MODELLING BEACH MORPHODYNAMICS FOR SOUTHERN GOLD COAST BEACH NOURISHMENT PROJECT AT BILINGA BEACH

Fang Yuan[1] and Ron Cox[2]

A new cross shore process model NSBEACH (New SBEACH) has been applied to the Southern Gold Coast Nourishment Project at Bilinga beach (Australia) where nearshore nourishment and bar movement with beach berm and dune building have been simulated. Following the extension of the Tweed River training walls in the late 1960s, the downdrift Southern Gold Coast beaches to the north suffered extensive and prolonged erosion. Between 1988 and 1996, 6.6 million m3 of sand was deposited in both onshore and nearshore locations along the beaches of the Southern Gold Coast. Extensive post-nourishment beach monitoring data shows the recovery of Bilinga beach with the nearshore nourished material transported onshore. There have been many unsuccessful attempts to numerically model the beach recovery processes following the nearshore nourishment on the Southern Gold Coast. Most coastal models have been developed for prediction of storm erosion and as such have limited abilities in simulating bar movement and onshore accretion with beach recovery over extended periods of time. NSBEACH (New SBEACH) has been developed with the ability to simulate short term storm erosion and the longer duration recovery processes under natural or nourished conditions. NSBEACH has been successfully applied at Bilinga beach over an extended simulation period of 8 months with both erosion and accretion responses of the beach successfully simulated.

Keywords: Southern Gold Coast Beach Nourishment Project; shoreline model; SBEACH; accretion

INTRODUCTION

The Southern Gold Coast beaches in Queensland Australia experienced extreme coastal erosion following the 1960s extension of the Tweed River training walls In NSW to the south that interrupted the longshore sediment transport to the north (Fig. 1). As indicated in Table 1, between 1988 and 1996, 6.6 million m^3 of sand was deposited in both onshore and nearshore locations along the beaches of the Southern Gold Coast. Overall 3.4 million m^3 was deposited in the nearshore at depths of 6 to 10.5m below Australian Height Datum (AHD). The 1989 and 1990 stages as shown in Fig. 2 were centered on the Bilinga beach compartment. Regular beach and bathymetric surveys prior, during and following the nourishment showed the recovery of Bilinga beach with the nearshore nourished material slowly transported onshore. Subsequent beach management decisions have been based on analyses and interpretation of the measured beach profile data. There have been many unsuccessful attempts to numerically model the beach recovery processes following the nearshore nourishment on the Southern Gold Coast. The predominant reason for poor results being that most coastal models have been developed for prediction of storm erosion and as such have limited abilities in simulating bar movement and onshore accretion with beach recovery over extended periods of time. A numerical model NSBEACH (New SBEACH) has been developed based on some of the existing modules within the SBEACH (Storm-induced BEAch CHange) model. Significant modifications have been made to SBEACH to overcome the acknowledged limitation in simulating beach recovery. NSBEACH has been successfully compared with the SUPERTANK experiment and Collaroy-Narrabeen beach data from NSW Australia in previous studies (Yuan and Cox, 2013). In this paper, it will be used to simulate both erosion and accretion/recovery response at Bilinga Beach following the beach nourishments of Nov 1989 and Jan to May 1990 over an extended 8 month period from August 1990 to April 1991.

GOLD COAST BACKGROUND

The Gold Coast is a world-class tourist attraction with an economy heavily dependent upon the many millions of visitors that arrive all year round. The Gold Coast City Council has long recognised the value of its coastline and beach assets with an extensive program of beach management. Boak et al. (2001) overview of the coastal management of Gold Coast provides valuable information of the past beach conditions. In summary, the Gold Coast beaches are constantly affected by variable wave conditions causing erosion and accretion cycles. Due to the extension of the Tweed River training walls in the 1960s the Southern Gold Coast beaches subsequently suffered prolonged erosion and by the 1980s were extremely vulnerable to storms and cyclones. The historical survey data indicates that, before the 1988 to 1990 beach nourishments for the Southern Gold Coast beaches, significant upper beach erosion occurred at Kirra and south Bilinga beach (Meisner, 1991). Table 1 summarizes the total

[1] School of Civil and Environmental Engineering, UNSW Australia, Sydney NSW 2052, Australia. Email: f.yuan@unsw.edu.au
[2] Australian Climate Change Adaptation Research Network for Settlements and Infrastructure, Civil and Environmental Engineering, UNSW Australia, Sydney NSW 2052, Australia. Email: r.cox@unsw.edu.au

of 6.6 million m3 beach nourishments undertaken in several stages on the Southern Gold Coast beaches between 1988 and 1996.

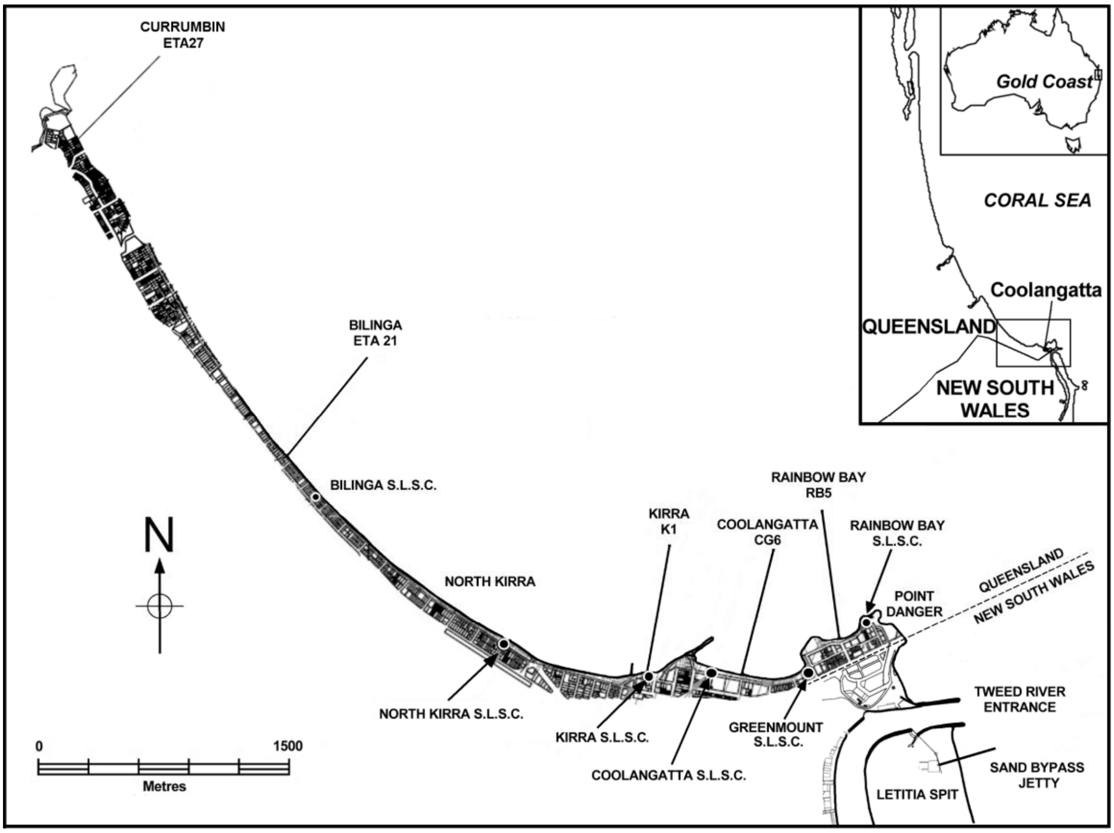

Figure 1. Location of Southern Gold Coast, Australia. (Source: Strass et al., 2013)

