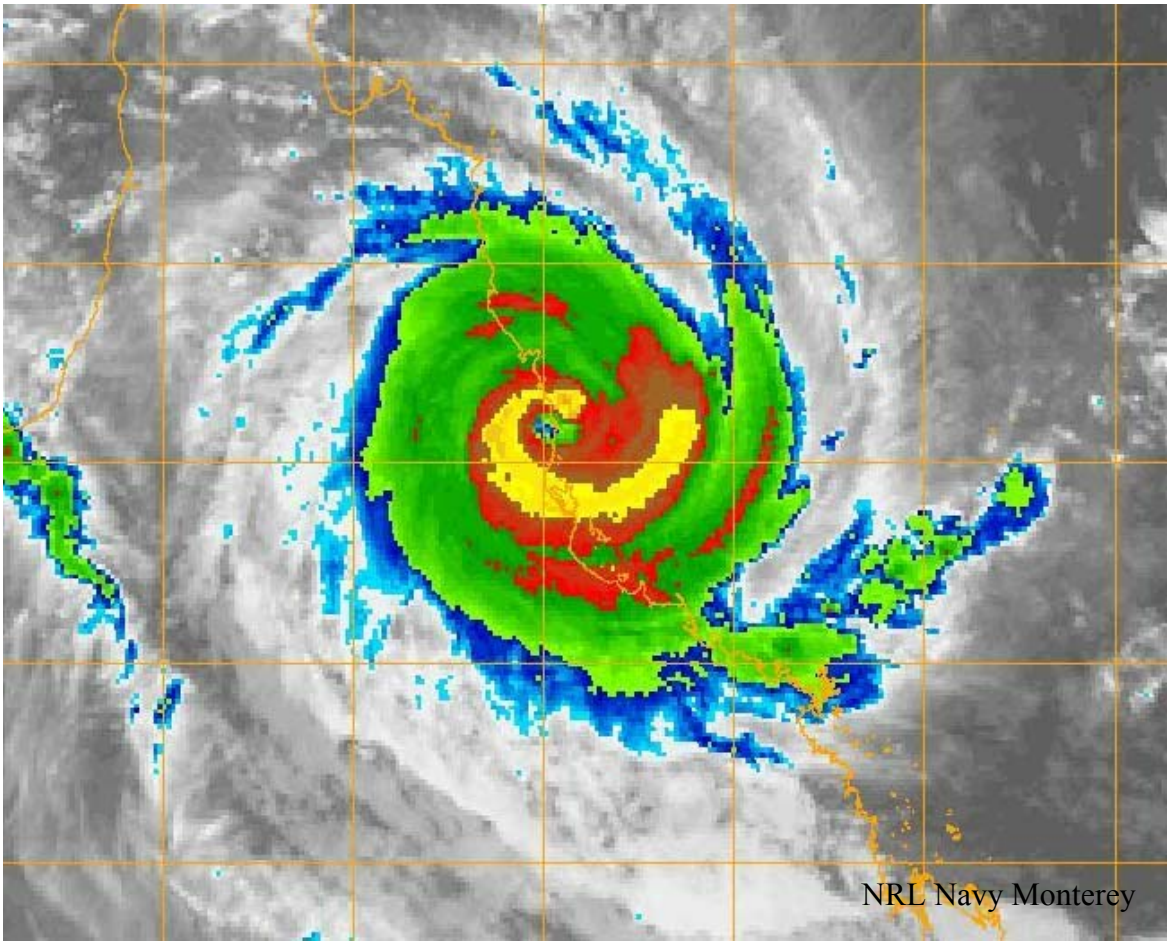
Australian Government
Bureau of Meteorology

Cyclone LARRY Forum Report

James Cook University - Townsville Campus

7 April 2006



Preliminary results from post-impact surveys conducted in the aftermath of Severe Tropical Cyclone LARRY making landfall at Innisfail Queensland 20 March 2006

Report edited by Jim Davidson
Regional Director (Queensland)
Bureau of Meteorology




Forum Objectives

Stakeholders to share preliminary results from community and field surveys conducted in the immediate aftermath of Severe Tropical Cyclone LARRY. These early surveys were mostly carried out along the coastal strip between Cairns and Cardwell. Other areas with major damage include the nearby Atherton Tablelands and islands in the cyclone's path. A more specific goal was to attempt to allocate a Category to LARRY at the time of landfall.

