levels (0.45 m). The beach was able to quickly recover during the calmer conditions. Accretion of the upper beach resulted in the formation of a small berm, centered at +2.7 m, between 30 November and 1 December. Between 2 and 4 December a larger berm formed, centered at +1.2 m, overlaid on the preexisting beach profile. The location of the second berm at a lower level was the result of the lower tide range and wave energy during that time, which limited the upper extent of the swash.

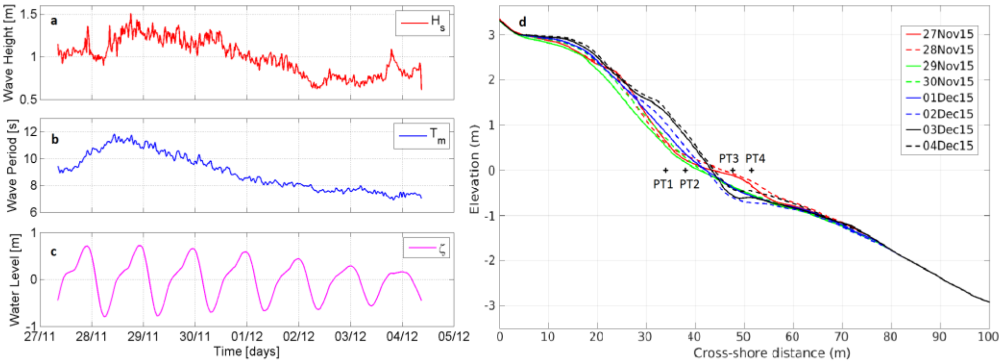

Figure 2. Measured offshore significant wave height (a), mean wave period (b), tide elevation (c), and beach profile changes (d) during the field experiment. The horizontal position of the four pressure sensors along the transect (PT1, PT2, PT3, and PT4) are shown (+).

3. Numerical Model

3.1 *Model Description*

XBeach is a coastal area morphodynamic model that, when released in 2006, was primarily used to simulate beach erosion during storms (van Thiel de Vries, 2009; McCall et al., 2012). However, during the past decade, a number of updates and physical processes implementations have made the model more widely applicable to different types of coasts, such as gravel beaches. The 'Kingsday' version (XBeach version 1.22, revision 4567) is used in this work. Below, the relevant aspects of the XBeach model concerning onshore sediment transport mechanisms and swash zone dynamics are briefly described. For brevity, model equations are not presented here; rather, the reader is directed to the Kingsday XBeach manual (Roelvink et al., 2015) for a well-detailed description of the model.

In the Kingsday XBeach model, wave propagation is simulated using two different modes: 1) a *hydrostatic mode*, where short-wave propagation is computed at the wave-group scale using wave action balance equations while long-waves are resolved separately, propagated using shallow water equations; and, more recently, 2) a *non-hydrostatic mode*, where both short- and long-wave motions are resolved using shallow water equations with a non-hydrostatic pressure term, similar to a one-layer version of the SWASH model (Zijlema et al., 2011). While the non-hydrostatic mode directly determines the non-linear shape of short-waves, the hydrostatic mode does not.

Sediment transport is computed using advection-diffusion equations, where the Eulerian flow velocity is applied to the bed and suspended load transport formulations of Soulsby (1997) and van Rijn (2007a; 2007b). In non-hydrostatic mode, short-wave non-linearity is implicitly accounted for in the flow velocity at the bed, therefore no correction is necessary to enable onshore sediment transport. However, in hydrostatic mode, the sediment advection velocity has to be modified by adding an onshore velocity component related to the magnitude of wave non-linearity. This velocity component is estimated based on values of asymmetry and skewness derived from the local Ursell number according to the model of Ruessink et al. (2012). Computed asymmetry and skewness values are tuned using factors to control the magnitude of their contribution to the onshore velocity (keyword: *facAs* and *facSk*, respectively). The value of these factors are 0.1 by default.