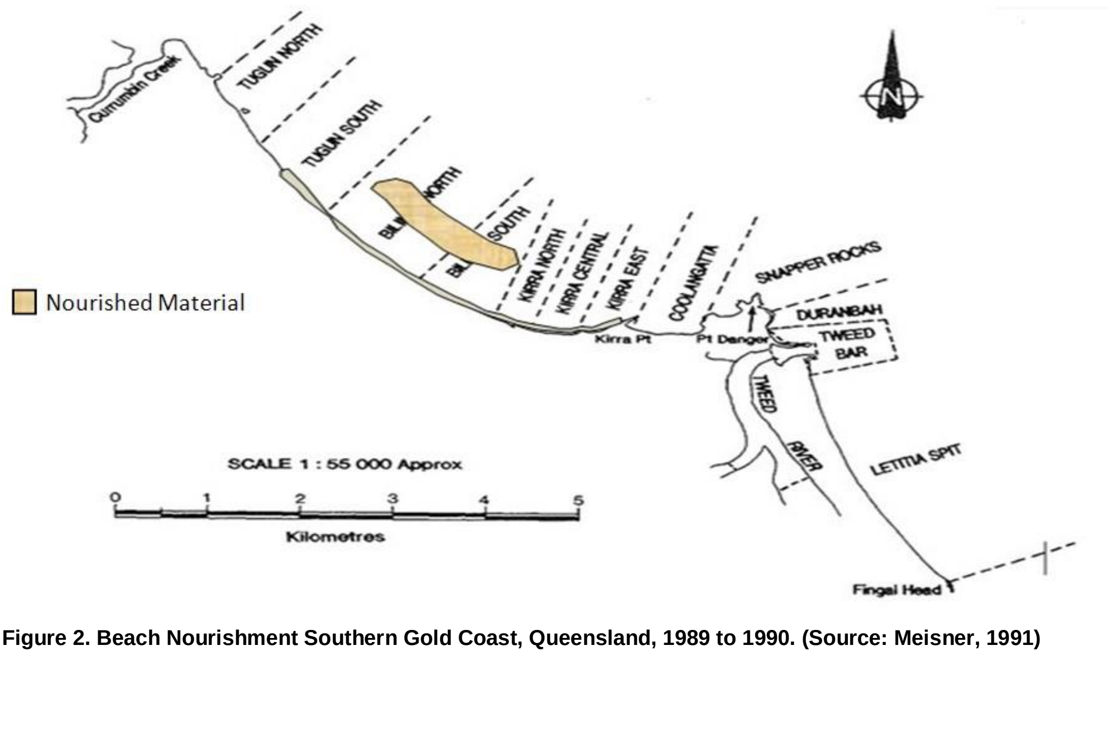

Figure 2. Beach Nourishment Southern Gold Coast, Queensland, 1989 to 1990. (Source: Meisner, 1991)

Year	Start Location	End Location	Volume Nourished	Depth of Nourishment	Observation after the nourishment
1988	Kirra Point K1	South Bilinga ETA20	Total of 1.5 Million m^3 nearshore nourishment	6m to 10.5m below AHD	Storm condition for over a year after nourishment project complete, erosion seen at north end and accretion still observed at the toe of the boulder wall.
16 Nov - 30 Nov 1989	George st Bilinga	Toolona st Tugun	395100m^3 nearshore nourishment	6m to 9m below AHD	Survey shows nourished bar moved shoreward and flattened from Jan 1990 to May 1992
19 Jan – 25 May 1990	Miles st Kirra K1	Tugun ETA24	3.2 Million m^3 onshore nourishment	0m to 2.75m above AHD	Behaviour affected by wave climate following erosion and accretion cycles
Apr 1995- Aug 1996	Snapper Rocks RB5	North Kirra beach K30	1.5Million m^3 nearshore nourishment	6m to 10 m below AHD	From May 1995 to Aug 1998, no significant profile change is observed, the offshore nourishment formed an offshore bar

Table 1. Beach Nourishment Summary Table from 1988 to 1996 at Southern Gold Coast

Later in in 2000, the integrity of the Southern Gold Coast beaches was ensured when the NSW and Queensland governments co-operated and jointly funded the Tweed River Entrance Sand Bypassing Project with the construction of a permanent pier south of the Tweed entrance. The pier has 10 sand slurry pumps that deliver an average of 500,000 m^3 by buried pipelines to selected downdrift locations (Duranbah, Snapper Rocks and Coolangatta).

Meisner (1991) modelled the beach response for the Kirra 1988 nourishment stage using UNIBEST-LT and UNIBEST-TC. Although the model failed to predict both bar and upper beach morphology change, the report includes a large number of measured beach profiles which provides a useful resource for future analysis. In this paper, the model NSBEACH will be used to simulate both erosion and accretion/recovery response at Bilinga Beach following the major beach nourishments of 1988 to April 1990 over an extended 8 month period from August 1990 to April 1991.

Wave Climate

The Southern Gold Coast embayment stretches from Snapper Rocks to Currumbin and includes the beaches of Coolangatta, Kirra, Bilinga and Tugun (Fig. 1). With the strong curvature of the embayment differential longshore transport processes are dominant over the longer term with an estimated annual rate of 500,000m^3 (Delft Hydraulics Laboratory, 1970). However, during the simulated 8 month period (10 August 1990 to 4 April 1991), the onshore migration of nearshore nourished material and bar movements are dominated by cross shore transport processes for which SBEACH and NSBEACH models are applicable. During the nourishment project, the wave conditions at Kirra point were measured by wave buoys at -15m AHD, with wave data being recorded four times a day from 25 Aug 1988 to 31 Dec 1990. After 1st Jan 1991, the data was recorded at hourly intervals (Beach Protection Authority, 1997). All waves recorded at Gold Coast before July 2007 are non-directional. The average significant wave height and peak wave period at Kirra point are respectively 0.75m and 9s with an average tidal range of about 1m (Strauss et al., 2013).

