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NUMERICAL MODELLING AND VIDEO ANALYSIS OF INTERMEDIATE BEACH STATE TRANSITIONS

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ABSTRACT

Numerical modelling of beach morphodynamics is generally recognized as a valuable tool for scientists and coastal managers. However, the utility of numerical models is constrained by our ability to establish that the theoretical dynamics match reality. The integrated modules for simulating wave propagation, hydrodynamics and sediment transport in Delft3D, developed by Delft Hydraulics, were applied to simulate observed beach state transitions in response to wave-induced forcing. Initial model bathymetry was derived from hydrographic surveys conducted at Narrowneck beach during the pre- and post-construction phases of the Narrowneck artificial reef (Boak, McGrath and Jackson 2000, Hutt, Black and Mead 1998).

The present study addresses the validity of morphological modeling of an exposed beach by comparing the evolution of a numerical model with data observed using remote imaging. Narrowneck beach on the Gold Coast is a micro-tidal, exposed coast subject to a highly variable wave climate. This beach is monitored by an ARGUS Coastal Imaging system generating high temporal frequency geo-referenced estimates of wave dissipation that may be used to infer sub-tidal bar morphology (Alexander and Holman 2004, Aarninkhof and Ruessink 2004, Turner, Dronkers, Roman, Aarninkhof and McGrath 2001). The numerical model was broadly validated, in that, when driven by similar conditions, the surf zone morphological development is consistent with that observed via optical sensing.

1. INTRODUCTION

There are inherent difficulties in collecting suitable data for adequate validation of spatial and temporal bathymetric models of beach evolution. Because of this, relatively few studies perform empirical validation of nearshore morphological models (Sutherland, Peet and Soulsby 2004). Most

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model validation studies have focussed on hydrodynamics, rather than bar morphology (Grunnet, Walstra and Ruessink 2004). Studies incorporating the use of video images and numerical models are often restricted to a qualitative comparison of emergent features (Ranasinghe, Symonds, Black and Holman 2004). Video analysis allows for a more objective analysis of morphology than is possible with visual classification by expert observers (Lippmann and Holman 1990).

The hydrodynamic processes driving sediment transport on dynamic beaches varies as a result of the underlying morphology for a given wave climate. The classification of natural bar morphologies most often follows the Wright & Short (1984) scheme which was derived from a study of naturally occurring beach states along the Australian coast from 1979-1982. The observed states broadly range from reflective, intermediate and dissipative surf zones. The Intermediate states can be further divided into Longshore Bar & Trough, Rhythmic Bar & Beach, Transverse Bar & Rip and Low Tide Terrace. Wright & Short found a good association between these identified beach state and environmental parameters relating to breaking wave height and sediment characteristics.

Associated with the underlying bar morphologies representative of each beach state we expect to see variations in the hydrodynamic responses due to the interactions of incoming waves with the bedforms. The most commonly occurring hydrodynamic responses for intermediate beach states are longshore currents, rip circulation cells and rip feeder currents. The signature derived from the surface reflectance due to wave breaking and dissipation in the near shore can be used as an independent classifier for remote detection of beach state (Browne, Strauss, Tomlinson and Blumenstein 2006). The two extreme classifications of dissipative and reflective beach states are rarely observed at our study site, and the Intermediate Low Tide Terrace state did not occur during the observation period.

The integrated suite of modules within Delft3D, developed by Delft Hydraulics in co-operation with Delft University of Technology is applied to simulate the coastal morphological responses at Narrowneck beach, Gold Coast, Australia. The model is built around the FLOW module which computes the hydrodynamics and transport and with the addition of the WAVE module can account for wave-driven currents and their interaction on the sediment transport. The model is applied here in 2DH mode and solves the unsteady shallow-water equations consisting of horizontal momentum, continuity and transport. The shallow water assumption reduces the vertical momentum equation to a hydrostatic pressure equation. The equations can be solved on either a rectangular curvilinear, or spherical grid. A detailed description of the recent advances in the 'Online' model formulations and model validations is provided in Lesser, Roelvink, van Kester, and Stelling (2004).

The morphological characteristics and wave climate of the study site are outlined in Section 2. This is followed by the observations and the data set used in the study in Section 3. The numerical model is described in Section 4, model results are discussed in Section 5 with some conclusions in Section 6.

2. STUDY AREA

The city of the Gold Coast in Southeast Queensland, Australia extends from the New South Wales border to the south, the site of the Tweed River sand bypassing project, to South Stradbroke Island to the north, the site of the Gold Coast Seaway sand bypassing project. Between is some 47 kilometres of clean sandy beaches and a number of world-class surfing locations providing a popular tourist destination and an area experiencing extremely high population growth. The maintenance and management of the city's beaches is vital to the Gold Coast economy as is the provison of safety for inexperienced swimmers drawn to the warm waters of the region.

