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Comparison of two wave models for Gold Coast, Australia

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ABSTRACT

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Managing hazards associated with shoreline responses to extreme events and the provision of safe boating access is an ongoing concern for coastal authorities. The open sandy coastline of Gold Coast city is a wave dominated coast with a highly variable wave climate and a narrow continental shelf thus experiencing substantial variations in long-shore transport rates. Detailed wave transformation information is central to further investigations of sediment transport processes as complex bathymetry associated with trained river entrances and rocky headlands causes localised interruptions to the overall northward littoral drift. Temporal variations in wave energy are driven by a wide range of swell direction and size while spatial variations occur as a result of the strong refraction during particular swell events. This paper presents a comparison of two near shore wave models of the region using MIKE 21 and SWAN. The transformation of waves arriving from offshore is simulated using the models for selected time series of wave parameters. The parameterized boundary conditions are derived from NOAA Wave Watch III global wave model data. Model output is compared with observed data from existing wave recording buoys at Gold Coast Seaway and Point Lookout. The inclusion of wind in the modelling undertaken did not improve the models' accuracy and winds in excess of 10 ms^{-1} led to an over-estimation of significant wave height while increasing the processing time. Sheltering of the near-shore site during southerly swell conditions was well-represented by the modelling.

ADDITIONAL INDEX WORDS: *Wave models, Wave refraction, Wave measurement, Wind growth*

INTRODUCTION

The Gold Coast is exposed to a highly variable wave climate with a net northward littoral drift of approximately $500,000 \text{ m}^3/\text{yr}$ (DHL 1970). 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 and subsequent refraction often results in an oblique wave approach angle near-shore. It is this dominant condition that results in the net northward littoral drift. From December to May, cyclones may form generating large seas and N to NE swells. Average deep-water significant wave heights generally range from 0.8 – 1.4m with mean periods of 7 – 9 seconds. Extreme events such as cyclones can produce wave heights up to 14m and wave periods up to 18 seconds (ENVIRONMENTAL SERVICES DIVISION 2004).

This study aims to compare the performance of the wave models SWAN and MIKE21 SW in the Gold coast region as shown in Figure 1 using boundary data for the closest NOAA WW3 grid point to the study site, 31.5km East of Surfers Paradise at 28S, 153.75E, and two wave-rider buoys located in the study area. There is a continued interest in coastal process research in this rapidly growing region and accurate wave analysis and forecasting provides the foundation for further hydrodynamic and morphological investigations.

METHODS

DHI Mike21 wave model

MIKE21 Spectral Wave (SW) model is one of the state-of-the-art numerical modelling tools for studying spectral wind-wave modelling. The model is based on flexible mesh and therefore is particularly applicable for simultaneous wave analysis both on regional and local scale. Flexible mesh allows for coarse spatial resolution for offshore area and high-resolution mesh in shallow water and at the coastline. The model simulates wave growth by the action of wind, non-linear wave-wave interaction, dissipation due to white-capping, dissipation due to bottom friction, dissipation due to depth-induced wave breaking, refraction and shoaling due to depth variations, wave-current interaction and effect of time-varying water depth.

The process of white capping in MIKE21 is represented by a dissipation function formulated by KOMEN *et al.* (1994). Mechanisms that are taken into consideration in white-capping formulation are pressure-induced decay (HASSELMANN 1974) and the attenuation of short waves by the passage of large whitecaps and the extent of whitecap coverage. The source term for wave breaking is written by ELDEBERKY and BATTJES (1996) based on wave breaking formulation derived by BATTJES and JANSSEN (1978). The contribution of wave breaking can be tuned using the breaker parameter γ or α (a parameter which controls the rate of dissipation), having a typical value between 0.5 and 1.0. In terms

of bottom friction, MIKE21 provides four possibilities for the determination of dissipation coefficient including: a constant friction coefficient based on tests with regional versions of WAM model (KOMEN *et al.* 1994), a constant friction factor proportional to rms wave orbital velocity at the bottom, a constant geometric roughness size suggested by WEBER (1991) in conjunction with friction factor expression of JOHNSON and CARLSEN (1966) and a constant median sediment size D_{50} . The quadruplet nonlinear wave-wave interaction in the spectral wave module is described by the Discrete Interaction Approximate (DIA) parameterisation, (HASSELMANN *et al.* 1985).

MIKE21 SW model is appropriate for both off shore and near shore wave modelling as it includes two different formulations:

- Directional decoupled parametric formulation,
- Fully spectral formulation.