The available wave data at Kirra was provided by the Queensland Coastal Impacts Unit - Science Delivery Division, Department of Science, Information Technology, Innovation and the Arts (DSITIA). Wave conditions at different locations for the selected period are plotted in Fig. 3. The wave data from the project deployed Kirra buoy and another buoy at Surfers Paradise were unfortunately missing much data during the project period (Fig. 3). Preliminary model simulations using Kirra and Surfers Paradise wave data did not reproduce the offshore bar movement simply due to the poor wave data. Therefore, an almost complete hourly wave data set from nearby Byron Bay for the period was provided by Manly Hydraulics Laboratory. In Fig. 3, the depth of closure is calculated using the Byron Bay wave data to check for offshore movements with respect to the known Bilinga

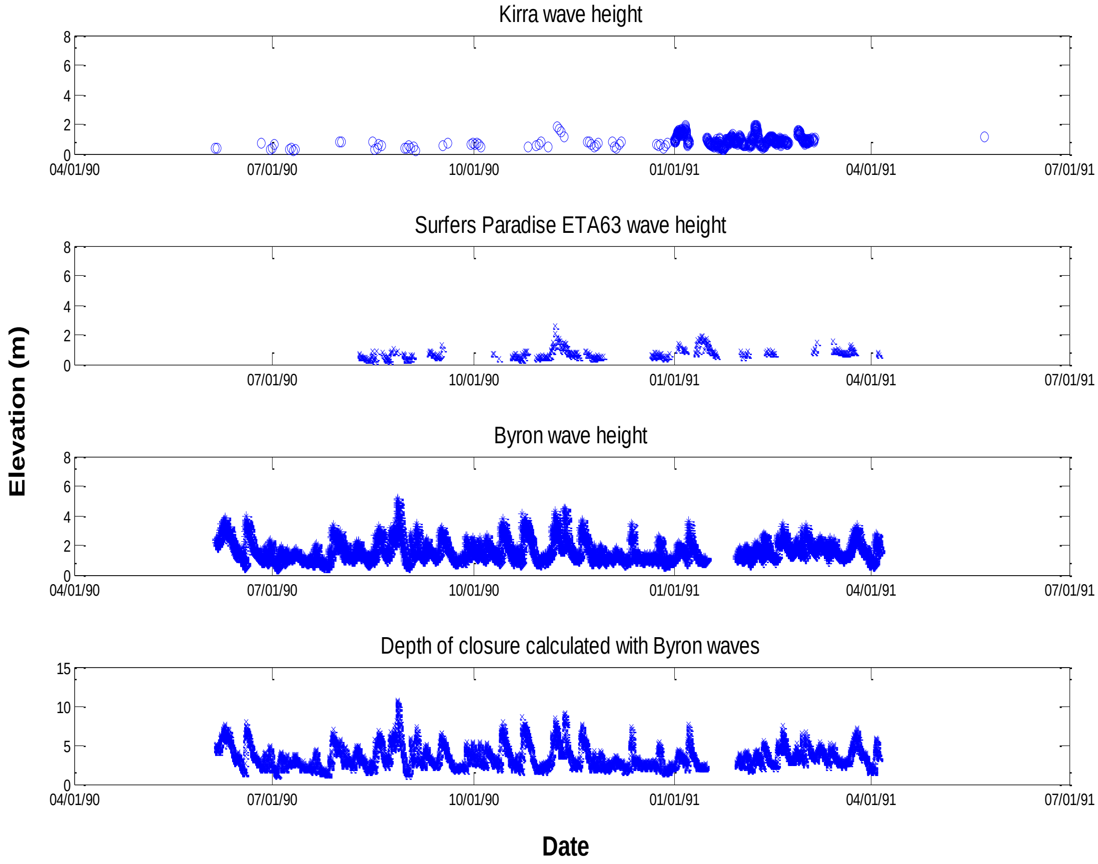

Figure 3. Wave data comparison for different locations.

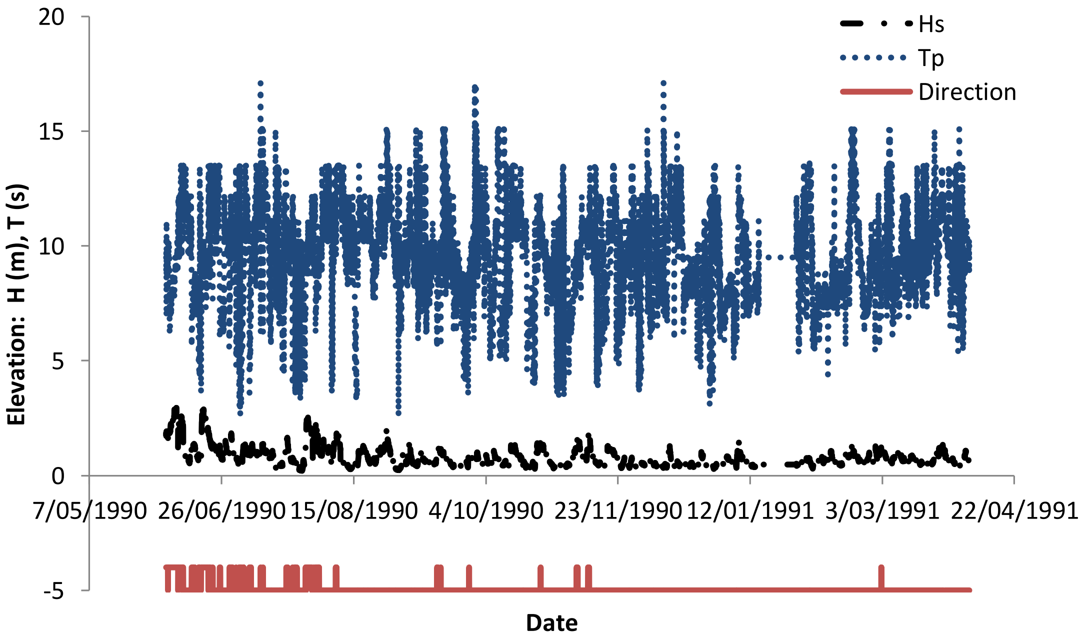

Figure 4. Billinga wave climate (scaled Byron); Hs is significant wave height; Tp is wave period; and transport direction scale: erosion= -4, accretion= -5.

nearshore nourishment location at 6m to 9m below AHD. Correlations for simultaneous measurements from Kirra and Byron buoys were used to constitute a wave climate for the Southern Gold Coast area over the period of consideration. The scaled Byron Bay wave data to Bilinga for the simulation period is shown in Fig. 4. From the transport direction plot at the base of Fig. 4, it can be seen that both erosion and accretion cross shore transport processes are involved during the simulation period. However, longer cycles of accretion are observed and the onshore coastal processes dominate during the modelled period.

