Modeling of May 1996 East Coast Low Event

in South-East Queensland

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Introduction

East Coast Lows (ECL) are intense low pressure systems that form dangerously close to Australia's eastern seaboard. They occur on average several times each year in this area and are notorious for producing severe weather such as flooding rain, dangerous seas and damaging wind gusts. They may form in a variety of weather situations. In summer they can be ex-tropical cyclones. At other times of the year, they will most often develop rapidly just offshore within a pre-existing trough of low pressure due to favourable conditions in the upper atmosphere. ECLs may also develop in the wake of a cold front moving across from Victoria into the Tasman Sea. The sea surface temperature gradients associated with the warm eddies of the East Australian Current also contribute to the development of the low pressure systems. (Callaghan, 2009).

Background and Study Location

Commencing on 30 April 1996 and continuing into early May, the southeast corner of Queensland experienced extreme weather conditions that lead to severe major flooding that was tragically responsible for the loss of five lives. The heavy seas, strong winds, heavy rainfalls and flooding during this period were associated with an ECL that persisted in the region for several days.

Storm force winds, gusting up to 65 knots at Moreton Island, directed east to east-northeasterly gales onto the southern Queensland coast causing wild seas and severe beach erosion. Higher than normal tides inundated low lying coastal areas.

The development of the May 1996 ECL was very much in the definitive fashion in which these systems evolve. At 9pm 30 April 1996 a small low was located east of Townsville and by 9am 1 May 1996 it had moved down the coast to be east of MacKay. It reached peak intensity near Brisbane between 9am and 3pm 2 May 1996 with a central pressure of 997 hPa. (Bureau of Meteorology, July 1996).

The historical frequency of ECL events similar to May 1996 ECL prompted this study, and in particular the numerical simulation of this event to estimate the inundation levels in Gold Coast waterways. Figure 1 shows the study area and available buoy and tide gauge measurements in this area. The following sections examine the development of models for the meteorological forcing and hydrodynamic response to this event.

Meteorological Modelling

High-resolution meteorological modelling enables small-scale wind and pressure features to be reproduced that are too small to be resolved by global atmospheric models but are apparent in satellite images. The use of these local atmospheric models provides more detail of the wind/pressure fields thereby enhancing surge/wave modelling.

A local WRF (Weather and Research Forecasting) meteorological model was configured within a domain over the coast of Australia. It covers an area of 1900 x 1700 km with a grid spacing of 4.5 km. The model was initialized throughout the domain using meteorological analysis fields including wind, temperature, relative humidity, and geo-potential height, and then forced only at the boundaries of the outer domain for the duration of the model run. The model outputs include wind components at 10 m above sea level and mean sea level pressure fields. These fields are used to force the storm surge model.