In his opening comments, Jim Davidson flagged that the Bureau had initial plans to hold the 7th (Australian) Tropical Cyclone Coastal Impacts Program (TCCIP) Workshop in Cairns later in the year - in August (or thereabouts). The Townsville Forum could be seen as an important milestone in the lead-up to the TCCIP Workshop. The outcomes from the TCCIP Workshop will then be fed into the 6th International Workshop on Tropical Cyclones (IWTC-VI) to be held in Costa Rica in November 2006. The Queensland Tropical Cyclone Coordination Committee (QTCCC) is also a key "stakeholder".

Summary of Forum Outcomes

The Forum was successful in that it provided an opportunity for the key agencies to report on the preliminary results from the various community and field surveys. However the meeting failed to reach any scientifically supportable conclusion on the Category of LARRY at landfall. Evidence presented showed a possible range from a high Category 3 to a low Category 5. To attempt to resolve the matter, more field survey work was called for along with detailed wind and storm tide modelling of the event.

LARRY could be classified as a "midget" cyclone due to the limited range of the (very) destructive winds. Moreover, the cyclone was moving relatively quickly at landfall thereby restricting the time that the area was experiencing cyclonic winds and airborne debris. It was also fortunate that tides were quite low so Storm Tide was not a significant factor. Two major issues discussed at the Forum were the complex nature of LARRY's eye and inner core structure at landfall, and the related variation in observed wind gusts both spatially and across elevated terrain as evidenced by "streaky" damage patterns.

Overall, the Bureau's warning service during LARRY rated highly in the community surveys with the new Tropical Cyclone Forecast Map being especially well received. Some problems with accessing the warnings on the Internet and through the local Media were identified and are being addressed by the Bureau. During LARRY, the Bureau's communication links to the Internet were subject to unprecedented demand with the estimated number of "hits" on the day of landfall being in excess of 60 million. Although hourly Cyclone Warnings commenced some 10 hours prior to landfall, some people would have preferred an earlier start. It is understandable that communities under threat seek regular reassurance from the authorities and the Bureau is conscious of this responsibility.

Two particular areas were considered to warrant further investigation. At the time of the Forum, little attempt had been made to survey the damage on the nearby islands and it was also not apparent that any agency was planning to undertake a study of the economic impact of the event on the Tourism sector. Moreover, the results of aerial surveys and the analyses of high-resolution satellite imagery were still largely unavailable.

Forum Participants

Bureau of Meteorology (Bureau) – Jim Davidson, Jeff Callaghan, Peter Otto, Dr Jeff Kepert, Dr Linda Anderson-Berry, Alan Sharp & Kevin Tory

Geoscience Australia (GA) – Dr Bob Cechet & Dr Matt Hayne

James Cook University Centre for Disaster Studies (CDS) – Dr David King, Dr Douglas Goudie & Dr Allison Cottrell

James Cook University Cyclone Testing Station (CTS) – Dr John Ginger & Cam Leitch

Environmental Protection Agency (EPA) – David Robinson

Systems Engineering Australia (SEA) – Dr Bruce Harper

Department of Emergency Services (DES) – Warren Bridson, Wayne Preedy & Narelle Marschke