Beach Profile Analysis

In addition to the surveys taken during the Southern Gold Coast beach nourishment project, Bilinga beach profiles include long term Gold Coast survey lines from Bilinga South (ETA21) to Tugun South (ETA23.7). During major storms in 1967 and early 1989, the Southern Gold Coast was severely eroded, and beach width reduced significantly. The stages of beach nourishments performed to restore the beach width after 1988 are given in Table 1. Fig. 5 shows various key profiles during the nourishments at Bilinga Beach in November 1989 and through Jan to April 1990. Survey on 14th Nov 1989 represents the beach profile before nourishment work began. On the 5th Jan 1990, a clear offshore bar is observed showing the nearshore nourishment of 395,100 m^3 at water depth 6m to 9m below AHD is completed. The finishing survey after the completion of 3,230,600 m^3 onshore nourishment on the beach above 0 AHD is shown on the 27th Apr 1990.

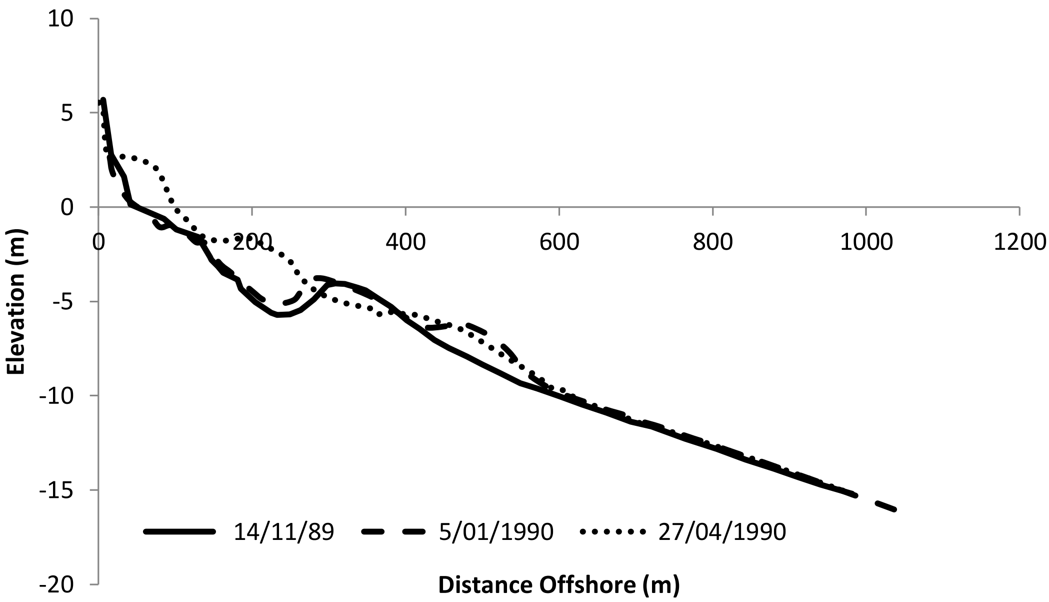

Figure 5. Bilinga beach profile survey at ETA22.5 during nourishment period 1989 to 1990.

A three-dimensional time plot covering the whole length of Bilinga Beach from ETA21 to ETA23.7 is shown in Fig. 6. First subplot in Fig. 6 shows the completion of nearshore placement shaded by medium blue at 500 m offshore. The second subplot shows the completion of upper beach onshore nourishment and significant beach width growth on the southern side of Bilinga beach. Moreover, the nearshore nourishment is already flattened during this three months but still observable. Subplot 3 shows a stronger barred post storm beach profile in Aug 1990 and subplot 4 indicates the completely flattened nourishment at depths of 6m to 9m below AHD and accretion on the upper beach.

MODEL

The Gold Coast has an extensive long term data set incorporating sub-aerial and bathymetric surveys. Utilising this data set, there are numerous journal and conference papers discussing the changes in beach profiles and morphological processes. Numerical modelling is limited with attempts to simulate the beach profile changes at various locations within the wider Gold Coast including: UNIBEST-TC and UNIBEST-LT for 1988 Kirra nearshore nourishment (Meisner, 1991), SWAN wave output at Coolangatta Bay in 2004 (Castelle et al., 2009) and SBEACH and GENESIS for storm simulation in May 1996 at Surfers Paradise (Carley et al., 1999). The modelling results for short term storm erosion are reasonable but none found acceptable for longer term beach recovery, bar migration or onshore transport of nearshore placed sand nourishment.

A numerical model (NSBEACH) has been developed based on some of the existing modules within the SBEACH (Storm-induced BEAch CHange) model. SBEACH is a numerical model for simulating cross-shore storm-induced beach change developed by US Army Corps of Engineers which has the potential to simulate long-term recession processes when empirical coefficients are derived numerically from process-based models (Roelvink and Broker, 1993). SBEACH simulates beach profile change including the formation and movement of major morphologic features such as bars and berms under varying storm waves and water levels (Rosati et al., 1993) within an economical computation time. However, SBEACH model performance is limited in application to short-term storm erosion events. NSBEACH continues to use the energy flux and dissipation theory in shoreline modelling. Significant modification has been made to SBEACH to overcome the previous limitation in simulating beach recovery. The new model NSBEACH (New SBEACH) includes onshore transport and beach accretion, advanced numerical methods for long-term simulation, redefined swash zone width, as well as inundation projection caused by sea level rise. The cross-shore transport only limitation in the model is acknowledged as a simplification to full 3-dimensional capability. An advantage is high efficiency in simulating relatively long-term cross-shore coastal processes in the developed model (Yuan and Cox, 2013).