Predicted sediment transport rates in XBeach were found to be excessive in areas exposed to high flow velocities; therefore additional processes were introduced to limit this (de Vet, 2014). At high flow velocities, sediment dilatancy has the effect of hindering erosion due to the flow of water into the bed (van Rhee, 2010). This effect was incorporated into the sediment transport formulations (keyword: *dilatancy*) by modifying sediment mobilization (i.e., the critical Shields parameter) based on the permeability of the sediment.

Bed slope effects also have an impact on the magnitude and direction of sediment transport (Walstra et al., 2007). Originally, the bed slope effect on the transport magnitude was controlled by a correction factor proposed by Soulsby (1997) (keyword: *facsl*). More recently, the model of Talmon et al. (1995) has been implemented to also account for bed slope effects on the direction of transport (keyword: *bdslpeffdir*).

To simulate bed friction, the model uses a friction factor based on a chosen bed friction formulation (keyword: *bedfriction*). A number of bed friction formulations are implemented, with the Chezy formulation used by default. The choice of bed friction formulation affects the distribution of the friction factor in the model domain. The Chezy formulation maintains a constant friction factor throughout the domain, while the friction factor varies with depth when using the Manning formulation, being higher in shallower water.

A groundwater model was implemented which simulates water level fluctuations within the bed, and groundwater exchange with surface water via infiltration and exfiltration (McCall et al., 2012) (keyword: *gwflow*). The groundwater model uses mass continuity equations in combination with Darcy's law for incompressible laminar flow within porous media including terms for laminar and turbulent hydraulic conductivity. The model has generally been applied to gravel beaches (McCall et al., 2015); however, for coarse sandy beaches, such as Nha Trang beach, this model is also applicable.

3.2 *Model Set-up*

3.2.1 Boundary Conditions

Non-hydrostatic simulations were performed in an attempt to reproduce the observed beach profile changes over a 6-day period from 28 November to 4 December, 2015. In order to reduce simulation times, a one-dimensional (1D) grid was used. The along-shore-averaged cross-shore profile on 28 November was used as the initial bathymetry for the model (Figure 2d), and subsequent profiles are used for comparison to the model predictions. The along-shore-averaged beach profile is used because it accounts for the non-uniform distribution of erosion and accretion patterns along the beach attributed to the beach cusps. For the non-hydrostatic simulations (keyword '*instat* = nonh'), a 300 m long domain was used with a constant grid spacing of 0.5 m in depths below 1.75 m (the breaker and swash zone of the beach). The grid spacing gradually increases to 2 m at 4.75 m depth and is kept constant until the model boundary at 5.93 m depth.

A timeseries of pressure readings from the offshore ADCP was corrected to account for dynamic pressure variations, and transformed to 6 m depth accounting for wave shoaling based on linear wave theory. The depth-averaged velocity (required for the boundary condition input) was computed from the surface elevation using linear wave theory. In order to simplify the 1D simulations, waves are represented arriving normal to the beach. Since the wave boundary conditions are fed into the model 'real-time', no morphodynamic up-scaling is used (i.e., keyword: '*morfac* = 1'). The model determines the time step based on a prescribed maximum Courant number (0.7 by default).

3.2.2 Optimal Parameter Settings

Initial simulations using default parameter settings in XBeach resulted in the beach being considerably eroded, contrary to the observed pattern of accretion. Assuming that this was due to incorrect parameter values related to sediment transport and swash processes, several parameters were tested in order to improve model performance. Of the parameters tested, five were shown to have a positive influence on the results: *bedfriccoef*, *facsl*, *bdslpeffdir*, *dilatancy*, and *gwflow*. The default and 'optimized' values for these parameters are shown in Table 1 below.