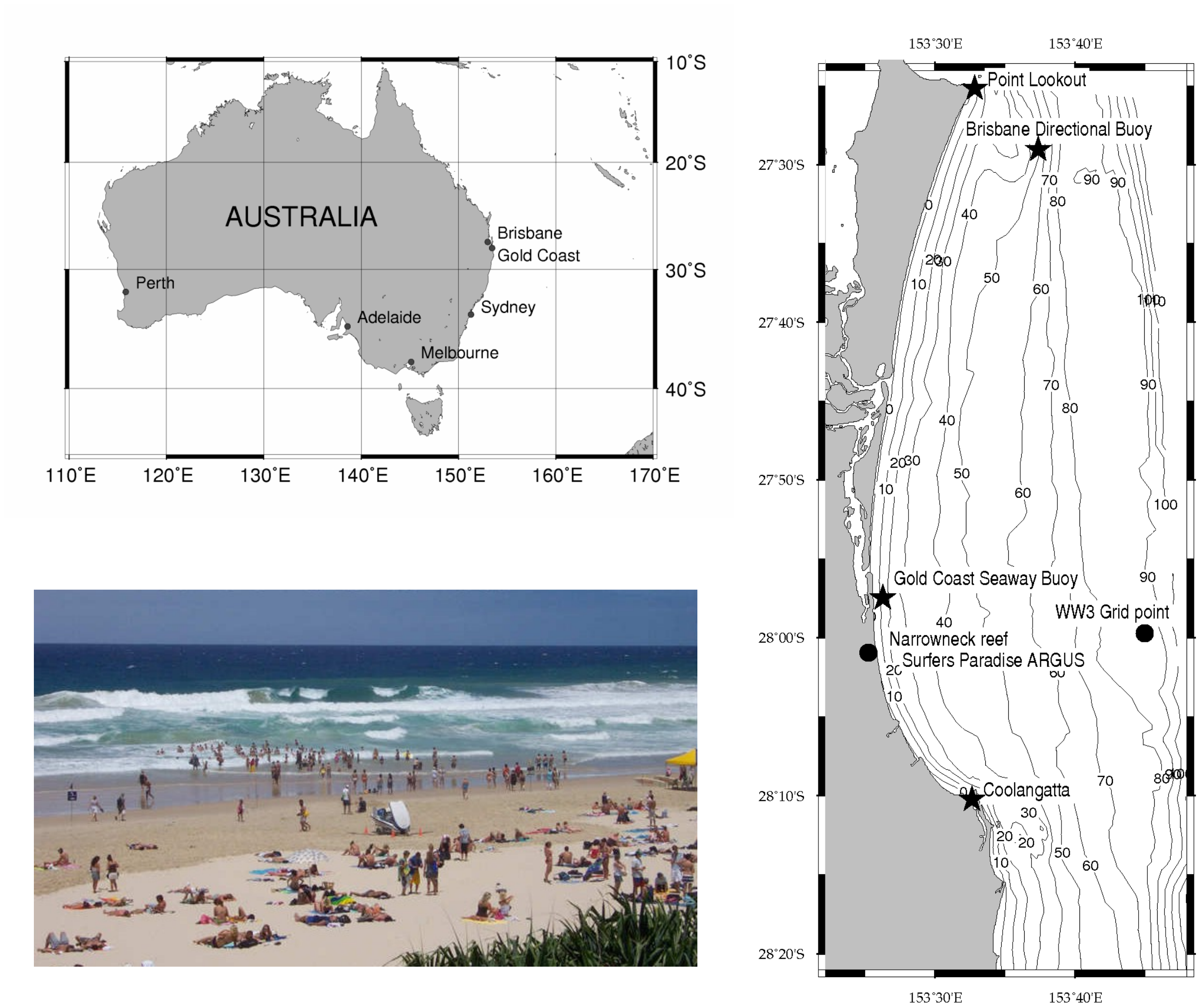


Figure 1 Location of study site, Surfers Paradise Beach, Gold Coast, Queensland.

Narrowneck beach is located just north of Surfers Paradise at the northern end of the Gold Coast, Queensland (Figure 1). Typical of the open east coast Australian beaches, it is exposed to a highly variable wave climate and typically presents a double-barred system with bar and trough topography and experiences a net northward littoral drift of approximately 500,000 m^3/yr (DHL 1970).

Median sediment size is 0.2 − 0.22mm, the primary source of natural sand is derived from the Clarence and Richmond Rivers in NSW which produce quartz and feldspar sand grains (Moffatt 1991). The tidal range is classed as micro tidal and tidal amplitudes vary up to 2.1m with a mean range of 1m. Sand is generally transported within a 15m depth of water with the limit of offshore transport and onshore transport being 22m and 30m respectively.

The winter wave climate is dominated by the eastward passage of low pressure systems to the south which generate moderate to high energy S to SE swell. The narrow, sediment rich continental shelf refracts the swell with the result being an oblique wave approach angle. It is this dominant condition that results in the net northward littoral drift. During summer months, particularly December to May, cyclones may form which either cross the coastline or move away to the east and south east generating large seas and N to NE swells. These larger swells, often with associated destructive winds, result in episodes of severe coastal erosion. Average deep-water significant wave heights generally range from 0.8 – 1.4m with mean periods of 7 – 9 seconds (Jackson, McGrath and Tomlinson 1997).

Extreme events such as cyclones can produce wave heights up to 14m and wave periods up to 18 seconds (Environmental Services Division – Coastal Services 2004). Typically, while waves over 1.5m will result in the formation of a storm bar along Gold Coast beaches, the reflective extreme of the Wright and Short (1984) beach state model is seldom observed.

Narrowneck beach has a surf zone width ranging from 150 – 200m with an inner, attached, continuous bar cut by few rips. During or after high wave events deep rips may occur every 200 – 250m. This is consistent with observations of similar Australian beaches by Short (2006) and the suggestion that rip spacing is closely related to wave period and wave energy. The outer bar can be cut by more widely spaced rips with a continuous deep trough between the inner and outer bar. This beach has been ranked as a 6 on a hazard scale of 1 – 10, with 10 being the most hazardous (Short 2000).

The Narrowneck site is particularly vulnerable to episodic erosion due to the existing seawall, (built in 1923 to protect the newly constructed highway), which is located 35m seaward of the general seawall alignment (Jackson, McGrath and Tomlinson 1997). In response to the economic impacts of significant episodes of erosion and the threat to infrastructure, the Northern Gold Coast Beach Protection Strategy (NGCBPS) was developed aimed at decreasing the magnitude of economic loss following storm events by increasing the volume of sand within the storm buffer seaward of the ocean front boulder wall (Boak, McGrath and Jackson 2000). The strategy aimed to reduce ongoing sand nourishment and included the installation of a multi-functional submerged geotextile reef breakwater.