The first formulation is suitable for near shore and the second one is more suitable for off shore spectral wave modelling. In this study the first formulation has been used, as the study area is mainly located within the coastal waters. This formulation is based on parameterisation of the wave action conservation equation. The parameterisation is achieved by introducing the zeroth and first moment of the wave action spectrum as dependent variables, whereas in the fully spectral formulation the directional-frequency wave action spectrum is the dependent variable. (DHI, 2005)

Model setup (MIKE21 SW)

Several MIKE21 simulations were performed on a PC, covering the period from 23 to 30 January 2005. The model domain, depicted in figure 1 is approximately 1800 kilometres square. To set up the MIKE21 SW model the following three steps are taken

- Grid generation- the grid generation process is undertaken automatically by the MIKE21 model. In this process a two-dimensional (flexi mesh and depth averaged) grid represents the study with 18721 elements and 9643 nodes. The resolution of elements progressively increases shore-wards.
- Boundary conditions - model has three types of boundaries.
 - An open boundary on the east where swells with given significant wave height, direction and period propagate into the model area. Boundary data used in this modelling exercise is extracted from NOAA WW3 and includes 3 hourly significant wave height and direction.
 - North and south boundaries that are defined as lateral boundaries. For lateral boundary a one-dimensional calculation of the basic equations is solved along the boundary line. The information of the incoming waves in the start point and the end point of the line are obtained from the connected boundary lines.
 - Western boundary, which is land. This boundary is regarded as a closed boundary. No wave can enter the model domain through this boundary and the outgoing waves are fully absorbed in this boundary.

Calibration- Several model simulations were undertaken to calibrate the model, with each run varying specific parameters such as wave breaker parameter or friction factor. The calibration was performed for a nine-day period, beginning January 23, 2005 and ending January 31, 2005. This representative time period was selected because it included both high and low energy swells (ranging between approximately 1 and 3 metres) entering the model. Calibration was conducted against measured significant

wave height, peak wave period, and peak wave direction measured at Gold Coast Buoy located at a depth of 20m near the centre of the model domain.

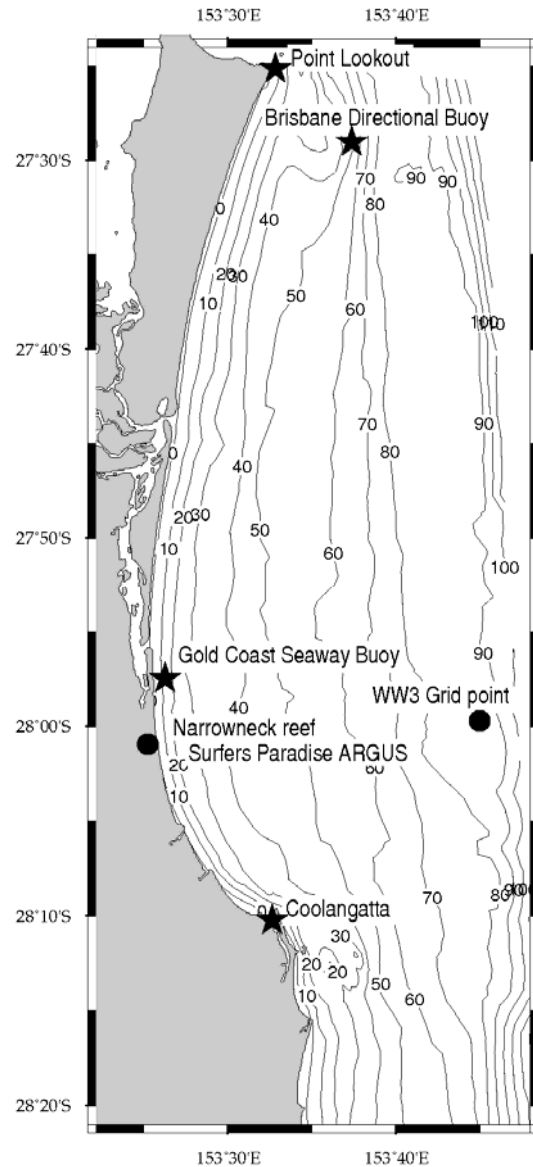


Figure 1: Gold Coast model location map

Swan wave model

The SWAN wave model (HOLTHUIJSEN *et al.* 1993, RIS *et al.* 1998, BOUJ *et al.* 1999) for simulating wave propagation was applied to the Gold coast region. SWAN is based on the discrete spectral action balance equations, is fully spectral and can provide realistic estimates of wave propagation in the coastal zone. The action balance equation is solved with a full discrete 2-dimensional wave spectrum and an iterative technique is applied to allow propagation of waves in all directions over the domain.

