15th Australasian Wind Engineering Society Workshop
Sydney, Australia
23-24 February 2012

Meteorological Aspects of Cyclone YASI with a focus on the Landfall Phase

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Abstract

Severe Tropical Cyclone YASI made landfall between Innisfail and Cardwell around midnight on 2 February 2011 as one of the most powerful and largest cyclones to have impacted the state since records commenced. Fortunately, there was no direct loss of life and no serious injuries were reported. However, wind and storm surge damage along that section of the coast and nearby islands was quite extensive with insured losses of $Aus1.3B (Insurance Council of Australia, 2011). YASI was the 4th cyclone in the Queensland region during the 2010-11 season, coming on top of record rains in the previous 6 months and widespread flooding in December and January.

Improvements in numerical prediction enabled the Bureau to alert Queenslanders almost a week prior to landfall that YASI could form and later be a threat to the state. As YASI approached the coast, the Queensland Tropical Cyclone Warning Centre (TCWC) warned of wind gusts to Category 5 strength and the likelihood of a dangerous storm surge. At landfall, an eye pressure below 930 hPa was recorded along with a storm surge in excess of 5 metres. Wind estimates from interpretation of high quality satellite imagery placed the highest mean wind at around 200 km/h, equivalent to a borderline Category 5 cyclone.

Introduction

This paper will analyse the meteorological aspects of Cyclone YASI with an emphasis on the landfall phase. Included are summaries and brief analyses of observations taken near landfall, and an outline of some of the uncertainties associated with classifying the strength of YASI near landfall.

When tracking across the Coral Sea, YASI passed directly over Willis Island, a permanently staffed Bureau of Meteorology facility located 400 km east of Cairns. To ensure their safety, occupants were evacuated the day before the cyclone struck. Significant damage occurred on the island, both to the natural environment and to the Bureau's facility. As of December 2011 Willis Island was well on the way to being completely rebuilt and restaffed with radar services having been fully restored.

As YASI came ashore, crossing near Mission Beach, major impacts were reported in the nearby region through media and numerous other sources. These included:

- One indirect death at Bambaroo, near Ingham, due to asphyxiation from indoor use of a generator;
- Over 100 properties completely destroyed and damage to over 2000 properties;
- Cuts to the Bruce Highway between Townsville and Ingham due to flooding;
- Significant erosion damage to beaches and coastal infrastructure in the Mission Beach to Cardwell area;
- Disaster declarations for Cairns, Mareeba, Innisfail, Townsville, Mackay, Rockhampton, Gladstone, Mount Isa and Longreach regions.

Landfall Characteristics

Motion

YASI maintained a westerly or west-southwest track throughout its entire lifetime. This was due to a firm mid-level atmospheric ridge being located over southern Australia and the Tasman Sea which remained very slow moving. Near and after landfall YASI shifted to a more southwesterly track as middle level ridging built over the Coral Sea to the east of the system.

Structure

YASI was a medium to large system with active thunderstorm activity present in all quadrants from the time the system entered the Brisbane TCWC area of responsibility. The radius of gales (270 nm or 500 km) was generally largest in the southeast quadrant as the system approached landfall and in the northeast quadrant after landfall. The eye diameter was close to 45km, as measured by radar at landfall.

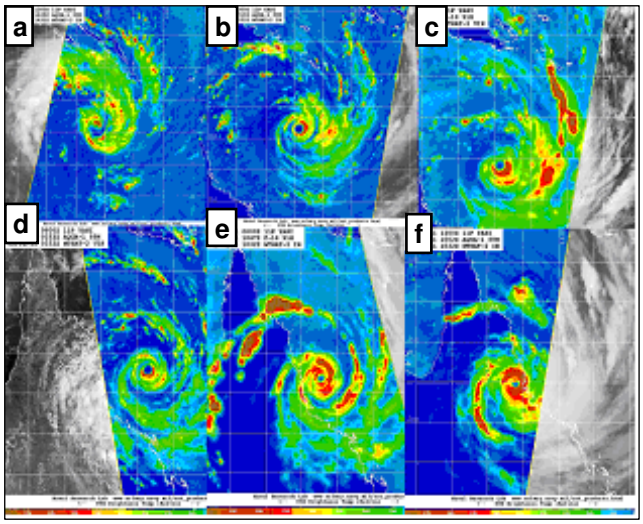

Figure 2. 85GHz microwave imagery of YASI's development (times in AEST). a) AMSRE 12:35am 1/2/11 b) AMSRE 1:18am 2/2/11 c) SSMIS 8:11am 2/2/11 d) AMSRE 1:32pm 2/2/11 e) SSMIS 8:47pm 2/2/11 f) AMSRE 2:02am 3/2/11. (Images courtesy of http://www.nrlmry.navy.mil/tc_pages/tc_home.html.)