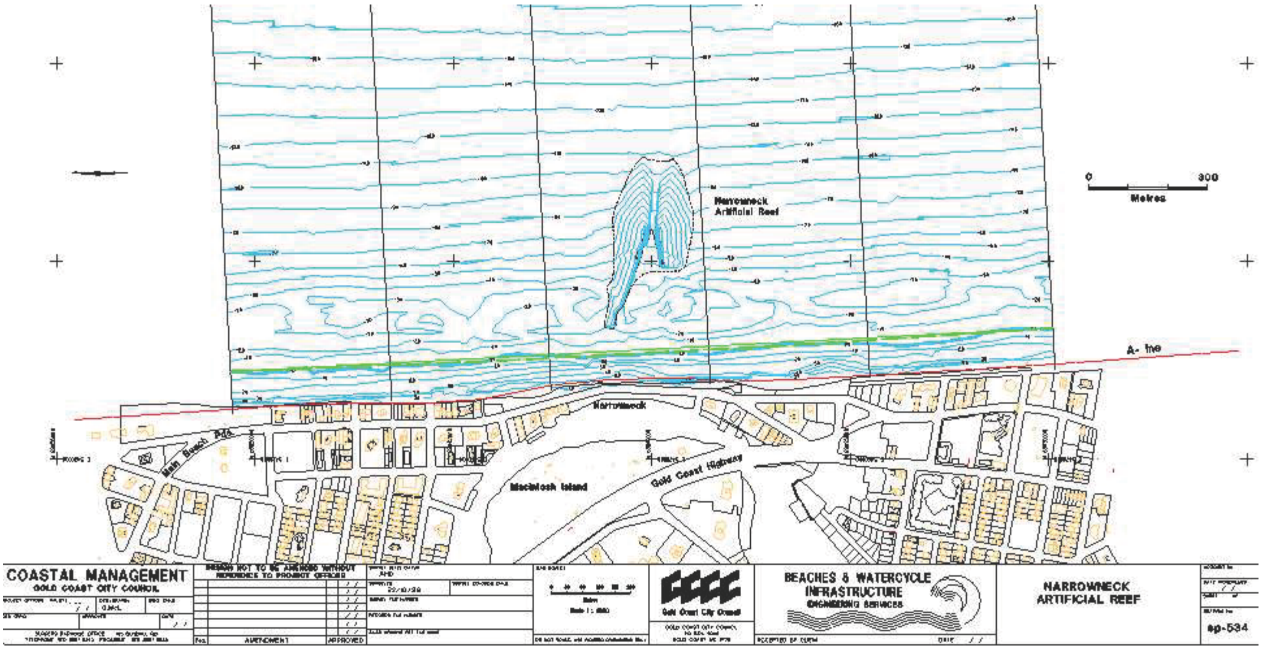


Figure 2 Narrowneck reef design.

The reef (Figures 2 and 3) provides a control point to stabilize the up-drift nourished sand (Turner et al. 2000). Nourishment began in February 1999 and continued until June 2000. The first reef construction phase began in August 1999 until December 2000. Additional geo-containers were placed on the reef during a second construction phase ending January 2001. The sand-filled geo-containers vary from 150-300 tonnes, and are typically 20m by 5m. The reef is 450m long and 205m across and consists of 416 bags (Turner 2001). Depth ranges from -1m to -10m below chart datum (Boak et al. 2000). The reef was designed to be placed far enough offshore to discourage the formation of a tombolo and to allow sufficient longshore transport to prevent extreme erosion of the downdrift beaches. Additional sand was also expected to pass over the submerged structure (Ranasinghe, Hacking and Evans 2001).

Figure 3 Narrowneck artifical reef

3. OBSERVATIONS AND DATA COLLECTION

Bathymetric data has been obtained for the study area from hydrographic surveys conducted at Narrowneck beach during the pre- and post-construction phases of the Narrowneck artificial reef (Boak et al 2000, Hutt, Black and Mead 1998). Additionally survey data was acquired in April 2006 from Gold Coast City Council (GCCC).

An instrumented sled fitted with pressure gauges and GPS has been developed for obtaining more frequent surveys of beach profiles, the sled can be deployed from jet-ski by GCCC lifeguards and winched ashore. Various designs were considered following a review of sea sled survey techniques available in the literature. Smith et al (1997) provides an overview from as early as 1945 up to and including the motorized CRAB of the Field Research Facility of the U.S. Army Corps of Engineers. Of paramount importance to our design was that the sled be portable enough to be easily deployed by jet-ski in order to maximize data collection between significant swell events. Monitoring of the sled with a submersible video camera demonstrated the ability of the sled to follow bed contours while being towed at speeds up to 5 knots.

4. NUMERICAL MODELLING

The integrated modules for simulating wave propagation, hydrodynamics and sediment transport in Delft3D, developed by Delft Hydraulics, were applied to simulate observed transitions in intermediate beach state in response to wave-induced forcing. The FLOW module of Delft3D (version 3.25.04) computes tide, wind and wave induced currents in two or three dimensions. It solves the unsteady shallow-water equations for motion, continuity and transport on an orthogonal curvilinear or spherical co-ordinate grid (Lesser et al 2004).

Wave-induced forcing is included with the Delft3D-WAVE module using the SWAN (Ris et al, 1999) wave model. SWAN is based on the discrete spectral action balance equation (Hasselmann et al., 1973), is fully spectral and can provide realistic estimates of wave propagation in the coastal zone. SWAN computes wave generation by wind, bottom friction, white-capping and depth-induced wave breaking dissipation and non-linear wave-wave interactions. (Booij et al 1999; Ris et al 1999). Idealised initial model bathymetry consisting of a longshore uniform outer and inner bar and trough morphology as shown in Figure 4 was derived from Gold Coast city council survey profiles.