It should be noted that: 1) when using *bedfriction* to change the friction formulation, corresponding values for *bedfriccoef* are the recommended Chezy and Manning values given in the XBeach manual; 2) the optimal value used for *facsl* is recommended by de Vet (2014); 3) *bdslpeffdir* and *dilatancy* are simply switched on; 4) *gwflow* is switched on, but other parameters then have to be specified; 5) *gw0* is set to the mean high water level; 6) *kx*/*ky*/*kz* is calculated using the Hazen equation $k = 10^{-2}D_{10}^{2}$, where D_{10} is approximately 0.32 mm at the study site; and 7) *gwhorinfil* is simply switched on. The effect of these parameter settings on the model output are shown in the Results section following.

Table 1. 'Optimal' parameter settings used in the simulations. **Main** (*dependent*) parameters are shown in **bold** (*italic*).

Keyword	Parameter Description	Default	Optimal
bedfriction	Bed friction formulation	Chezy	Manning
> *bedfriccoef*	Bed friction coefficient	55	0.02
facsl	Factor for bed slope effect	1.6	0.15
bdslpeffdir	Modification of sediment transport direction based on the bed slope	None	Talmon
dilatancy	Switch to reduce critical shields number due to dilatancy	0	1
gwflow	Switch to turn on groundwater flow module	0	1
> *gw0*	Groundwater level	0.0	0.28
> *kx* / *ky* / *kz*	Darcy flow permeability coefficient in x / y / z direction	0.0001 m/s	0.001 m/s
> *gwhorinfil*	Switch to include horizontal infiltration from surface to groundwater	0	1

4. Results

4.1 *Validation of the 'Optimal' Settings*

Several processes and parameters influencing onshore sediment transport processes in the swash zone had to be optimized in order to reproduce the observed beach profile changes with reasonable accuracy (Table 1). Model results using these settings are compared to the beach profiles measured daily during the field experiment (Figure 3). Very little erosion actually occurs in the model at the beginning of the simulation. On the other hand, the beach quickly begins to accrete in the inner surf zone during the first low tide, and at the upper extent of the swash during the following high tide. During its onshore movement, sediment is sourced from the outer surf zone, being mobilized at depths of ~4 m. After three days, the model simulated the formation of a small berm at the top of the beach, as observed in the measurements, centered at +2.3 m. Thereafter, the model also simulates the formation of a larger berm, centered at +0.8 m, by the end of the 6-day period. Although the model does well in simulating the formation of the observed berms, they are centered ~ 0.4 m lower on the beach slope than what was observed. During the simulation, absolute differences between the predicted and measured beach profiles do not exceed 0.6 m.

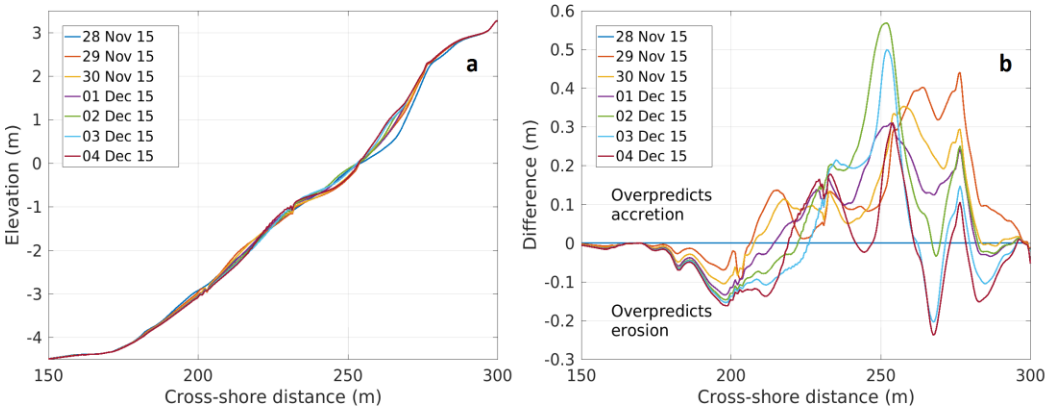

Figure 3. (a) Predicted beach profile changes. (b) Raw difference between the predicted and measured beach profiles. Positive (negative) values indicate that the model over-predicts accretion (erosion).

