Department of Science, Information Technology and Innovation

Tropical Cyclone Marcia 2015

Storm Tide Monitoring and Post Cyclone Coastal Field Investigation

Coastal Impacts Unit, DSITI

December 2015

Queensland Government

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Executive summary

In February 2015 Severe Tropical Cyclone (TC) Marcia crossed the Queensland coast at Shoalwater Bay approximately 70 km north of Yeppoon. Before making landfall, the system underwent a process of rapid intensification and adopted a track that forecast the system to cross the coastline on a rising tide during a spring tide cycle. The likelihood of storm surge on top of the high tide level resulting in a total storm tide level greater than the Highest Astronomical Tide (HAT) posed a real and immediate threat to nearby coastal communities.

TC Marcia crossed the coast on a rising spring tide and continued to travel inland on a southerly track as it weakened, to cross the coast again near the Sunshine Coast as a tropical low. DSITI Storm Tide Gauges (STG) measured the progressive elevated sea levels caused by the resulting strong wind and low atmospheric pressure along the coast. During this period the closest gauge to the crossing location, Rosslyn Bay, measured a surge of 0.60 m just after high tide when TC Marcia was located nearest to the gauge. A maximum storm tide height of 5.44 m above Lowest Astronomical Tide (LAT) was observed at high tide and included 0.45 m of surge resulting in a 0.30 m exceedance of HAT at this location. The highest measured surge of 1.97 m was observed at Port Alma, with smaller surges and drops in atmospheric pressure at other gauges coinciding with the system travelling south.

The system produced strong wave conditions causing beach and dune erosion in the impacted areas. The closest DSITI wave measuring buoy to the crossing location is Emu Park, which measured a maximum individual wave height of 6.97 metres. This was the third highest individual wave measured at the site. Emu Park also measured the highest significant wave height of 4.03 m since commencing operations in 1996. High ranking wave heights were also recorded by moored wave buoys at Mackay and Gladstone. The influence of the system was also recorded by wave buoys in south east Queensland, but to a lesser extent as the system tracked inland along the coast and moved back out to sea near Bribie Island.

Coastal Impacts Unit staff from DSITI, working collaboratively with staff from the Australian Bureau of Meteorology, conducted a post event field trip to investigate the main impacted coastal region between Shoalwater Bay and Rosslyn Bay. The investigation resulted in visual assessments of the impact on the coast zone in addition to measured beach profiles and debris line elevations, which provided an indication of the total inundation level reached in each area. From the investigation it was found that due to high dunes the impact of the inundation was best classified as that of a collision regime, where inundation resulted in the erosion and scarping of the foredunes, causing undermining of structures and vegetation in this area. Debris consisted mainly of pumice stone either deposited as small sections of over-wash left sitting above the scarp lip, or collected in piles against the southern end of individual beaches as a result of the alongshore forces. The highest debris level surveyed was 5.5 m AHD at One Mile Beach (about 2.7 m above HAT), with other significant levels observed at Freshwater Bay and Farnborough Beach.

The information contained in this report provides an overview of the damage resulting from waves and storm surge during TC Marcia. The resulting information is used to support further research and projects and to help Queensland communities to be more aware and resultantly, better prepared against the risk of inundation from storm tide in future events.

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Glossary

Table 1 Glossary of terms

Term	Description
AHD	Australian Height Datum
AUSPOS	Online GPS processing service
BoM	Bureau of Meteorology
BPA	Beach Protection Authority (Queensland)
CIU	Coastal Impacts Unit, DSITI
COPE	Coastal Observation Program Engineering
CORS	Continually Operating Reference Station
D_p	Direction of the peak period (T_p) waves
DSITI	Department of Science, Information Technology and Innovation
GPRS	General Packet Radio Service
HAT	Highest Astronomical Tide
H_{max}	The maximum zero up-crossing wave height in a 26.6 minute record
hPa	Hectopascals which is a measure of pressure. 1 hPa = 100 Pascals or 1 millibar
H_s	Significant wave height, the average of the highest one-third of the zero up-crossing wave heights in a 26.6 minute wave record.
Hz	Hertz which is a measure of frequency (1/s)
LAT	Lowest Astronomical Tide
m	Metres which is a measure of length or distance
MSL	Mean Sea Level
MWS	Mean Water Surface
NTRIP	Network Transport of RTCM via Internet Protocol
QPWS	Queensland Parks and Wildlife Services
RTCM	Radio Technical Commission for Maritime Services
RTK GPS	Real-Time Kinematic Global Positioning System
s	Seconds which is a measure of time
STG	Storm Tide Gauge
TC	Tropical Cyclone
TN	True North
T_p	The wave period corresponding to the peak of the energy density spectrum (frequency domain)
T_z	The average period of all zero up-crossing waves in the record (time domain)
UHF	Ultra High Frequency
USGS	United States Geological Survey

1 Introduction

Tropical Cyclone (TC) Marcia crossed the coast at Shoalwater Bay approximately 70 km north of Yeppoon on Friday 20 February 2015 during a spring tide period. Developing as a tropical low in the Coral Sea, the system initially moved in a westerly direction away from the Queensland coast. On Wednesday 18 February as the system began to move south the Australian Bureau of Meteorology (BoM) issued a cyclone watch cautioning areas between St Lawrence and Double Island Point. The system was classified a category 1 tropical cyclone later that night. The following day, TC Marcia moved south west toward the coast undergoing a process of rapid intensification and was classified as a category 4 cyclone by Thursday night and a category 5 cyclone early on Friday morning. During this period, the Capricorn Coast was experiencing high spring tides with the highest tide of the day for Rosslyn Bay of 0.16 m below Highest Astronomical Tide (HAT) predicted to occur on Friday morning at 08:32 am. TC Marcia crossed the coast between 07:30 am and 08:30 am, on the rising tide near high tide (Figure 1). The combined effect of high tides and a high category cyclone crossing the coast presented a considerable threat by way of coastal inundation to nearby regions.

The system weakened as it tracked inland in a southerly direction along the coast, and was downgraded to a low pressure system late that night near Kapaldo, approximately 130 km west of Hervey Bay. The system continued to track in a south east direction, crossing the coast again near the Sunshine Coast and then, after traveling as far south as the New South Wales border, turned north east and headed out to sea (Figure 2).

As the system approached the coast, it posed a threat to coastal communities in terms of extreme winds and potential inundation from the sea. Typically as a cyclone approaches the coast, ocean water levels rise as a result of strong onshore winds and reduced barometric pressure. This rise in water level is known as storm surge and can cause inundation and flooding of coastal areas. The destructive capacity of a storm surge significantly depends on the height of the tide at the time the cyclone crosses the coast, and wave setup produced by increased wave heights. The combined water level from these three processes is referred to as “storm tide” and can cause inundation of coastal areas depending on the cyclone characteristics, the stage of tide near landfall and the local typography. For the macrotidal region of Central Queensland (spring tide ranges of 4 to 6 m) the stage of tide can mean the difference between a minor erosion event to a significant coastal inundation impacting infrastructure and communities.

The Coastal Impacts Unit (CIU) of DSITI provides assistance to emergency managers during these events by providing technical advice related to storm tide including maintaining a statewide monitoring network for storm tide and waves. Following a significant event, CIU can undertake post event field investigations to examine coastal impacts including erosion and inundation levels. This information provides an invaluable resource for future planning and disaster management.

This report details information collected by CIU during and following TC Marcia, and consists of Storm Tide Gauge (STG) recordings and wave buoy measurements for the affected areas as well as post event investigations comprising visual damage inspections, beach profiling and debris line surveys for the region between Shoalwater Bay and Rosslyn Bay. Due to the extraordinary nature of such events and the brief window in which data must be collected in a dynamic environment, observations made in this report provide a rare and valuable insight into the effect of storm tide on the Queensland coast.

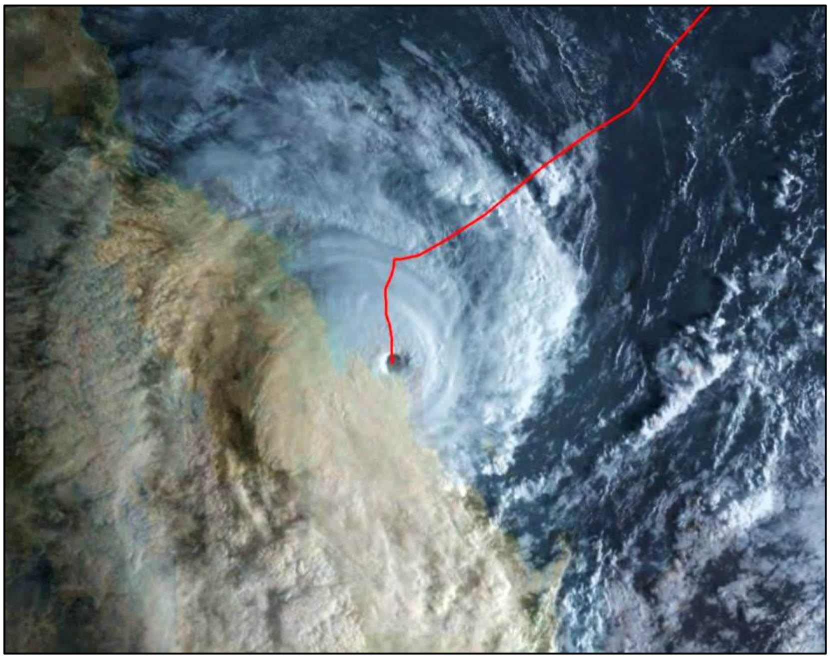

Figure 1 TC Marcia making landfall at Shoalwater Bay*

**Based on "20150219.2032.MTSAT2.vis.13P.MARCIA.SHEM ", MTSAT-2 imagery provided by the U.S. Naval Research Laboratory*

2 Recorded coastal monitoring data

2.1 Storm tide data

CIU operates a storm tide monitoring network of 35 tide gauges along the Queensland coastline. Data from the storm tide gauges (STG) are downloaded at varying intervals (typically every 30 minutes), converted to plots and published on the Queensland Government website for general use (www.qld.gov.au/tides). Additionally, near real time data from the network is provided by CIU to the Australian Bureau of Meteorology (BoM) and emergency departments as part of its Storm Tide Advisor initiative.

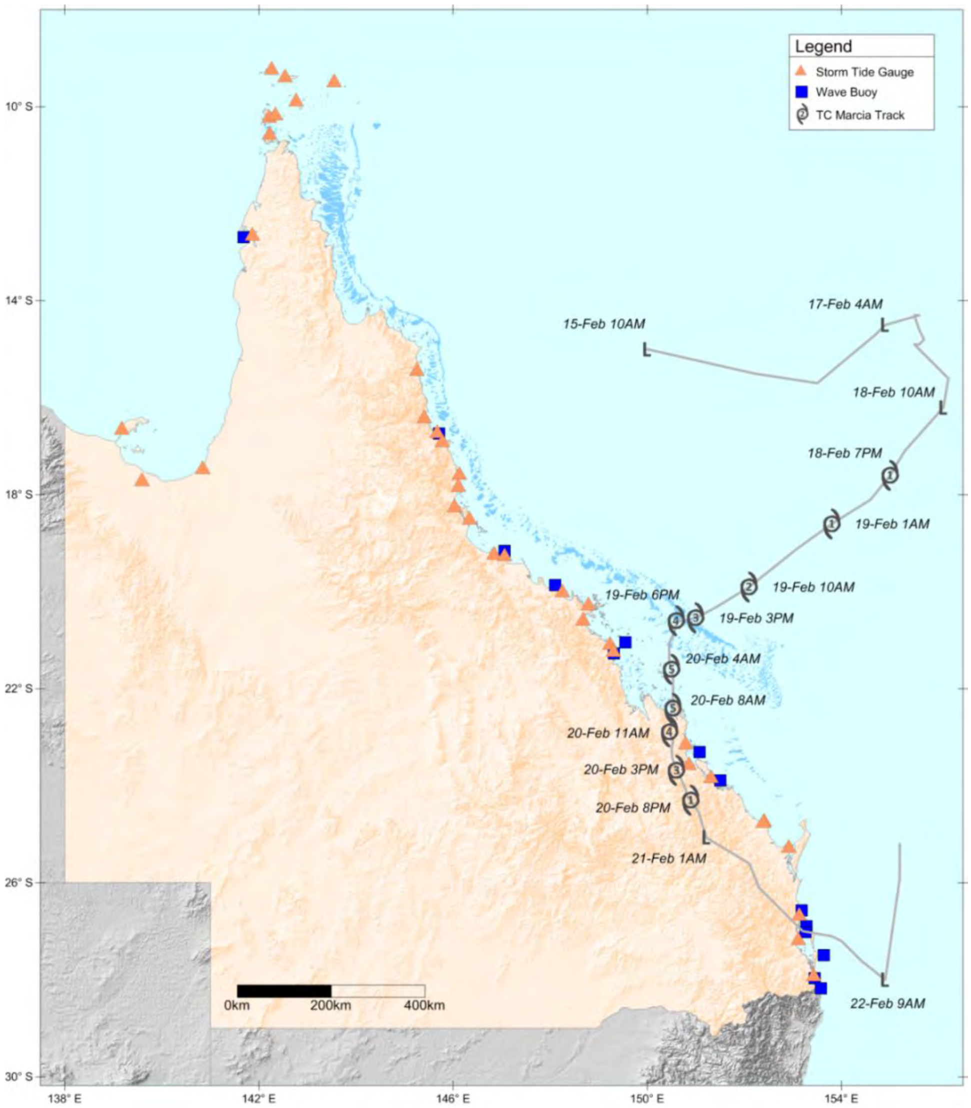

Figure 2 DSITI storm tide gauge and wave monitoring buoy locations and cyclone track (track courtesy of BoM).

It should be noted that the majority of STG are located within harbours or on structures such as jetties. This means they are either mostly offshore of the surf zone or protected from waves and so do not measure the wave setup (which is largest close to the shore, refer Figure 3). It is possible that adjacent beaches may experience higher storm tide levels than those recorded.

During the event, storm tide data was gathered and analysed for the closest operating gauges including: Mackay; Dalrymple Bay; Rosslyn Bay; Port Alma; Gladstone; Burnett Heads; Urangan;

Mooloolaba and Gold Coast for the period 18 to 24 February 2015. Plots showing measured storm tide level, predicted tide, storm surge and atmospheric pressure are shown in Figure 4 through Figure 12. For each figure a line has been marked to show the time of landfall of the system at Shoalwater Bay and the approximate time when the system was closest to each respective gauge.

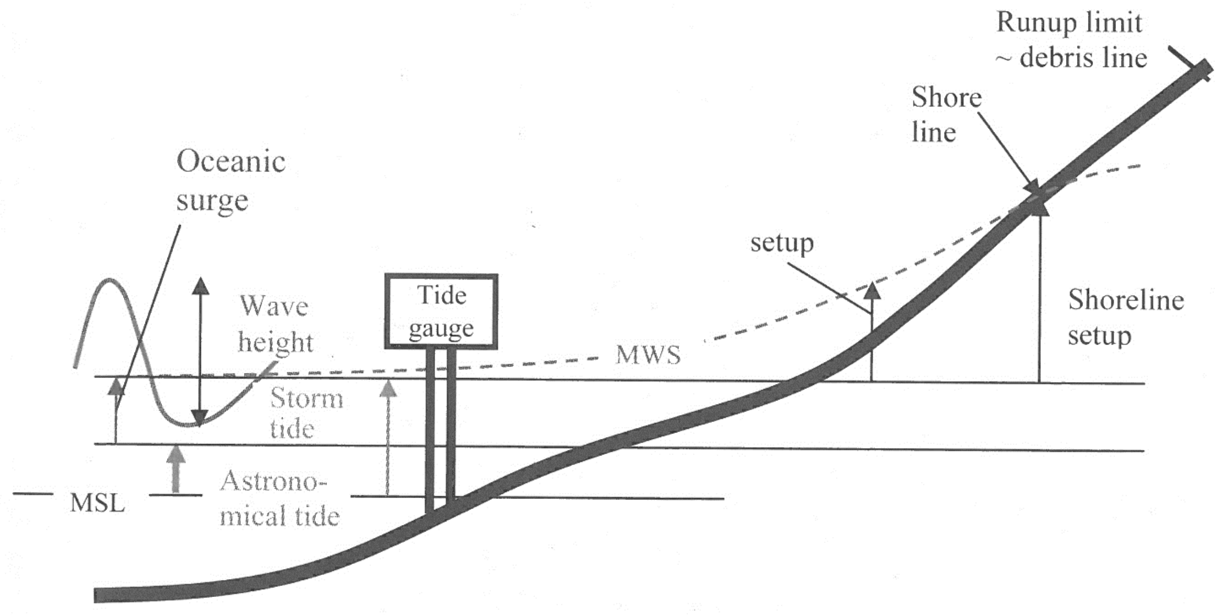

Figure 3 Wave setup and run-up (Nielsen, 2009).

Observation of the data shown demonstrates that the surge behaves similar to a coastal trapped wave moving with the meteorological system as it progressed southwards, diminishing in amplitude as the system weakens, with increases in amplitude where the movement is impeded such as Port Alma (at the mouth of the Fitzroy River) and Urangun (Hervey Bay).

The nearest STG to the crossing location, Rosslyn Bay, experienced a maximum surge of 0.60 m at 12:13 pm on 20 February 2015. The influence of the tides resulted in a peak storm tide of 0.30 m above HAT occurring slightly earlier at 10:01 am. This gauge also recorded the lowest observed atmospheric pressure from the STGs measuring 986 hPa. The data for Rosslyn Bay illustrates the temporal variation of the surge, with positive surges occurring with the passage of the weakening cyclone southwards and inland of the STG as a result of the strong onshore winds, reaching a maximum when the cyclone was situated west of the STG. As the system progressed further south, there is a shift to offshore winds producing a negative surge.

The largest observed surge was 1.9 m at Port Alma occurring several hours after landfall as TC Marcia was situated to the west of this location. However, the total storm tide level at this location did not exceed HAT because the surge occurred on a falling tide with a range of 5.4 metres. At Gladstone, HAT was breached on the high tide following TC Marcia making landfall. As the system decreased in intensity and tracked inland toward south east Queensland, gauges in the area recorded lower yet notable surges as the system moved past each gauge. For Mooloolaba, the small surge combined with the high spring tides at the time resulted in a minor exceedance of HAT.