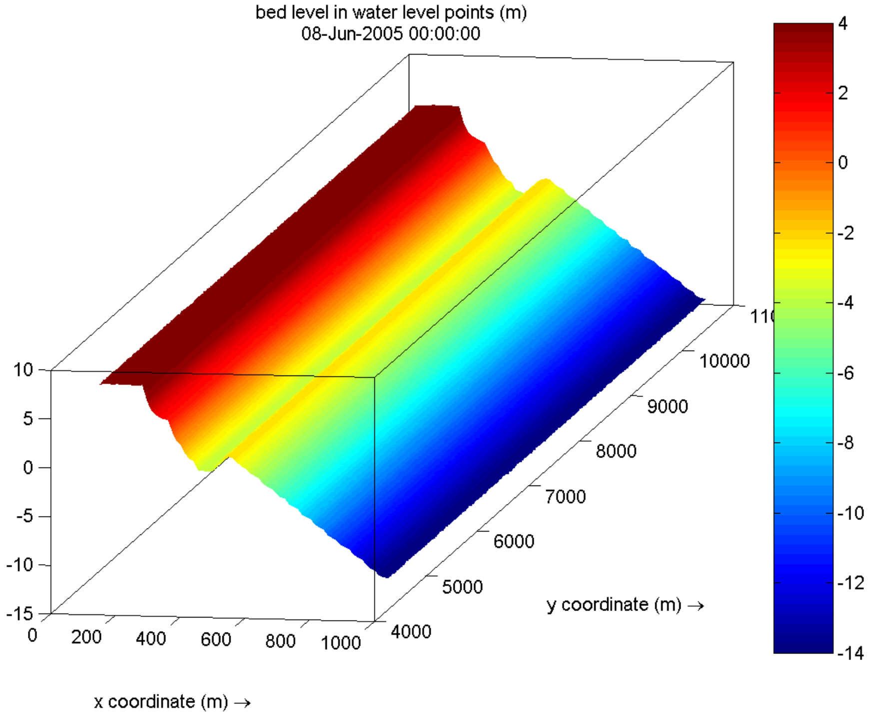


Figure 4 Idealised initial bar trough morphology

When wave effects are incorporated in Delft3D the wave module is run first over the initial bathymetry. The wave grid consists of two nested grids to account for inaccuracies arising near the boundaries. The regional scale wave grid is 15 x 195 grid with cells 80 x 80m, representing 1.2 km cross-shore and 15.6km alongshore. Grid cell size was selected following a series of sensitivity tests using progressively smaller grid cell sizes and with reference to literature of modelling similar morphological features (e.g. Smit, Reniers, Stive and Roelvink). While larger grid cell spacing resulted in a reduced computational time, the ability to resolve smaller morphological features also decreased. The refined area grid thus chosen was 74 x 477 grid cells of 13x13m. A communication files stores the output from the initial wave simulation for input into the FLOW module on a grid of 69 x 466 cells of 13x13m.

NOAA WW3 nowcast data is used to derive representative deep-water boundary conditions for the coarse regional wave model and calibrated with in situ recordings of significant wave height, period and direction obtained from Waverider buoys to provide wave boundary conditions for the morphological model. The boundary conditions consist of the following parametric input for SWAN.

- Spectral shape JONSWAP with a peak enhancement factor 3.3
- Significant Wave Height (Hs)
- Peak Period (Tp)
- Wave Direction (Dp)
- Directional spreading (M)