Data from the four pressure sensors located on the instrumented beach profile transect (PT1, PT2, PT3 and PT4) were compared to model predictions at the same locations for water level variations (Figure 4) and significant wave height (Figure 5). The average measured elevation of the pressure sensors were 0.62, 0.27, -0.37, and -0.67 m, respectively, with PT1 and PT2 located in the swash zone and PT3 and PT4 in the inner surf zone. The water depth and significant wave height at each sensor was strongly modulated by the tide.

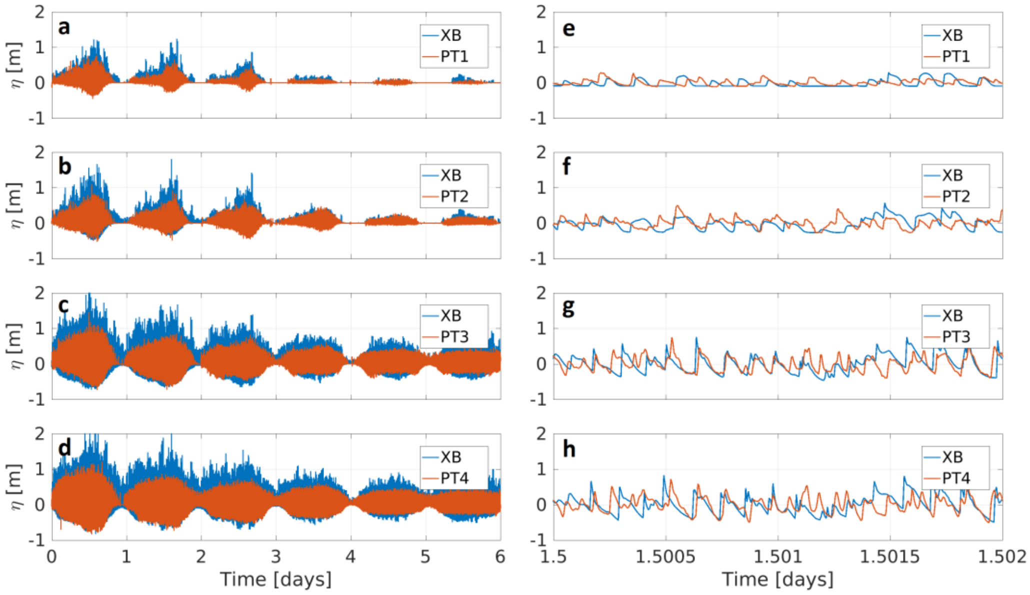

Figure 4. Predicted (blue) and measured (red) water surface elevation at pressure sensor PT1, PT2, PT3, and PT4 for the total simulation period (a – d, respectively) and for a 3-minute segment at time = 1.5 days (e – h, respectively). Note that time = 0 on the x-axis is on 28 November, 2015.

The model simulates wave height transformation and rup-up reasonably well when compared to the data from the pressure sensors. Wave crest heights are slightly overestimated (Figure 4 a–d); however, the periodicity and wave shape are comparable between the data and model predictions (Figure 4 e–h). It is useful to note that the ADCP data used for the boundary conditions was not synchronised with the pressure sensor data, resulting in slight phase differences between the measured and predicted timeseries.

In order to compare the two timeseries, the significant wave height was computed over a 15-minute period for both datasets (Figure 5), with root-mean-square error (RMSE) and correlation coefficient (R2) values shown in Table 2. Waves are slightly better predicted in the swash zone than in the inner surf zone, as they have lower RMSE and higher R^2 values. The result is, however, encouraging as it shows that while the optimisation process focused on parameters directly controlling sediment transport and swash processes, the hydrodynamic forcing was well reproduced.