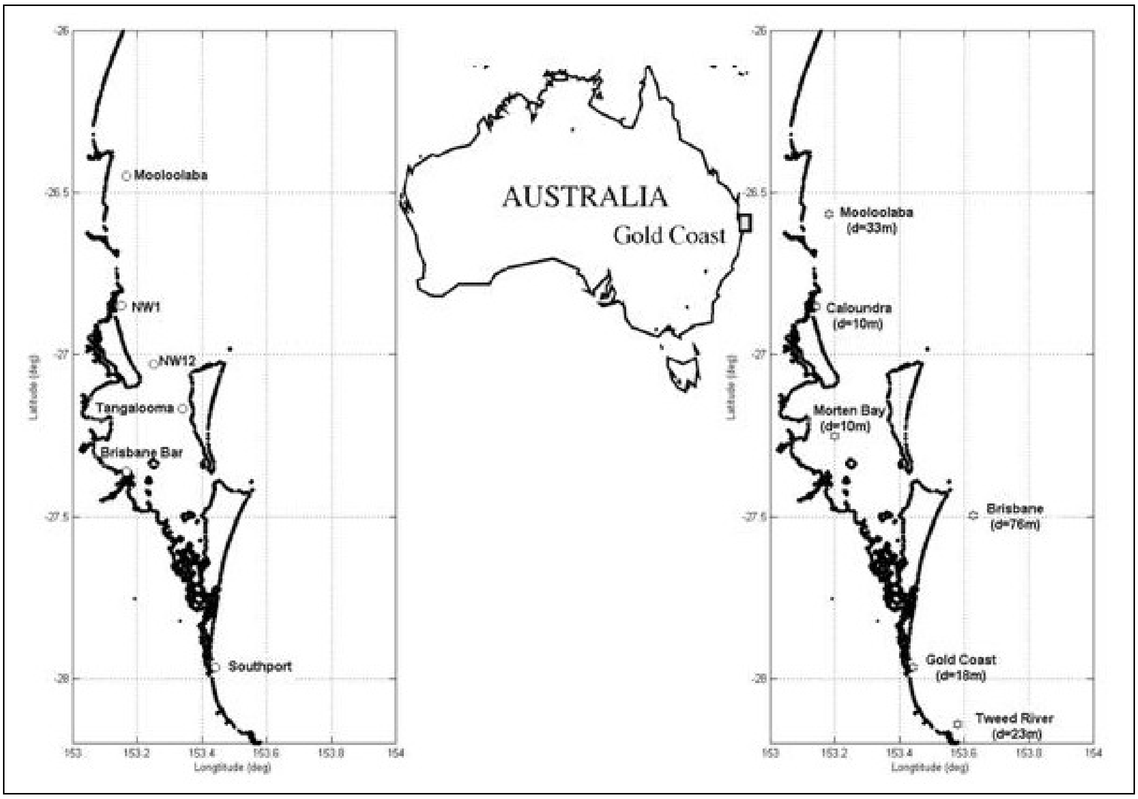

Figure 1. Study area and available tide gauge (left) and buoys (right) in the area

Storm Surge Modelling

The storm surge model includes a set of regional and local hydrodynamic and spectral wave models (MIKE21 HD and MIKE 21 SW, Davies (2008, 2009)). These models have unstructured meshes. Regional models cover an area of approximately 1750 x 1850 km with mesh size of 20 to 0.1km, while the local models cover an area of approximately 80 x 25 km with mesh size of 2 m to 20 m. Figure 2 shows the regional and the local mesh files. These sets of models were forced by WRF wind and pressure fields. Time step was considered as 300s and model was run for seven days. The flow chart in Figure 3 shows the following sequence of model runs and their linkages:

1) Regional HD model using the simulated wind and pressure fields.
2) Regional SW model using the simulated wind field and surface elevation map from the regional HD model.
3) First local HD model: Water level boundaries (wind induced surge boundaries) extracted from the regional HD model results combined with pure tidal signal to generate storm tidal boundaries are forced on the local HD model and run. The result of this model will be storm tide (storm surge + pure tide).
4) Local SW model: Surface elevation map from the local HD model results, as well as wave energy spectrum boundaries extracted from regional SW results, are forced to the local SW model.
5) Second local HD model: Wave radiation stress map from the local SW model as well as storm tidal boundaries (same as step 3) are forced on the local HD model.