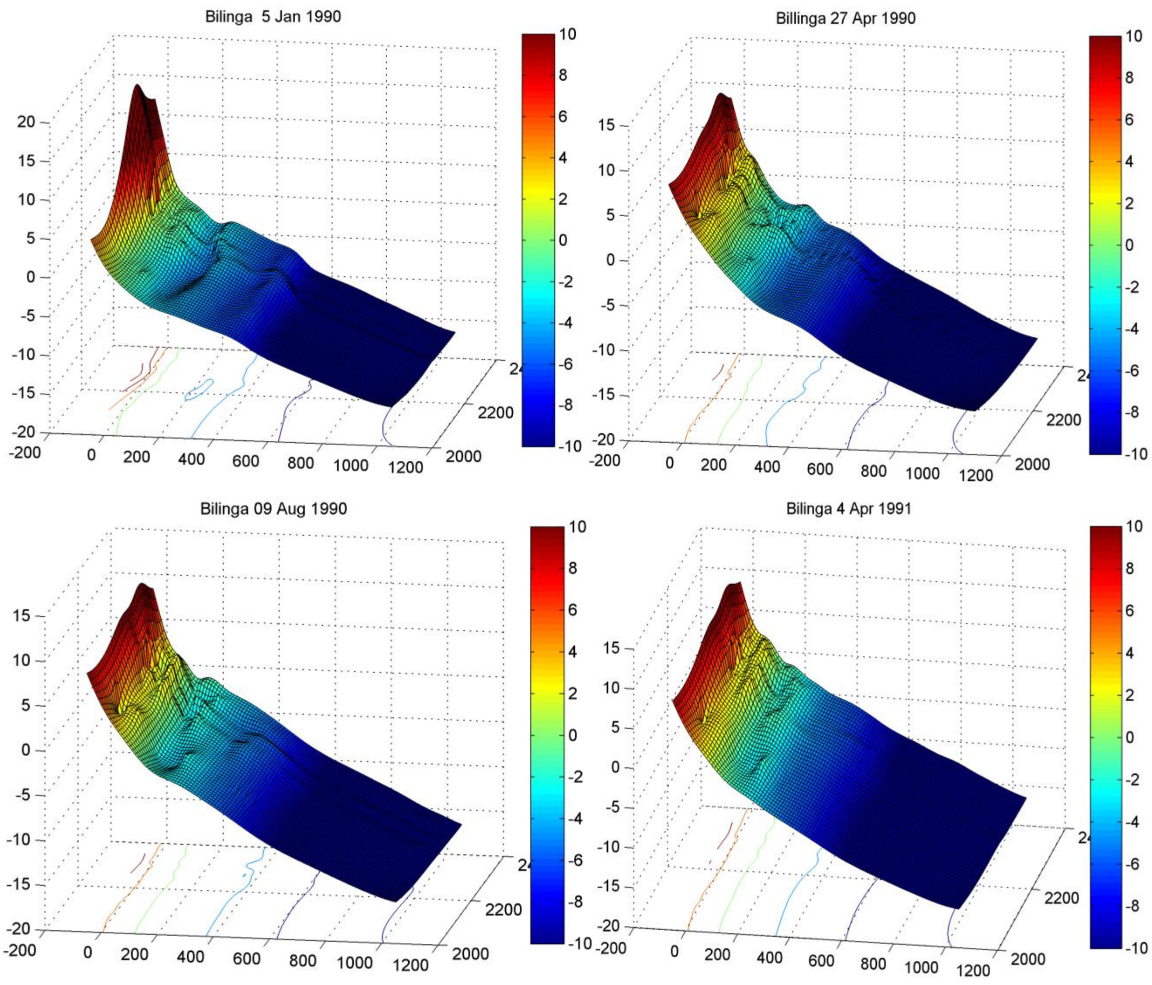

Figure 6. Bilinga beach 3-dimensional plots.

Methodology

The numerical model applies the breaker decay model of Dally, Dean, and Dalrymple (1984) to represent the energy dissipation process due to wave breaking. It allows the initial input as deepwater wave climate. The energy conservation equation is expressed using wave energy flux (F) as:

$$\frac{\partial}{\partial x}(F\cos\theta)=\frac{\in}{d}(F-F_s) \qquad (1)$$

where F_s = stable wave energy flux; € = empirical wave decay coefficient; d = the sum of still water depth (h) and wave setup/setdown (η); and Θ = wave angle. The momentum equation is used to calculate the displacement of wave setup/setdown from the radiation stress in the cross-shore direction (S_{xx}) as:

$$\frac{dS_{xx}}{dx}=-\rho g d\frac{d\eta}{dx} \qquad (2)$$

where radiation stress S_{xx} is determined from wave properties. Hereafter the sediment transport rate in different zones can be determined from the result of Eq. 1 & 2 using SBEACH transport rate equations. The model applies the mass conservation equation to determine the profile elevation within a horizontal grid cell (Δx) at each time step:

$$\frac{\partial h}{\partial t}=\frac{\partial q}{\partial x} \qquad (3)$$

where q=cross-shore transport rate; h=still water elevation; and Δt= time step. Sediment is allowed to move between cells, and the total volume of sediment is conserved across the profile. In NSBEACH, onshore transport direction is enabled. The most influential parameters affecting correct berm and bar location and volume are wave steepness (H_o/L_o), fall velocity (ω) and slope (tanα) terms. The transport direction equation is based on Hattori and Kawamata's (1980) paper where onshore-offshore relationship is determined from both laboratory and field data (Eq. 4). The model is applicable for surf zone transport with equilibrium concept.

$$\frac{(H_o/L_o)\tan\alpha}{\omega(d_{50})/(gT)}\begin{matrix} < & \mathit{onshore} \\ = 0.5 & \mathit{equlibrium} \\ > & \mathit{offshore}\end{matrix} \qquad (4)$$

where H_o = deep water wave height; L_o= deep water wave length; d_{50}=sediment size; T= wave period; ω = fall velocity; and tanα = slope.

The transport rate within the swash zone is sensitive to the time varying seaward end of the swash zone (DFS). In SBEACH model the swash zone depth (DFS) is an input value which stays constant with different wave climate and it extremely limits the swash zone boundary in the offshore directions. In NSBEACH, DFS height is calculated based on the wave run-up height and beach foreshore slope (Yuan and Cox, 2013). This enables more accurate swash zone transport rate calculations and beach profile changes.

In order to improve SBEACH model with the capability to predict long-term simulation without significantly increasing the computational time, a new numerical method is engaged. In SBEACH, the numerical method employed is a second order Implicit Euler method. It works well for short term analysis. However, when the time step increases, the solution becomes unstable due to the low order of accuracy in time domain causing fluctuations in the sign of the derivative terms and significant inaccuracies (Slingerland and Kump, 2011). NSBEACH has incorporated a combination of a three-level implicit method presented by Richtmyer and Morton (1967) and a trapezoidal rule. Within the surf zone, the trapezoidal rule is used to enable large beach profile changes to develop such as features like berms and bars. For the offshore zone, Richtmyer and Morton's numerical method is used to make the profile more convergent and smooth. To improve the accuracy and avoid model instabilities, the von Neumann stability analysis is performed. From the calculation, small discretised time domain and space domain are preferred, i.e. Δt=15min, 30min, 60min and Δx=1m, 2m, 4m.