Apologies: Dr Steve Turton, John Rossiter, Graham Jones & Dr Jonathan Nott

Forum Agenda

1. Introduction by Bureau of Meteorology
(Jim Davidson & Jeff Callaghan)

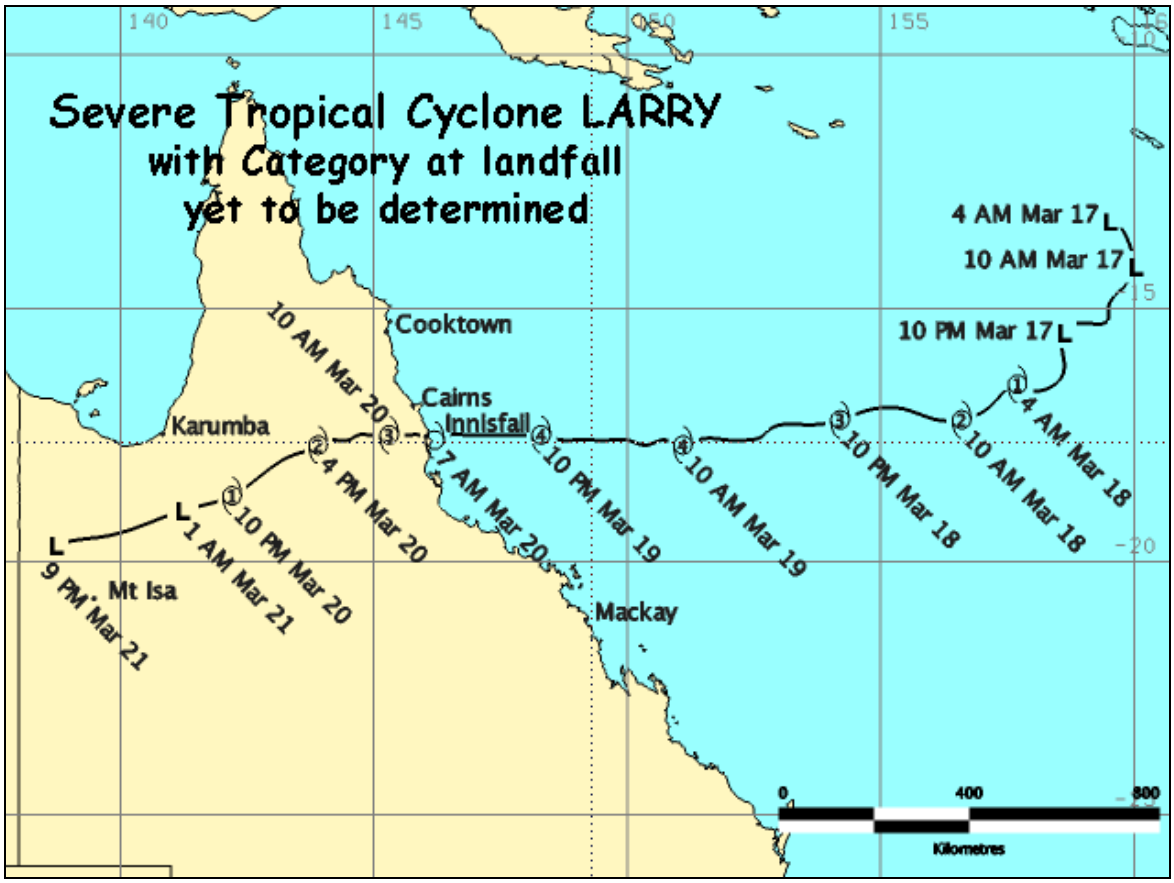
2. Community surveys
(a) JCU-CDS
(b) GA (Bob Cechet & Matt Hayne)

3. Field surveys (wind impact)
(a) JCU-CTS (John Ginger)
(b) GA (Bob Cechet & Matt Hayne)
(c) SEA (Bruce Harper)
(d) Bureau (Peter Otto)

4. Field surveys (storm tide impact)
(a) EPA (David Robinson)
(b) GA (Bob Cechet & Matt Hayne)
(c) SEA (Bruce Harper)
(d) Bureau (Peter Otto)

5. Open debate and synthesis of preliminary findings

Editor's Note: The following reports have been reformatted a little to ensure document compatibility but no changes have been made to the original manuscripts. Not all the material was presented at the Workshop which simply reflects "works in progress".