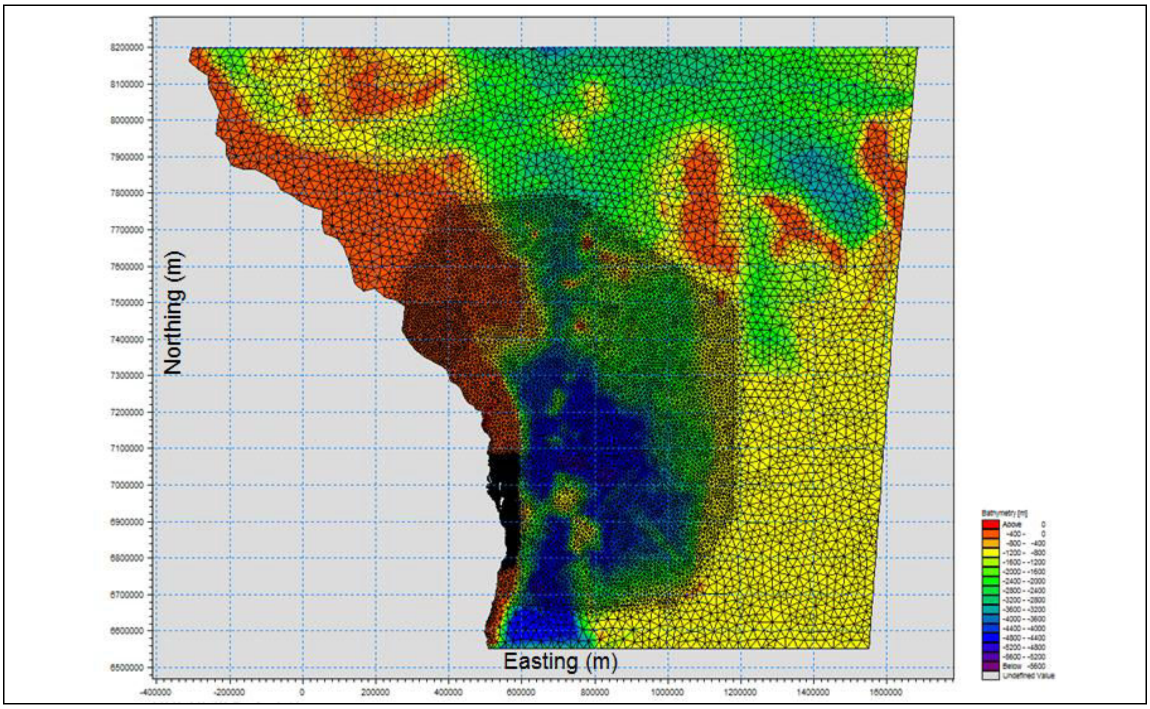

Figure 2. Model Domain. Large area represents the regional grid size while the smaller dark mesh represents the local gird.

Model Verification

Some of the results of model verification at the Gold Coast buoy are shown in Figure 4 as an example. Model–data comparison using three statistical parameters: root mean square error (rmse); bias; and correlation coefficient (cc) are summarized in Table 1 for all the buoys operating at that time. According to this table, generally the result of the model (including significant wave height, maximum wave height, wave period, peak wave period and peak wave direction) in offshore areas has better agreement with measurements comparing to the buoys located in shallow waters. Wave direction has the least accuracy among the wave parameters. Figure 5 shows the comparison between the model results and tide gauge measurement at Mooloolaba. Table 2 shows the related statistical parameters of comparison for all the tide gauges. The results of this comparison are also satisfactory. Figure 6 shows the map of maximum significant wave height and maximum storm tide generated during May 1996 ECL. From these results, a maximum significant wave height of 6 m and maximum storm tide level of 1.2 m was generated near to Gold Coast.