Table 2 Recorded surge levels during TC Marcia

Location (HAT)	Highest observed Tide (m LAT)	Highest observed surge (m)	Lowest observed pressure (hPa)
Mackay (6.58 m)	19-Feb 11:08 6.48 m	19-Feb 16:54 0.30 m	20-Feb 03:48 999.5 hPa
Dalrymple Bay (7.14 m)	19-Feb 11:04 6.96 m	19-Feb 16:10 0.27 m	20-Feb 03:22 998.2 hPa
Rosslyn Bay (5.14 m)	**20-Feb 10:01 5.44 m	20-Feb 12:13 0.60 m	20-Feb 12:48 986.3 hPa
Port Alma (5.98 m)	20-Feb 10:34 5.93 m	20-Feb 15:30 1.94 m	20-Feb 15:01 986.9 hPa
Gladstone (4.63 m)	**20-Feb 10:00 4.72 m	20-Feb 15:34 0.43 m	20-Feb 17:26 997.6 hPa
Burnett Heads (3.67 m)	19-Feb 08:50 3.59 m	21-Feb 01:30 0.21 m	21-Feb 02:55 1000.5 hPa
Urangan (4.28 m)	20-Feb 09:47 4.25 m	21-Feb 05:04 0.42 m	21-Feb 04:09 1001.2 hPa
Mooloolaba (2.17 m)	**21-Feb 09:54 2.20 m	21-Feb 15:03 0.34 m	21-Feb 14:30 1002.0 hPa
Gold Coast (1.91 m)	20-Feb 08:58 1.85 m	22-Feb 15:55 0.34 m	21-Feb 15:12 1003.7 hPa