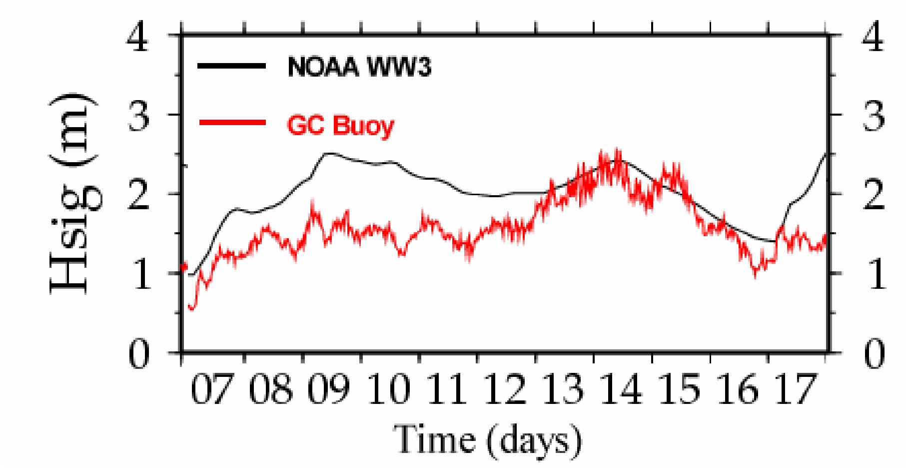


Figure 5 Significant wave height at boundary (NOAA WW3) & GC buoy locations

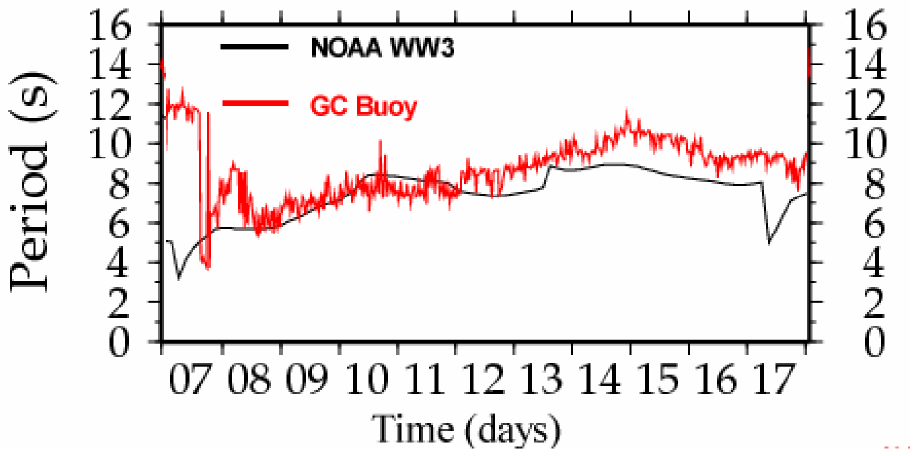


Figure 6 Peak wave period at boundary (NOAA WW3) & GC buoy locations

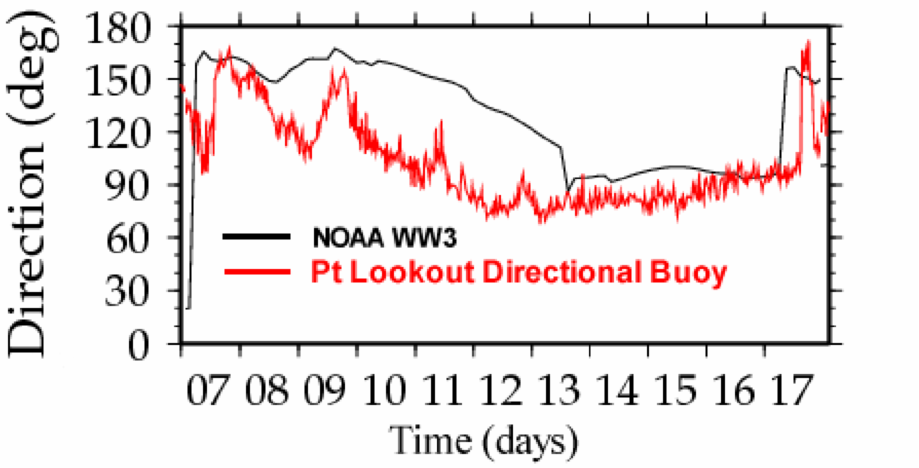


Figure 7 Wave direction at boundary (NOAA WW3) & Pt lookout buoy locations

Wind data used in the calibration of the wave transformation modeling was obtained from an automated weather station at the location of the Gold Coast Seaway (Figure 8).

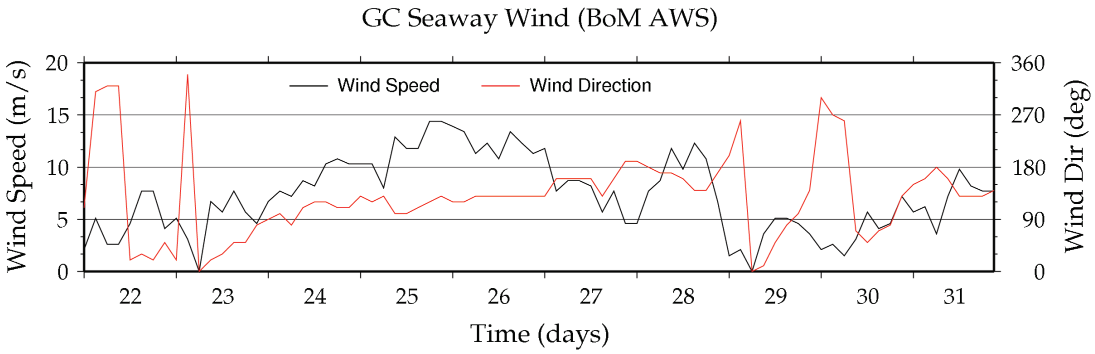


Figure 8 Wind speed and direction at Gold coast Seaway

An analysis of the wave model results (Figure 9) for the case with a constant wind field applied over the domain revealed that there was little appreciable effect on nearshore wave heights for the period considered and therefore wind effects were not included in the WAVE module (Strauss & Mirferendesk 2006)

Wave set-up is accounted for in FLOW so is not included in the WAVE module, wave-induced forces are computed on the basis of the gradient of the radiation stress tensor (Booij et al, 1999). Depth-induced breaking in shallow water was included with the following parameters selected for the Battjes & Janssen (1978) bore-based model.

- Coefficient for rate of dissipation, *Alpha* = 1.0
- Breaker Parameter Hm/d, *Gamma* = 0.73

Bottom friction type JONSWAP is selected according to Hasselman (1973) and tested with values for both wind sea, 0.067m^2s^{-3} and swell 0.038 m^2s^{-3}. Since we are primarily interested in swell wave forcing during calm weather, processes of wind growth, whitecappping and quadruplet wave-wave interactions were de-activated. Wave propagation due to refraction and frequency shift were activated.

Implementing the 'online' sediment transport version of Delft3D now allows the density effects of suspended sediment to be accounted for and bottom changes due to the sediment transport are updated and accounted for during each time step of the flow simulation.

A morphological scale factor (morfac) can be chosen to scale up the morphological changes since the time scale is much less than that of the hydrodynamics. A flow model run for 120 time steps of 0.1min with a morfac of 20, corresponds to 4 hours of morphological change after which the WAVE model is run again to update the wave field for the changes in bathymetry.

The depth averaged transport model (Bijker 1971) accounts for long-shore currents and cross-shore set-up due to gradients in the radiation stress terms and increased bed-shear stress. The enhanced bed shear stress due to turbulence from breaking waves and currents, resulting in increased bed roughness is accounted for using the parameterization of Soulsby et al. (1993) and co-efficients of Bijker (1967). A summary of the user defined model parameters are listed in Table 1.

Model	Parameter	Value
Waves	Spectral Shape	JONSWAP
	- peak enhancement factor	3.3
	- Depth induced breaking (α) (Battjes & Jansen, 1978)	1
	- breaker height to depth ratio (γ)(Battjes & Jansen, 1978)	0.73
	Bottom Friction (JONSWAP)	0.067 m^2s^{-3}
Flow	Computational Time step	12 s
	Lateral Boundaries	Neumann
	Seaward Boundary	Water level
	Bottom Friction (Chezy) (U, V)	65, 65
	Horizontal Eddy Viscosity	1 m^2/s
	Horizontal Eddy Diffusivity	0.1 m^2/s
Transport	Median sediment diameter D_{50}	200 μm
	Morphological Scale factor	20