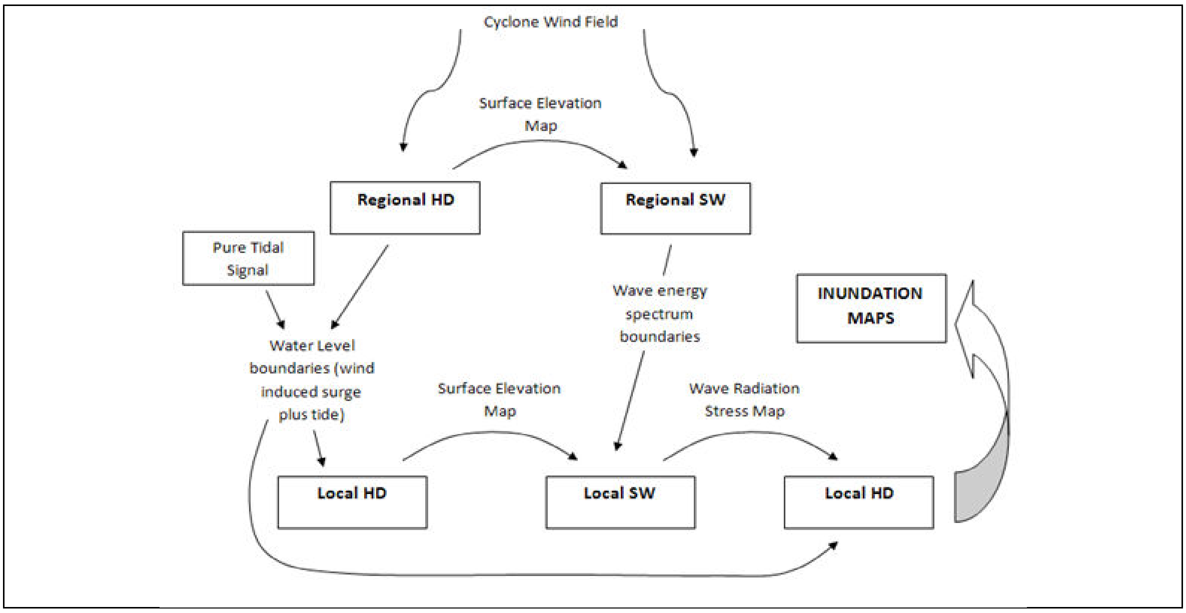

Figure 3. Storm surge modelling approach

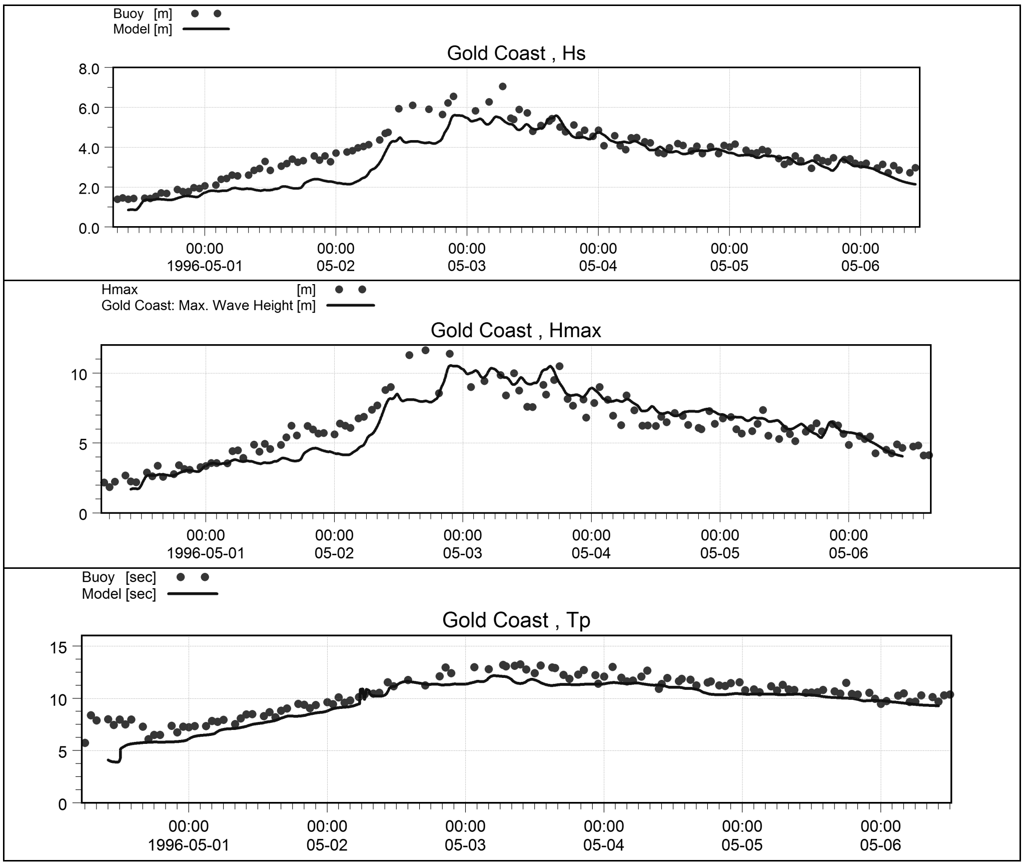

Figure 4. Comparison of model results with Gold Coast buoy records

Table 1. Statistical parameters related to wave comparison for May 1996 ECL event