Pressure observations

Pressure readings were obtained from the eye of YASI on 4 occasions. Firstly from the Coral Sea Tsunameter #2, located near 14.8S 153.6E, then Willis Island Meteorological Office, Clump Point (courtesy of DERM) and Tully Sugar Mill. Using a Wind-Pressure (W-P) Relationship (Courtney and Knaff, 2009) estimated peak winds (10 minute mean wind) for YASI have been calculated from these pressure readings.

Minimum Pressure (hPa)	Location	Date & Time (AEST)	Implied Mean Wind from W-P Relationship
929	Tully Sugar Mill	12:30am 3/2/11	114 kt (211 km/h)
930	Clump Point	Midnight 2/2/11	113 kt (209 km/h)
937.2	Willis Island	9:52am 2/2/11	110 kt (204 km/h)
941	Coral Sea Tsunameter #2	9:00pm 1/2/11	105 kt (194 km/h)

Table 1. Pressure observations from Tropical Cyclone YASI.

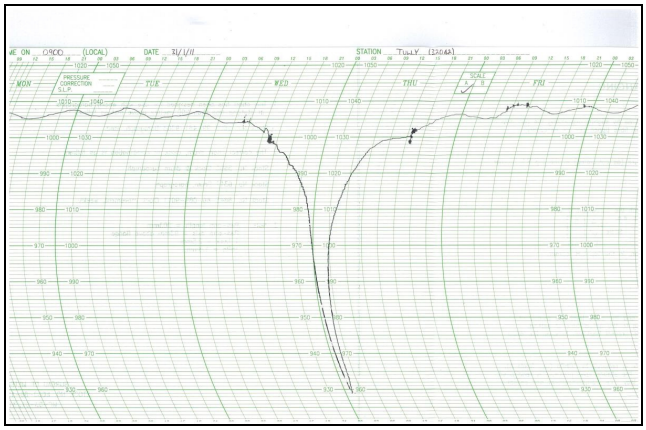

Figure 1. Barograph from Tully Sugar Mill showing the passage of the eye of Cyclone YASI. The pressure rapidly dropped to 929 hPa at 12:30am AEST 3 February as the eye passed overhead.

Wind observations

Severe Tropical Cyclone YASI passed through a network of Automatic Weather Stations (AWS) situated off the Queensland east coast. Below are the mean winds and peak gusts observed by Bureau of Meteorology AWS both offshore and over land during Cyclone YASI. None of these sites are considered likely to have captured the maximum winds of YASI as it passed by.

Peak Mean Wind (knots)	Location	Date and Time (AEST)
83 (154 km/h)	Willis Island	8:20 am 2/2/11
74 (137 km/h)	Lucinda	2:14 am 3/2/11
70 (130 km/h)	Flinders Reef	2:00pm 2/2/11
57 (106 km/h)	Townsville Airport	1:28am 3/2/11
51 (94 km/h)	South Johnstone	12:31am 3/2/11
50 (93 km/h)	Hamilton Island	11:08pm 2/2/11
50 (93 km/h)	Arlington Reef	2:30am 3/2/11
47 (87 km/h)	Bougainville Reef	4:30pm 2/2/11
41 (76 km/h)	Marion Reef	9:10am 2/2/11
39 (72 km/h)	Alva Beach	4:24pm 2/2/11
39 (72 km/h)	Richmond Airport	10:00am 3/2/11
35 (65 km/h)	Julia Creek	2:40pm 3/2/11

Table 2. Peak Mean Winds (10 minute) measured during Cyclone YASI.