The default JONSWAP spectral shape was applied and the wave breaking and bottom friction parameters were adjusted in multiple model runs to obtain the best agreement with buoy data obtained from the Gold coast wave-rider buoy.

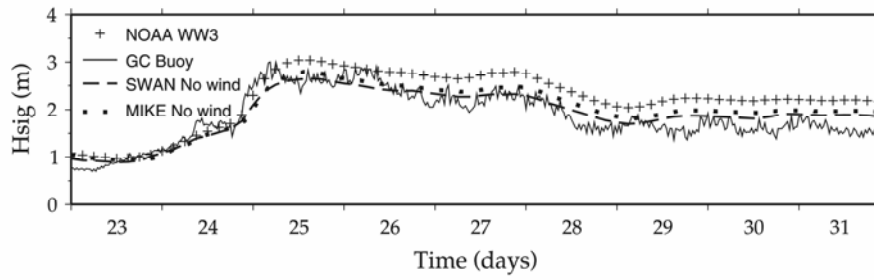


Figure 2: Model Hsig comparison calibration period

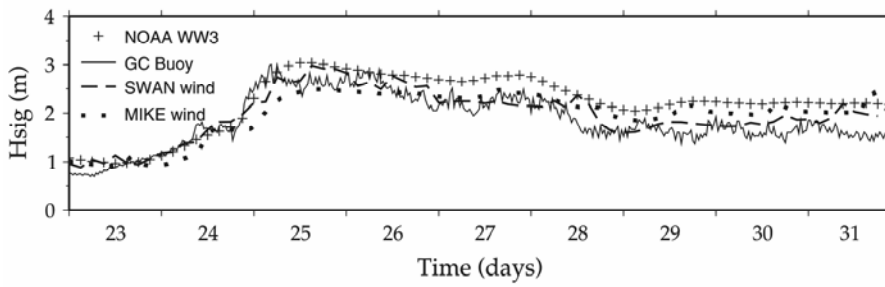


Figure 3: Model Hsig comparison calibration period (spatially uniform wind)

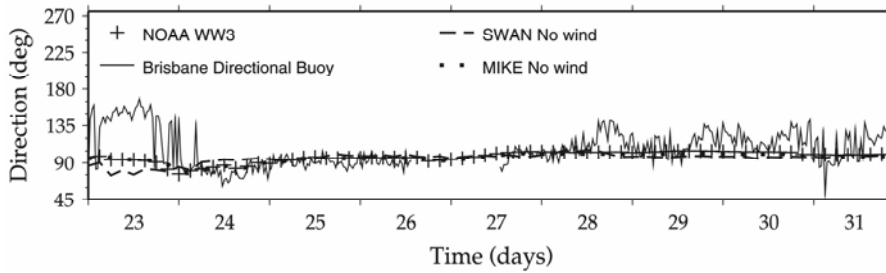


Figure 4: Wave direction

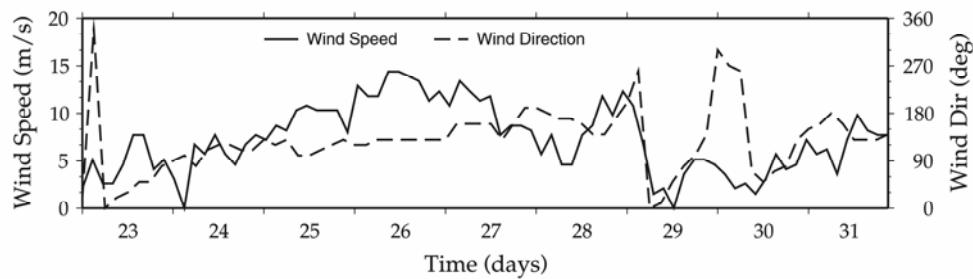


Figure 5: Wind data (Bureau of Meteorology, Australia)

