Cyclone *Althea* Revisited

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Abstract

Severe tropical cyclone Althea *in December 1971 remains as one of the most significant modern examples of cyclone impacts on the Queensland coast.* Althea *was chosen as a demonstration storm tide hindcast event as part of the recent inter-governmental study, "Queensland Climate Change and Community Vulnerability to Tropical Cyclones, Ocean Hazards Assessment Stage 1". The study assesses the current state-of-the-art of numerical modelling of tropical cyclone surface forcing and the underlying ocean response (storm surge, currents, waves and wave setup) within the context of potential climate change. This paper re-examines various aspects of* Althea *and its resulting coastal impacts, focussing on the importance of accurate representation of the meteorological forcing and reliable field data. Some preliminary wave hindcasting is used here to complement the storm tide study and to consider the added contribution of wave setup to total water levels along the Townsville foreshore.*

1. Introduction

Severe tropical Cyclone *Althea* crossed the coast of Halifax Bay on Christmas Eve 1971, the centre passing within 33 km north of the City of Townsville (Figure 1). The peak wind gust measured at the airport was 55 m s^{-1} (106 kn) and 15% of all houses in Townsville suffered at least a significant level of damage and 2.5% of these were uninhabitable (Trollope and Stark 1972). The cyclone caused a very significant storm surge of 2.9 m at Townsville, which fortunately occurred shortly after a low tide, and total water levels were only slightly above HAT. However, saltwater entered properties at Rowes Bay and Pallarenda and the Strand seawall was extensively damaged. Many vessels sheltering in Ross Creek were also damaged and left stranded above tide levels. Initial open coast debris levels suggested the peak surge occurred in the vicinity of Toolakea, 19 km north of Townsville.

Althea was especially significant in its raising the collective consciousness of the potential threat of tropical cyclones to a modern tropical city. It spawned a considerable range of research initiatives into both building standards and ocean response that has led to better planning decisions across the State and a more disaster-resilient community.

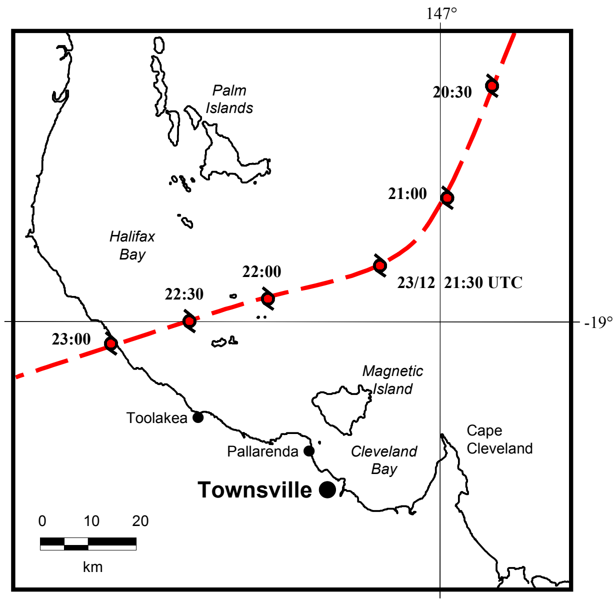

Figure 1 The track of *Althea*.

2. Meteorology

The tropical cyclone was tracked by satellite during its early stages, revealing an eye of varying quality for 3 days prior to landfall, and radar images were available from Mt Stuart at Townsville on the final day (BoM 1975). The storm centre passed near automatic weather stations at Lihou Reef, Willis Island and Flinders Reef, which provided wind and pressure values. The storm followed a generally steady path towards the coast but with some short-term digressions, which became more variable near the coast and at landfall, where the speed of translation seemed to increase. Satellite analysis, combined with AWS data from Lihou Reef, indicated that the storm probably reached maturity on the day before landfall with a central pressure of about 950 hPa. The conclusion at the time was that *Althea* might have subsequently fallen short of its full potential. Reports of calm periods lasting 20 to 30 min from a number of small coastal communities near landfall suggested an inner eye diameter at that time between 8 to 12 km. Callaghan (1996) revisited the radar data and assessed the variation in eye diameter as between 5 km and 16 km, attributed to the presence of a double-eyewall feature (Figure 2). This shows that both the inner and outer storm eyes were shrinking as the storm neared the coast. There were no wind or pressure measurements between Townsville and the point of landfall and the intensity assessment at that time was 952 hPa, extrapolated from the airport record (BoM 1975). Because of the shrinking eye, Callaghan questions whether higher winds may indeed have been experienced closer to the position of the estimated peak surge.