Sequence of Events

Saturday 18 March

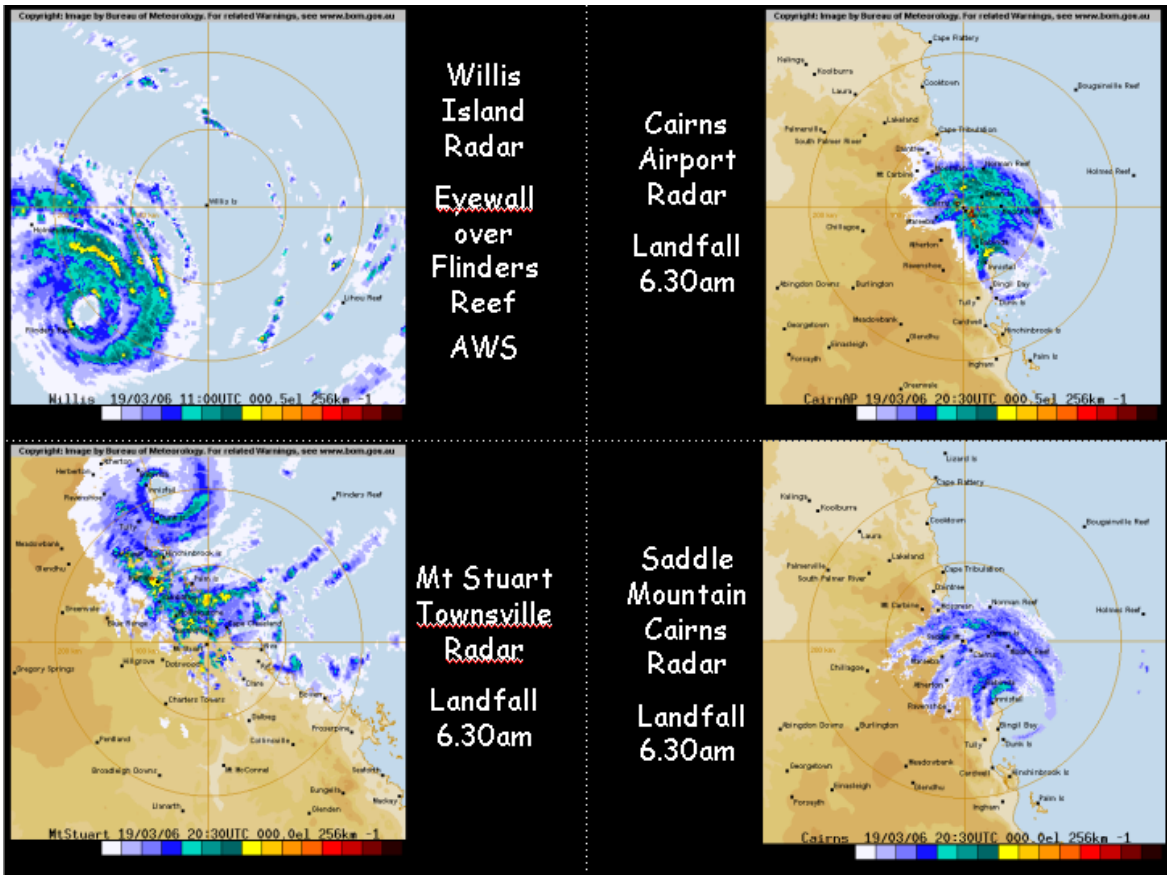
- 4am – cyclone named LARRY
- 8am – Cyclone Watches commence
- 5pm – Cyclone Warnings commence
- 11pm – Larry becomes a severe cyclone