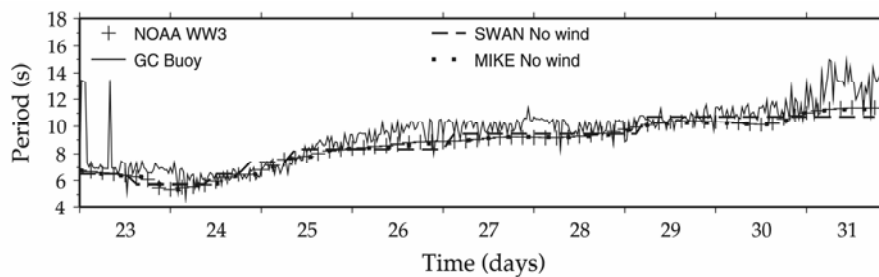


Figure 6: Peak Wave Period

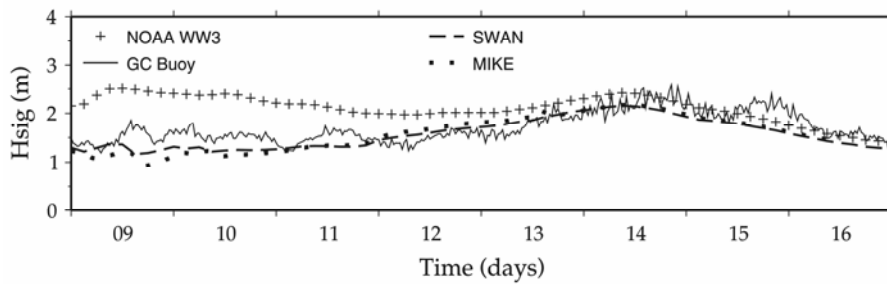


Figure 7: Calculated SWAN, MIKE21 SW and Gold coast waverider significant wave height, January 9-16, 2005

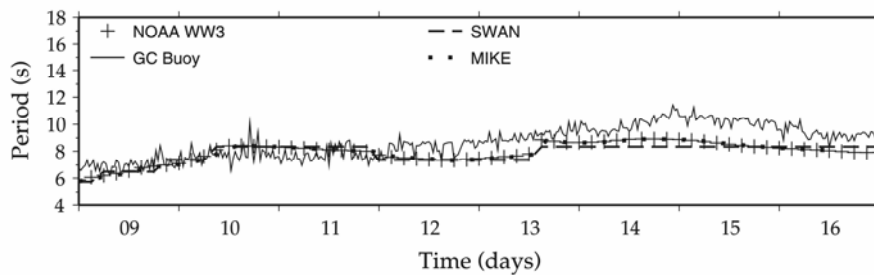


Figure 8: Calculated SWAN, MIKE21 SW and Gold coast waverider peak wave period, January 9-16, 2005

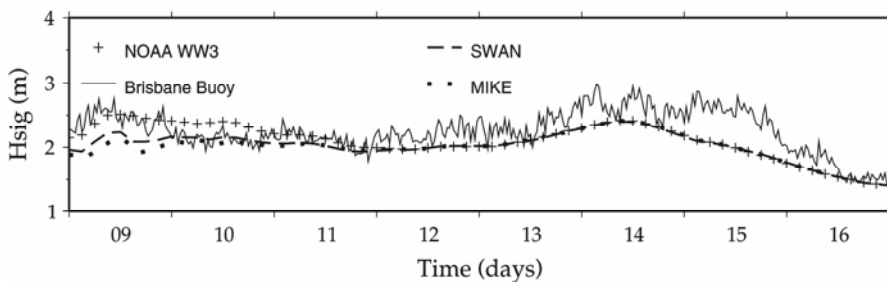


Figure 9: Calculated SWAN, MIKE21 SW and Brisbane waverider significant wave height, January 9-16, 2005

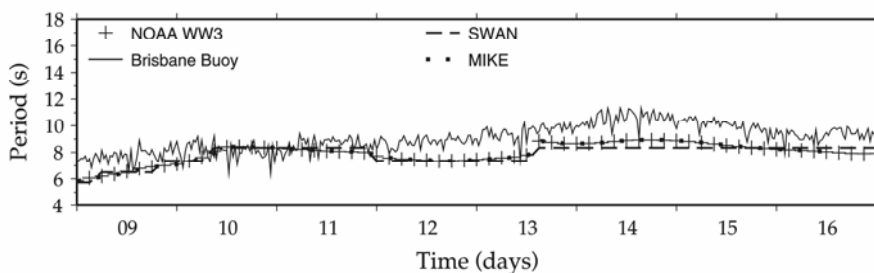


Figure 10: Calculated SWAN, MIKE21 SW and Brisbane waverider peak wave period, January 9-16, 2005

SWAN computes wave generation by wind, bottom friction, white-capping and depth-induced wave breaking dissipation and non-linear wave-wave interactions. Nested grids consisted of coarse deep water bathymetry for the region and detailed near-shore longshore uniform outer and inner bar and trough morphology derived from recent survey profiles supplied by Gold Coast City Council.