Buoy Name	**Statistical Parameter**	**Maximum wave height (Hmax)**	**Significant wave Height (Hsig)**	**Peak Wave Period (Tp)**	**Wave Period (Tz)**	**Peak Wave Direction (degree, Nautical convention)**
Brisbane (d=76m)	bias	-0.62	0.23	0.53	0.92	-
	cc	0.90	0.94	0.96	0.93	
	rmse	1.73	0.77	0.75	1.21	
Gold Coast (d=18m)	bias	0.09	0.46	0.86	-	-
	cc	0.87	0.90	0.94		
	rmse	1.12	0.71	1.08		
Tweed River (d=23m)	bias	0.43	0.76	0.97	0.7	-2
	cc	0.88	0.91	0.93	0.93	-0.20
	rmse	1.26	0.98	1.25	0.86	2

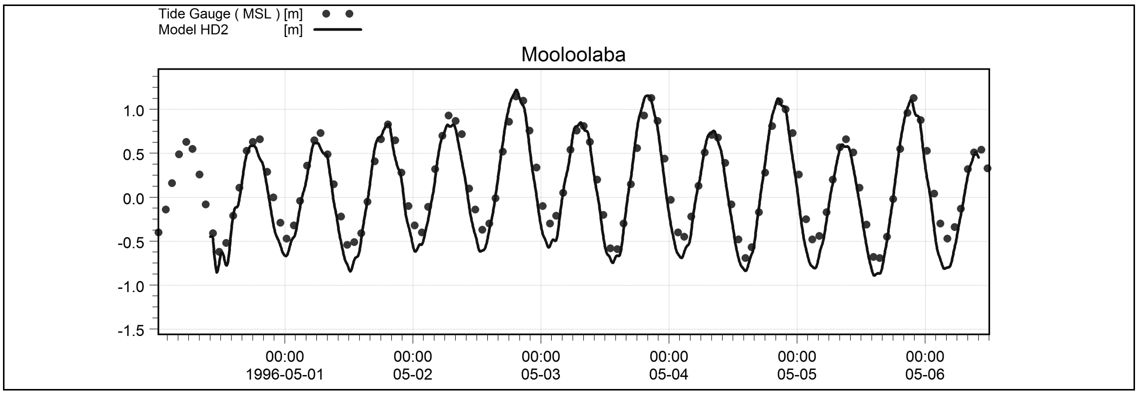

Figure 5. Comparison of model result with Mooloolaba tide gauge

Table 2. Statistical parameters related to water level comparison for May 1996 ECL event

Tide Gauge Name	bias(m)	cc	Rmse (m)
Brisbane Bar	0.16	0.97	0.23
Mooloolaba	0.12	0.98	0.18
Southport	0.13	0.97	0.18

Beach Erosion

XBeach (Roelvink, 2009) was used to model the erosion impact of the May 1996 ECL. The model was previously calibrated using measured wave and water level data from the Gold Coast buoy and closely (temporally) spaced surveys at ETA 67 for the May 2009 ECL. Due to the lack of 2D bathymetry for the entire Gold Coast region, the model was run in profile mode along 4 transects spanning the Gold Coast where recent survey data was available. Figure 7 (left) shows the location of these transects. Running the model in profile mode assumes longshore gradients in momentum flux (and therefore gradients in longshore processes) are negligible.

Pre-storm surveys were between Feb. and Oct. 1995 and post-storm surveys were done within 1 month of the storm (May/June 1996). The significant gaps between the surveys will degrade model-data comparison. However, temporal gaps such as these are quite common and it is still worth assessing total predicted erosion volumes. Results were compared against pre and post-storm upper beach volumes (V) and shoreline (s) position (as measured by 0 m AHD). Results for Narrowneck (ETA 67) are shown in Figure 7 (right) and summarized in Table 3. On average, the model predicted upper beach erosion between $-40 < \Delta V < -25$ m3/m and shoreline retreat between $-15 < \Delta s < -5$ m.