Table 1 Model parameter settings

5. MODEL RESULTS

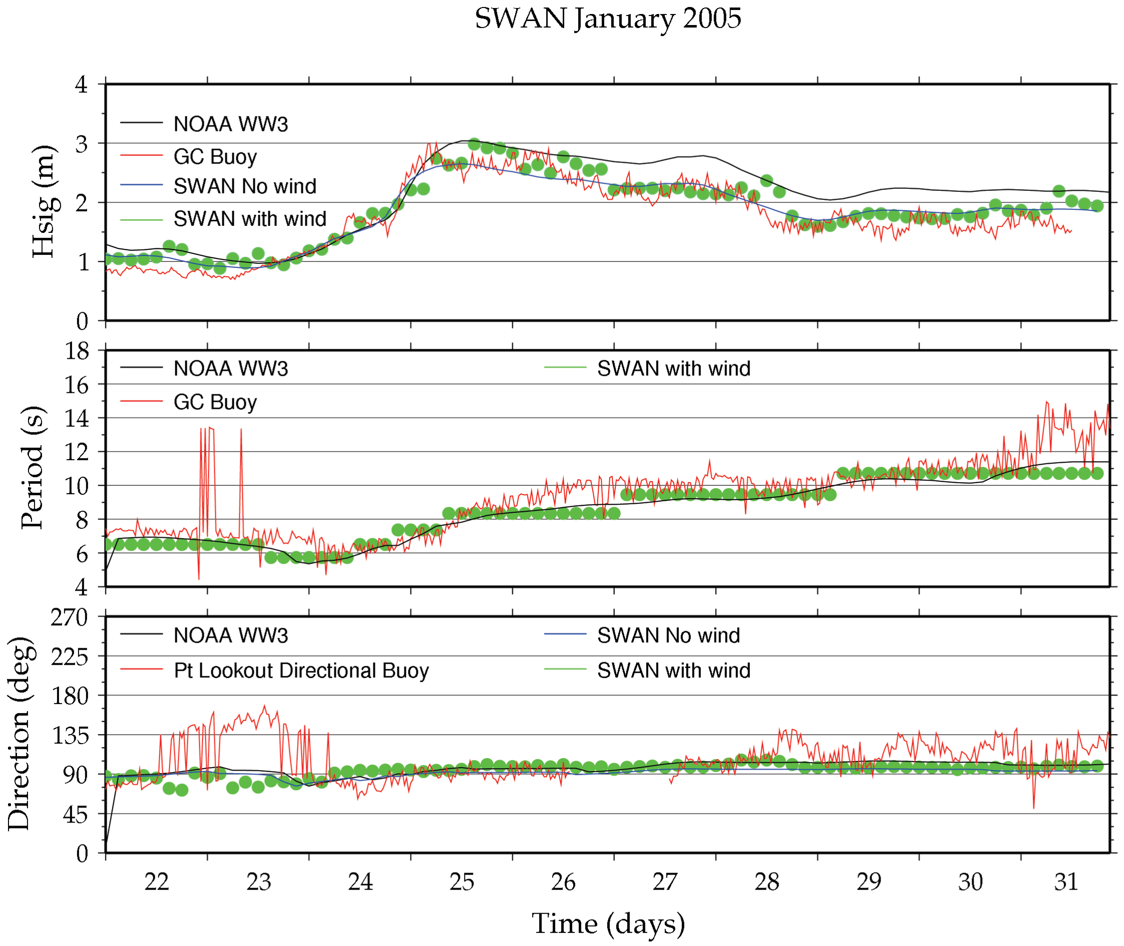
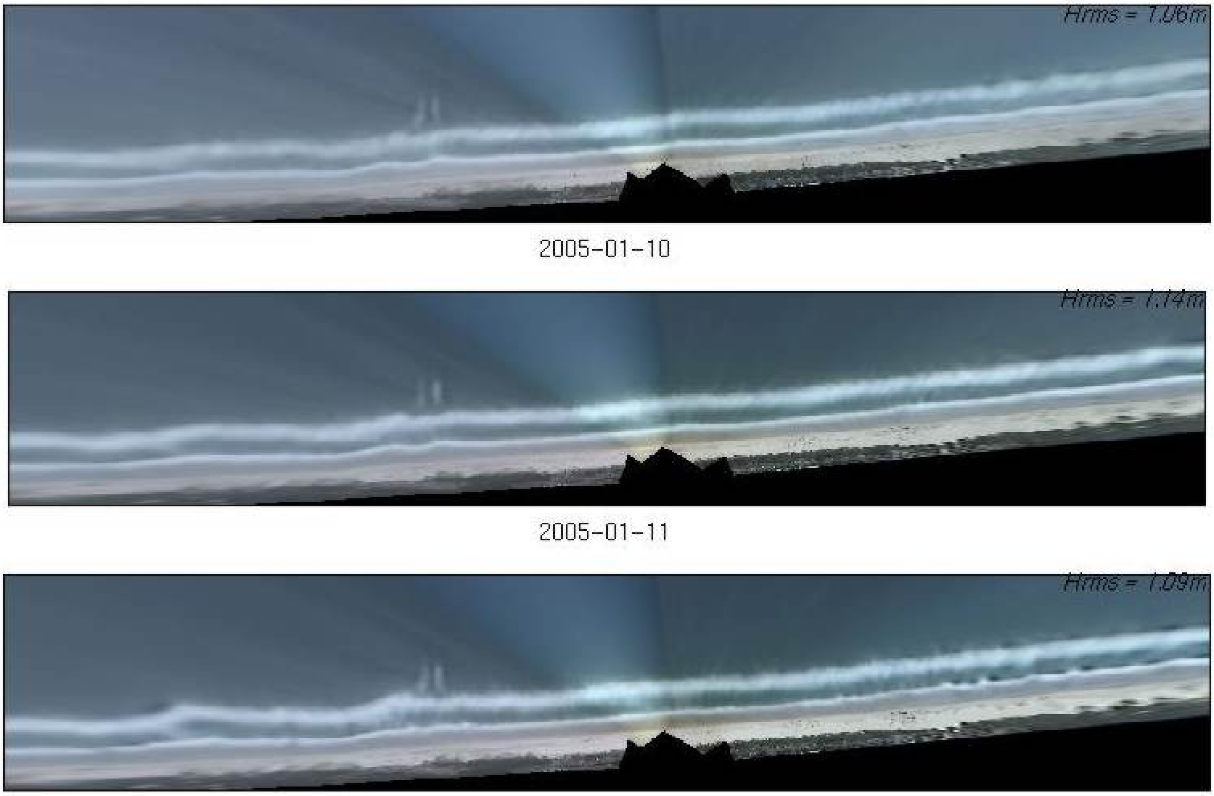