RESULTS

Overall, NSBEACH is shown to model the coastal recovery process quite well over the extended simulation period of 8 months. The simulation area is indicated in Fig. 7 from ETA21 to ETA23.5. Both erosion and accretion response of the beach are successfully simulated by NSBEACH. In contrast, SBEACH predicted only erosion of the nourished beach volume and had insufficient ability to model long-term coastal changes. The changes in beach volume are calculated for comparison between measurements and the SBEACH and NSBEACH simulations. Selected model results are shown in Fig. 8 to 10. Each figure shows a comparison between SBEACH, NSBEACH model results and measured profiles. NSBEACH shows good agreement in comparison to measured profile where the onshore movement of the nearshore nourished material has been successfully simulated. Upper beach profile predictions by NSBEACH are consistent with observed survey data. On the other hand, SBEACH model is unable to reproduce the Bilinga coastal process for this simulation period. This is because SBEACH model is limited to short-term storm erosion simulation and does not incorporate onshore transport nor beach recovery. Therefore, instead of predicting onshore bar movement SBEACH predicts a large amount of dune erosion.

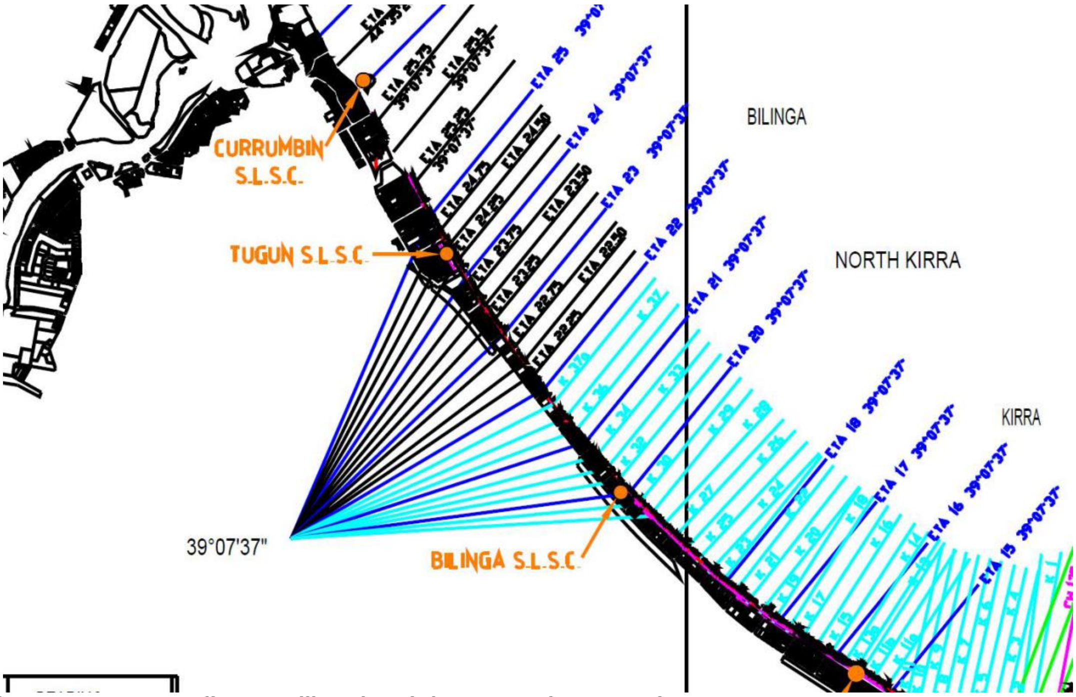

Figure 7. Survey ETA lines at Bilinga beach (source: Meisner, 1991)

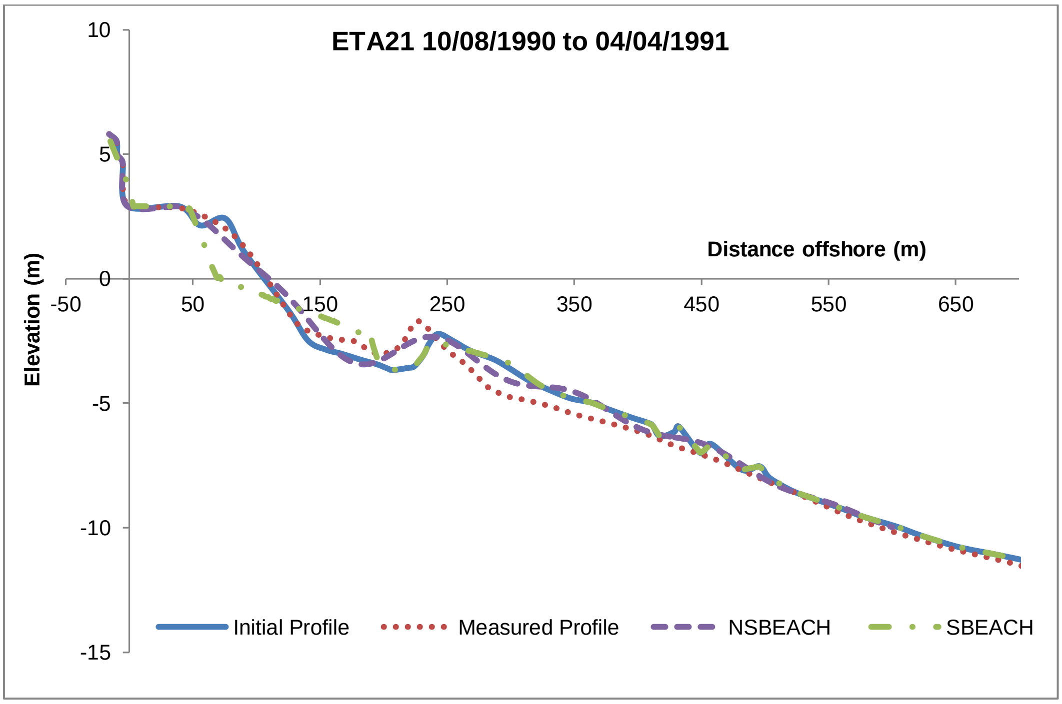

Figure 8. Modelling results for ETA21.