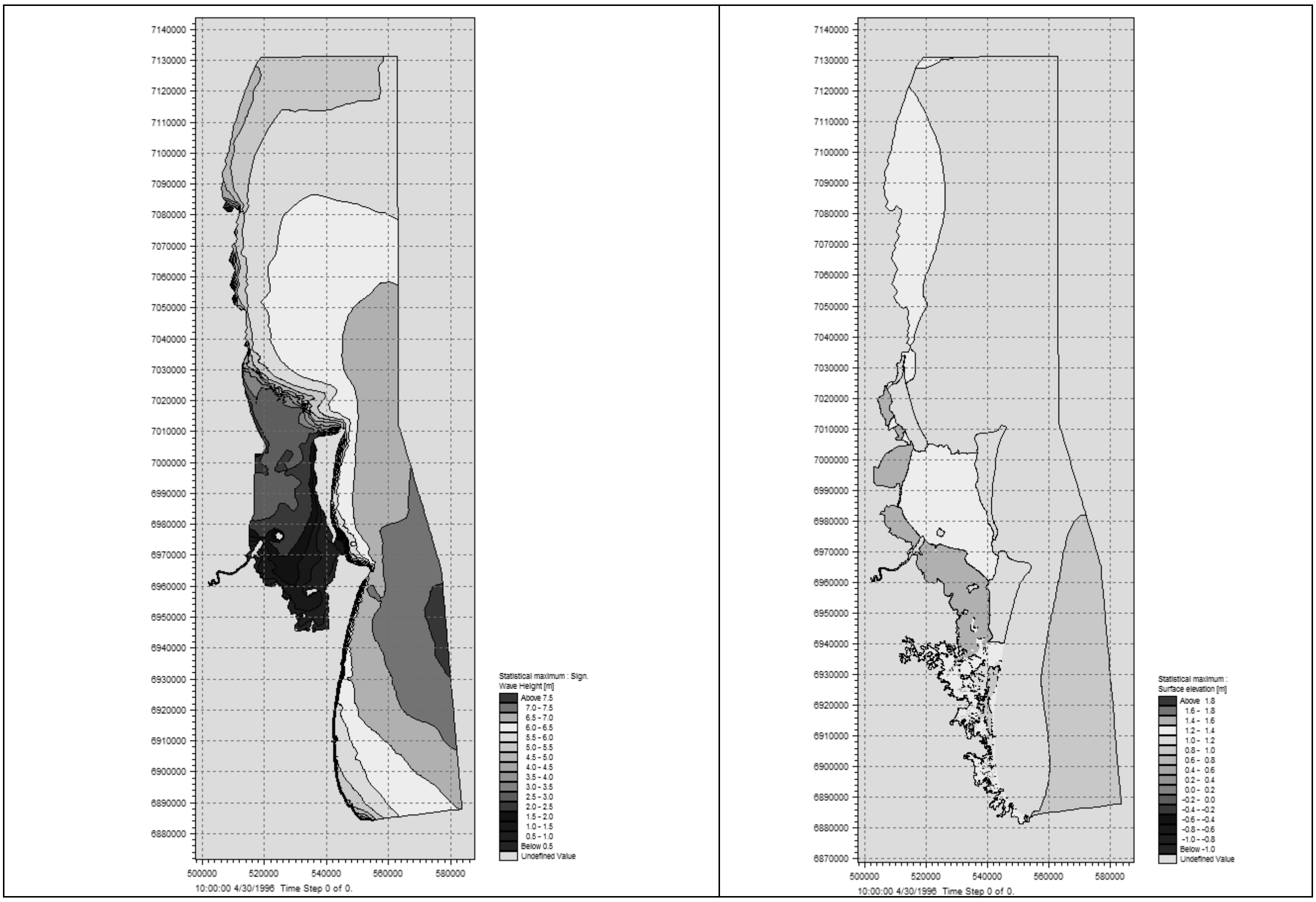

Figure 6. Maximum of significant wave height (Left) and storm tide level (Right)