Model Setup (SWAN)

The SWAN model domain consisted of two nested grids, with boundary forcing applied at the eastern boundary of the larger grid. Parameterised wave data obtained from NOAA Wavewatch III global wave model at 28S, 153.75E is applied at the Eastern

boundary at 3hr intervals. As with the MIKE 21 SW model the calibration was performed using data obtained from the Gold coast Seaway waverider buoy.

RESULTS

Both models were calibrated using wave data from 23rd January to 31st January. The models were run both with and without wind data obtained from the Gold coast Seaway Automatic Weather Station (AWS) operated by the Bureau of Meteorology Australia (Figure 5). In all cases the temporal variation in wind forcing was applied spatially uniformly over the model domain.

Analysis of MIKE21 SW results

The results of model simulations for significant wave height H_s , peak wave period T_p and direction D_p with corresponding wind and wave parameter input are presented in the figures 2 to 6. The model was compared with the corresponding data registered at the 20-metre deep Gold Coast buoy. The comparison has been made for two different cases, with wind and without wind. Figure 2 and 3 shows up to 0.5 metre wave height attenuation over the distance between boundary at 90 metre deep water and the Gold Coast Buoy. It can be seen that the models provide a better prediction of wave climate during the period between 25th and 28th January (high energy swell) than the period between 28th and 31st January (low energy swell). In general the no wind model provides better results than model runs including wind for this time period.

Analysis of SWAN model results

Model results for significant wave height taken at the location of the Gold Coast Seaway waverider buoy are shown in figures 2 for the case with no wind and Figure 3 with wind. SWAN without wind initially overestimates the observed data by approximately 0.25m. During this period north to northeast winds of 3-7 ms^{-1} and a predominantly south swell were recorded by the Brisbane directional wave-rider buoy which is not present in the NOAA WW3 boundary data. The inclusion of wind in the model displays a small fluctuation in H_s which is not reflected in the buoy data. From midday on the 23rd to 24th of January, 2005 there is evidence of a 12-14 second period south-east swell component in addition to the short period 1m easterly wind waves detected by the Brisbane directional waverider buoy. This short-lived event is not present in the parameterised boundary forcing data and does not appear to have any significant effect on the near-shore Gold coast buoy observations. The period from the 24th to the 27th is characterised by a rise in easterly swell to 3m accompanied by southeast winds of 10-15 ms^{-1} . Both wind and no-wind SWAN simulations fit the observed data well throughout this period. For wind speeds over 10 ms^{-1} the inclusion of wind in the model overestimates the observed buoy data. Overall the model results are within 0.25m of the observations for the 9-day period.

Comparison of MIKE21 SW and SWAN results

SWAN appears to exhibit greater sensitivity to wind fluctuations than MIKE21 SW however the inclusion of wind did not improve the overall accuracy of either model. The processing time increased substantially, particularly for MIKE21SW; therefore wind was not included for the validation data. Validation simulations (Figures 7 to 10) were performed with data from 9th to 16th January, 2005. Both models overestimated the attenuation of the 2.5m H_s at the boundary to 1-1.5m at the Gold coast buoy location during a south swell event which lasted until 11th January. As the swell direction gradually turned easterly the model accuracy improved. Wave period in all cases showed little change from the boundary data. Comparison of model output at the location of the Brisbane wave-rider buoy at a depth of 73m underestimated H_s by approximately 0.5m for the 9th January, improved from 10th January to 13th January and decreased again during the easterly swell conditions toward the end of the validation data-set. It should be noted that the boundary input data was also substantially less than the observations for this period.

CONCLUSIONS

The over-estimation by the model with wind generally occurs during wind speeds in excess of 10 ms^{-1} and may indicate that the wind data recorded onshore at the Gold coast Seaway entrance may not be representative of the wind between the model

boundary and the buoy. Wave-current interaction was not considered in this study and may have contributed to the underestimation of H_s particularly for the deep water site. The parameterised wave input data did not account for the possibility of multiple swell sources and improved monitoring of deep water wave and wind conditions may also improve model results. Sheltering of the Gold Coast buoy site during southerly swell conditions was adequately represented by the modelling.

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