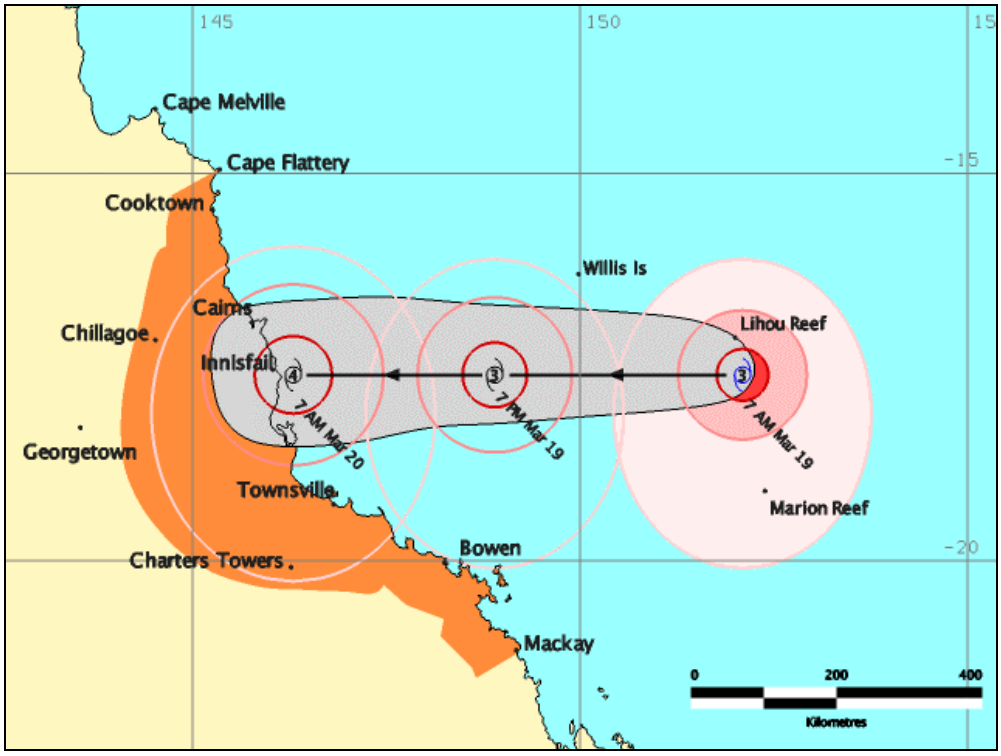
Sunday 19 March

- 2.30am – 1st preliminary Storm Tide Warning
- 11.30am – 1st quantitative Storm Tide Warning
- 8pm – hourly Cyclone Warnings commence

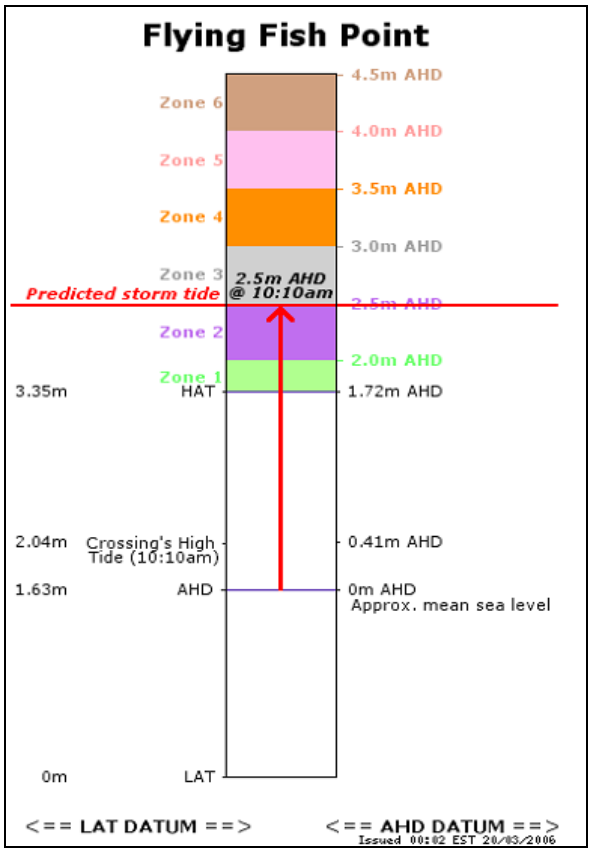
Monday 20 March

- 6am to 7.20am – cyclone eye crosses the coast
- 3pm – Larry no longer a severe cyclone
- 5pm – hourly Cyclone Warnings cease
  (Final Warning – Advice No 36 – 2am on Tuesday)

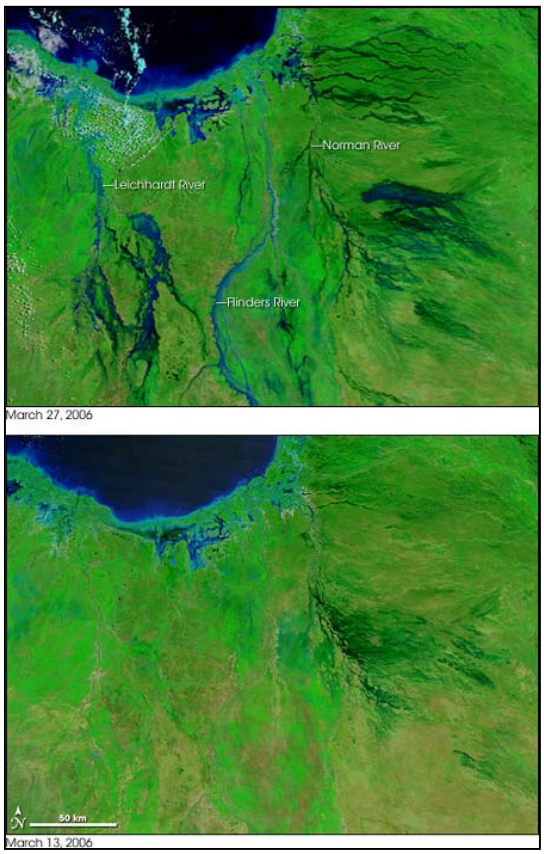




New Tropical Cyclone Forecast Map



New Storm Tide Graphic



NW Qld Flooding ex-LARRY

Tropical Cyclone Category Scale
(Queensland version)