** indicates breach of HAT

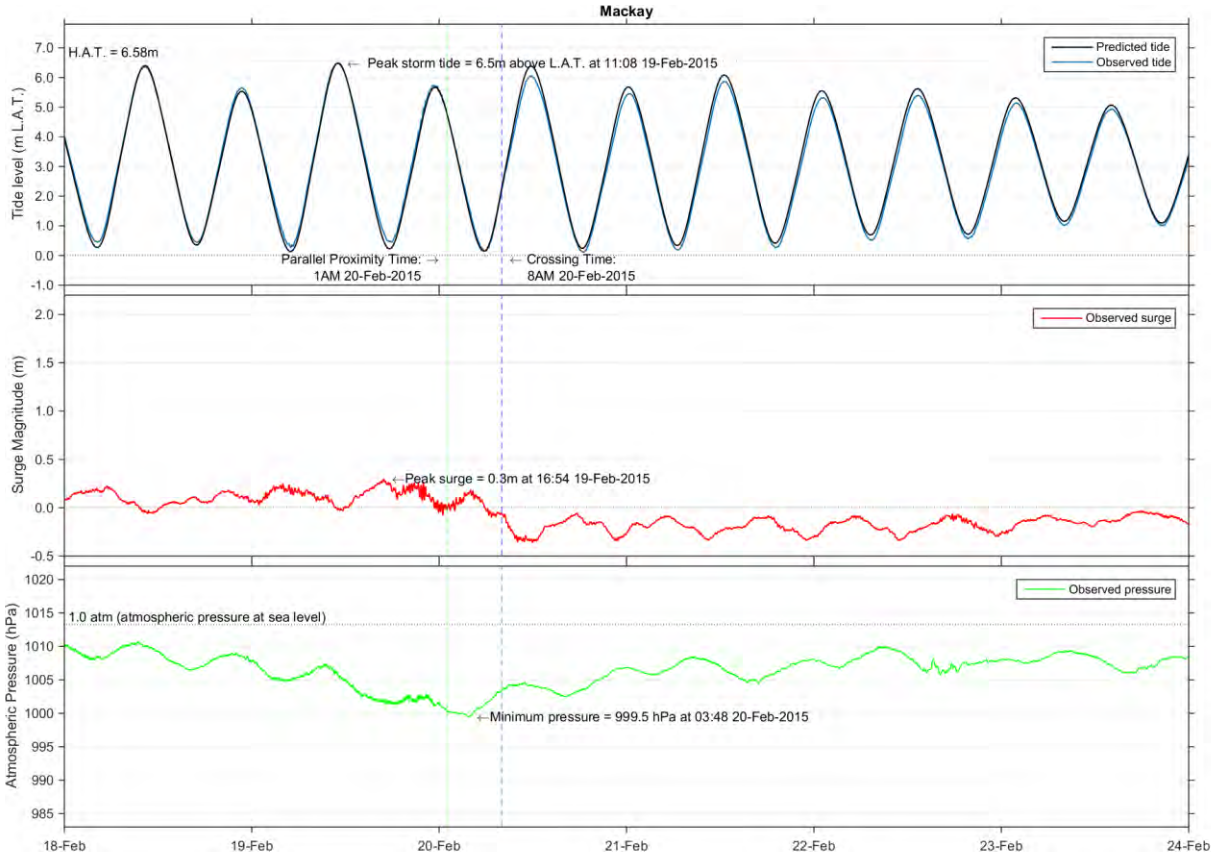

Figure 4 Recorded storm tide levels and atmospheric pressure – Mackay

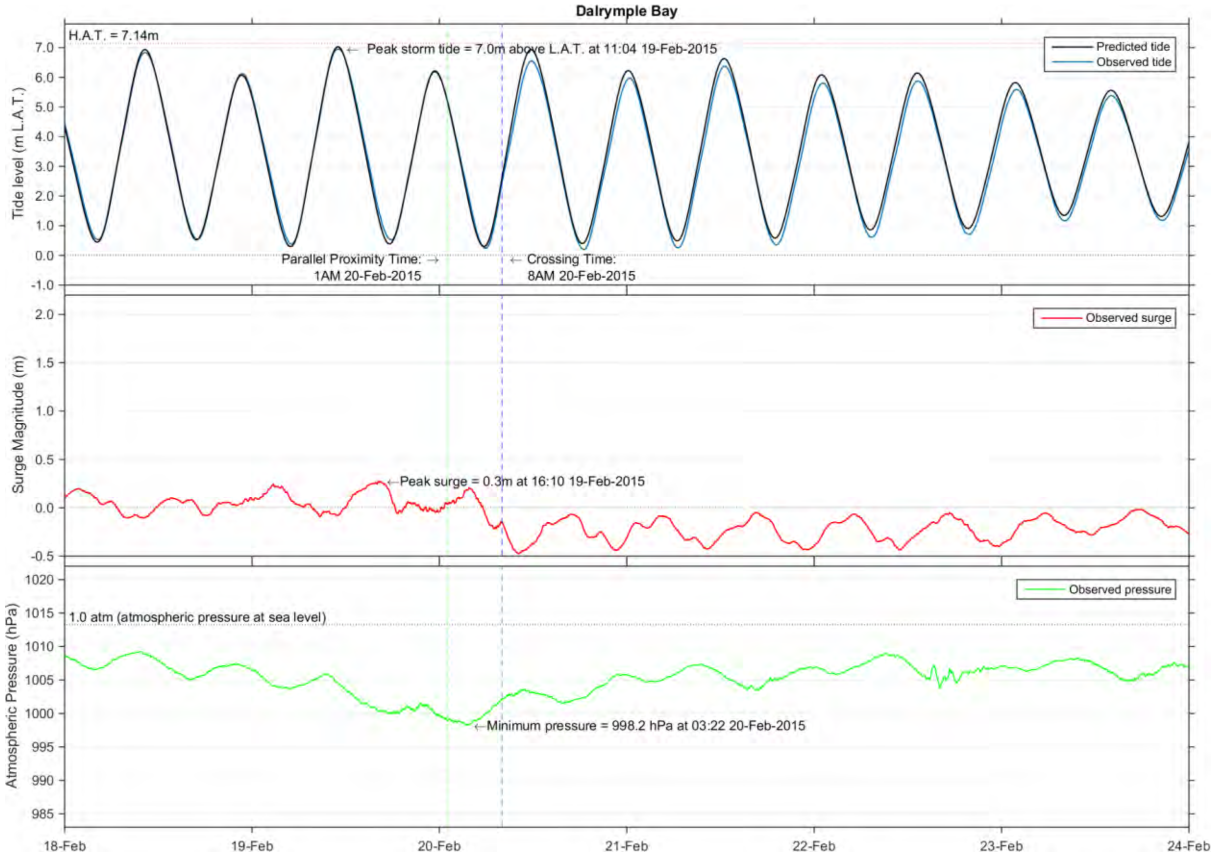

Figure 5 Recorded storm tide levels and atmospheric pressure – Dalrymple

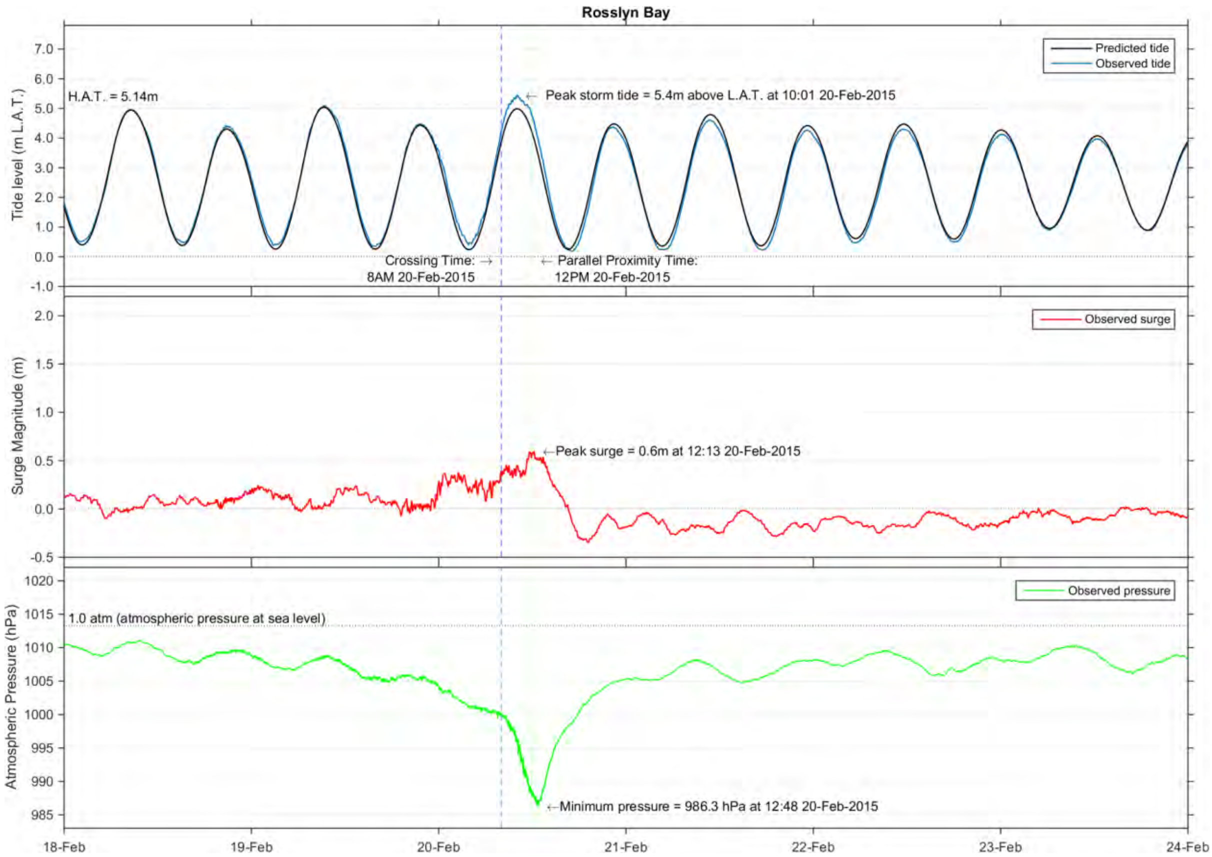

Figure 6 Recorded storm tide levels and atmospheric pressure – Rosslyn Bay

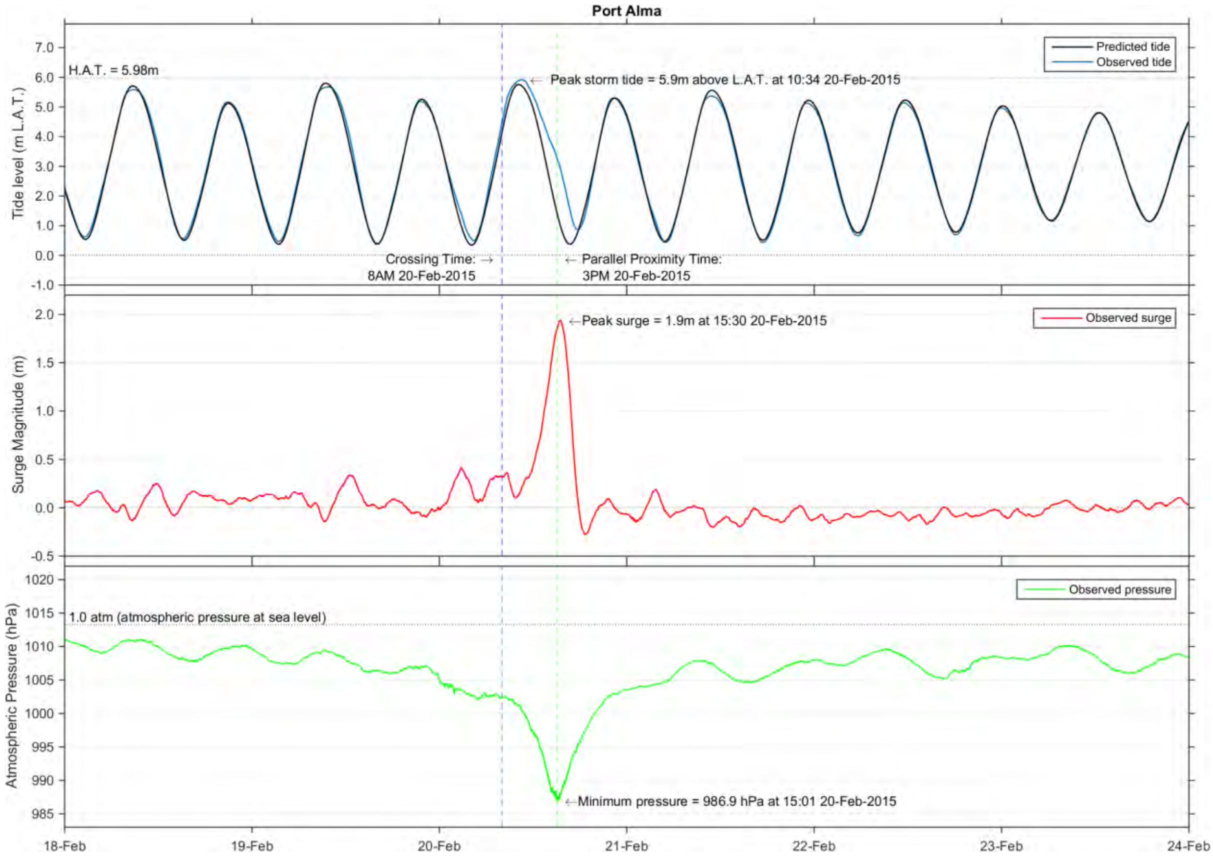

Figure 7 Recorded storm tide levels and atmospheric pressure – Port Alma

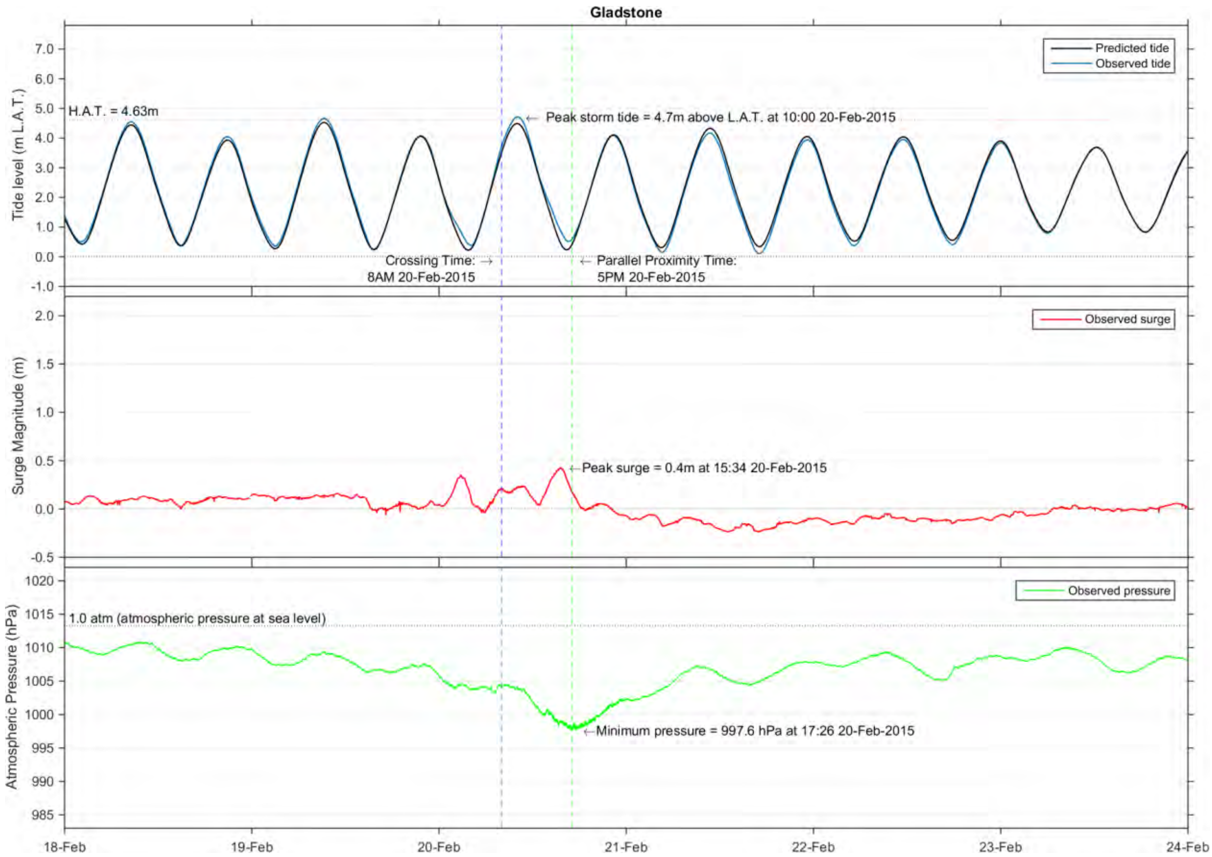

Figure 8 Recorded storm tide levels and atmospheric pressure – Gladstone

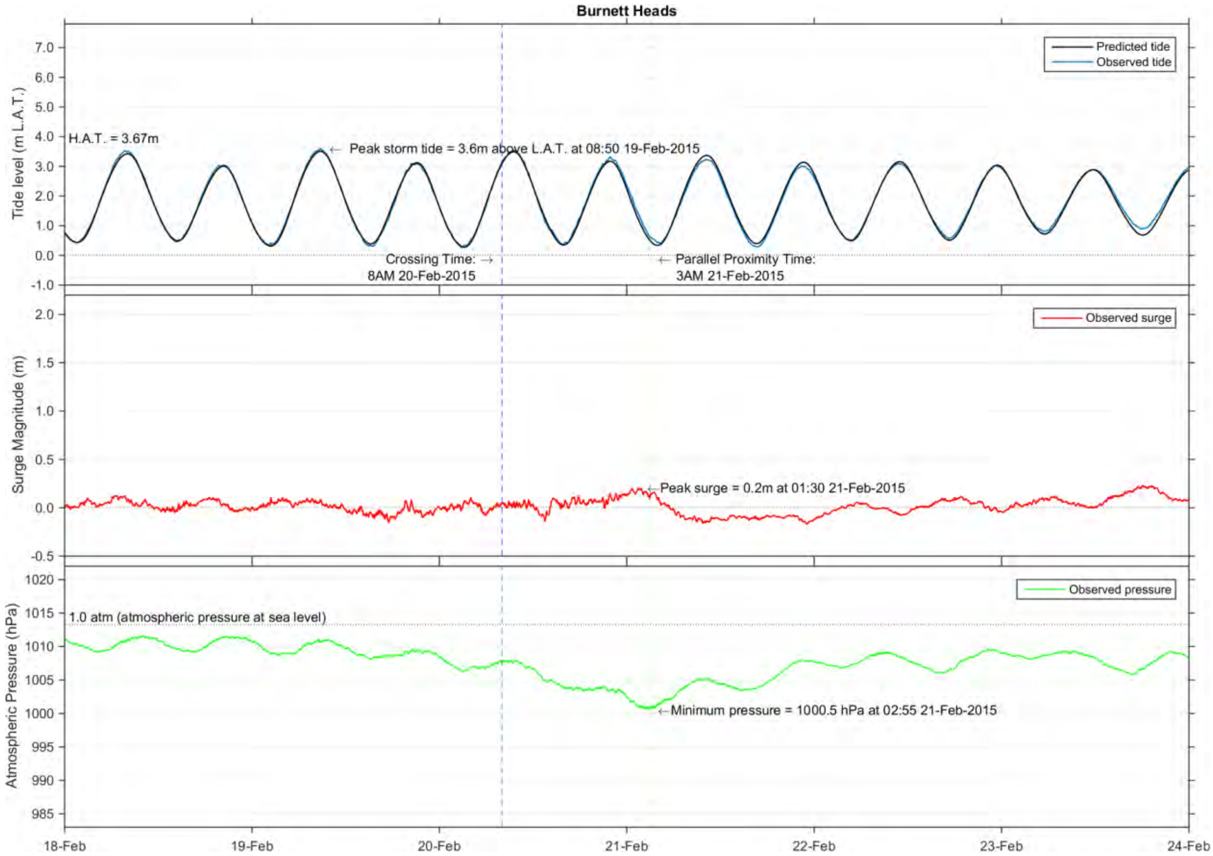

Figure 9 Recorded storm tide levels and atmospheric pressure – Burnett Heads

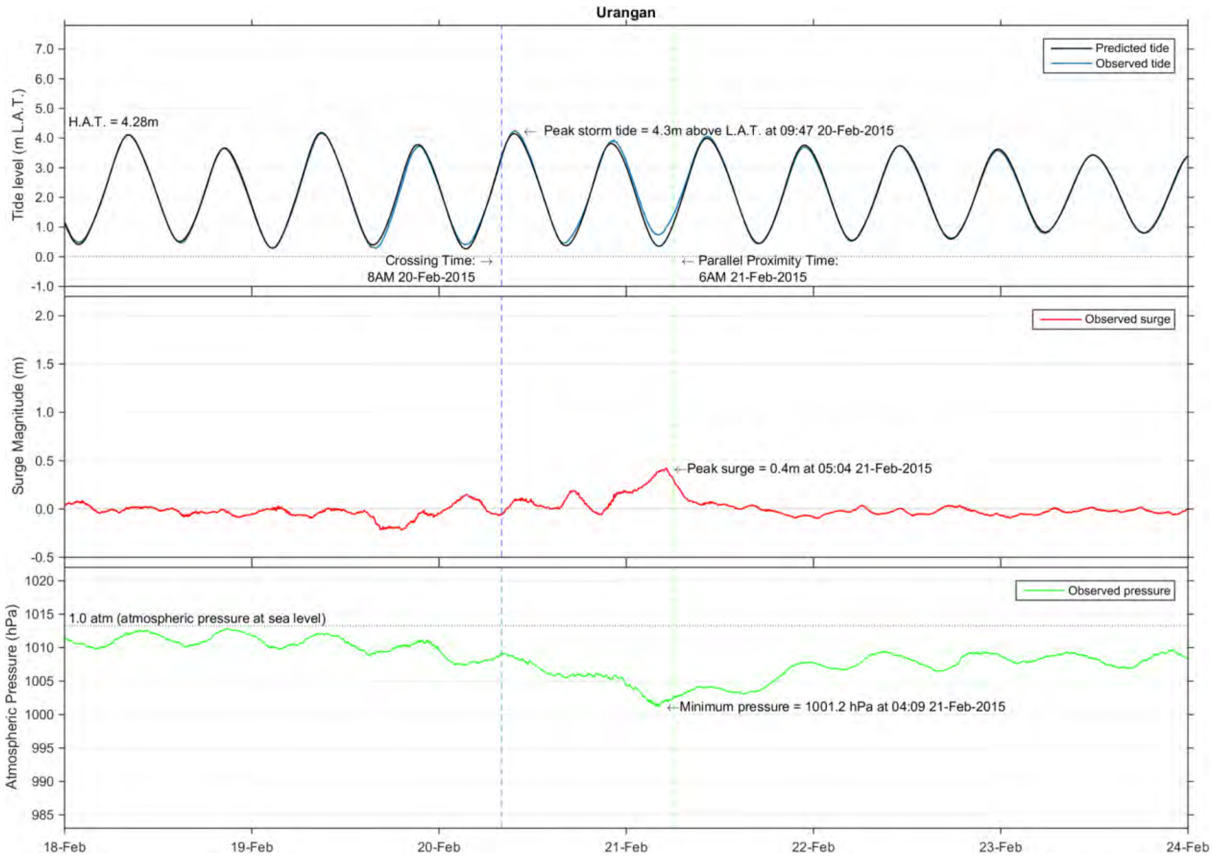

Figure 10 Recorded storm tide levels and atmospheric pressure – Urangan

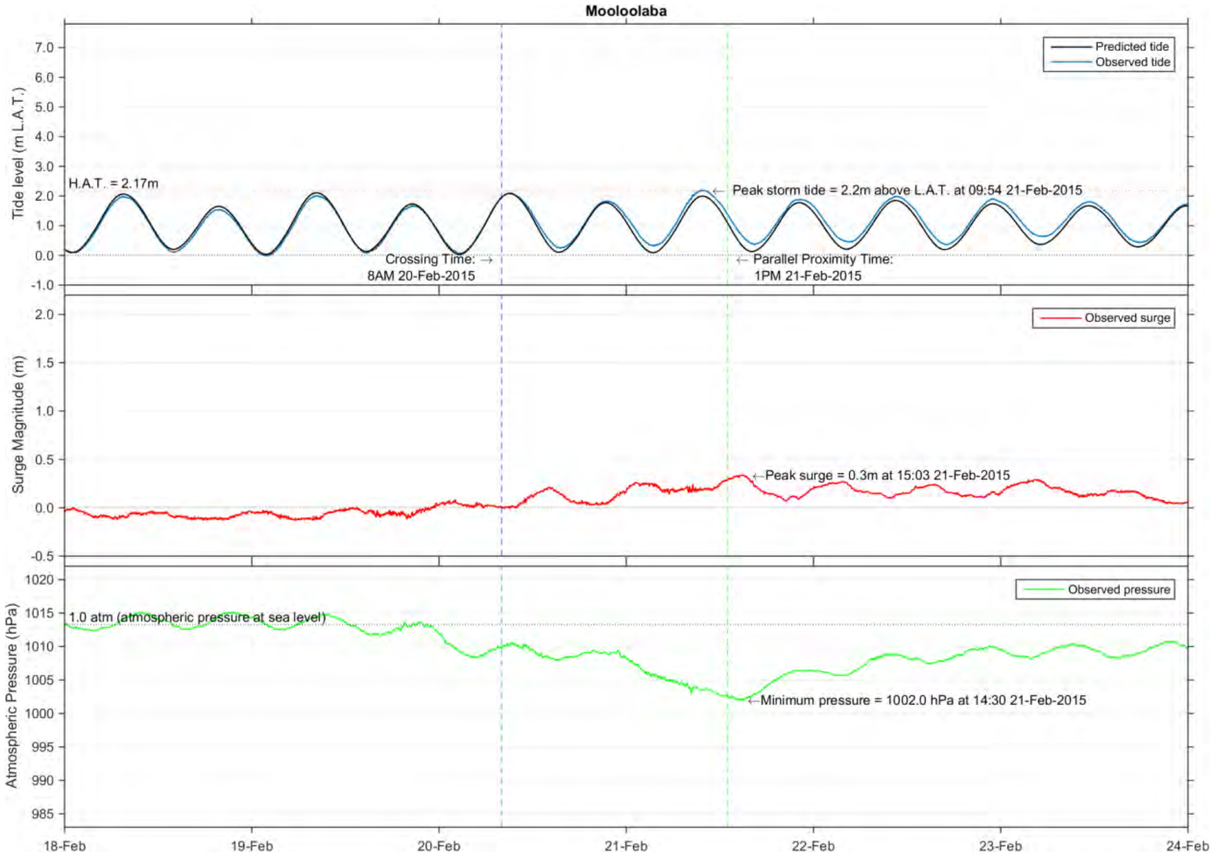

Figure 11 Recorded storm tide levels and atmospheric pressure – Mooloolaba

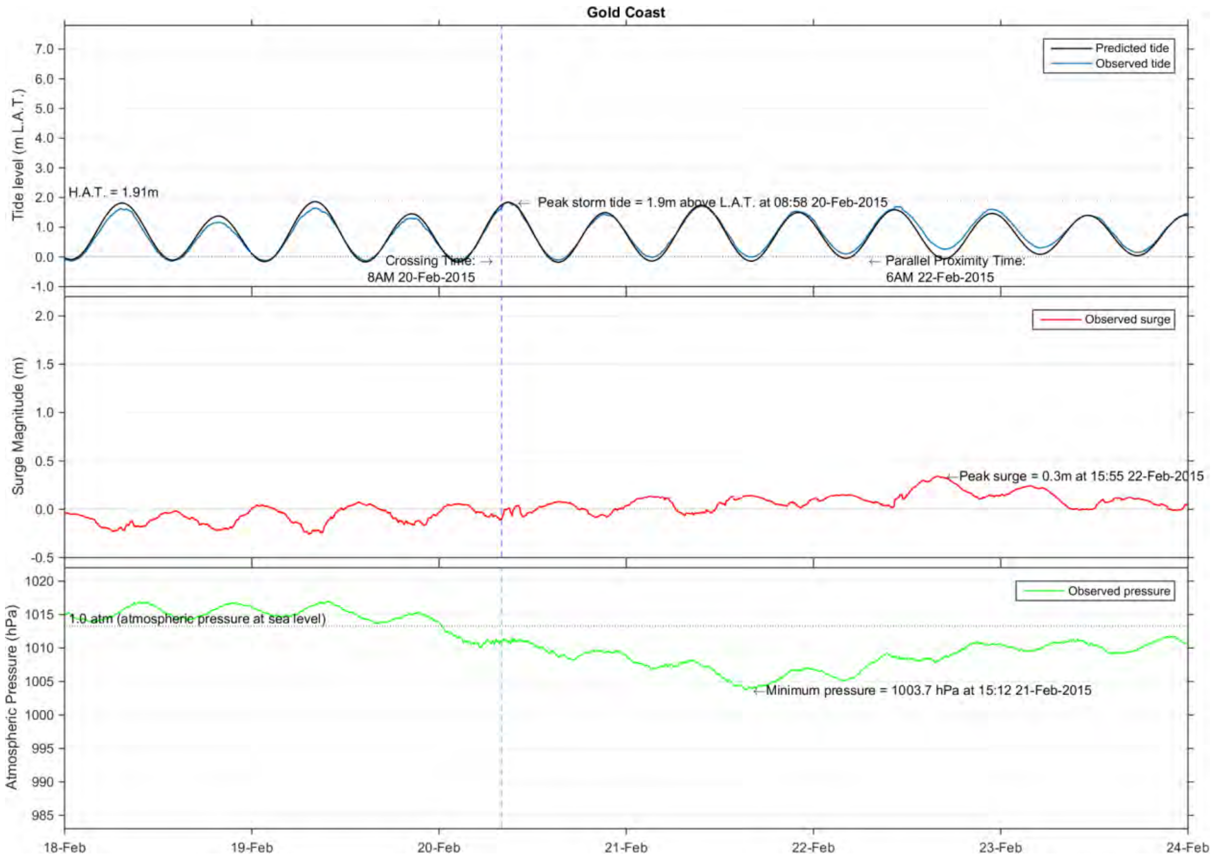

Figure 12 Recorded storm tide levels and atmospheric pressure – Gold Coast

2.2 Wave data

Coastal Impacts Unit, DSITI operates a network of 14 wave monitoring stations along the Queensland coastline, the locations of which are shown in Figure 2. Each monitoring station utilises a moored Datawell Waverider buoy to record wave height, period and direction at a single point which is then transmitted to a nearby shore station. Processed data from the shore station are downloaded at regular intervals (typically hourly) and displayed graphically on the Queensland Government website for general use. In addition, near real time data from the wave monitoring stations is provided by Coastal Impacts Unit to emergency departments as part of its Storm Tide Advisor initiative.

Based on the track taken by TC Marcia, data from wave monitoring stations between Mackay and Tweed Heads for dates between 18 and 28 February 2015 have been used in this analysis. Peak significant (Hsig) and maximum (Hmax) wave heights for the 10 stations in this region are presented in Table 2.

Wave height statistics are based on a 26.6 minute sampling period at a sampling interval of 1.28 Hertz. The significant wave height (in metres) is defined as the average of the highest one-third of the zero up-crossing wave heights in a record. The maximum wave height represents the maximum individual wave height (Hmax) recorded at each station during the event.

Table 3 Recorded wave heights during TC Marcia

Location (start of record)	Maximum significant wave height (Hsig m)	Rank	Maximum individual wave height (Hmax m)	Rank
Mackay (1975)	19-Feb 22:30 3.64 m	#7	20-Feb 01:00 5.88 m	-
Hay Point (1977)	19-Feb 22:30 2.08 m	-	19-Feb 22:00 4.52 m	-
Emu Park (1996)	20-Feb 13:30 4.03 m	#1	20-Feb 14:00 6.97 m	#3
Gladstone (2009)	20-Feb 15:00 2.98 m	#3	20-Feb 16:30 5.50 m	#4
Mooloolaba (2000)	18-Feb 09:30 3.25 m	-	18-Feb 07:00 6.19 m	-
Caloundra (2013)	19-Feb 07:30 3.17 m	#1	19-Feb 07:30 6.24 m	#1
North Moreton (2010)	19-Feb 12:30 2.96 m	#7	19-Feb 11:00 6.18 m	#4
Brisbane (1976)	22-Feb 14:30 4.52 m	-	22-Feb 13:00 8.52 m	-
Gold Coast (1987)	23-Feb 01:00 3.74 m	-	23-Feb 01:00 6.84 m	-
Tweed (1995)	22-Feb 17:00 3.49 m	-	23-Feb 03:00 6.55 m	-

Table 3 also indicates the duration of wave recording at each site by way of installation year, and a ranking for any wave records which comprise records in the top ten of all Hsig or Hmax for each site. The highest recorded wave resulting from TC Marcia was 8.52 m at Brisbane as the ex-TC moved out to sea. Because large wave conditions are common at this location, being a relatively deep site, the more notable recordings for this event are those at Emu Park, Mackay, Hay Point and Gladstone as they are located near the area where TC Marcia exhibited its higher intensity. The Emu Park buoy recorded its highest significant wave height (4.03 m) since logging began in 1996, occurring when TC Marcia was in close proximity. The following record logged the third highest individual wave (6.97 m) recorded at the location. High ranking waves were similarly observed by Mackay and Gladstone buoys.

Caloundra and North Moreton wave buoys measured high ranking wave heights during the period. However, wave recording at these stations is relatively new commencing in 2013 and 2010 respectively. Therefore, these sites have not experienced a large number of storms. Additionally the high ranking records occurred early on 19 February while TC Marcia was still some distance away. A weak coastal trough forming over south eastern Queensland could possibly have had an additional influence on these locations.

Figure 13 shows the time history plot of the significant and maximum wave heights as the system tracked towards and down the coast. Additionally the peak period and peak period direction (i.e. the direction the waves with the most energy are coming from) is indicated for each of the sites. It can be seen that there is a noticeable increase in the measured wave heights as the system passes in close proximity to each recording location, followed by a calmer sea state in the following days. For Emu Park and Gladstone buoys there is also a notable direction change experienced when TC Marcia is in close proximity and becomes the dominant wind force for wave generation. For Emu Park, the peak period increases to 8.9 seconds at the peak of the wave event.

In addition, the buoys provide both frequency spectral density estimates as well as descriptive directional parameters based on the first four Fourier coefficients. These being the mean wave direction, directional spread, skewness and kurtosis as proposed by Kuik, van Vledder and Holthuijsen (1988). The directional parameters provide an estimate of the directional spectra based on the assumption of unimodal directional distribution. The resolution of this data depends on the type of buoy deployed. For the Emu Park buoy, 64 frequency bins are provided between 0.025 and 0.58 Hertz.

Figure 14 shows the development and decay of the sea state as a result of TC Marcia at the Emu Park monitoring site. As can be seen, the spectra is essentially unimodal in the frequency domain with rapid development of wave energy as the cyclone neared the buoy location, followed by rapid abatement as the system continued south. Figure 15 shows the directional spectra as polar plots, demonstrating the shift in direction during the peak of the event, as well as a narrowing of the directional spread which is consistent with swell waves.

Data gaps in the Emu Park records are a result of loss of power to the shore station for the period 21 to 25 February. It is anticipated that when the offshore buoy is retrieved for its next service that the data will be backfilled based on the log files from the buoy’s internal memory.

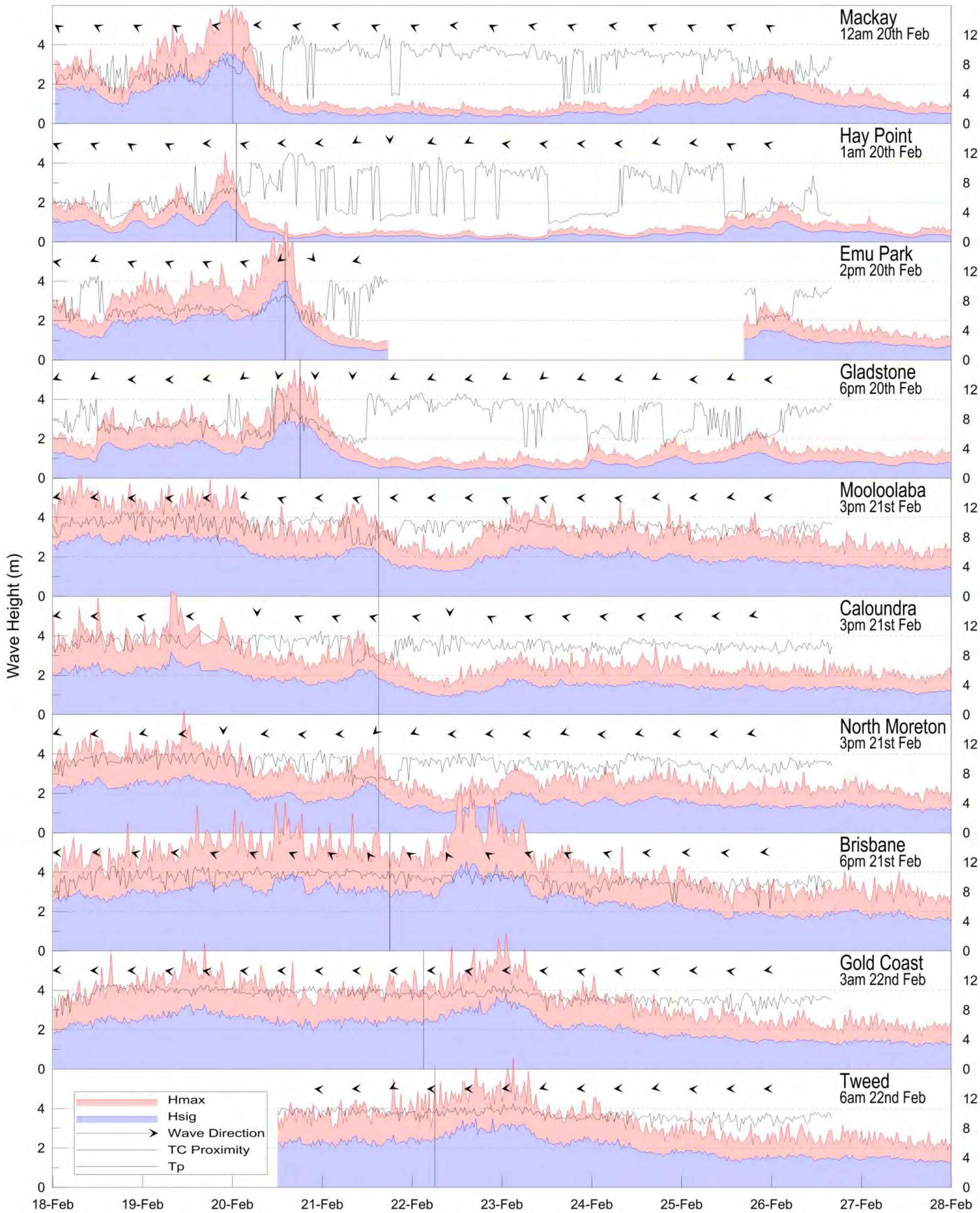

Figure 13 Significant and maximum wave height and direction at DSITI wave monitoring locations

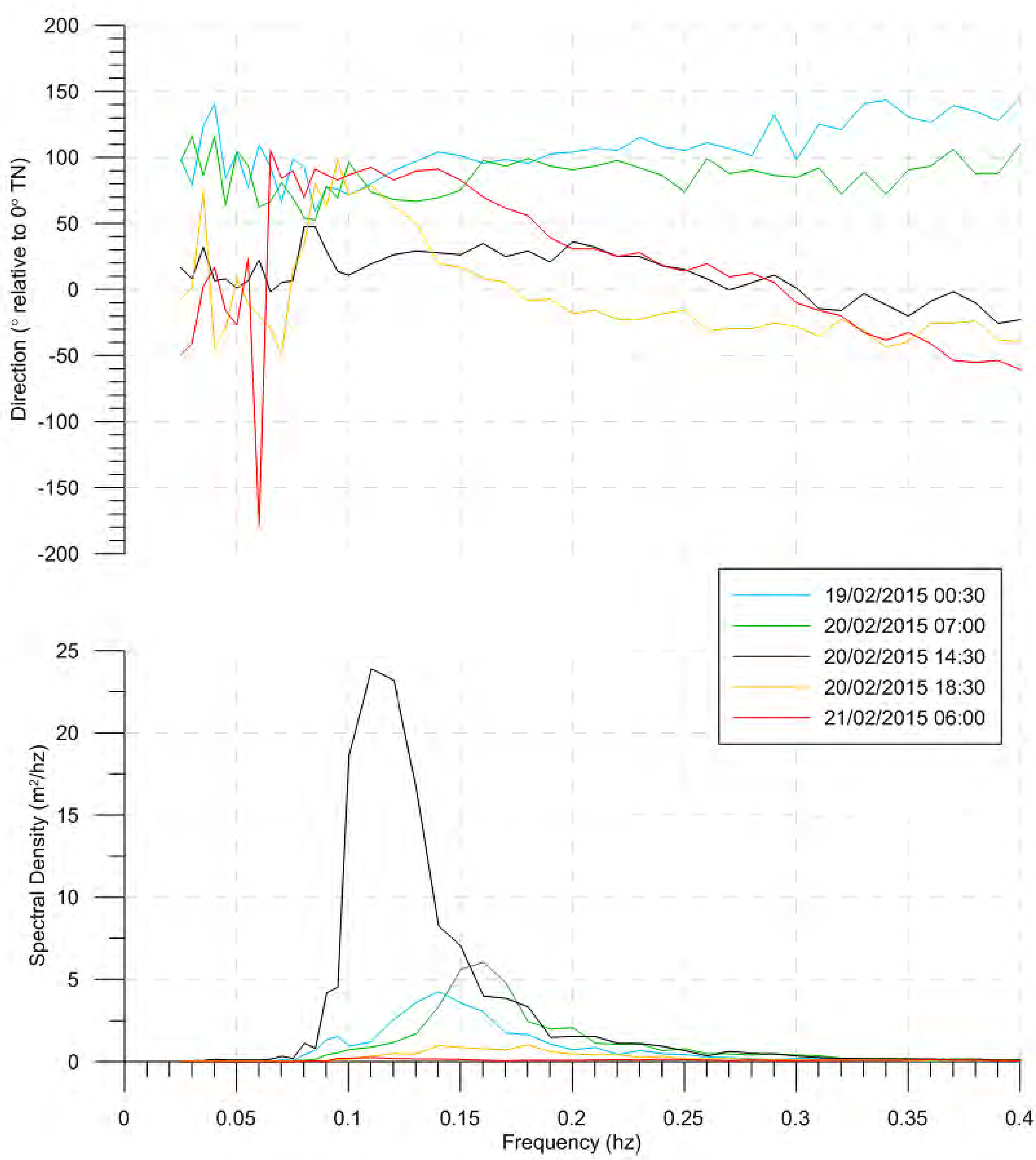

Figure 14 Emu Park wave spectra during TC Marcia.