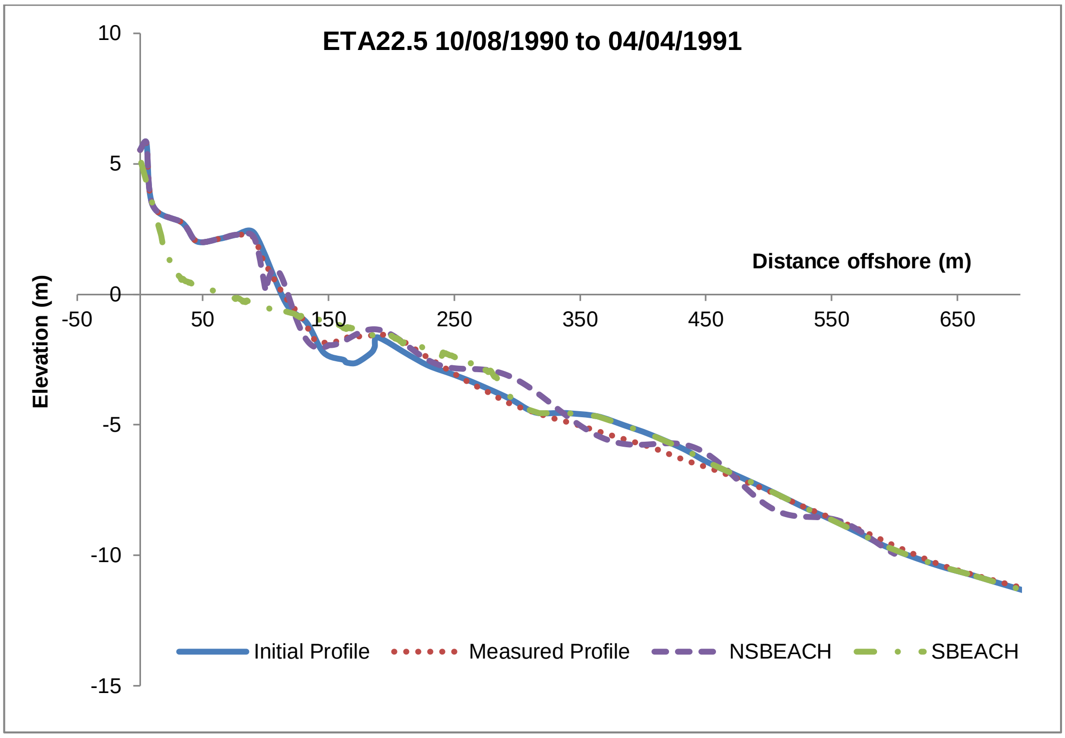

Figure 9. Modelling results for ETA22.5.

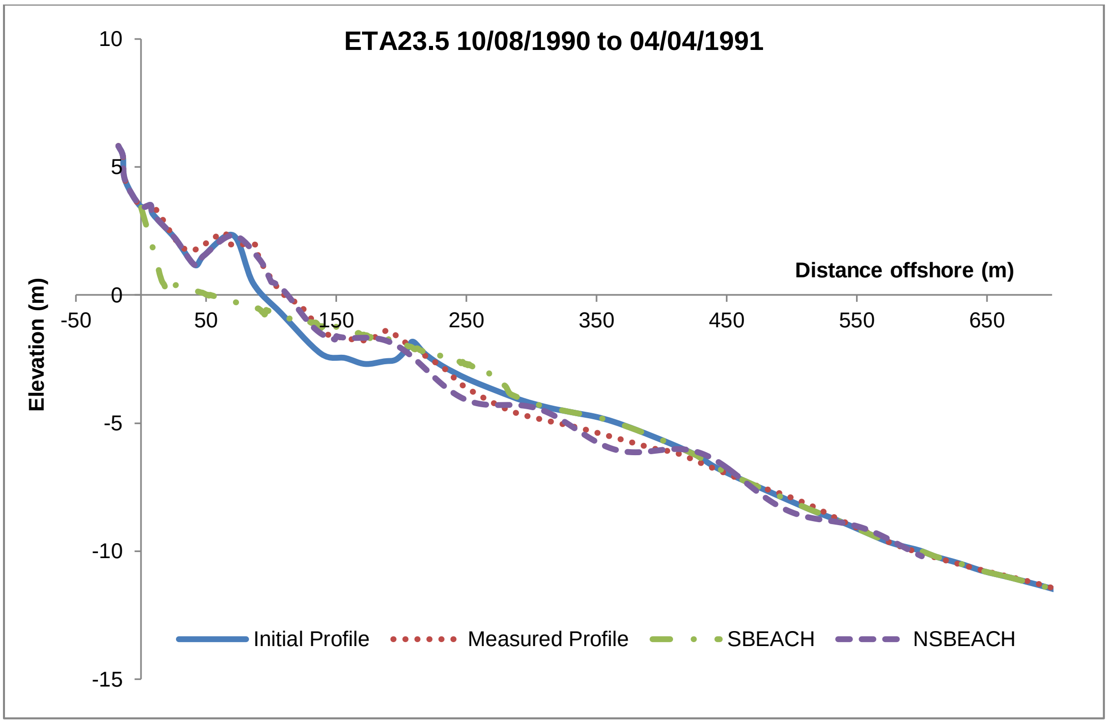

Figure 10. Modelling results for ETA23.5.

Error Analysis

A post-processing analysis has been proposed to identify instabilities, check accuracy and assist in assessing model performance and reliability. The methodology includes the calculation of the average root mean square error (RMSE) and residual (RES) as given in Eq. 5 and Eq. 6 respectively.

$$RMSE = \sqrt{\frac{\sum_{j=1}^{N_p}\left(y_{m,j} - y_{p,j}\right)^2}{N_p}} \qquad (5)$$

$$RES = \frac{\sum_{j=1}^{N_p}\sqrt{\left(y_m - y_p\right)^2}}{\sum_{j=1}^{N_p}\sqrt{\left(y_i - y_m\right)^2}} = \frac{RES_{upper}}{RES_{lower}} \qquad (6)$$

Where y_m = measured final profile elevation, y_p = predicted final profile elevation, y_i = initial profile elevation, N_p = number of points across profile, and j= x-axis location.

The average values of RES and RMSE calculated for Bilinga beach profiles from beach dune crest to offshore limit are listed in Table 2. Table 2 illustrates NSBEACH model's better performance than SBEACH. Nonetheless, it is difficult to differentiate the model's performance from the average RES and RMSE values alone and such traditional error analysis methods may not be a good indication of model performance if based on average differences between the predicted and measurement/initial values across the profile. For a beach profile extending to deep water, there will be little variation in neither measurement nor model predictions beyond the depth of closure. Despite large deviations between model and measurement that may occur across the bar, the swash zone and the beach berm, the RMSE and RES values being averages may appear reasonable since they are weighted by the good fit to the extended profile beyond the depth of closure.

An alternative error presentation is proposed in which the difference in displacement is directly calculated at each spatial point across the profile. In the example of Fig. 11 for ETA 23.5, SBEACH model results show substantial variation in the swash zone (x<100m) and nearshore bar region (200m<x<300m). On the contrary, overall NSBEACH modelling results are consistent with the measured profile.