Tropical Cyclone Category	Central Pressure Normal Cyclone	Central Pressure Midget Cyclone	Wind Gusts km/h	Wind Gusts knots	Wind Gusts m/sec
1	> 985	> 985	< 125	< 67	< 35
2	970-985	975-985	125-170	67-92	35-47
3	945-970	960-975	170-225	92-121	47-63
4	920-945	940–960	225-285	121-154	63-79
5	< 920	< 940	> 285	> 154	> 79

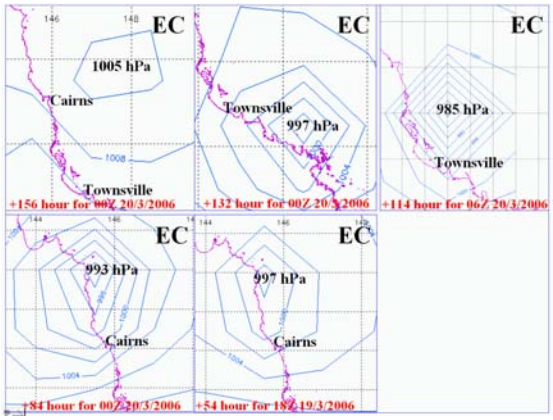
*Note that all wind gust values in the above table are rounded to the integer. A "**midget**" tropical cyclone is a system where the radius to the outermost closed isobar is 100-200 km. The radius of gales is often 110 km or less.*

For further information on Severe Tropical Cyclone LARRY:
http://www.bom.gov.au/weather/qld/cyclone/tc_larry/

Forecasting Report on Severe Tropical Cyclone Larry (Jeff Callaghan)

Numerical Forecasts

The first hint of the possibility of a significant system affected North Queensland came from the long range forecasts from the European Centre for Medium Range Weather Forecasting Centre (EC) (see below in Figure 1). The 114-hour forecast for 0600UTC 20 March 2006 showed a cyclone with central pressure of 985hPa moving in towards Tully. Following this however the EC progressively backed away from this scenario and leading up to the event (Figure 2) the various models only forecast a weak low to affect North Queensland. These are the numerical forecasts, which were available to forecasters late on the 18th and early on the 19th March local time.



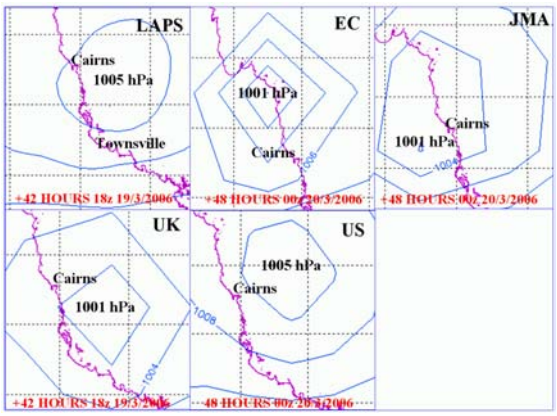
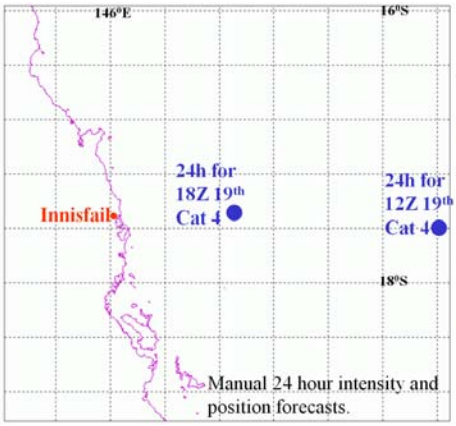


Figure 1(left). EC Mean sea level pressure distribution forecasts
Figure 2(right). Numerical model forecasts based on analyses at 0000UTC 18 March 2006.

Manual Forecasts

Using locally developed forecasting techniques; the Brisbane Tropical Cyclone Warning Centre Forecasters correctly forecast the intensification of *Larry* to a Category four tropical cyclone. (see Figure 3).