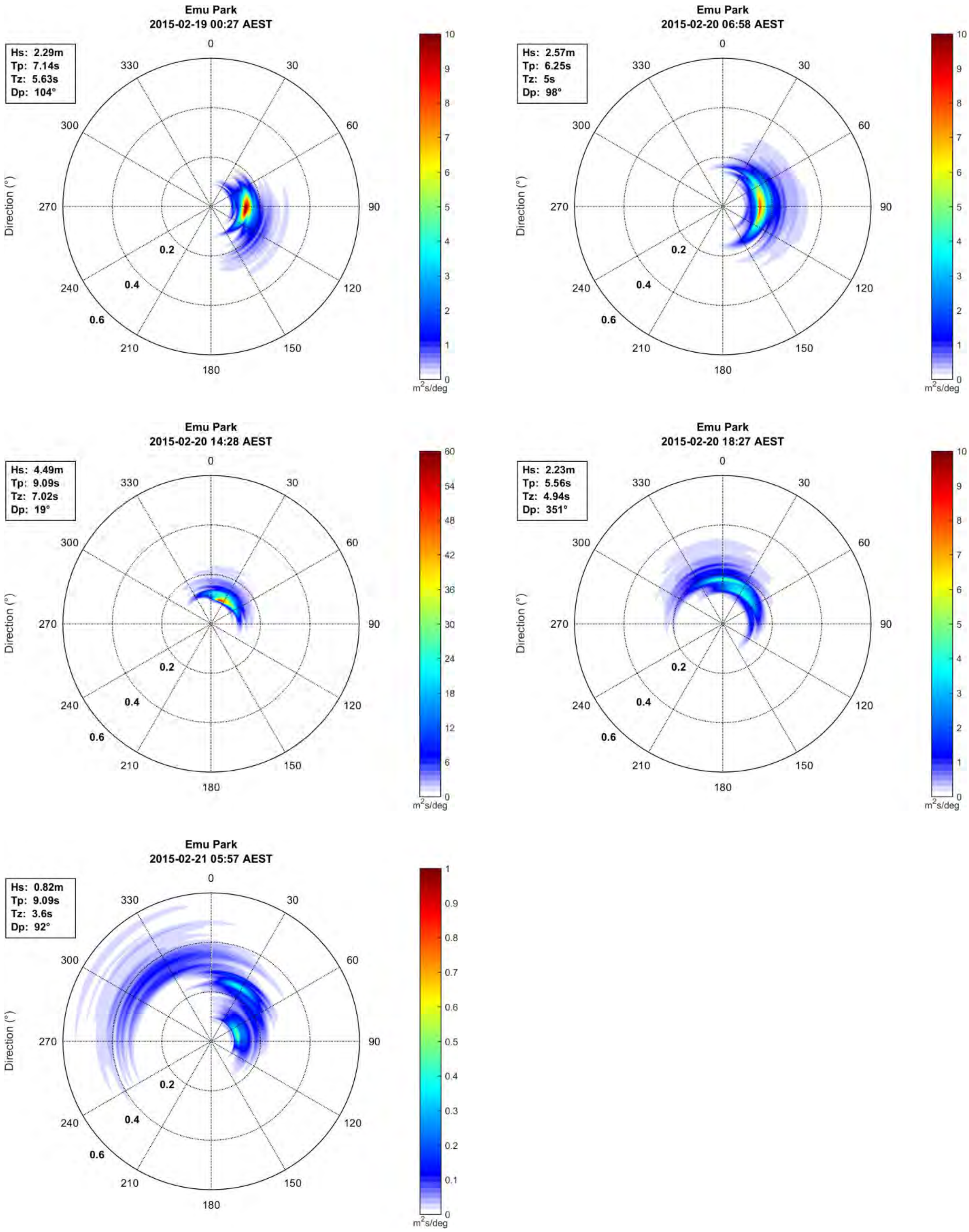

Figure 15 Emu Park directional wave spectra during TC Marcia.

3 Post event field investigation

Following significant events, the Coastal Impacts Unit mobilises to collect evidence of possible storm tide inundation and to inspect coastal impacts such as beach erosion to assist future planning and emergency management. These activities should be done quickly before any evidence disappears by either natural or anthropogenic means.

Field investigations were undertaken in collaboration with staff from BoM to visually assess damage to the coastline as a result of TC Marcia, and to investigate signs of coastal inundation. Staff were also involved in topographic surveys of inundation levels and beach profile surveys in areas that were conducive to real time kinematic GPS surveying within time constraints.

The following provides details of the study area and the field investigations undertaken. The remaining sections provide the results of this investigation. Select photographs have been included in the site condition report, with full-sized versions as well as additional photographs located in Appendix B.

3.1 Study area

3.1.1 Site selection

The field investigation focused on the region where the greatest coastal impacts from the ocean would have occurred, being in the region of landfall when the onshore winds were the strongest. It was expected that the coastal areas most affected by TC Marcia would be immediately south of the crossing location where the rotational nature of the system would create maximum onshore winds (in the vicinity of the radius of maximum winds), thus producing the greatest storm surge. However, this event was more complex in relation to storm tide in that the system continued to travel inland of and adjacent to the coast, producing a southerly moving surge similar to a coastal trapped wave. Additionally TC Marcia crossed at Shoalwater Bay on a rising tide, but the peak surge at Rosslyn Bay (70 km south) occurred after the tide had started to fall. It is therefore possible that the greatest storm tide occurred somewhere in between these two locations when the surge coincided with high tide. The inspections therefore concentrated on the region between Shoalwater Bay and Rosslyn Bay on the Capricorn Coast.

The beaches investigated depended on having access to the site. The locations inspected are provided in Figure 16.

The investigation focused on the effects of TC Marcia on the mainland. No attempt was made to document the impact on nearby islands including the Keppels, though it was understood that there was significant dune erosion in these areas.

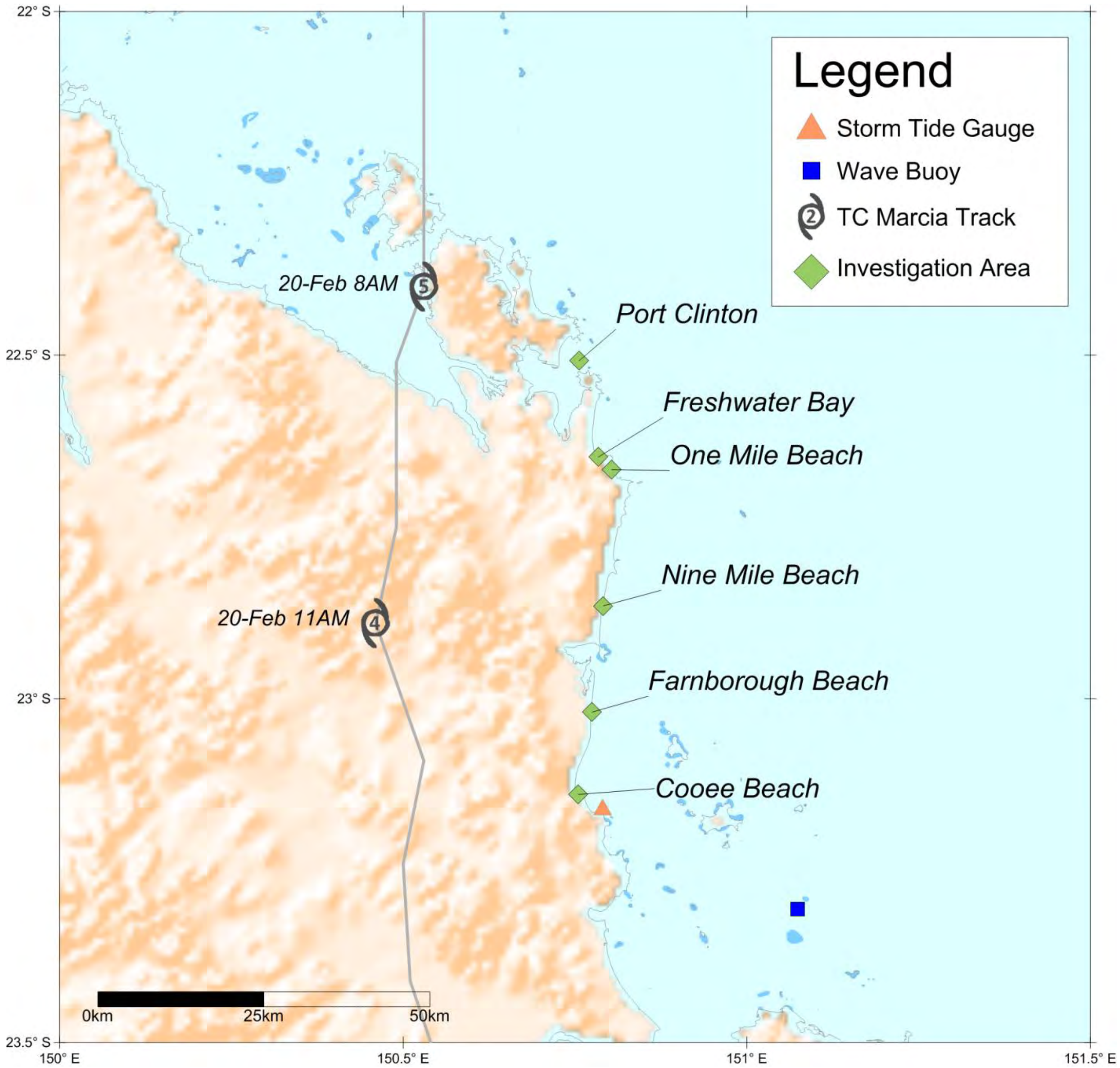

Figure 16 Locality map of post tropical cyclone Marcia field inspection

3.1.2 Site characteristics

The Capricorn Coast is located on the Central Queensland coast within Livingstone Shire. The main townships for the region are Yeppoon and Emu Park. The coastal zone consists predominantly of sandy macrotidal beaches and headlands. The bathymetry of Keppel Bay is complex and unique along Queensland's east coast. Near the mouth of the Fitzroy River, the bathymetry is quite flat and shallow with the 20 m contour being about 25 km offshore. The bathymetry steepens north of Farnborough Beach such that the 20 m contour is only about 4 km offshore at Nine Mile Beach. As a result, the beaches to the south of Yeppoon are dissipative (Masselink and Short, 1993) and characterised by steep upper beach profiles with wide tidal flats at low tide. To the north, the beaches and nearshore bathymetry are steeper and so exposed to higher wave energy. The foredunes along the Capricorn Coast are typically within the range of 5 to 12 m AHD. Behind these dunes the topography varies along the coast. To the south of Corio Bay the topography is predominantly parallel accretion ridges amongst headlands. To the north of Corio Bay, the onshore topography is dominated by high parabolic dunes and blowouts formed during the Pleistocene and Holocene accretion periods. These dunes are in the order of 100 m AHD.

There are a number of small islands within Keppel Bay, the larger being Great Keppel and North Keppel. These two islands influence the bathymetry in their lee, with the 10 m contour extending to them. Further offshore to the north east is the Capricorn Channel and the southern extent of the Great Barrier Reef which is approximately 180 km offshore. The Capricorn Coast is adjacent to the region where the continental shelf is widest. About 100 km to the south east are the Capricorn and Bunker Groups of coral islands and reefs (Figure 17).

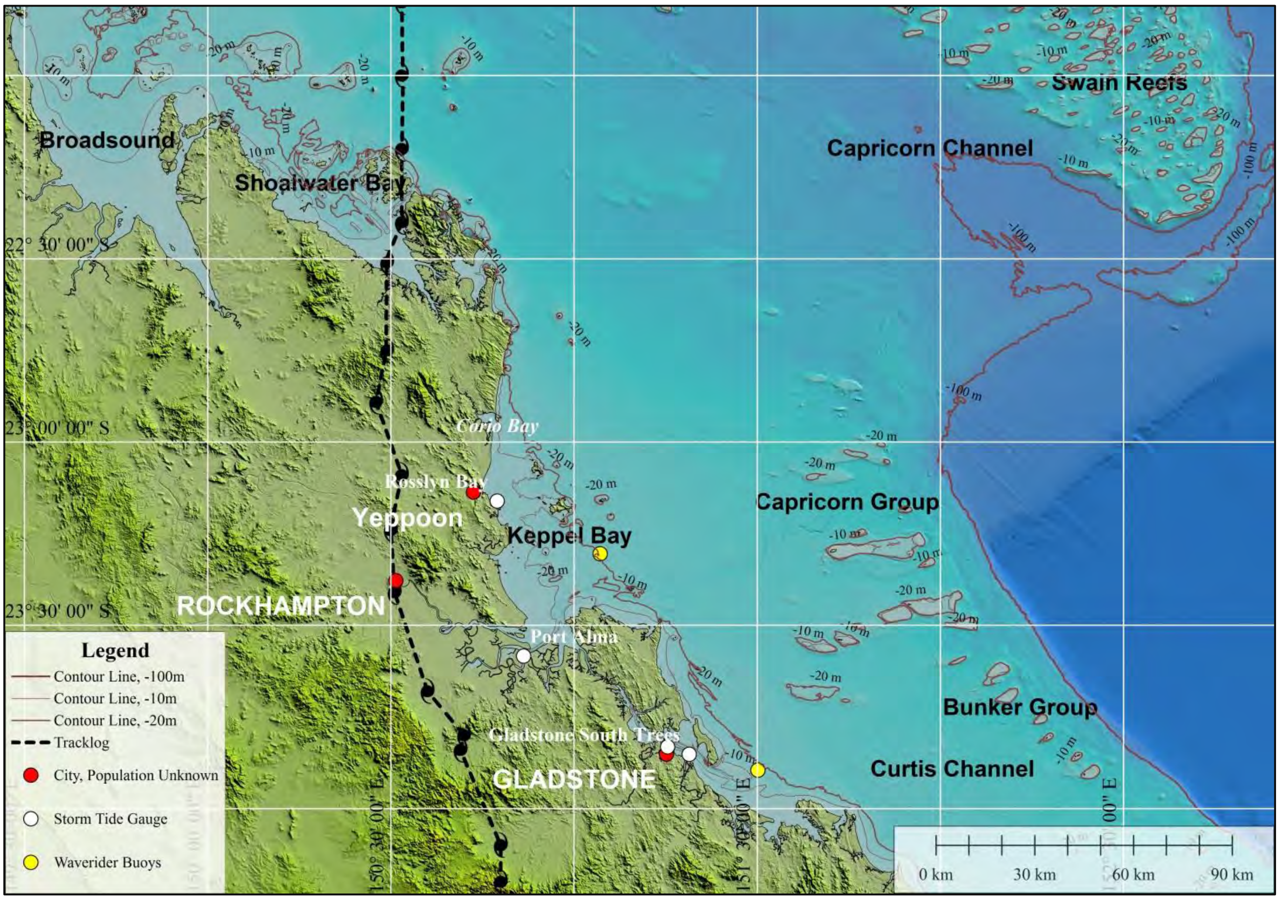

Figure 17 Capricorn Coast

The Capricorn Coast is exposed to a moderate climate of mixed sea and swell waves, their influence being governed by the complex bathymetry, reefs and islands. Higher wave energy would be expected to the north of Corio Bay where the bathymetry steepens significantly. Wave data recorded by the Emu Park waverider buoy suggests the median significant wave height for this site is about 0.75 m but can exceed 3 m in extreme events (Figure 18). The peak wave period typically ranges between 2 and 17 seconds with 70 per cent of all records ranging between 3 and 7 seconds (Figure 19). Peak wave directions range between 60 and 120 degrees true north (Figure 20).

The Capricorn Coast is part of a macrotidal region between Gladstone and Mackay. The semidiurnal spring tide ranges in this region are mostly within 4 to 6 m, amplifying to a 9 m tidal range near St Lawrence (Figure 21).

The complex bathymetry and large tides will significantly influence the storm tide level along the coast. Further detail about the Capricorn Coast between Cattle Point and Stockyard Point is described in BPA (1979).