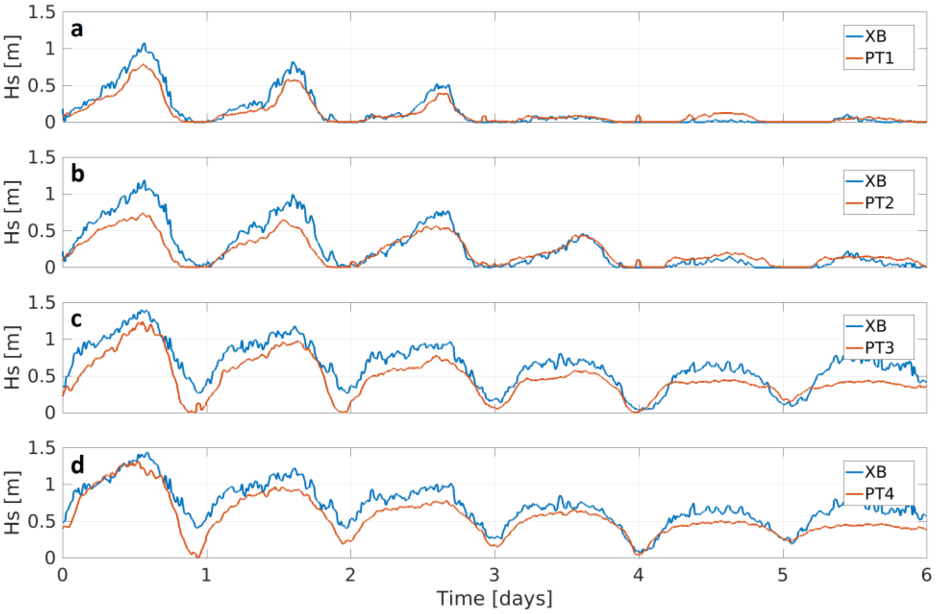

Figure 5. Predicted (blue) and measured (red) significant wave height at pressure sensor PT1, PT2, PT3, and PT4 for the total simulation period (a – d, respectively). Note that time = 0 on the x-axis is on 28 November, 2015.

Table 2. Root-mean-square error (RMSE) and correlation coefficient (R^2) between the predicted and measured significant wave height at each of the pressure sensor locations.

Location	**RMSE (m)**	**R^2 (-)**
PT1	0.08	0.97
PT2	0.14	0.94
PT3	0.21	0.92
PT4	0.19	0.92

4.2 *Individual Effect of the 'Optimal' Settings*

The individual effect of each of the main 'optimal' parameter settings on the final profile is shown in Figure 5, after 3 and 6 days of simulation. For each case, the parameter in question was set to its default value, while the other parameters remained at the optimal setting. The RMSE and Brier skill score (BSS) at the end of the simulation is shown in Table 3. The BSS is computed as $BSS = 1- var(p-m)/var(p_o-m)$, where *var* is variance, *p* and *m* are the predicted and measured beach profiles at the end of the simulation, and subscript *o* refers to the predicted beach profile using all the 'optimal' parameter settings. Negative BSS values indicate a worse prediction compared to the base case, p_o.