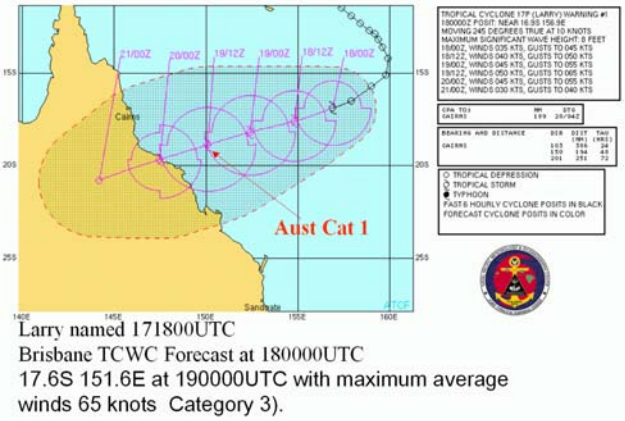


Figure 3 (left). Manual tropical cyclone position and intensity forecasts.
Figure 4 (right). The 0000UTC 18 March 2006 Joint Typhoon Warning Centre forecast on the web.

Other Agency Forecasts

Comments from some members of the public lauded the products issued on the web from the Joint Typhoon Warning Centre. These opinions must surely have been formed from only cursory inspection of these web products. For example in Figure 4 the warning issued by the JTWC at 0000UTC 18 March 2006 shows a category 1 tropical cyclone at 0000UTC 19 March heading towards Townsville. The corresponding forecast from Brisbane was for a category 3 tropical cyclone east of Innisfail. The Brisbane forecast at this time for 0000UTC 20 March 2006 placed the cyclone over Kurrimine Beach (unfortunately not on the web). The JTWC at this time had Larry over Townsville.

Intensification up to Landfall

Various remote sensing data indicated Larry intensified right up to landfall. Radar data from Mount Stuart radar shows the eye contract up to landfall while approximately remaining the same distance from the radar (Figure 5).

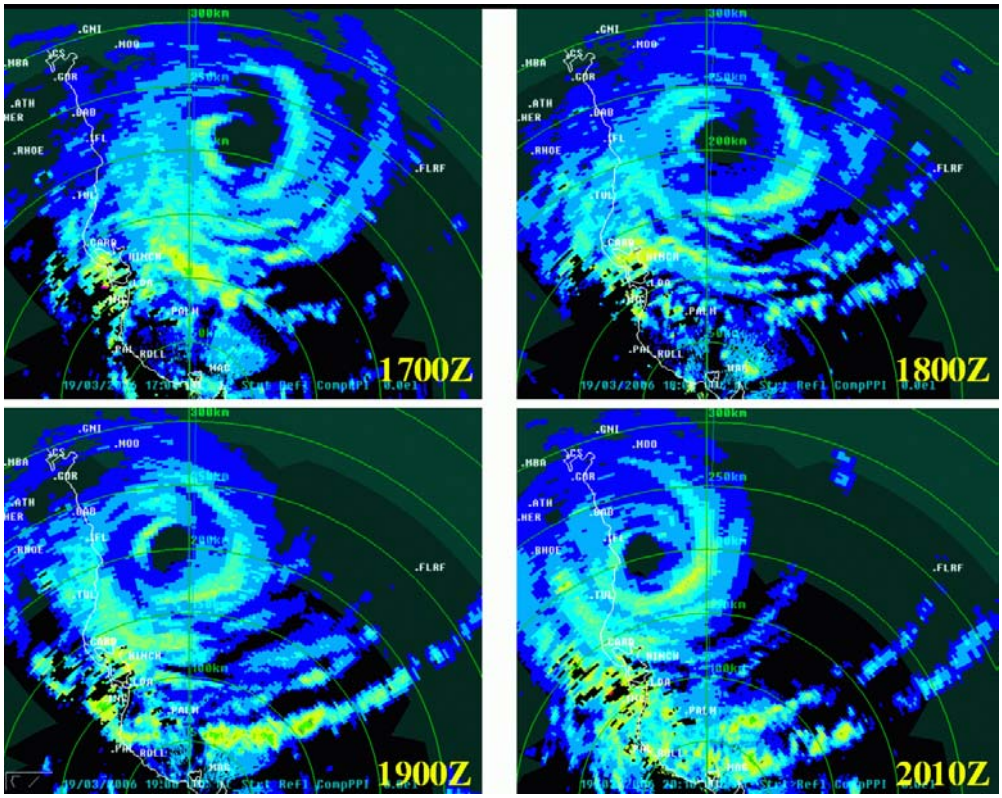


Figure 5 Radar rain echoes showing tropical cyclone Larry approach the coast from 1700UTC 19 March 2006 to 2010UTC 19 March 2006.