Peak Wind Gust (knots)	Location	Date & Time (AEST)
111 (206 km/h)	Willis Island	8:20am 2/2/11
100 (185 km/h)	Lucinda	11:31pm 2/2/11
90 (167 km/h)	Flinders Reef	2:00pm 2/2/11
73 (135 km/h)	Townsville Airport	1:23am 3/2/11
70 (130 km/h)	South Johnstone	12:17am 3/2/11
63 (117 km/h)	Hamilton Island	11:08pm 2/2/11
60 (111 km/h)	Arlington Reef	2:30am 3/2/11
59 (109 km/h)	Alva Beach	4:24pm 2/2/11
58 (107 km/h)	Richmond Airport	8:00pm 3/2/11
58 (107 km/h)	Bougainville Reef	4:30pm 2/2/11
54 (100 km/h)	Marion Reef	12:31am 2/2/11
51 (94 km/h)	Julia Creek	10:00pm 3/2/11

Table 3. Peak Wind Gusts (3 second) measured during Cyclone YASI.

Wind estimates from satellite imagery

High resolution satellite imagery showed YASI at landfall having a well defined eye region and being a highly symmetrical system. The 3-hour averaged manual Dvorak analysis (Dvorak 1984, 1995) indicated an intensity of T6.5 and a resultant maximum mean wind of 110 knots (205 km/h with gusts to 285 km/h).

The SATCON analysis technique (CIMSS, CIRA) for estimating wind from satellite imagery is regarded as the most reliable currently available. The SATCON intensity estimate for midnight AEST 2 February, just prior to landfall, gave a 1 minute mean wind of 131 knots. Assuming that the technique does provide reasonable guidance, the following steps of converting the 1 minute mean wind to the equivalent 10 minute mean wind and 3 second gusts is no trivial task. An estimate of the wind gusts at landfall will be offered in the Workshop presentation, citing the new wind conversion Guidelines (Harper et al 2010).

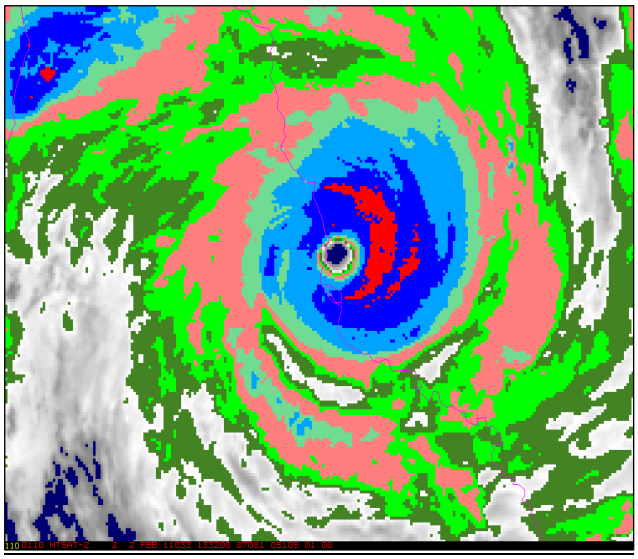

Figure 2. MTSAT Enhanced Infra-Red image of YASI at 11:30pm AEST 2 February, 2011. Here YASI exhibits a well defined eye and vigorous convection in all quadrants just prior to landfall.

Wind modification considerations

While YASI was a marginal Category 5 cyclone, the extent of impacts felt by communities near the very destructive eyewall were reportedly closer to those expected in a Category 4 system (CTS Technical Report No. 57). Consequently, a number of factors need to be considered when exchanging views on tropical cyclone intensity and observed or estimated wind speeds or gusts.

This paper will not attempt to quantify how each of these uncertainties may have directly affected YASI's wind field, but will simply identify those uncertainties:

- Tropical cyclone intensity is defined by the maximum mean wind speed over open flat land or water. This will generally be experienced around the cyclone eye-wall.
- A Category 5 tropical cyclone is officially defined by maximum mean winds of at least 200km/hr. The associated wind gusts will vary in space and time with the Bureau's Category Scale setting the lower limit at 280 km/h.
- At the point of landfall the strongest winds may have occurred at sea, a likely scenario given the lower surface roughness there. Also offshore islands, chiefly Hinchinbrook Island, were likely to have reduced wind speeds and gusts on the mainland. This is particularly true for the Cardwell area.
- Wind estimates from damage assessment and the few available anemometers are unlikely to have captured the peak gusts in the system. This is because of the highly variable nature of wind distribution and gustiness associated with a tropical cyclone.
- The effect of steep topography between Cairns and Cardwell is likely to have degraded the structure of a tropical cyclone as it approached the coast while playing a significant role in modifying its wind field.