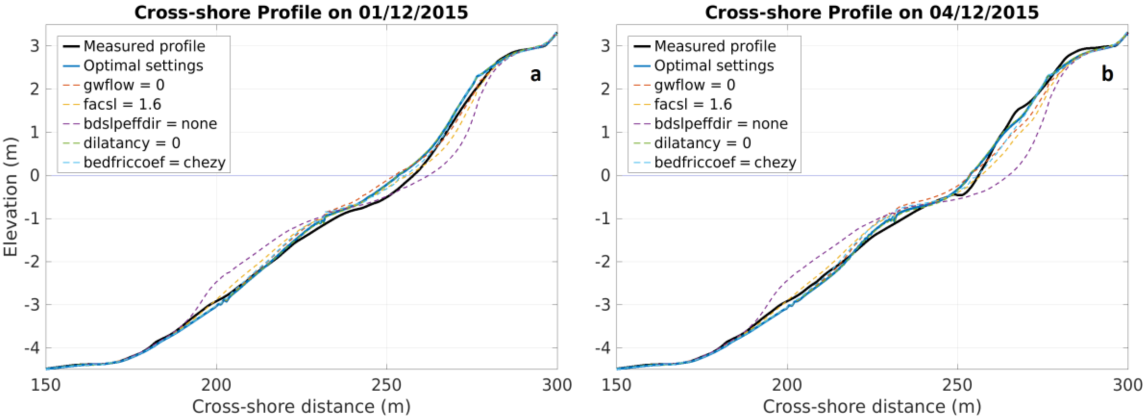

Figure 6. Measured (solid black line) and predicted using all of the optimal settings (solid blue line) beach profiles mid-way (a) and at the end (b) of the 6-day simulation period. Dashed lines show the effect of setting one of the 'optimal' parameters at its default value (see legend for color code).

Table 3. Root-mean-square error (RMSE) and Brier skill score (BSS) at the end of the simulation period.

Simulation	**RMSE (m)**	**BSS (-)**
All optimal settings	*0.114*	-
bdslpeffdir = none	0.485	-16.52
facsl = 1.6	0.217	-2.51
gwflow = 0	0.186	-1.66
bedfriction = chezy	0.149	-0.71
dilatancy = 0	0.106	0.13

It is shown that the parameter which most negatively affects the results is *bdslpeffdir*. Without bed slope correction for the sediment transport direction, the model will substantially erode the upper beach face. The slope of the beach face becomes very steep, equal to the limit imposed in the model on the bed slope in water (keyword: *wetslp* = 0.3 by default). On the other hand, keeping *dilatancy* turned off (default setting) slightly improves the model result. Since switching it on does not significantly affect the results, it may be useful to keep this setting since this process may prove to be more important during erosive conditions.

Through a process of elimination, by comparing better performing simulations with worse ones, it is shown that, if not corrected, *bdslpeffdir* and *facsl* result in erosion of the beach; otherwise, if inlcuded, it will maintain the observed 0.125 beach slope. With the groundwater module switched on, the model will allow sediment to settle at the upper reach of the swash due to infiltration of water into the bed.

Using the Manning friction formulation allows the model to better represent berm formation compared to the Chezy friction formulation. This is likely due to the high friction values in very shallow water in the swash, which helps to reduce flow momentum and allow higher levels of sedimentation, when combined with the groundwater module.

5. Discussion

5.1 *Governing Accretion Processes*

The results have shown that the physical processes implemented in the non-hydrostatic Kingsday version of XBeach are able to satisfactorially simulate beach accretion and berm formation above the still water level and fairly represent wave conditions in the inner surf and swash zones. Tests with the optimal parameters in Table 1 have shown that enabling the correction of sediment transport rates based on the bed slope using *bdslpeffdir* and *facsl* inhibits unrealistic erosion of the beach and allow it to maintain a stable beach slope. Groundwater flow is shown to be the main process contributing to berm formation, since even with the aforementioned bed slope corrections enabled, if the groundwater flow model is not swtiched on then the model predicts a plain beach slope and will not form any berms. It should be noted that the value of *kx*/*ky*/*kz* used in the model has a large influence on this process – higher values promote greater accretion – therefore this value should be chosen with care. Increseased bed friction in the swash also allows sediment to settle at the limit of wave runup, thereby enhancing berm formation.