Figure 9 Wave model response including wind forcing

The first three days of January 2005 were characterized by low long period SE swell (Hs < 1m, Tp ~ 10-12 seconds), and light winds followed by three days of low energy wind waves from the northeast. From the 7th to the 10th January 2005 there was a 1.5m SE swell event with S winds which resulted in the formation of a longshore bar & trough morphology in the study area (Figure 10). This event persisted until the 12th January 2005 at which time the swell direction changed to easterly with a corresponding rise in Hs to 2m and Tp to 10 seconds, representing a higher energy swell with a shore normal approach angle (Figures 5, 6 and 7).



2005-01-10

2005-01-11

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Figure 10 ARGUS timex plan view images displaying linear bar and trough morphology in response to obliquely incident waves with significant wave height of 1.5m and peak period of 6-8 seconds. (Source: WRL, UNSW)

The relatively stable long-shore bar & trough morphology (Figure 10) represents the initial condition for the morphodynamic modeling of the beach adjacent to the artificial reef. The subsequent change in the wave climate around the 13th resulted in significant changes to the bar morphology. Substantial curvilinearity of the outer bar developed as the initially steady long-shore current evolved into complex three dimensional circulation and induced a transition to transverse bar & rip morphology (Figure 11). The transition to transverse bar and rip morphology is often associated with a decrease in wave energy while an increase is reported to 'reset' a barred beach to the linear bar & trough state (e.g. Ranasinghe et al 2004). Here we observe the development of transverse bar and rip morphology during an increase in wave energy which suggests that, for this particular beach and the local wave climate, the angle of wave incidence may have a more significant role in influencing beach state transitions.

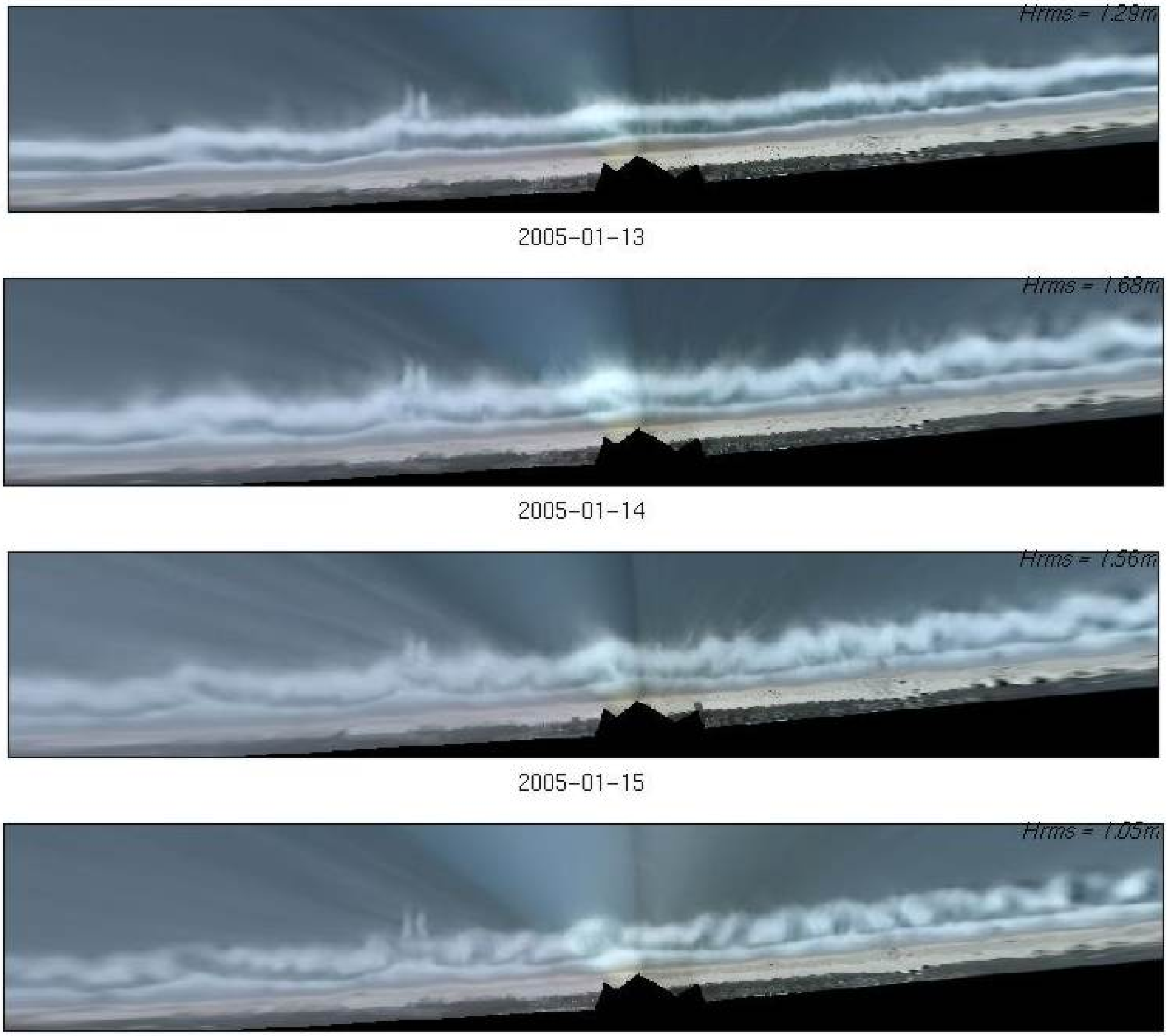

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Figure 11 ARGUS timex plan view images, displaying the transition to transverse bar and rip morphology in response to shore-normal incident waves of 2-2.5m significant wave height and peak period of 10 seconds. (Source: WRL, UNSW)