Storm surge

A large storm surge was observed near and to the south of Mission Beach at the time of coastal crossing. This was exacerbated by the large area of onshore winds in YASI's southern hemisphere.

A 5.33 metre storm surge was observed at the Department of Environment and Resource Management (DERM) tide gauge at Cardwell (DERM, 2011). This was 2.2 metres above the Highest Astronomical Tide (HAT) predicted for the year. This anomaly occurred at 1:20am AEST 3 February on a falling tide. Widespread, yet less substantial, sea inundation occurred on the late morning high tide on 3 February between Cairns and Alva Beach. Peak tide levels for this later event, measured at the DERM Townsville tide gauge, were close to 0.6m above HAT and produced inundation in parts of the city.

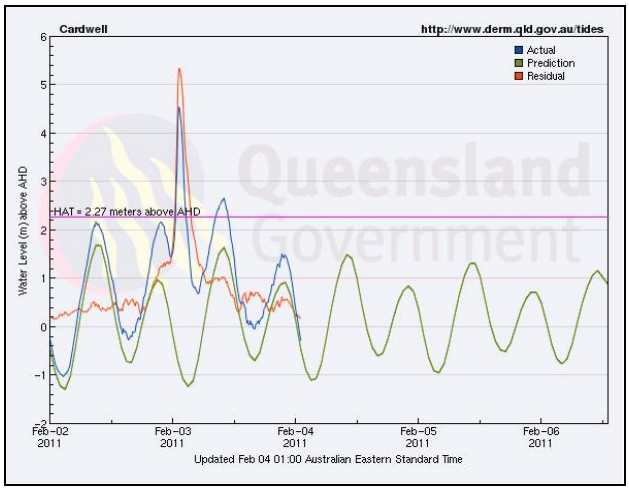

Figure 3. A 5.33m storm surge reading from the Cardwell tide gauge at 1:20am AEST 3 February. (Image courtesy of DERM).

Waves and swell

The large area of strong winds circulating about the centre of YASI contributed significantly to wave generation along the east tropical coast of Queensland. These waves were mitigated to some degree by the Great Barrier Reef. The DERM waverider buoy off Townsville measured waves up to 9.6 metres, peaking at 7pm AEST 2 February. It should also be noted that there was a gap in data at the likely time of peak heights and that waves were most probably higher than the measured 9.6m (DERM, 2011).This is a new record for the site; the previous highest recording being 6.6 metres.

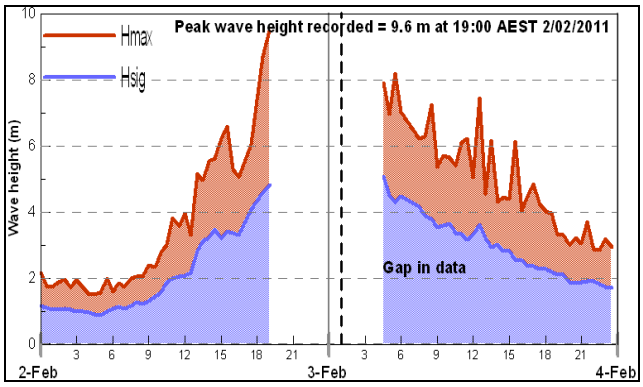

Figure 4. Time series plots of wave height recorded at Townsville. (DERM, 2011)

Rainfall and flooding

Widespread heavy falls of rain occurred to the south of the cyclone and were generally in the order of 200 to 300mm in the 24 hours to 9am AEST Thursday 3 February. These rainfalls mostly occurred in the area between Cairns and Ayr where some flooding was also reported. The highest totals were South Mission Beach 471mm, Hawkins Creek 464mm, Zattas 407mm and Bulgun Creek 373mm. These reporting sites were in the catchments of the Tully and Herbert Rivers.