Table 2. RES and RMSE error analysis for NSBEACH and SBEACH model

Profile	RES		RMSE	
	SBEACH vs. Measured profile	NSBEACH vs. Measured profile	SBEACH	NSBEACH
ETA21	1.3689	0.8316	0.2390	0.1375
ETA22.5	2.6728	1.3076	0.2782	0.1272
ETA23.5	1.4819	0.6181	0.2946	0.0981

Model Performance Assessment using Brier Skill Scores (BSS)

The Brier Skill Scores (BSS) method is useful for comparing the performance between two models. It has been widely applied in meteorology and coastal morphodynamic modelling by Sutherland et al.(2004), Splinter et al. (2014), Davidson et al.(2013) and Van Rijin et al.(2003). Formulation of BSS is shown in Eq. 7 (Sutherland et al., 2004). The measurement errors in data should include contributions due to errors in predicting amplitude, phase and mean.

$$BSS = 1 - \frac{\sum\left[\left|x - x_m\right| - \Delta x\right]^2}{\sum\left(x - x_b\right)^2} \qquad (7)$$

Where x is the measured profile value; x_m is the modelled profile value; x_b is the baseline model value and Δx is the measurement error in data. The BSS value is calculated to check the model performance against the baseline model, and positive BSS value indicates that the model performs better than the baseline model.

The model performance analysis using BSS was carried out to compare NSBEACH with SBEACH at different measurement error values for the three Bilinga profiles presented earlier. Four error levels at Δx=1cm, 5cm, 10cm and 20cm have been chosen. The selection of error values is based on the accuracy of survey methods. For LiDAR surveys, the vertical error is approximately ±15cm, and for

RTK-GPS and image-derived survey methods the vertical error is around ±3cm (Harley et al., 2010). The results of BSS assessment between model NSBEACH and SBEACH is shown in Table 3.

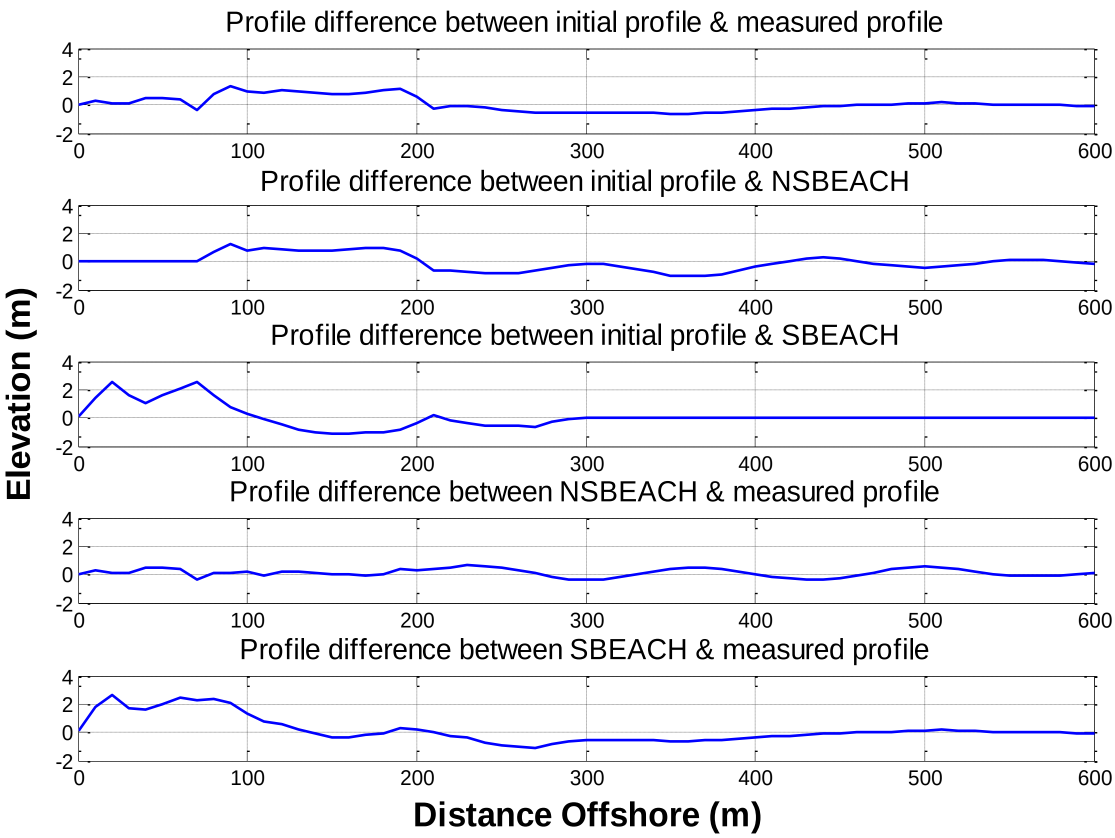

Figure 11. Spatial profile difference graph for error analysis on results for ETA23.5 (Refer to Figure 10)

Table 3. Brier Skill Scores for NSBEACH and SBEACH model comparison				
Profile	**BSS for NSBEACH in comparison with SBEACH as baseline model**			
	Δx=0.01m	Δx=0.05m	Δx=0.1m	Δx=0.2m
ETA21	0.681	0.727	0.775	0.845
ETA22.5	0.798	0.823	0.849	0.881
ETA23.5	0.895	0.916	0.937	0.960

Splinter et al. (2014) have provided a qualitative skill assessment criteria based on Brier Skill Scores which present as a performance indication vector shown in Table 4. Based on these indication vectors, the model performance in comparison to the baseline model can be easily grouped. Values from Table 3 show that NSBEACH performs excellently in comparison to SBEACH for profiles ETA 22.5 and ETA 23.5 irrespective of error values from 1cm to 20 cm. For ETA 21, NSBEACH shows good performance in comparison to SBEACH for error values from 1cm to 10cm, and excellent performance for error value of 20cm.

Table 4. Summary of qualitative Skill Assessments Based on Brier Skill Scores(BSS) (Splinter et al., 2014)				
Skill	**Poor**	**Fair**	**Good**	**Excellent**
BSS	0-0.3	0.3-0.6	0.6-0.8	>0.8

CONCLUSION

The Southern Gold Coast nourishment project at Bilinga beach, Australia, has been successfully modelled by the newly developed model NSBEACH. In comparison to SBEACH simulation results and observation data, NSBEACH model gives encouraging results for the accretion and erosion response on the upper beach as well as onshore and offshore migrations of the bar and nearshore nourishment. The ability to model cross shore morphological processes and beach profile change over relatively longer-term time scales is proven in an extended simulation including erosion and accretion cycles over an 8 month period following substantial beach nourishment.

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