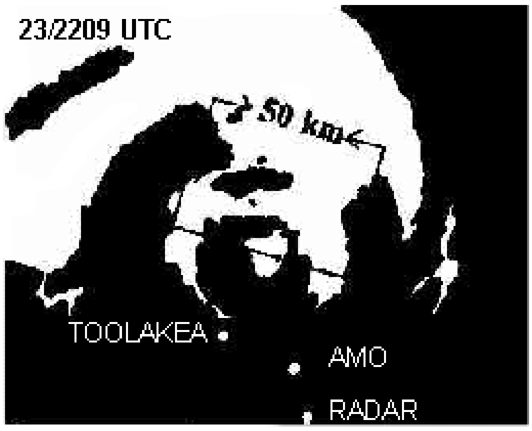

Figure 2 Radar analysis (Callaghan 1996).

3. Coastal impacts

Althea caused widespread and significant coastal changes within Halifax and Cleveland Bays. The impact of the storm surge was extensive, being at least 0.5 m above predicted tide between Cairns, 290 km to the north and Mackay, 320 km to the south. Chart-recording tide gauges at a number of sites provided accurate water level values and these can be augmented with estimates from a beach debris survey undertaken between Ingham and Ayr by Hopley (Trollope and Stark 1972).

The Townsville harbour tide gauge recording is shown in Figure 3, also showing the predicted tide for the period and the residual (surge) component. The total storm tide at the Townsville gauge peaked at 2.53 m AHD, occurring on a predicted tide level of -0.35 m AHD, giving a resultant surge magnitude of 2.9 m.

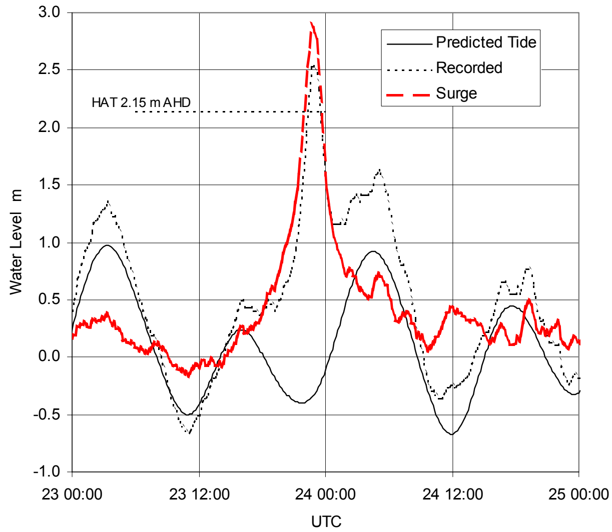

Figure 3 Tide gauge record at Townsville.

BoM (1975) also reports debris estimates (which include wave setup and runup influences) from a Townsville Harbour Board report by Shepherd. Table 1 summarises all these values relative to the storm track, where positive landfall distances indicate locations southwards of the track. The Tobruk Pool reading is reputedly "stillwater" inside the kiosk, presumably represented by a watermark. If accurate, this represents a possible 2 m wave setup and/or runup component at this point, which is almost adjacent to the harbour tide gauge in Ross Creek.

At North Ward, another debris level estimate yielded a peak water level magnitude of 6.2 m. However, only the Townsville Harbour gauge can be considered a reliable "stillwater" surge amplitude because of its location within the harbour at the entrance to Ross Creek. The tide stilling basin filters the effect of waves and wave setup is not expected to occur inside the harbour due to its likely diffractive qualities, e.g. Dunn *et al.* (2000). The remaining values derived from debris heights remain only indicative because of the difficulty in not only estimating local RLs but also the influence of wave setup and runup on debris lines.