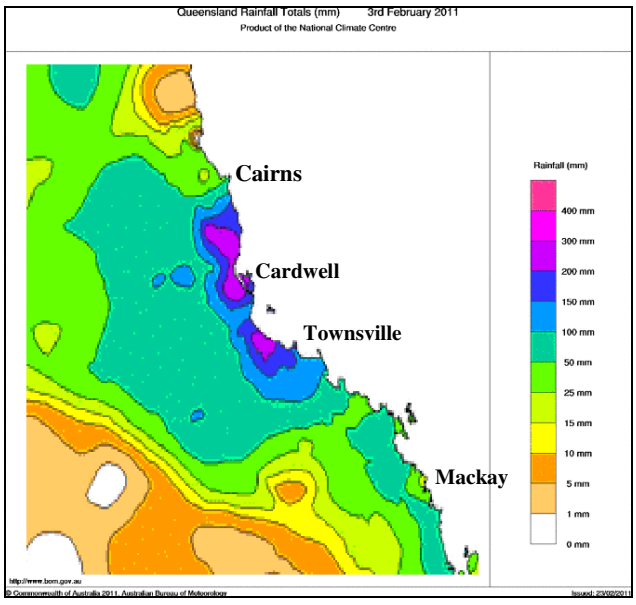

Figure 5. Rainfall total for northern Queensland on 3 February, 2011. (BoM, http://www.bom.gov.au/jsp/awap/rain/archive.jsp?colour=colour&map=totals&period=daily&year=2011&month=2&day=3&area=qd)

Forecast Performance

Computer modelling gave forecasters exceptional guidance on which to base forecasts and warnings of Tropical Cyclone YASI. As early as 10 days before landfall, and 6 days before YASI even formed, the European Centre for Medium Range Weather Forecasting (ECMWF) model guidance was suggesting a major cyclone impact on the east tropical coast of Queensland.

Once Tropical cyclone YASI had formed, ensemble prediction systems (EPS) showed consistent forecast tracks with very small uncertainty. This model guidance allowed forecasters to give a very early 'heads up' to emergency services and potentially affected communities well before official Tropical Cyclone Watches and Warnings were issued.

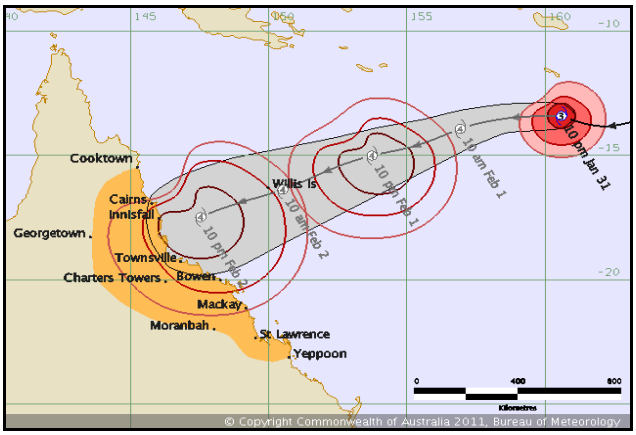

Figure 6. Forecast track map issued by the Brisbane Tropical Cyclone Warning Centre (TCWC) at 11pm AEST 31 January.

As YASI intensified and moved towards the east tropical coast of Queensland the Queensland TCWC was activated and issued the first Tropical Cyclone Watch at 1:49pm AEST 31 January. The first Tropical Cyclone Warning was issued at 11:09am AEST 1 February. In total 39 Tropical Cyclone Advices were issued in the series with the last Tropical Cyclone Warning cancelled at 10:32pm AEST 3 February. Throughout this event Cyclone Watches or Warnings were issued for coastal areas between Lockhart River and Yeppoon, and for inland areas westwards to include Mount Isa, Longreach and the southern Gulf of Carpentaria.

Conclusions

Severe Tropical Cyclone YASI has provided a timely reminder that significant cyclone impacts are a way of life on the Queensland east coast. This event has also shown that early disaster planning coupled with the Bureau's timely warnings can help mitigate against loss of life and property.

Following careful analysis of all available meteorological data, YASI's estimated maximum mean wind over the inshore islands and most exposed shoreline appear to be in the order of 200 km/h - equivalent to a borderline Category 5 cyclone.

If given the opportunity, a case study of tropical cyclone YASI will be offered for discussion at the next WMO International Workshop on Tropical Cyclone Landfall Processes.

Acknowledgements

Queensland Department of Environment and Resource Management (DERM).

Dr Chris Velden, Cooperative Institute for Meteorological Satellite Studies (CIMMS), University of Wisconsin - Madison, USA.

Dr John Knaff, Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, USA.

Bureau of Meteorology: Peter Otto, Joe Courtney, Vikash Prasad and Gavin Holcombe.

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