The sequence of ARGUS Timex images in Figure 11 display the rapid evolution of complex transverse bar and rips structures arising as a result of the change in wave climate around the 12th and 13th of January. Figure 12 shows a detailed section of the modelled results after 7 days of morphological time. The resulting morphological evolution of transverse bar and rip features in response to a shift to a shore normal incident wave direction is reinforced by the rip cell circulation, i.e there is a visible shoreward current over the shallow bars and return currents in the rip channels. Consistent with this near shore circulation is the development of rip head bars offshore from the rip channels where depth averaged current velocities diminish. The length scales of the bar and rip features present in the Timex images and modelled output compare well qualitatively. It appears that the depth-averaged approach has the ability to simulate this type of transition however attempts to provide a rigorous quantitative comparison still requires substantial additional effort.

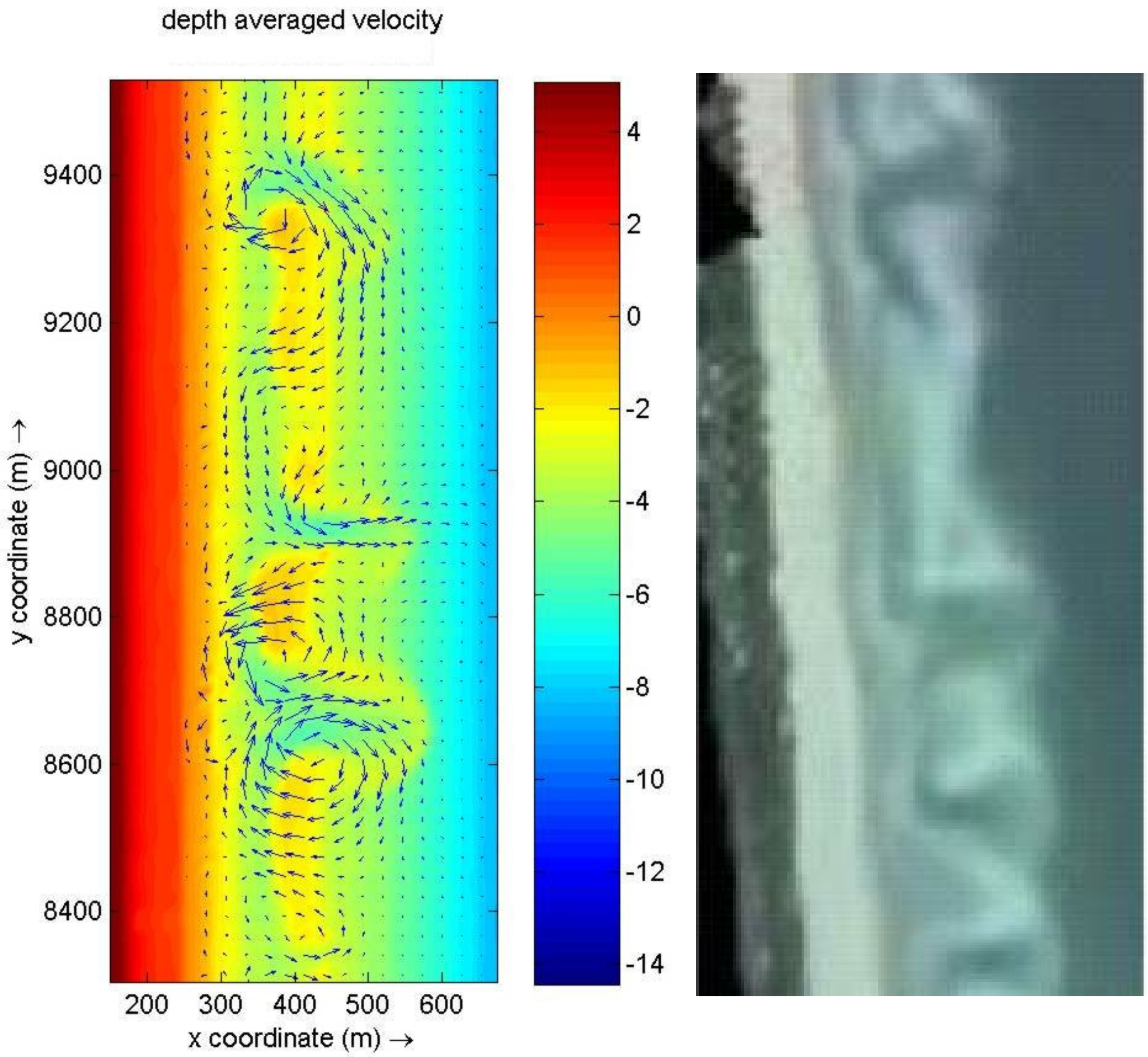

Figure 12 Model results (left) and Argus image displaying transverse bar & rip morphology (right)

7. CONCLUSIONS

The highly dynamic beach considered in this study changes quickly in response to wave climate. Long term monitoring with video images is becoming a useful tool for evaluating the morphological response to episodic events. Combined with advances in numerical modeling techniques and processing power it is becoming increasingly viable to produce detailed models of near-shore behavior at smaller temporal and spatial scales.

The beach state transition observed and modeled in this paper commonly occurs along this coast and represents a significant hazard to beach users due to rapid development of rip cell circulation. A transition to transverse bar and rip morphology occurring during an increase in wave energy has emerged which differs from the expected ‘reset’ to linear bar and trough morphology previously reported in the literature. Effective management of the buffer zone against erosion can benefit from an increased understanding of beach state transitions. Insight into the effects of hydrodynamic processes acting on bar morphology may be gained by continued long-term monitoring of beach state combined with numerical models of bar response to variations in offshore wave climate.

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