No measurements of wave heights or currents are available for this event, although the recession of the sandy coasts reported by Hopley ranged from typically 10 m up to 15 m.

Table 1 Summary of estimated peak waterlevel heights above predicted tide for *Althea*.

Location	Distance from Landfall	Level Reference	Waterlevel Height above Tide
	km		m
Cairns	-240	gauge	0.5
Mourilyan	-155	gauge	0.8
Lucinda	-50	gauge	0.9
Balgal	-18	debris	1.8 ?
Toolakea	19	debris	> 3.6 ?
Saunders Beach	26	debris	> 3.1 ?
Black River	30	debris	2.7 - 3.1 ?
North Ward	45.3	debris	6.2 ?
Tobruk Pool	46.5	mark	4.9
Townsville	47	gauge	2.9
Cungulla	88	debris	2.1 ?
Alva Beach	132	debris	1.8 ?
Beach Mount Beach	147	debris	< 1.8
Bowen	227	gauge	1.0
Mackay	385	gauge	0.9

4. Reconstruction of the event

Notwithstanding that *Althea* occurred close to a major population centre, there remained uncertainty over a number of important aspects of the event. Principal amongst these is the actual intensity of the storm, which was nominally based on extrapolating the 971.5 hPa reading at Townsville, assuming that the maximum winds occurred over the city. This yielded a radius to maximum winds of 38 km, which is potentially at odds with the later assessment by Callaghan (1996). In addition, given that the ocean response would be sensitive to the outer wind fields, recorded data from the offshore AWS were also examined in detail.

All official datasets were re-examined and discussed with Bureau of Meteorology personnel at the Queensland Regional Office in Brisbane. The original Dines anemograph and barograph records for Townsville were manually digitised in preference to using rather sparser National Climate Centre datasets and several other aspects such as timing and instrument adjustment were assessed. The radar positions in BoM (1975) were also reanalysed and a smooth track determined.

A trial and error comparison was then made between the available wind and pressure data and the predicted spatial and temporal variations within a tropical cyclone as predicted by the Harper and Holland (1999) analytical model. The model was systematically adjusted for reasonable values of the key parameters such as track, central pressure, windfield peakedness and radius to maximum winds. Error statistics were then collated from each of the major sites (Townsville, Flinders Reef and Lihou Reef) as well as other more distant locations. The Townsville airport record was adjusted slightly upwards to better represent overwater wind speeds, based on AS1170.2 methods, and the possible influence of nearby Castle Hill was also considered.

The wind and pressure modelling also included consideration of the surface windfield asymmetry, which is predominantly induced by the storm forward motion. Somewhat contrary to currently accepted theory, the best windfield calibration was obtained using a "left rear" wind maximum rather than a "left front". The "left rear" assumption not only significantly improved the wind speed calibration at the majority of sites, both near and far, but also affected the modelled storm surge result.

Re-analysis of radar images by Callaghan (1996) suggests that the radius of maximum winds of the outer eye decreased from 35 km to 25 km during the final 8 h approach to landfall. Applying this variation to the wind model showed essentially no difference in the predicted winds at Townsville and a nominal 30 km radius was adopted for the final track. Because of the relatively flat windfield peakedness indicated by the model fitting procedure, it then proved difficult to conclude that winds may have been higher between the city and the landfall point. Notwithstanding this outcome, the double-eyewall feature is not represented by the simplified parametric model and a narrow region of higher winds may still have existed as suggested by Callaghan. Such a feature's impact on storm surge levels over the whole region would likely be small but it may have been capable of inducing some localised effects.