Although wave heights are reasonably well-predicted in the swash zone, it is clear that the maximum extent of runup is lower than what was observed since the berms produced in the model are centered at a lower elevation. A similar result (pattern of accretion modelled correctly, but with a clear spatial shift in position) was obtained by van Rooijen et al. (2012), who used an earlier version of XBeach (which did not include groundwater infiltration) to simulate swash zone dynamics during an accretive and erosive event at a site in Le Truc Vert, France. The discrepancy in the result was attributed to an underestimation of wave setup, which was not investigated here. However, it could also be the case that for overly high bed friction values in the swash will limit the extent of the run-up.

As shown in Figure 4, the model slightly overestimates waves in the inner surf zone. This is partly due to imprescise depths in the outer surf zone where data gaps were present in the beach profile measurements (c.f. §2.2.1). Water depths in these locations are likely to be more shallow as sediment was eroded from the beach at the start of the experiment and deposited in this area. This would increase the level of wave dissipation further offshore and reduce wave heights in the inner surf zone toward those observed. Despite the measurement error in the outer surf zone bathymetry, the model was still able to simulate wave heights in the swash zone with good accuracy. Since parameters relating to sediment transport processes were tested in this work, there is still room for further optimisation of the model by calibrating other parameters related to wave and hydrodynamic processes in future work.

5.2 *Performance of Hydrostatic Mode*

Hydrostatic simulations were also performed, but were not as successful as the non-hydrostatic simulations in reproducing the observed accretion at Nha Trang. These simulations only resulted in the beach being continuously eroded (hence not shown figuratively). Using the optimal parameter settings in Table 1 and, additionally, turning on wave-current interaction (keyword: *wci* = 1) and setting *facAs* and *facSk* to a value of 0.3 (recommended by Voudouskas et al. (2012)), reduced the net erosion predicted by the hydrostatic mode. However, the result was still poor when compared to the outcome of the non-hydrostatic mode.

Pender and Karunarathna (2013) were able to get good results when simulating beach recovery at Narrabeen Beach, Australia, using the hydrostatic mode of XBeach. They, however, had to use different parameter settings to simulate erosion separate from accretion. Since, in this case, the non-hydrostatic mode simulations performed exceedingly better than the hydrostatic mode, it signifies that short-wave runup in the swash may need to be fully resolved in order to adequately predict accretive conditions, since wave-wave interactions play an important role in moving sediment up the beach face (Bahktyar et al., 2009).

However, given the need for a finely resolved grid, simulations using the non-hydrostatic mode are significantly more computationally expesive than the hydrostatic mode. It is therefore more useful to improve the predictive capability of the hydrostatic mode for simulating accretion. Indeed, such work has already begun. Recently, Elsayed and Oumeraci (2017), noting the difficulties in getting acceptable model results using the default settings for skewness and asymmetry, have shown that the tuning of *facSk* and *facAs* can be related to the bed slope. This was relationship was implemented in a more recent version of XBeach and tested on several cases for dune erosion with improvements noted in the results. This latest version of XBeach will be tested in future work.

Conclusion

The study site at Nha Trang beach, Vietnam, is often exposed to storm events and distant swell which causes beach erosion. However, the recovery of the beach can sometimes be rapid as observed during the field experiment. XBeach was used to simulate the observed beach accretion following an erosive swell event. Non-linear short-wave effects were fully resolved using the non-hydrostatic wave mode, resulting in the onshore transport of sediment and the formation of berms on the beach face. It was shown that bed slope corrections to the sediment transport equations were necessary to prevent erosion. Groundwater infiltration was found to be the main process accounting for berm formation allowing sediment to settle in the upper swash. The Manning friction formulation is also best suited for swash zone dynamics. The ability of the non-hydrostatic mode to resolve wave-wave interactions in the swash was advantageous, as similar simulations using the hydrostatic mode did not produce comparable results.

The validation of the XBeach model in this case provides a foundation for further model testing and comparison to other datasets which have concurrent measurements of erosion and accretion. For Nha Trang, and other locations in general, the ability of the XBeach model to use uniform parameter settings under various wave conditions will be useful for determining the long term stability of the beach.

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