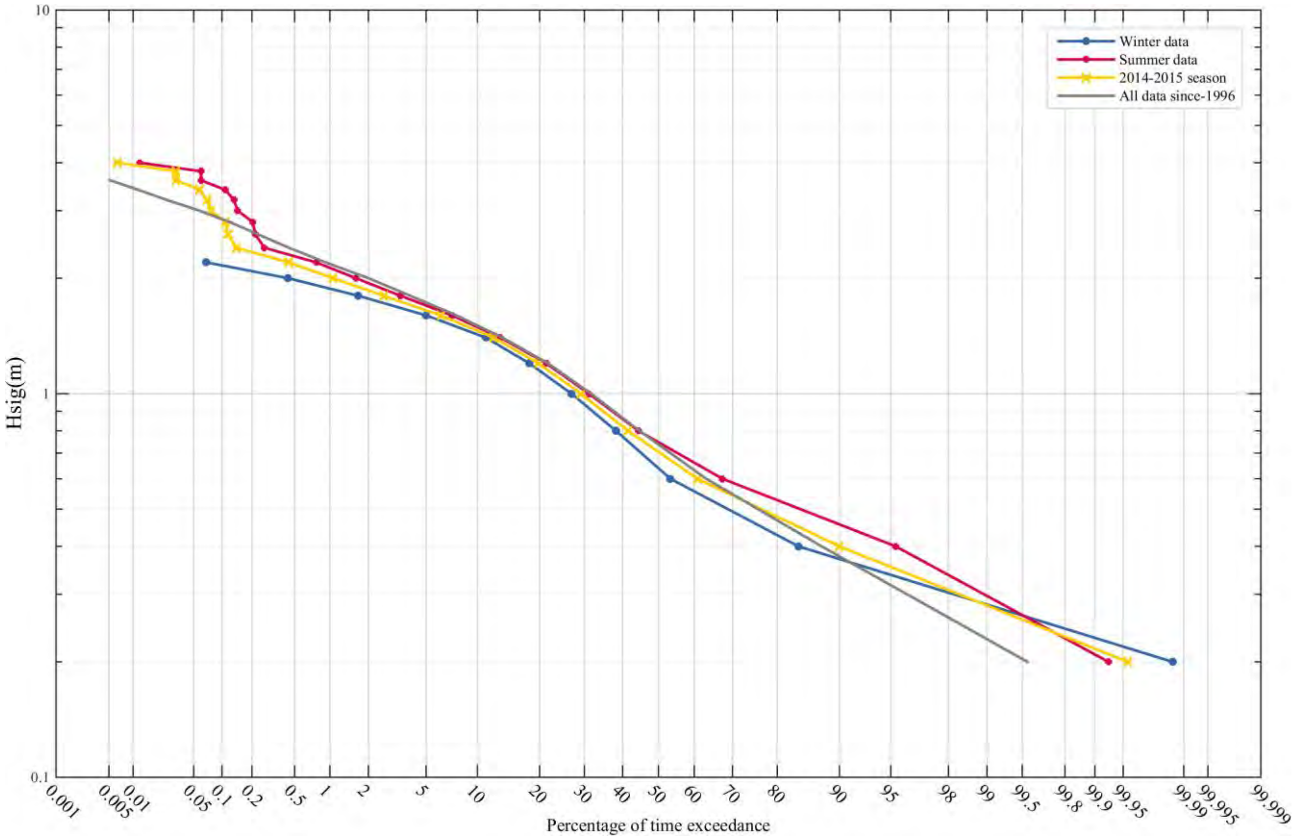

Figure 18 Hsig exceedance plot for Emu Park waverider data

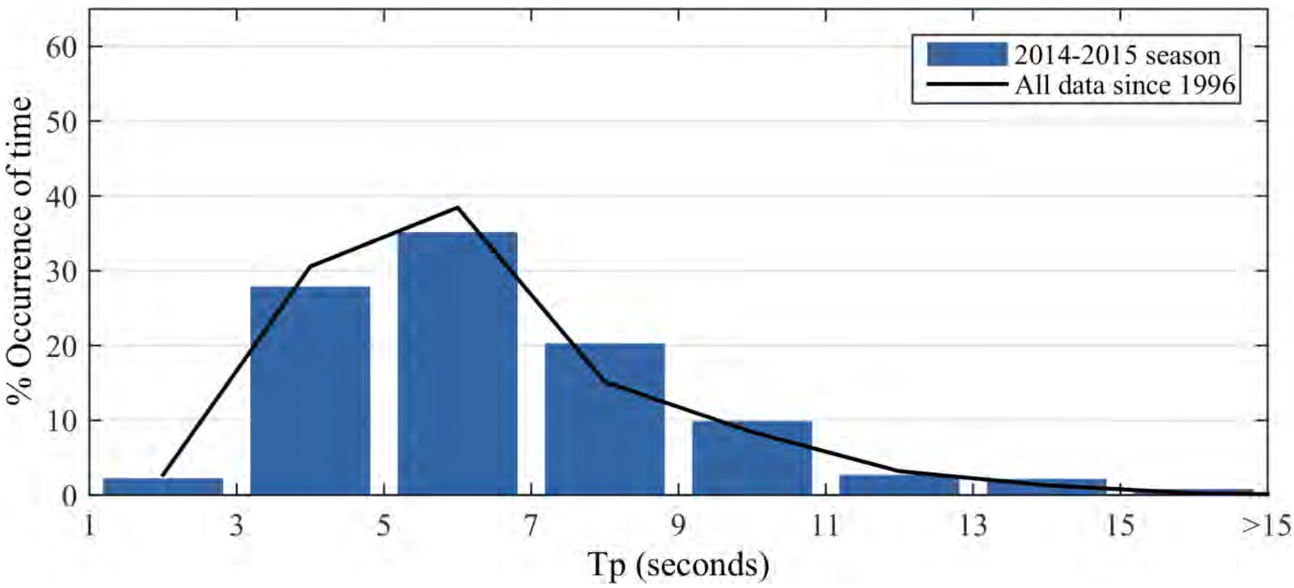

Figure 19 Peak wave period occurrence for Emu Park waverider data

Figure 20 Wave Access (BPA, 1979)

Figure 21 Tidal Characteristics (BPA, 1979)

3.2 Field activities

Coastal areas from Shoalwater Bay military training area south to Rosslyn Bay were inspected from 09 to 11 March 2015, two and a half weeks after the event. The Byfield and Shoalwater Bay areas were largely inaccessible following TC Marcia due to damage to beach access points, and large amounts of fallen timber restricting vehicular access along roads. Refer to Appendix B for field investigation photographs.

Figure 22 shows the tides at Rosslyn Bay for the weeks following TC Marcia. As the system crossed at the peak of a spring tide period, the reducing tide range over proceeding tides would be unlikely to have disturbed debris lines and other traces left over more elevated sections of the upper beach and foredunes. When weather forecast models projected deteriorating weather conditions for the end of the second week in March from a system which later developed into TC Nathan, the decision was made to advance the field investigation so that as much information about the impact of TC Marcia could be gathered before traces of debris and scarping were degraded.

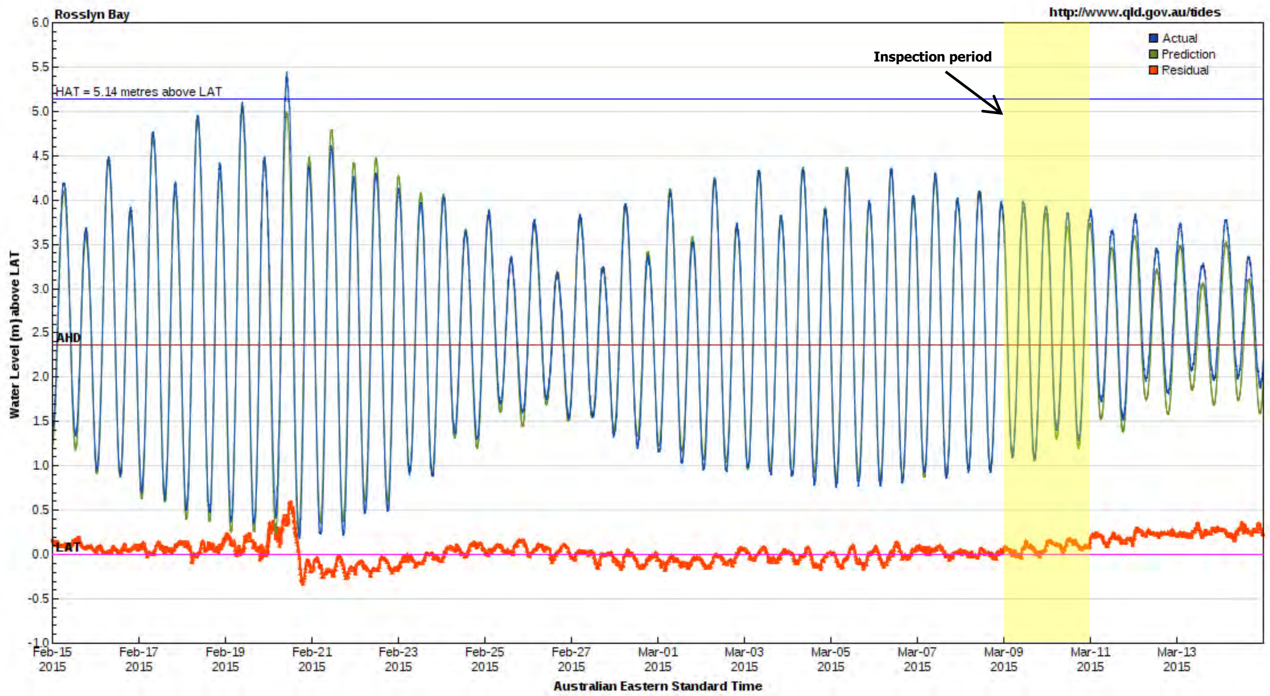

Figure 22 Tide Levels at Rosslyn Bay proceeding TC Marcia (yellow indicates inspection period)

Generally, the inspections involved a number of activities including:

- Visual Inspections: the gathering of photographic evidence of signs of coastal impacts and possible inundation as indicated by visual debris lines. Inspections were undertaken by either beach access by vehicle or observations from a boat.
- Beach profile surveys: undertaken by kinematic GPS along historic shore normal survey lines (where available) from the foredunes to the water. The choice of locations depended on a number of factors including local coastal impact, access, communications and time constraints.
- Debris line survey: with elevated and rough seas, buoyant debris such as pumice stone and vegetation creates distinct lines along the coast at the onshore extent of the waterline. These lines of debris provide an indication of the inland extent and height of inundation caused by the event. The level will be a combination of the storm tide as well as wave run-

up, which can be variable along the coast due to variations in beach slope and local breaking wave heights.

The activities undertaken for each location inspected are detailed in Table 4.

Table 4 Inspection activities during 09 to 11 March 2015

#	Date	Time (EST)	Location	Remarks
1	09/03/2015	1000–1500	Freshwater Bay	Survey and inspection of erosion, scarping and debris lines for selected points from the beach access track at the southern end for three kilometres. (Photography, beach profiles and surveyed debris points)
2	09/03/2015	1030–1400	Port Clinton	Queensland Parks and Wildlife Services (QPWS) facilitated examination of the Port Clinton area by boat. (Photography)
3	10/03/2015	1000–1200	One Mile Beach	Survey and inspection of erosion, scarping and debris lines at selected points along the beach. (Photography, beach profiles and surveyed debris Points)
4	11/03/2015	0900–1130	Nine Mile Beach	Visual inspection of damage to national park facilities, erosion, scarping and debris lines south of Freshwater Creek. (Photography)
5	11/03/2015	1300–1600	Farnborough Beach	Survey and inspection of erosion, scarping and debris lines at selected points along the beach. Inspection to damage at beach access points at Bangalee and Mercure Capricorn Resort. (Photography, beach profiles and surveyed debris points)
6	11/03/2015	1630–1715	Ross Creek/Cooee Bay/Rosslyn Bay	Inspection of rock wall, and immediate area, (Photography)

4 Beach conditions

4.1 Freshwater Bay

Freshwater Bay is located on the eastern side of the Shoalwater Bay military training area, approximately 55 km north of Yeppoon. The 10 km beach has a north-south orientation with a pocket formed at the southern end by the prominent rocky headland separating it from One Mile Beach (Figure 23).

Photograph 1 Receded bank previously encompassing pipe at Freshwater Bay

Photograph 2 Damage to beach access at Freshwater Bay

Freshwater Bay has a gentle beach slope and is characterised by low vegetated grey dunes at the southern end with high parabolic dunes further north of the order of 15 to 30 m AHD, causing three distinct types of impact to be visible. In the area near the beach access road at the south end, erosion had resulted in the retreat of the vegetated grey dunes which had been overtopped (Photograph 1). Vegetation and rubbish formed a mound of debris through the trees roughly 5 m inland of the erosion scarp and a number of larger undermined trees lay fallen along the beach. Wave action had removed posts from alongside the beach access road and shifted the rocks that formed the main ramp (Photograph 2). Local personnel provided advice that the grey dunes had receded several metres with an erosion scarp of 0.8 metres. In the area slightly to the north, the dune was buried beneath a mass of debris consisting of washed up timber, rubbish, and copious amounts of pumice stone. The entire front face of the dune was replaced by pumice. Further north, as the mud banks became sand and the height of the dune increased, the front face of the dunes had been eroded resulting in large areas of scarping.

Figure 23 Freshwater Bay and Port Clinton (aerial photography taken in 2014 courtesy the Queensland Government Globe)

4.2 Port Clinton

The Port Clinton area was visually inspected via boat by DSITI and BoM, facilitated by two local Queensland Parks and Wildlife Services (QPWS) rangers. The locations described below are numbered in Figure 23.

Within the more sheltered parts of Port Clinton along the South Arm (location 1), near vertical unvegetated dune faces were observed (Photograph 3). Most of the trees appeared to have been defoliated and much of the remaining foliage seems to have died off, possibly due to sea spray from high winds during TC Marcia. Rangers stated that mangroves were missing from the area. Along the eastern exposed tip of the south arm (location 2), a section of coast that is exposed to the ocean, only minor scarping was seen which appeared to affect tree stability. Evidence of a minor pumice stone debris line was observed along with wind damage to the tree foliage. Along the Clinton Low Lands (location 3), rangers pointed out mangroves were missing from the area. In addition coffee rock, usually covered, was exposed. The dunes appeared to have severe vertical scarping and trees have become unstable as a result (Photograph 4) and are also missing foliage. The area may have experienced a funnelling affect from the storm tide. The area adjacent to the dunes in Photograph 4 had been inundated quite severely.

At West Point (location 4) there was evidence of wind damage to vegetation, and a slight pumice stone debris line. However, no major erosion to the beach was observed. Along the exposed section of Port Clinton (location 5) extending north towards Flinders Watering Gully there was no major evidence of storm tide damage. The dunes faces were unvegetated. However, it is unclear whether this was a result of TC Marcia or a previous event. Scarping of less than 0.5 m was observed at the base of the dunes along with a slight pumice stone debris line.

Photograph 3 South Arm of Port Clinton (location 1)

Photograph 4 Scarping at Clinton Low Lands (location 3)

Between Flinders Watering Gully (location 6) and Delcomyn Bay (location 7) much of the exposed coast is rocky headland. Wind damage had affected much of the vegetation in this area. This area also contains a number of pocket beaches including a cobble stone pocket beach which contained a debris line made of logs and driftwood at the top of the beach face. Wind damage was also evident in this area too. Slightly further north of the cobble stone pocket beach was a sandy pocket beach which had scarping of 0.5–1 m in some sections. A number of trees have fallen potentially from foundation instability from scarping and wind damage.

At Pearl Bay (between locations 8 and 9), large sections of vegetation were missing and rangers stated that this area did not normally contain vegetation patches. Remaining vegetation seemed to have been stripped almost bare of foliage. Beach scarping was minimal in the area, but it had resulted in some uprooted trees. Toward the northern end of Pearl Bay (location 9), beach scarps were more evident and a much larger pumice stone debris line was observed (Photograph 5).

Photograph 5 Large pumice stone debris lines at the northern end of Pearl Bay

4.3 One Mile Beach

One Mile Beach is a smaller beach located just south of Freshwater Bay inside the Shoalwater Bay military training area and is about 50 km north of Yeppoon. The beach is adjacent to large parabolic dunes (Photograph 6) which form a complete barrier to any inundation. There were erosion scarps of up to 2 m high and where the foredunes were slightly lower, small break through areas existed where inundation had caused pumice stone to have been washed over. Towards the southern end of the beach, inundation caused large deposits of pumice stone to accumulate covering roughly 100 m of beach and the base of the headland (Photograph 7).

Photograph 6 One Mile Beach north end

Photograph 7 Pumice stone washed up at the southern end of One Mile Beach

Figure 24 Parabolic and blowout dune structure at One Mile and Nine Mile Beaches (aerial photography taken in 2014 courtesy the Queensland Government Globe)

4.4 Nine Mile Beach

Nine Mile Beach is approximately 30 km north of Yeppoon and is accessed via the Byfield National Park. The coastline consists of high parabolic and blowout dunes bounded by rocky headlands. Scarping was visible along the entire beach. In sections, trees had been undermined and lay at the base of the scarp face. At the northern end, dune erosion had caused the partial collapse of a dune stabilisation fence with the remaining section of fencing on the edge of the scarp about to fail (Photograph 8). Boardwalk entrances to Myrtella and Casuarina camping grounds had buckled due to sand loss, indicating that the dune has been eroded with an estimated inland retreat of 4 to 5 m and an erosion scarp of 1 to 2 m (Photograph 9). Along sections of the dune, pumice stone had been deposited on the dune slope above the erosion scarp indicating the height of inundation. At the southern end of the beach, deposits of pumice stone that had been washed up at the toe of the dune are estimated to be 1 m deep (Photograph 10).

Photograph 8 Undermined dune fencing at Nine Mile Beach

Photograph 9 Undermined walkway at Myrtella camping ground, Nine Mile Beach

Photograph 10 Pumice stone washed up at the southern end of Nine Mile Beach

4.5 Farnborough Beach

Farnborough Beach (Figure 25), located just north of Yeppoon, was inspected from Bangalee north to Sandy Point (southern side of Corio Bay). The dune system here can be described as truncated transgressive dunes with active dune blowouts (BPA, 1979). At Bangalee, the dune had been eroded resulting in: vegetation falling onto the beach; exposed plant roots (Photograph 11); damage to the 4WD beach entrance, walkway access points and fences; and scarping of the dune.

Where there were lower sections of foredune, deposits of pumice stone had been left on the scarp crest. Erosion of the foundation below the concrete 4WD access ramp at Mercure Capricorn Resort Yeppoon (Photograph 12) had caused the seaward slab section to subside and the walkway stairs had also been destroyed (Photograph 13). Further north, the speed limit sign on the beach had been repositioned, leaning to the side with its concrete base exposed as a result of wave action. Towards Sandy Point the impact on the coast was similar resulting in erosion and scarping of the high dunes in the order of 2 m (Photograph 14).

Figure 25 Farnborough Beach (aerial photography taken in 2014 courtesy the Queensland Government Globe)

Photograph 11 Destabalised vegetation and exposed roots at Bangalee

Photograph 12 Damage to the Mercure Capricorn Resort vehicle access at Bangalee

Photograph 13 Damage to walkway access at Farnborough Beach

Photograph 14 Beach erosion along Farnborough Beach

4.6 Cooee Bay

Cooee Bay is located 2 km south of Yeppoon (Figure 26). The area consists mostly of rocky headlands. However, there is a section of low lying properties just to the south of Ross Creek. At the western end of Ocean Parade where the dune was very low there were areas of overwash visible where sand from the beach had been transported inland onto nearby land parcels as well as uncovered sections of coffee rock along the beach. Damage to the groyne nearby on the southern side of Ross Creek was observed with a large section of the rock wall having collapsed where the battering force of the wave action had caused it to fail (Figure 27). Additionally, the extent of the beach erosion can be estimated by considering the height of sand against the rock before and after the event. Based on rough scaling it is estimated that 0.5 m to 1.0 m of sand was removed from the beach.

Figure 26 Cooee Bay and Ross Creek (aerial photography taken in 2014 courtesy the Queensland Government Globe)

Figure 27 Ross Creek Groyne, before and after TC Marcia (Courtesy Fugro Roames Pty Ltd, 2015)

5 Measured inundation levels

Debris lines comprising vegetation and pumice stone were surveyed by CIU staff to quantify inundation levels. The levels surveyed provide an indication of the maximum inundation level reached, including tide, storm surge, wave setup and run-up components. Each measured debris point represents the highest level for debris found at a particular point parallel to the coastline. As the morphology of the coast is varied, features, such as beach angle, beach slope, dune elevation and the presence of large bays, inlets or outcrops result in maximum inundation levels being extremely location specific.

A Real-Time Kinematic (RTK) Global Positioning System (GPS) was used to survey the inundation levels and beach profiles with an accuracy of 20 mm ±1 ppm relative to the reference marks shown in Table 5. Where it was unsafe to have staff stand atop the unstable cliff edge of large dune scarps, the height of the scarp was assessed using RTK to take a point at the base of the scarp then extending a staff to the top of the scarp and making an estimation of the top edge of the scarp. In some cases the base of the scarp was obscured by sand that had subsided after the event and not been washed away and estimations had to be made several metres seaward of the scarp face.