Figure 4 shows the comparison between measured and modelled pressures and 10 minute mean wind speeds at Townsville Airport. The modelled minimum pressure was within 2 hPa of the barograph. Wind speeds were matched with a peak error of -1.1% and a bias (across the half-magnitude width) of only 4.4%. Peak mean wind speed errors at the other sites were generally less than 3.5%. Estimated wind gusts from the model were within 5% of the Dines peak of 55 ms^{-1} at

Townsville and on Magnetic Island were essentially identical to the 59 ms^{-1} value estimated from a plastic hinge failure analysis of street signs (Trollope and Stark 1972). Wind directions were also generally well reproduced by the model.

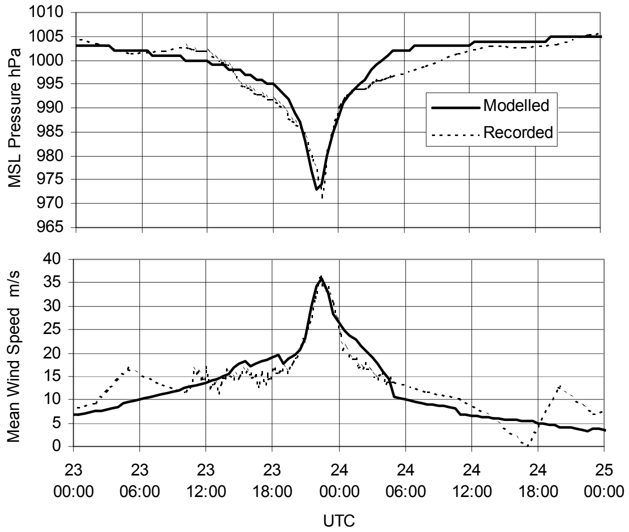

Figure 4 Comparison of modelled and recorded wind speed and MSL pressure at Townsville Airport.

5. Storm surge modelling

Storm surge modelling was carried out using the Marine Modelling Unit implicit 2D/3D numerical hydrodynamic model MMUSURGE (Bode and Mason, 1994). A 3-stage nested numerical model domain was established, consisting of an outer Coral Sea grid of 5 nmile resolution, a near-Townsville grid of 1 nmile and finally a Cleveland Bay grid of 0.2 nmile.

The standard model case was run in 2D (depth integrated) mode without wetting/drying activated but with non-linear advection. Bed friction was set at standard levels and no eddy diffusivity was invoked. Bathymetry and location of reefs were obtained from a number of sources and the cyclone was modelled with and without tidal influences.

Only five tidal constituents were available for the open sea boundaries, but the modelled tide response was only 0.05 m lower than the predicted low tide near time of landfall, which is close to the time of the peak surge. The following high tide however was underpredicted by about 0.15 m. Figure 5 compares the fine scale domain storm surge prediction with the measured tide gauge data at the modelled tide gauge site (circa 1971). The peak level is reproduced within 0.1 m. The comparison over the following 6 h is affected by the underprediction of the next high tide.

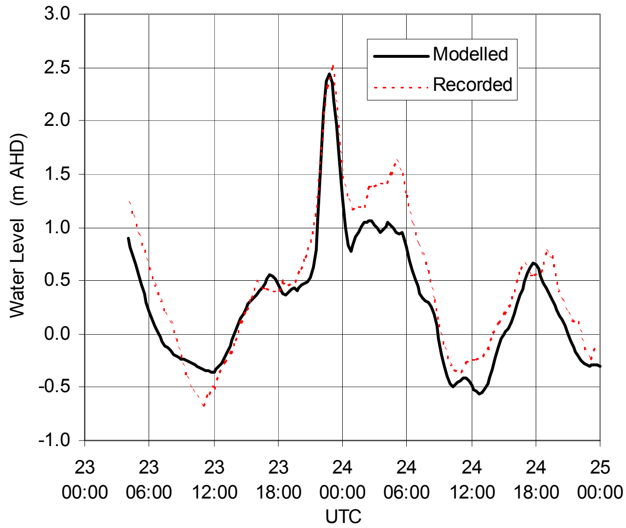

Figure 5 Comparison of modelled and recorded surge plus tide.