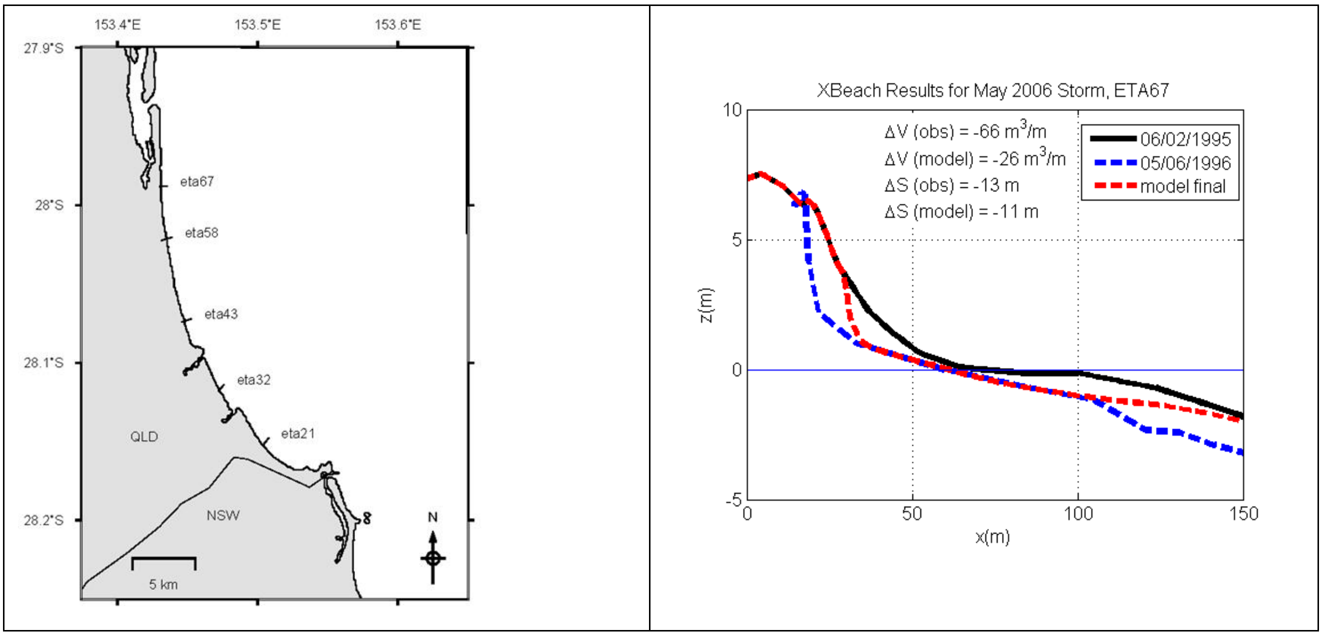

Figure 7. Transacts spanning the Gold Coast (Left).
Results from XBeach for ETA 67 (Narrowneck) using Mike 21 inputs for May 1996 ECL(Right)

Table 3. Comparison of modeled and observed erosion.

Profile	ΔV (Z > 0 m AHD) (m3/m)		Δ s (m)	
	Observed	**Model**	**Observed**	**Model**
ETA 21	-120	-39	-46	-11
ETA 43	-47	-31	-20	-15
ETA 58	-55	-30	-20	-5
ETA 67	-66	-26	-13	-11

Conclusion and Future Work

A storm surge model that explicitly considers tides and wave radiation stress gradients was setup and calibrated against the May 1996 ECL. The results of the model for both wave parameters and storm tide levels are satisfactory. Inundation maps can be prepared based on the results of storm surge model for coastal zone management purposes. A Beach erosion model was run for this event and predicted upper beach erosion between -40 < ΔV < -25 m3/m and shoreline retreat between -15 < Δs < -5 m.

Take Home Message

Establishment of a comprehensive monitoring system will improve the calibration of storm surge and beach erosion models resulting in more accurate model results for coastal waring system.

Acknowledgements

The authors would like to thank D. Metters from Maritime Safety Queensland for providing water level data and C. Acworth from DERM for providing buoy data. Funding for this research was provided by the Queensland Smart State Innovation Fund and Griffith University.

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