RTK surveys conducted at Freshwater Bay and One Mile Beach used GPS corrections via UHF radio from a temporary reference location due to the absence of Permanent Survey Marks with suitable elevation levels in the area. GPS readings were recorded for a 24-hour period and processed via AUSPOS (Geoscience Australia, n.d.) to establish the location and AHD elevation of the temporary reference point. RTK surveys conducted along Farnborough Beach and around Yeppoon obtained corrections via GPRS mobile data network from a Continuously Operating Reference Station (CORS) network. The reference location used was the AuScope station at Rosslyn Bay by way of Geoscience Australia’s NTRIP Caster. AusGeoid 2009 was used to convert Ellipsoidal height to AHD.

Table 5 RTK base reference locations

#	Latitude / Easting	Longitude / Northing	Ellipsoidal / AHD Elev.	Remarks (Zone 56)
1	−22°39’08.29850” 272691.392	150°47’16.69366” 7493278.604	62.509 m 10.263 m	Temp. reference established via AUSPOS File Reference: *TCMAR.15O* Antenna: *SOK GSR2700ISX NONE* Start time: *2015/03/08 23:10:30Z* End time: *2015/03/10 02:23:00Z*
2	−23°09’39.58844” " 273754.338	150°47’24.28230” 7436941.063	58.253 m 6.966 m	Rosslyn Bay AuScope station Reg13 certificate

The resulting inundation levels and beach profiles are presented in Appendix A. In each case a totem pole has been added showing storm tide evacuation zones based on Rosslyn Bay tidal planes and the framework provided by the National Storm Tide Mapping Model for Emergency Response (Department of Emergency Services et al, 2003). Debris elevations and scarp magnitudes from the beach profiles are summarised in Table 6. Debris elevations for the areas visited were in the range of 3.6 to 5.5 m above AHD, which is approximately 0.8 to 2.7 m above HAT based on the tidal planes for Rosslyn Bay. The highest debris point surveyed was located at the southern end of One Mile Beach where pumice stone had been washed up to create a solid pumice stone layer at the base of the beach knoll. Similar values were observed at Freshwater Bay, with maximum levels slightly lower for Farnborough Beach.

Table 6 Measured inundation levels following TC Marcia

Location		Ref.	Inundation (m above AHD.)	Scarp Ht. (m)
1	Freshwater Bay – 001	Figure 30	**4.9	1.7
2	Freshwater Bay – 002	Figure 31	5.3	3.0
3	Freshwater Bay – 003	Figure 32	-	4.4
4	Freshwater Bay – 004	Figure 33	**5.0	2.0
5	Freshwater Bay – 005	Figure 34	**4.7	2.0
6	Freshwater Bay – 006	Figure 35	4.4	-
7	Freshwater Bay – 007	Figure 36	**4.5	-
8	Freshwater Bay – 008	Figure 37	-	1.2
9	Freshwater Bay – 009	Figure 38	5.4	0.7
10	One Mile Beach – 001	Figure 40	3.6	2.3
11	One Mile Beach – 002	Figure 41	3.6	1.3
12	One Mile Beach – 003	Figure 42	4.7	1.9
13	One Mile Beach – 004	Figure 43	5.5	-
14	Nine Mile Beach	-	***5.4	-
15	Farnborough Beach – 001	Figure 45	4.8	~1.0
16	Farnborough Beach – 002	Figure 46	-	3.0
17	Farnborough Beach – 003	Figure 47	-	1.8
18	Bangalee – 001	Figure 48	**4.0	1.6
19	Bangalee – 002	Figure 49	3.9	1.4

Scarp heights are approximate only based on visual approximation and survey staff readings.

** indicates debris elevations that have been ascertained visually from a staff and thus have a lower accuracy class.

*** elevation was measured using a level based off an interpolated tide level as the RTK GPS was unable to receive a signal

Where available, comparison to historic Beach Protection Authority (BPA) beach profile data has been made for the four beach profiles taken at Farnborough Beach and is shown in Figure 44 to Figure 47. The BPA data is quite coarse due to extending over a much longer transect. However, with the exception of the ‘LIV215’ data it is possible to infer that since the previous survey in 1996, the dune has receded by tens of metres. Historic BPA data used was supplied ‘as is’ and no attempt was made to confirm its validity.

6 Storm impact rating

Tropical cyclones, east coast lows and large storms have the potential to cause significant morphological changes to the coastal landscape due to the interaction between elevated water levels, extreme wave energy and cyclonic winds on the shoreline. The eventual impact is dependent on many factors including: the shoreline sediment type; local bathymetry; beach slope; ocean barriers such as dune systems; cliffs and artificial structures; as well as the level of vegetation, upkeep and recent previous impacts.

Figure 28 shows a simplistic Storm Impact Scale developed by the United States Geological Survey (n.d.) which can be used to classify the morphological impact observed at the shoreline; the scale is based upon the interaction between the inundation and the dune system.

For the vast majority of the area investigated the relevant Storm Impact Rating was level 2 (Collision Regime). In this situation the elevated water level exceeds the toe of the dune but the dune crest is either too high or the inundation level too low for the dune to be overtopped. The seaward face of the dune must dissipate all incoming wave energy and is thus eroded leaving behind steep cliff like scarps when the water recedes. There is minimal to no impact from inundation behind the dune system.

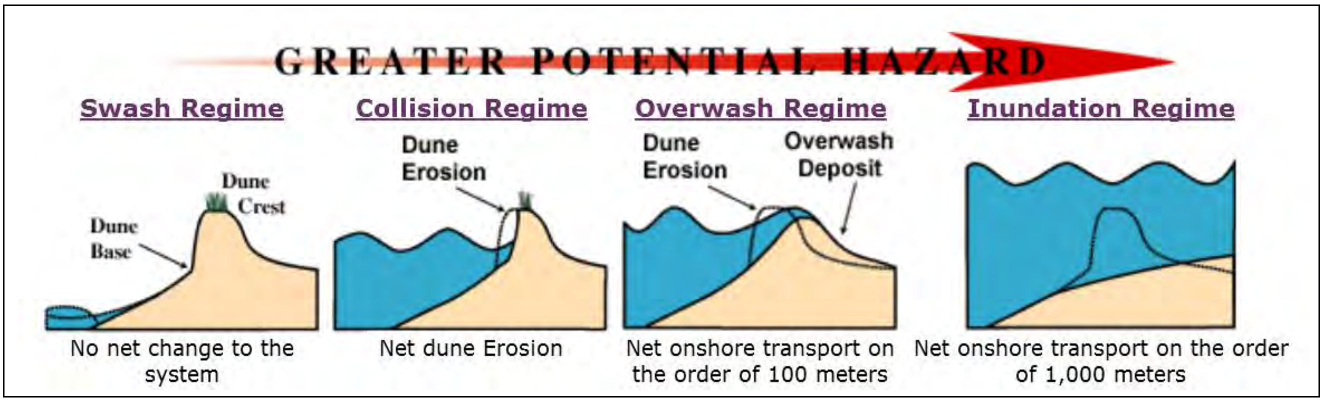

Figure 28 USGS Storm Impact Scale (courtesy *http://coastal.er.usgs.gov/hurricanes/impact-scale***)**

7 Conclusions

TC Marcia crossed the coast as a Category 5 severe tropical cyclone at Shoalwater Bay and subsequently weakened into a low as it moved down the coast before reaching south east Queensland and heading back out to sea. Though the effects of the system were visible in data from Queensland storm tide gauges and wave buoys from Mackay south, the most significant recordings were observed by the Mackay, Emu Park and Gladstone wave buoys and the Rosslyn Bay and Port Alma storm tide gauges.

Recorded storm tide gauge data showed a maximum exceedance above HAT at Rosslyn Bay of 0.30 m, while the Emu Park waverider buoy measured its highest significant wave height since recording began of 4.03 metres. The highest surge of 1.9 m was measured at Port Alma. Fortunately, it occurred near low tide such that the total storm tide was below HAT. Had this surge coincided with high tide, the water level would have exceeded HAT by 1.7 metres. This illustrates the significance of the stage of tide on the total storm tide for macrotidal regions, which could be the difference of minor beach erosion to significant coastal inundation.

Based on the surveyed debris elevation levels which include wave setup and run-up, it is probable that the inundation level experienced near Shoalwater Bay was greater than that at Yeppoon. The highest debris elevation surveyed was 5.5 m AHD at the southern end of One Mile Beach. This equates to approximately 2.7 m above HAT based on the tidal planes for Rosslyn Bay.

In the areas inspected between Shoalwater Bay and Rosslyn Bay, dune erosion had resulted in cliff like scarps of up to 2 m; however, with the exception of a few locations the dune crest had not been breached. Although TC Marcia rapidly intensified before crossing the coast, producing strong winds and large waves in the immediate area, high dunes had largely prevented inundation from impacting areas beyond the beach front therefore limiting damage due to inundation to undermining of vegetation and structures upon the foredune. Beach inspections were dependent on vehicle access within the time available. It is possible that the maximum inundation level experience by the event has not been mapped.

Historic beach profiles taken pre-1996 at Farnborough Beach suggest that this beach has receded tens of metres. However, there is insufficient recent data to suggest the impact of this event alone. The data does provide a valuable resource to examine long term impacts and baseline data for the assessment of any impacts of future events.

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Appendix A

Beach profiles surveyed 09 to 11 March 2015

A.1 Figure labels

A.1.1 Locality Map

- Red line – location of beach profile survey line undertaken by kinematic GPS
- Yellow triangle – location of debris line survey undertaken by kinematic GPS

A.1.2 Profile Figure

- RSBY – highest storm tide level observed during event at Rosslyn Bay storm tide gauge
- HAT – highest astronomical tide for Rosslyn Bay
- LAT – lowest astronomical tide for Rosslyn Bay
- AHD – Australian Height Datum
- Zones – relative seawater level heights for the Yeppoon Storm Tide Warning Graphic and respective zones (State Disaster Management Group, 2013)
- Beach profile – beach profile survey line undertaken by kinematic GPS
- BPA – historic Beach Protection Authority profile line
- Debris point – debris line survey undertaken by kinematic GPS in the vicinity of beach profile
- Toe point – survey point taken at the base of a dune scarp
- Top point – survey point taken at the top of a dune scarp
- Staff base – location of reference staff at the base of an unstable dune
- COPE pole – survey point of a Coastal Observation Programme Engineering (COPE) station