Next, the event was modelled at mean sea level and the results are given in Figure 6. The agreement between measured and modelled is almost exact, the peak error again being only 0.1m. Accordingly, non-linear tide and surge interaction appears quite weak in the Townsville context. The model was also run in full 3D mode, producing a small increase at the peak of 0.1 m.

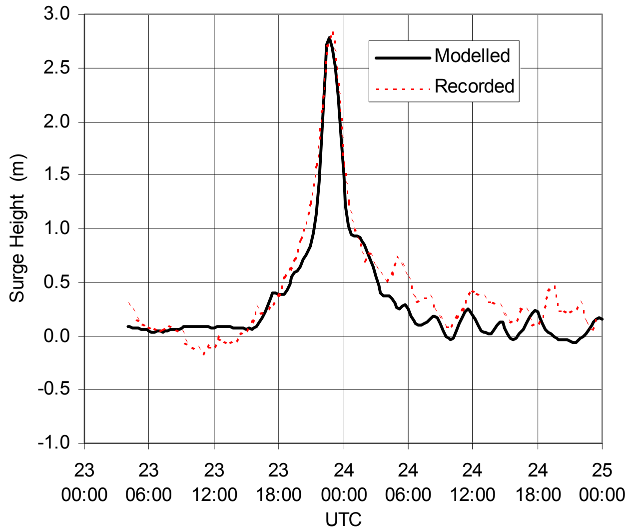

Figure 6 Comparison of modelled and recorded surge component.

A sensitivity test was also carried out to determine the influence of the Great Barrier Reef on the predicted storm tide at Townsville. The model reef boundaries were removed and *Althea* re-modelled, yielding almost no difference in the predicted peak storm surge at the harbour gauge.

As mentioned previously, the assumed wind field asymmetry was found to affect the surge dramatically, resulting in a 15% reduction if "left front" asymmetry was assumed. Figure 7 shows the modelled pattern of surge elevation and current near Townsville at the time of landfall. Peak modelled currents near Pallarenda are of the order of 2 m s^{-1}.

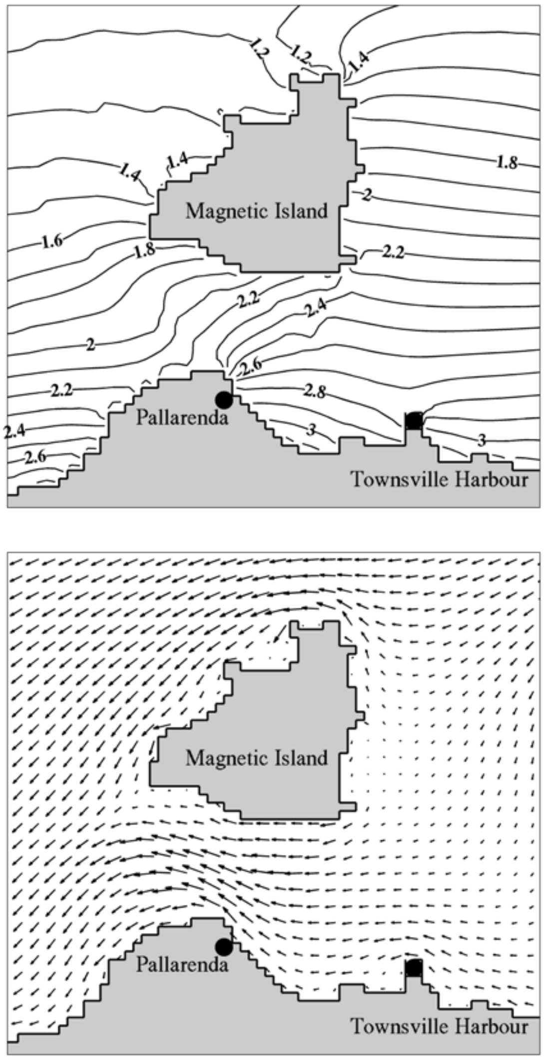

Figure 7 Modelled storm surge magnitude and currents at Townsville near the time of cyclone landfall.

6. Spectral wave modelling

Spectral wave modelling was undertaken using the Marine Modelling Unit 3rd generation spectral wave model WAMGBR (Hardy *et al.*, 2000) at a 500 m resolution. The model results are shown in Figures 8 and 9, predicting peak offshore significant wave heights of over 8 m reducing to approximately 2 m just offshore from Tobruk Pool. Magnetic Island can be seen to provide a considerable wave shadow from Kissing Point to north of Pallarenda. Figure 9 shows the modelled time history of wave conditions at sites ***A***, ***B*** and ***C*** as located on Figure 8. The model shows depth-limited wave-breaking commencing at the entrance of Cleveland Bay more than 10 km from the shore and extending throughout the bay. In this region, much of the incident wave momentum would be transferred into water currents rather than water setup.

At Tobruk Pool, wave setup was estimated from the modelled nearshore Hs and Tp as recommended by Nielsen in Harper (2001). A wave setup of 0.5 m is obtained using the model grid point nearest Tobruk Pool (***A*** in Figure 8), nominally 250 m offshore. By comparison, 0.75 m setup is obtained using results from grid point ***B*** approximately 2 km offshore, representing the incident wave near the harbour entrance. The adopted wave setup formula is supported by measurements derived from open coast beaches where deep water can be less than 1 km offshore and the surf zone is finite and well defined. In this extreme and complex wave condition, the calculated wave setup for Tobruk Pool should perhaps be considered as only approximate. Low frequency surf beat also may have played a role.

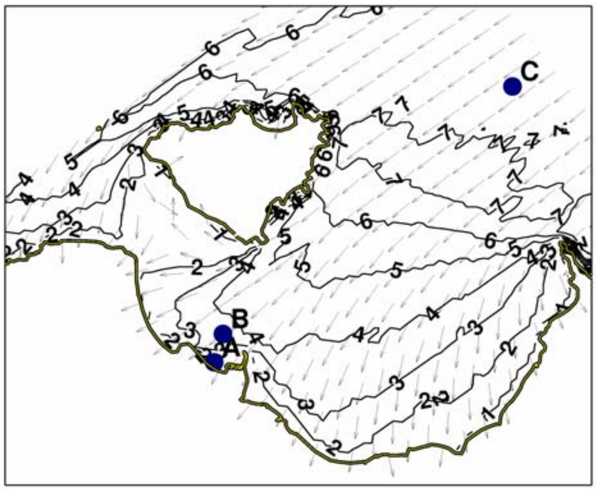

Figure 8 Modelled significant wave height contours and vectors of peak period. Point *A* indicates the nearest grid point to Tobruk Pool.

Nominal wave vertical runup values were also calculated, based on the irregular wave theory after Nielsen and Hanslow (1991). Assuming at least a 1 h peak water level persistence, this yields potential maximum runup heights at Tobruk Pool of 1.6 m, increasing to 2.1 m if a 1% runup statistic is assumed. Slightly higher values are indicated at North Ward due to locally increased wave exposure before the shadowing influence of Magnetic Island begins to dominate.

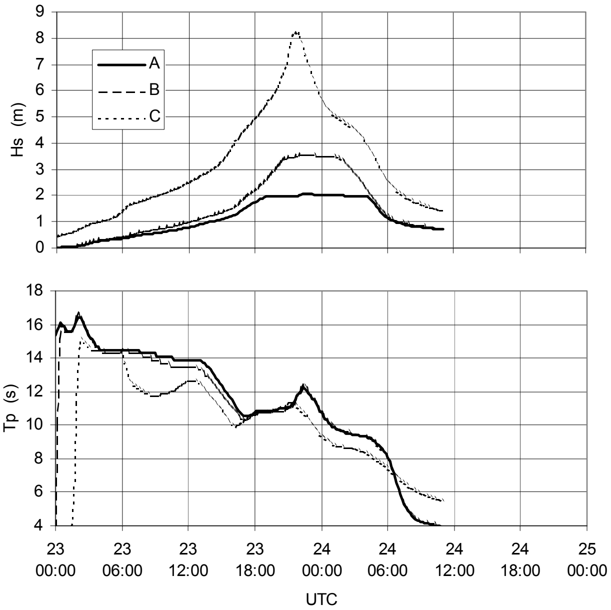

Figure 9 Modelled time history of significant wave height and peak spectral period for points *A* (near Tobruk Pool), *B* (offshore) and *C* (deep water outside Cleveland Bay).