Figure 29 Locality of Freshwater Bay profiles

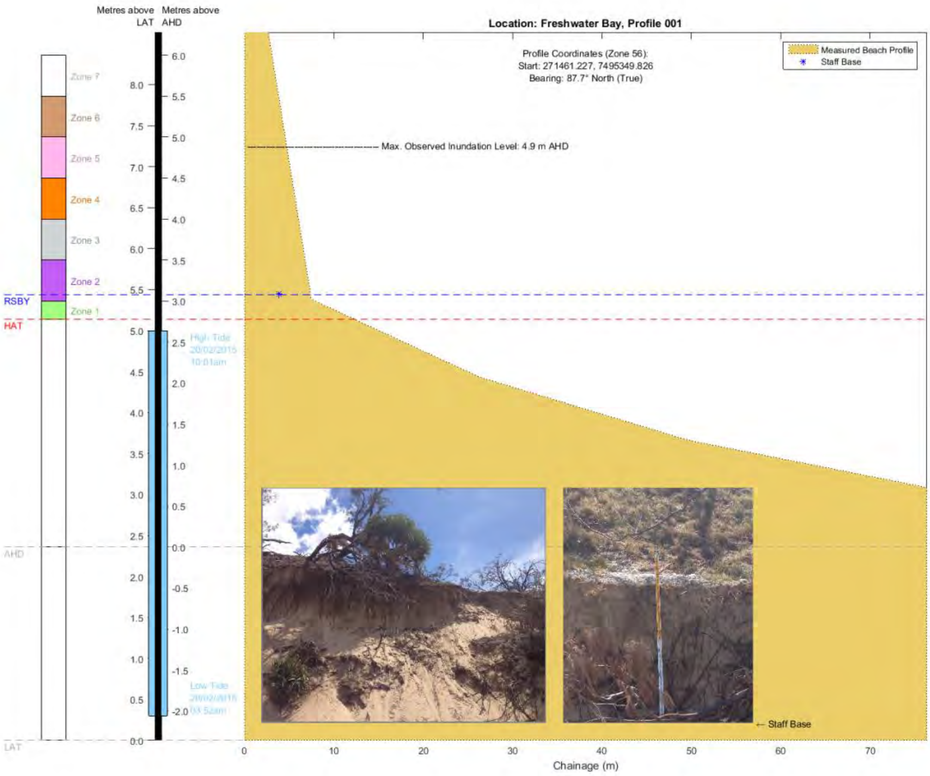


Figure 30 Freshwater Bay profile 01

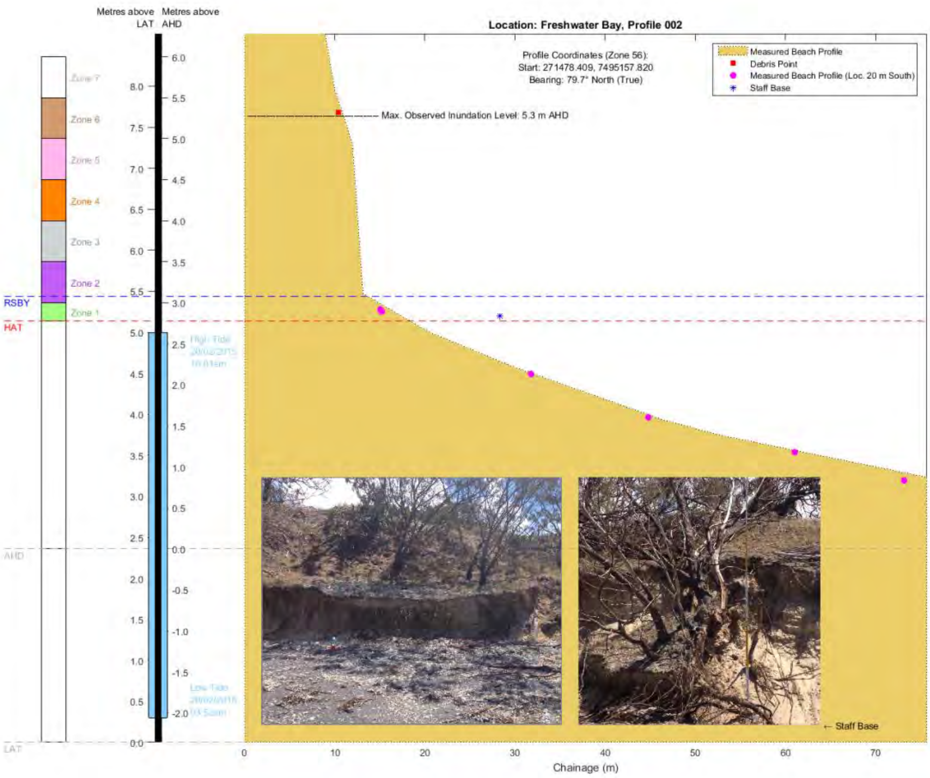


Figure 31 Freshwater Bay profile 02

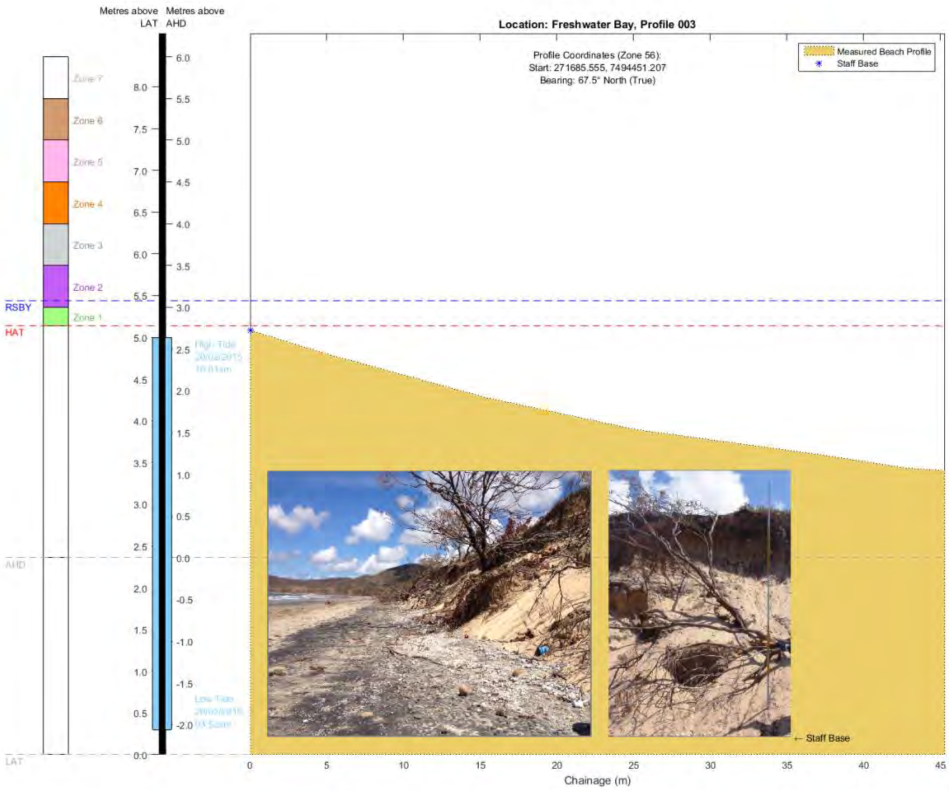


Figure 32 Freshwater Bay profile 03

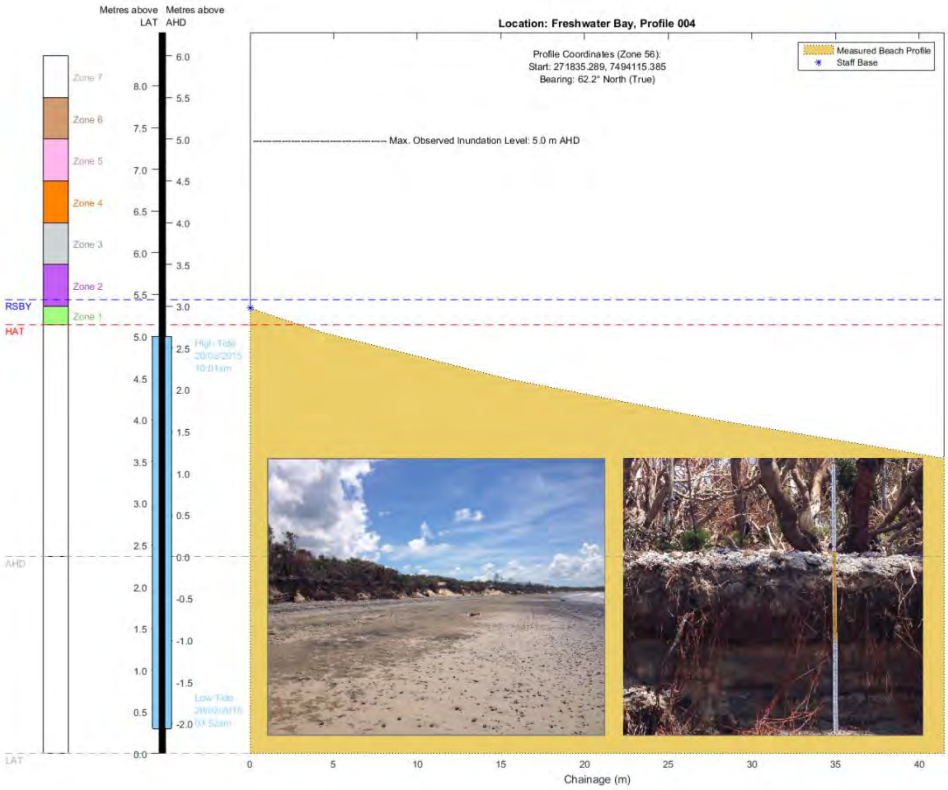


Figure 33 Freshwater Bay profile 04

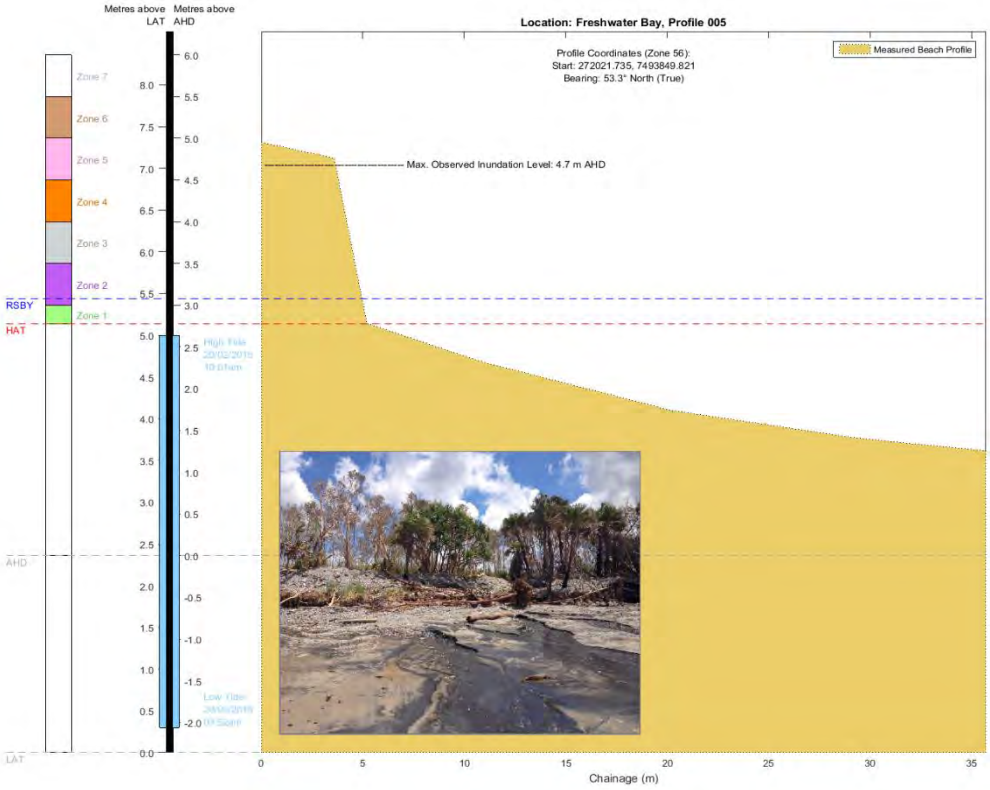


Figure 34 Freshwater Bay profile 05

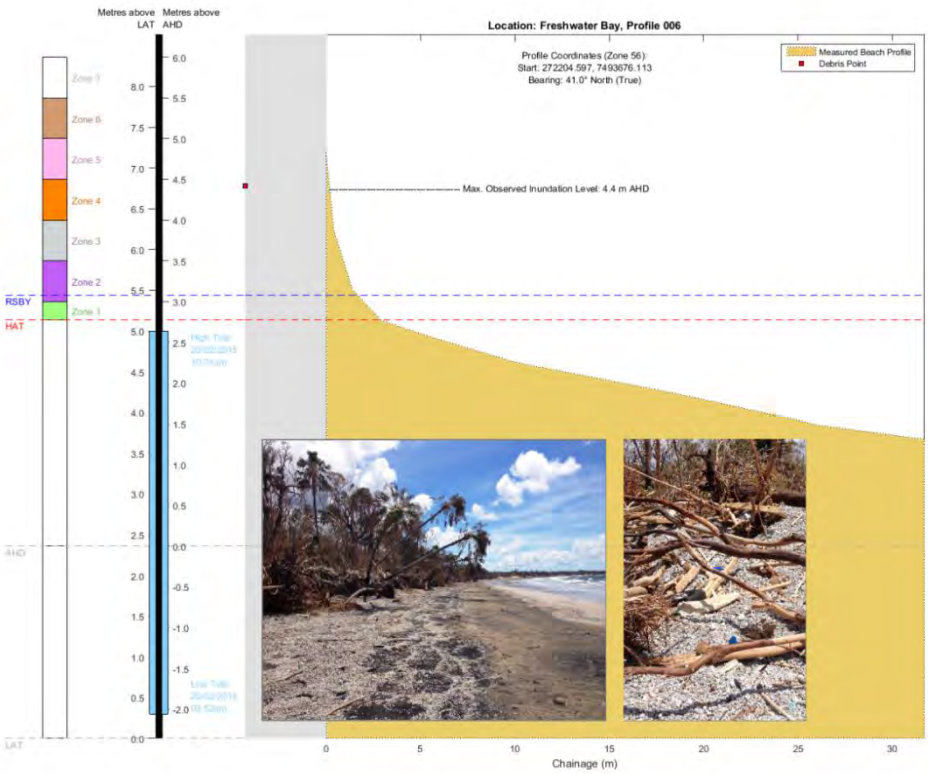


Figure 35 Freshwater Bay profile 06

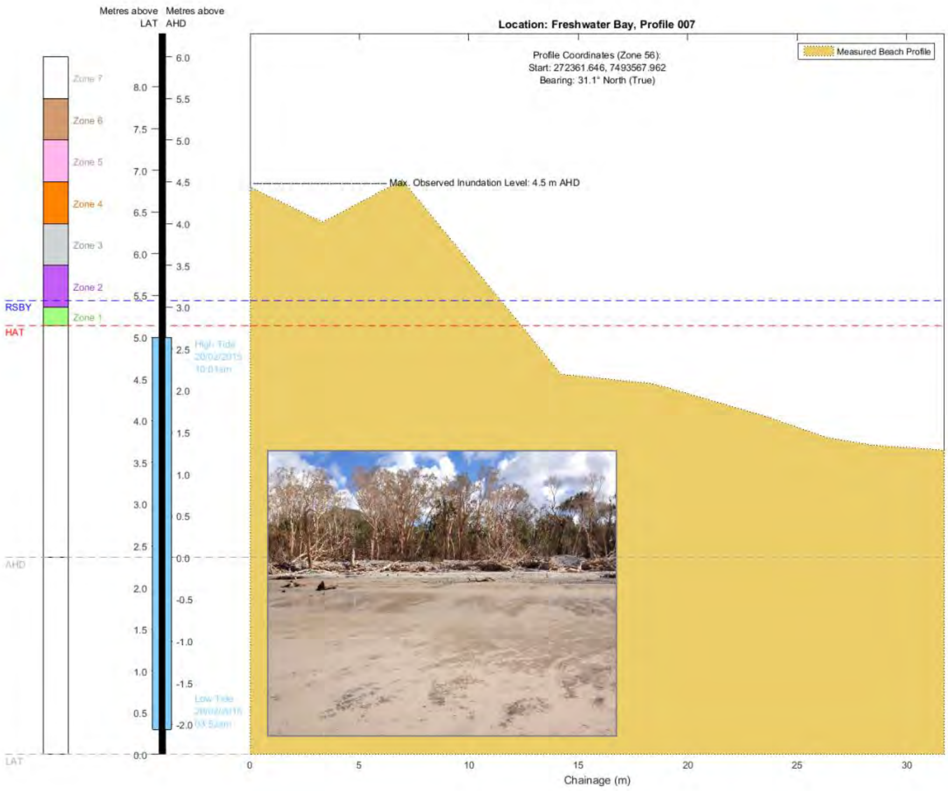


Figure 36 Freshwater Bay profile 07

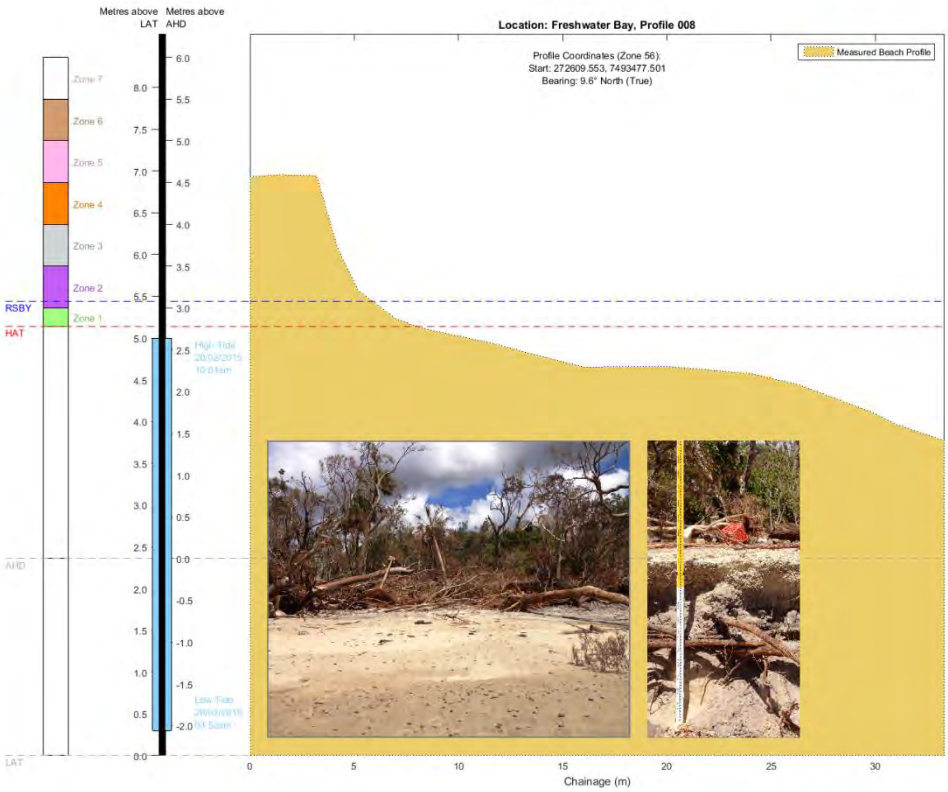


Figure 37 Freshwater Bay profile 08

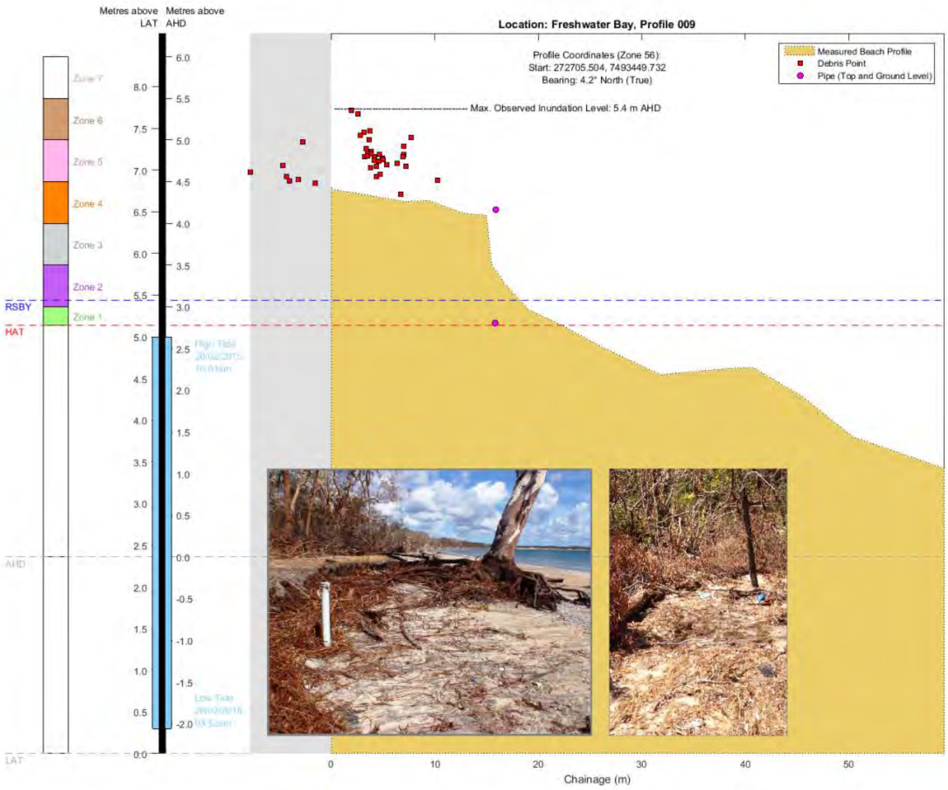


Figure 38 Freshwater Bay profile 09

Figure 39 Locality of One Mile Beach profiles

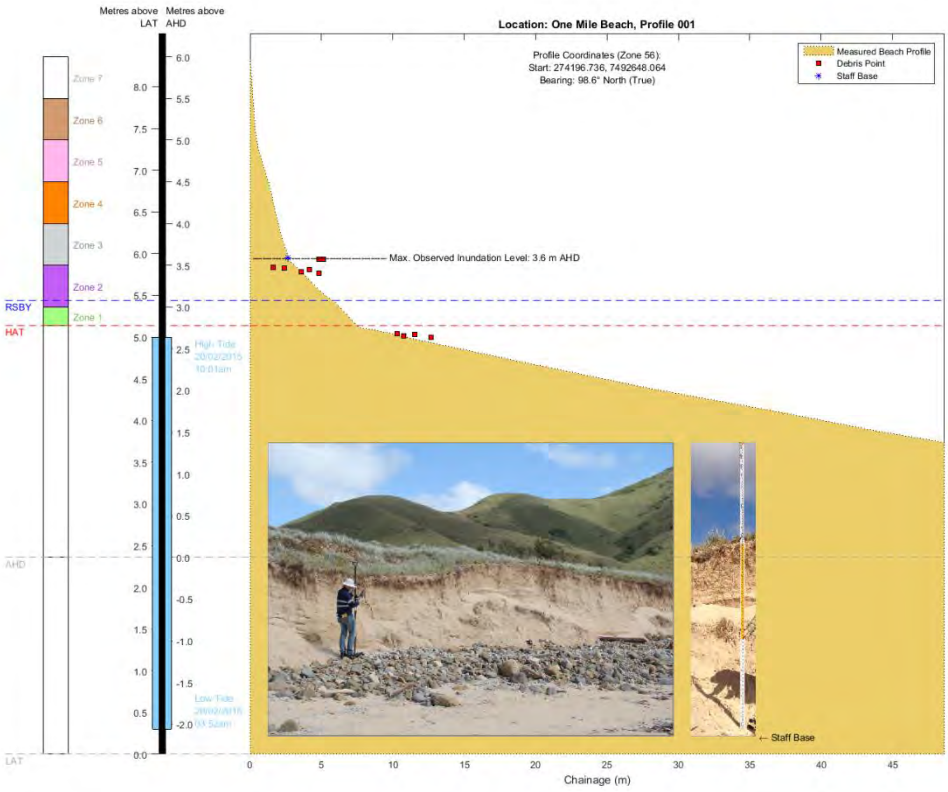


Figure 40 One Mile Beach profile 01

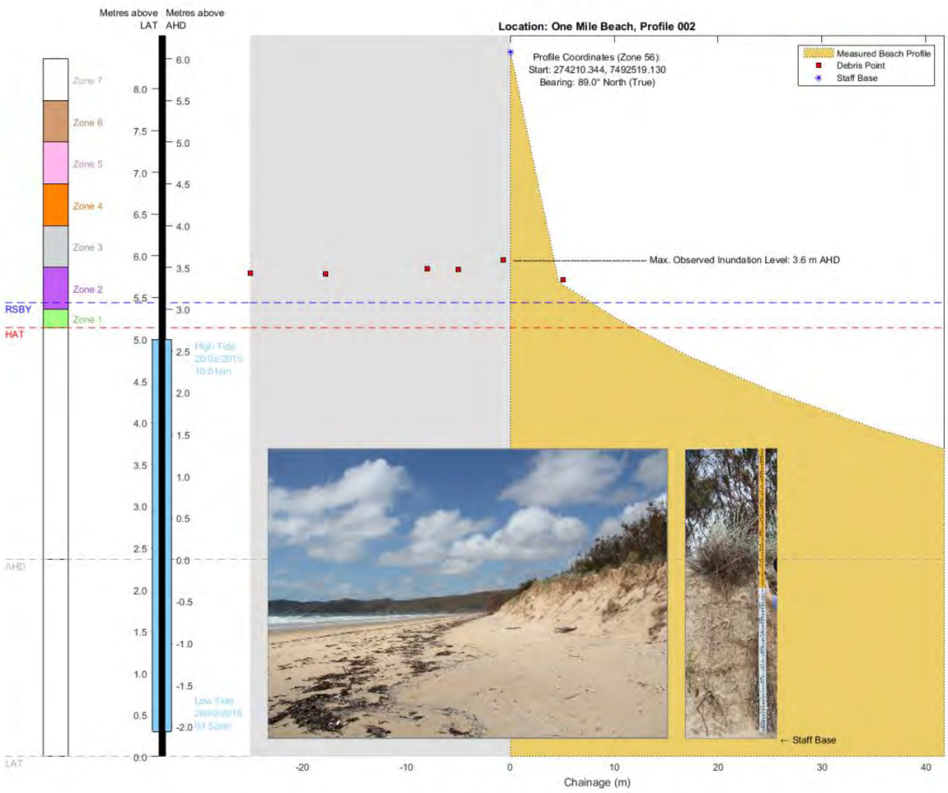


Figure 41 One Mile Beach profile 02

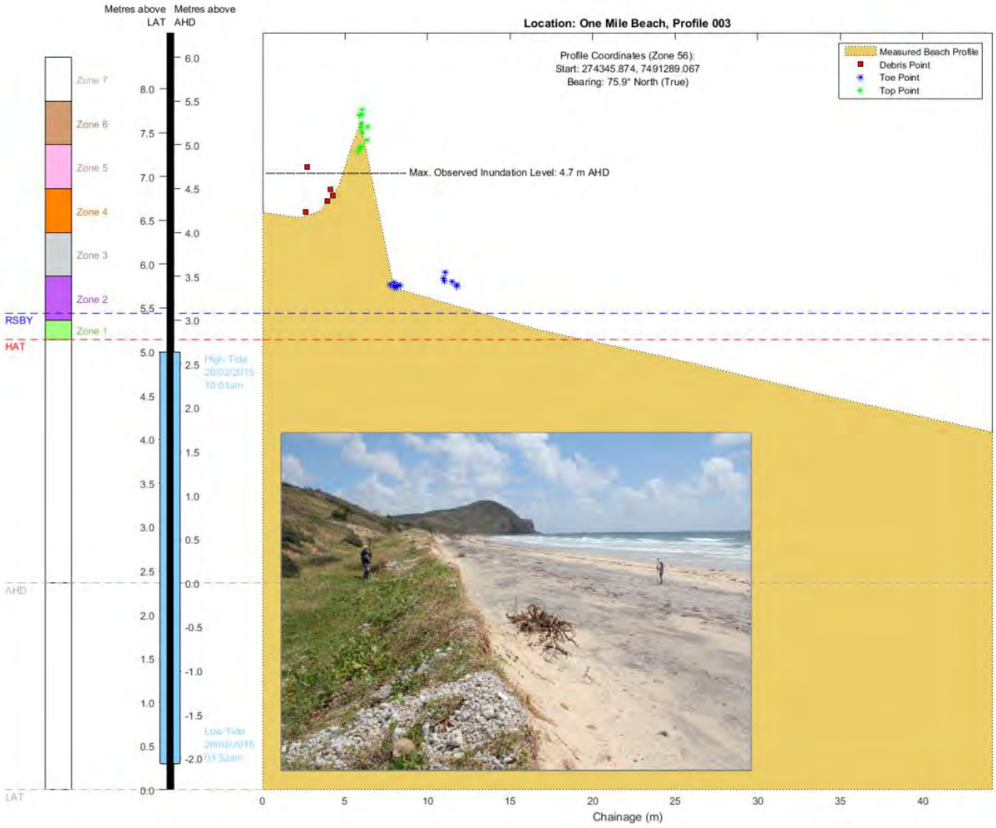


Figure 42 One Mile Beach profile 03

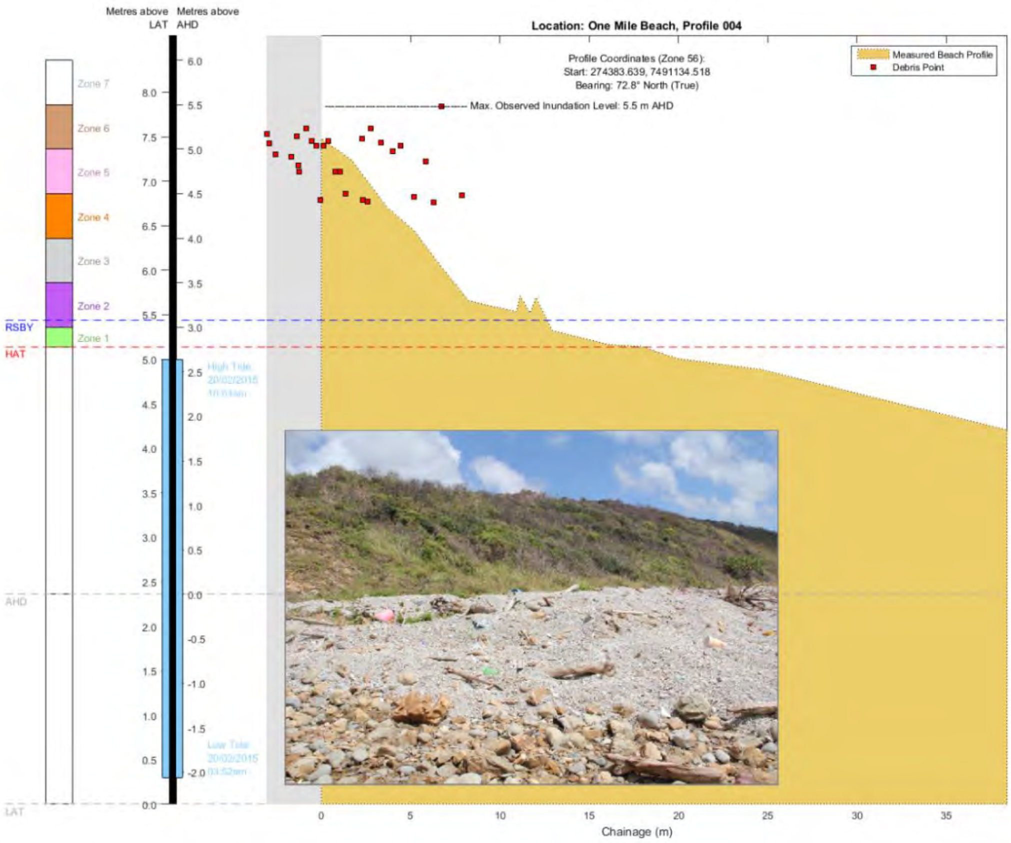


Figure 43 One Mile Beach profile 04

Figure 44 Locality of Farnborough Beach profiles

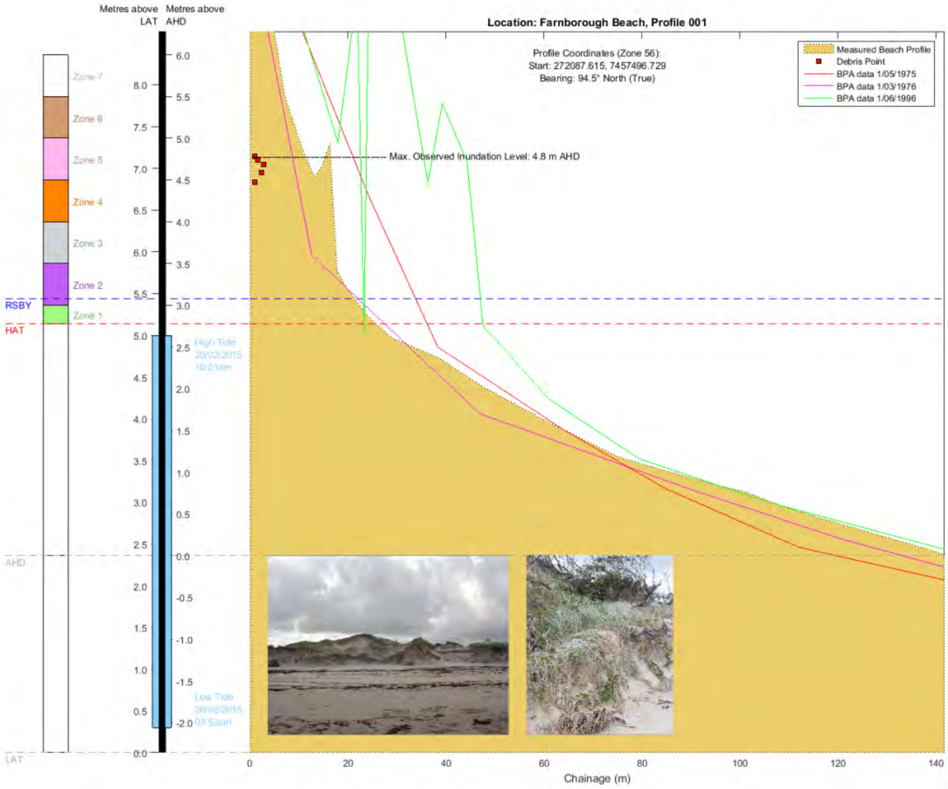


Figure 45 Farnborough Beach profile 01

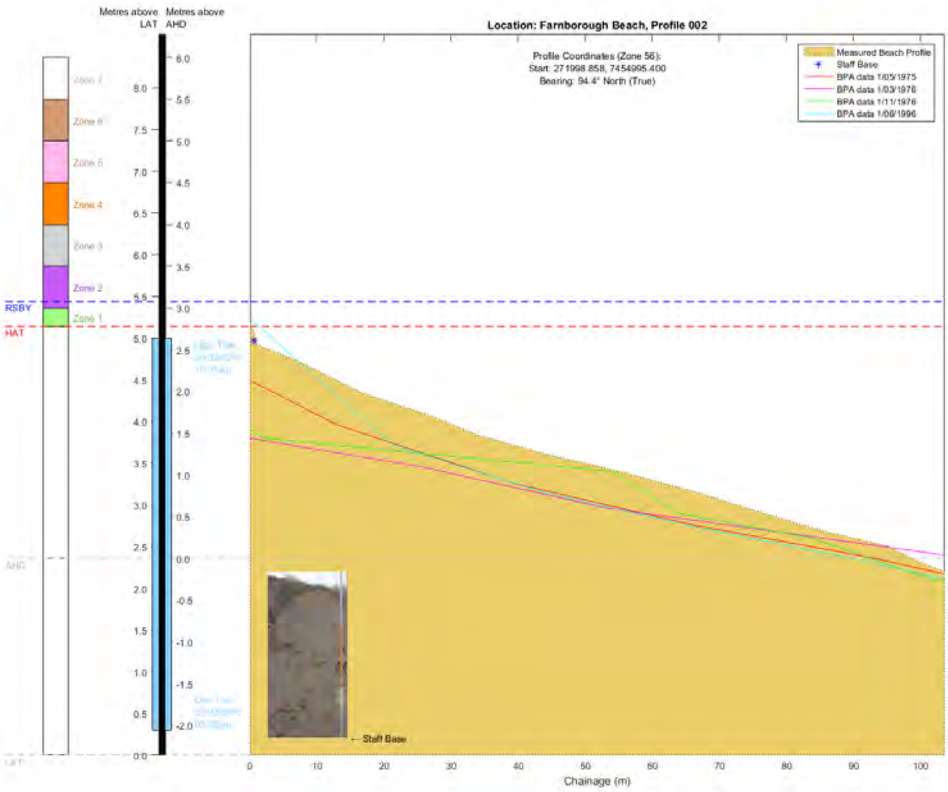


Figure 46 Farnborough Beach profile 02

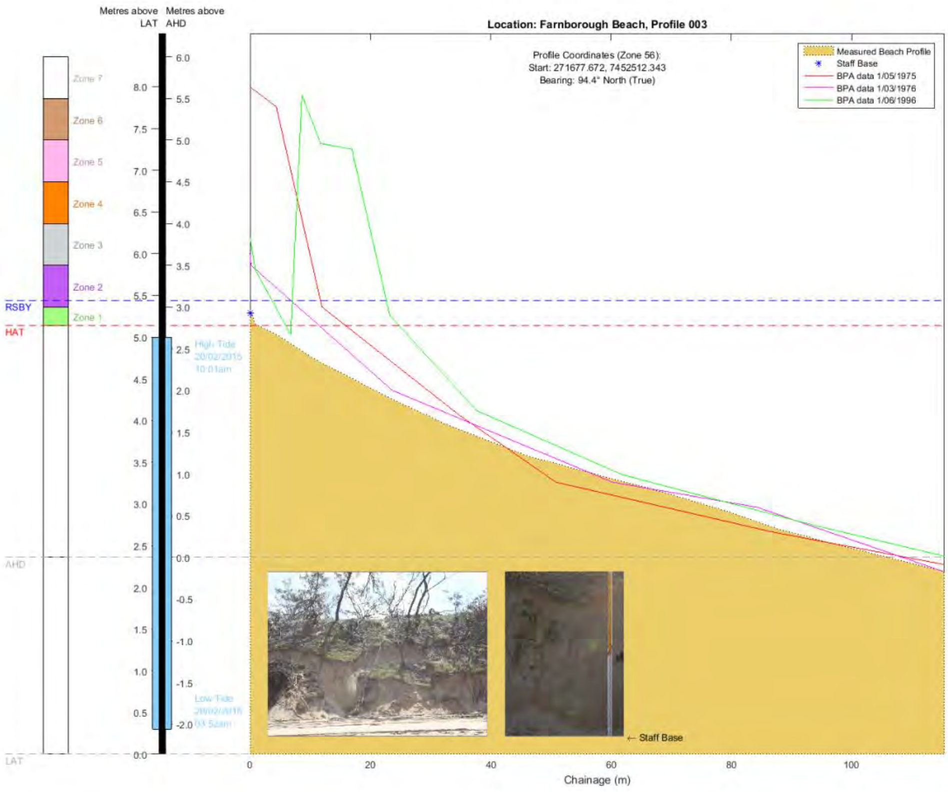


Figure 47 Farnborough Beach profile 03

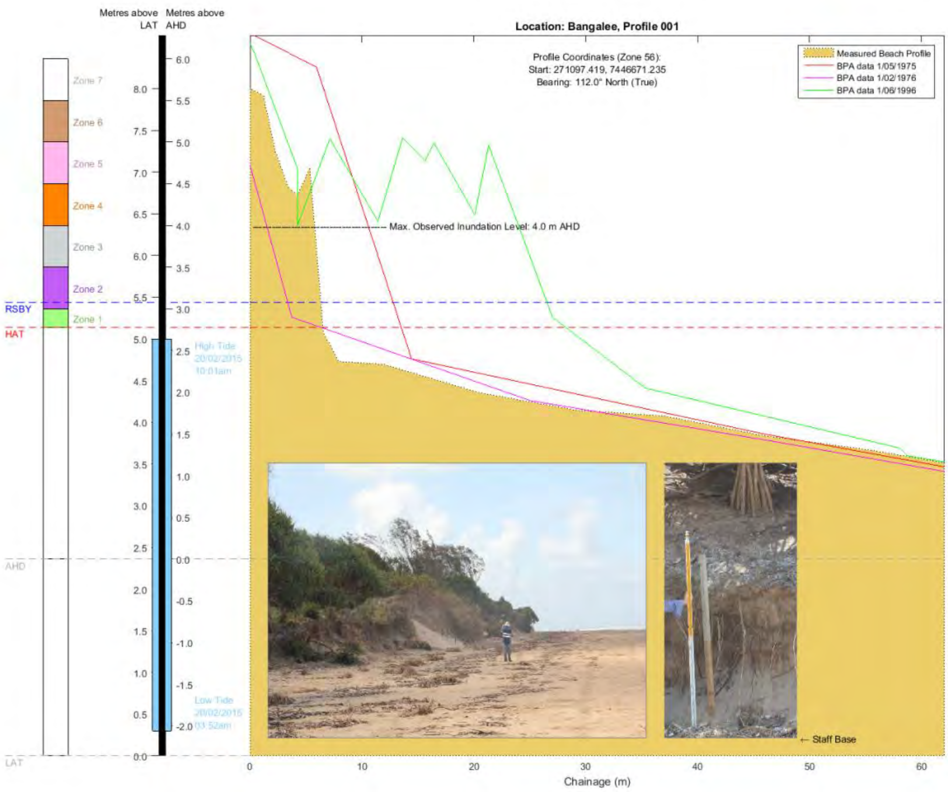


Figure 48 Bangalee profile 01

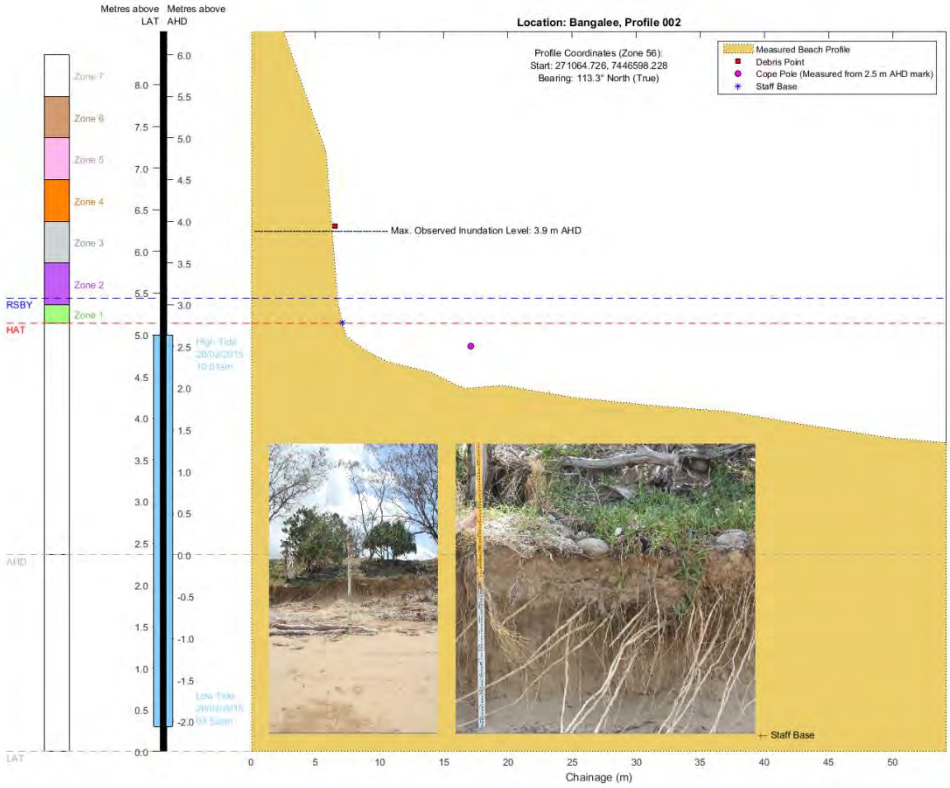


Figure 49 Bangalee profile 02

Appendix B

Photography captured during field investigation 09 to 11 March 2015

Photograph 15 Freshwater Bay, piles of logs washed up

Photograph 16 Damage to beach access at Freshwater Bay

Photograph 17 Freshwater Bay, accumulated vegetation debris

Photograph 18 Receded bank previously encompassing pipe at Freshwater Bay

Photograph 19 Freshwater Bay, bank of pumice stone and timber

Photograph 20 Freshwater Bay, pumice stone covering frontal dune

Photograph 21 Freshwater Bay, high dunes further north with scarping but less pumice stone

Photograph 22 Along South Arm of Port Clinton