7. Conclusions

The combined numerical modelling of winds, tide, storm surge and waves has provided insight into the likely distribution of peak coastal water levels induced by *Althea.* Figure 10 provides a final summary showing the comparison between the peak modelled alongshore values and the various estimated (squares) and measured (triangles) peak water level magnitudes from Table 1. The solid line is the modelled surge magnitude and suggests the peak storm surge occurred near Pallarenda with a height of 3.2 m. The dashed lines show the additional estimated wave setup and runup magnitudes. The comparisons show that the very highest reported water levels at Tobruk Pool and North Ward are at least consistent with possible maximum runup heights. Overall, the study shows the difficulty of estimating coastal water levels during such extreme conditions but confirms the ability of detailed numerical modelling to provide indicative estimates suitable for design.

8. Acknowledgements

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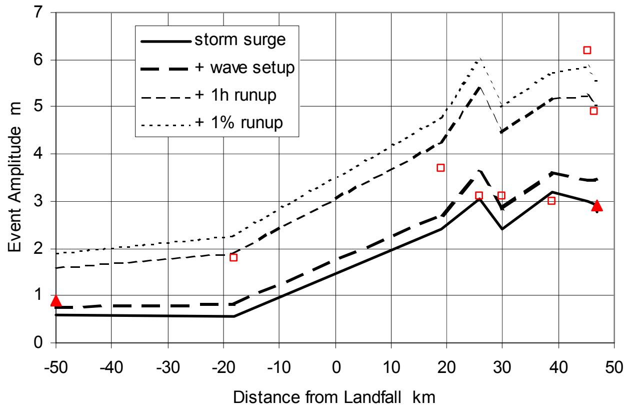

Figure 10 Comparison of modelled and measured alongshore surge profile for *Althea*.

9. References

Bode, L., and Mason, L.B. (1994) *Application of an implicit hydrodynamic model over a range of spatial scales*. Proc 6th Computational Techniques and Applications Conference (CTAC93), D. Stewart, H. Gardner and D. Singleton, Eds., World Scientific, Singapore, 112–121.

BoM (1972) *Report by Director of Meteorology on cyclone Althea*. Bureau of Meteorology, Dept of Science, AGPS, Canberra, July.

Callaghan J. (1996) *Tropical cyclones - analyses of the destructive wind zone.* Proc. Conf. On Natural Disaster Reduction NDR 96, IEAust*,* Sept, 341-345.

Dunn S.L., Nielsen P., Madsen P.A. and Evans P. (2000) *Wave diffraction and setup in jettied river entrances.* Proc. 27th Intl. Conf. Coastal Engin., IEAust, July, Sydney.

Hardy, T.A., Mason, L.B. and McConochie, J.D. (2000) *A wave model for the Great Barrier Reef.* Ocean Engineering, (in press).

Harper B.A. (*Ed.)* (2001) *Queensland Climate Change and Community Vulnerability to Tropical Cyclones, Ocean Hazards Assessment Stage 1.* Report prepared by Systems Engineering Australia Pty Ltd in assoc with James Cook University for the Queensland Government, March.

Harper B.A. and Holland G.J. (1999) *An updated parametric model of the tropical cyclone*. Proc. 23rd Conf. Hurricanes and Tropical Meteorology, American Meteor. Soc., Dallas, Texas, 10-15, Jan.

Nielsen P. and Hanslow D.J. (1991) *Wave runup distributions on natural beaches.* J. Coastal Research, Vol 7, 4, 1139-1152.

Trollope D.H and Stark K.P. (*Eds.*) (1972) *Cyclone Althea: PartsI and II.* James Cook University of North Queensland, March and October.