Photograph 23 Eastern exposed tip of south arm of Port Clinton

Photograph 24 Exposed coffee rock and shear dune face at Clinton Low Lands

Photograph 25 Scarping along dunes at Clinton Low Lands

Photograph 26 Wind damage at West Point

Photograph 27 Centre of exposed section of Port Clinton

Photograph 28 Just south of Flinders Watering Gully

Photograph 29 Cobble stone pocket beach in the vicinity of Flinders Watering Gully

Photograph 30 Sandy pocket beach in the Delcomyn Bay vicinity

Photograph 31 Vegetation patches at Pearl Bay

Photograph 32 Large pumice stone debris lines at the northern end of Pearl Bay

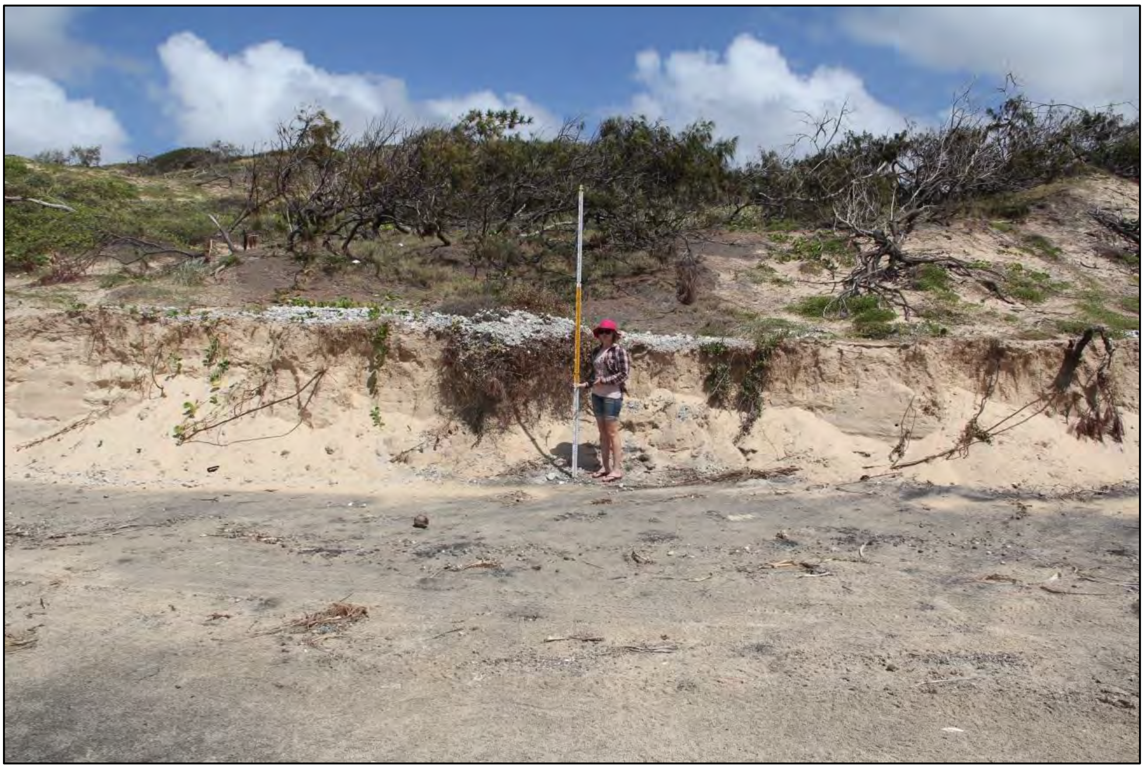
Photograph 33 One Mile Beach north end

Photograph 34 Undermined tree at One Mile Beach

Photograph 35 Pumice stone washed up at the southern end of One Mile Beach

Photograph 36 Undermined dune fencing at Nine Mile Beach

Photograph 37 Pumice stone washed on top of scarp at Nine Mile Beach



Photograph 38 Pumice stone washed on top of scarp at Nine Mile Beach

Photograph 39 Undermined walkway at Myrtella camping ground, Nine Mile Beach

Photograph 40 Pumice stone washed atop scarp, Nine Mile Beach

Photograph 41 Undermined walkway at Casurina camping ground, Nine Mile Beach

Photograph 42 Scarping through different sediment layers at Nine Mile Beach

Photograph 43 Pumice stone washed up at the southern end of Nine Mile Beach

Photograph 44 Bangalee Beach access undergoing repairs

Photograph 45 Destabilised vegetation and exposed roots at Bangalee

Photograph 46 Eroded dunes with damage to beach access

Photograph 47 Damage to the Mecure Capricorn Resort vehicle access at Bangalee

Photograph 48 Damage to the walkway access at Farnborough Beach

Photograph 49 Beach speed sign along Farnborough Beach

Photograph 50 Beach erosion along Farnborough Beach

Photograph 51 Pumice stone debris along Farnborough Beach

Photograph 52 Fallen timber at Sandy Point

Photograph 53 Damage to rock wall at Ross Creek

Photograph 54 Fallen timber at Wattle Grove, Cooee Bay

Photograph 55 Coastal property at Ocean Parade, Cooee Bay

Photograph 56 Collapsed palms due to beach erosion Ocean Parade, Cooee Bay