Microwave images of tropical cyclone Larry were obtained courtesy of the US Navy Research Laboratory Monterey (California) Satellite Section at the following URL http://www.nrlmry.navy.mil/tc_pages/tc_home.html. These are placed in Figure 6, which indicated the increase in convective rain and thunderstorm activity (red areas) around the centre as Larry approaches the coast and makes landfall.

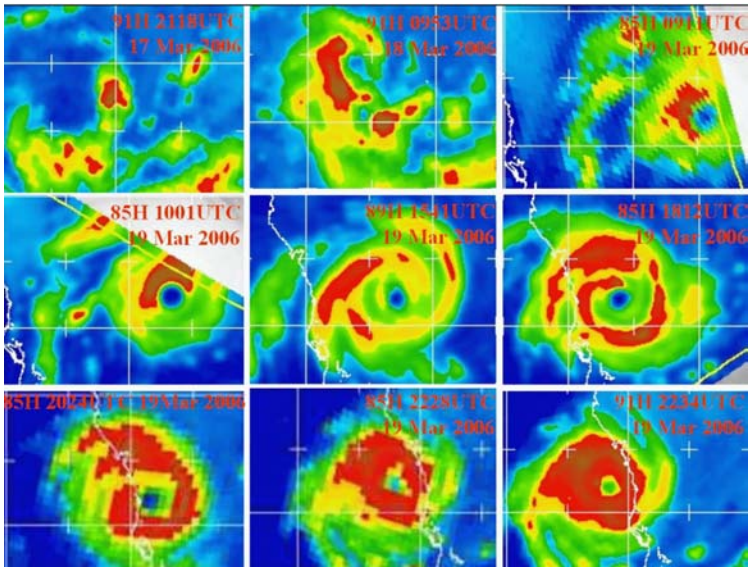


Figure 6. Microwave images of Larry from 2118 UTC 17 March to 2234UTC 19 March 2006.

The enhanced Infrared satellite images (one example in Figure 7) of Larry approaching landfall indicated a tropical cyclone near the transition from Australian category four intensity to Australian category five intensity.

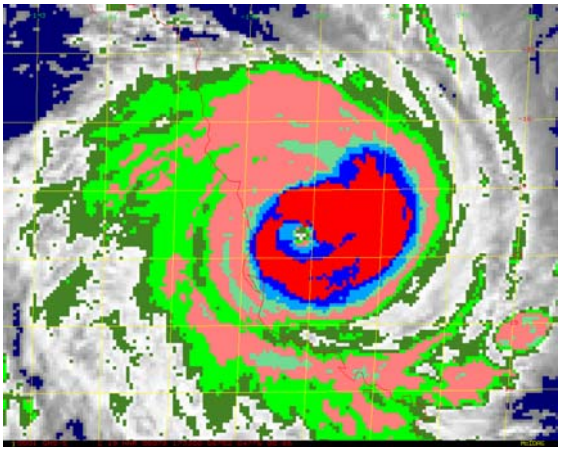


Figure 7. Infrared image at 1733UTC 19 March 2006.

Size of Larry at Landfall

Below in Figure 8 we compare Larry with two midgets (Ada and Tracy) and the very large circulation of tropical cyclone David. Ada is by far the tiniest and Larry is a little larger than Tracy although Larry had a larger eye as viewed from radar. The radar eye of Larry was around 30km in diameter as it neared the coast. The diameter of the radar eye of Ada contracted to 18km while the radar eye of Tracy at landfall was elliptical with a major axis of 12km and a minor axis of 8km. The concept of 'midget' tropical cyclones originated at the Joint Typhoon Warning Centre in the days of Chip Guard. The definitions used to define a midget is when the radius of gales is 110km or less. Larry thus qualifies to be called a midget. Midgets have a much higher central pressure (in the order of 20hPa) for a given intensity compared with a large cyclone.

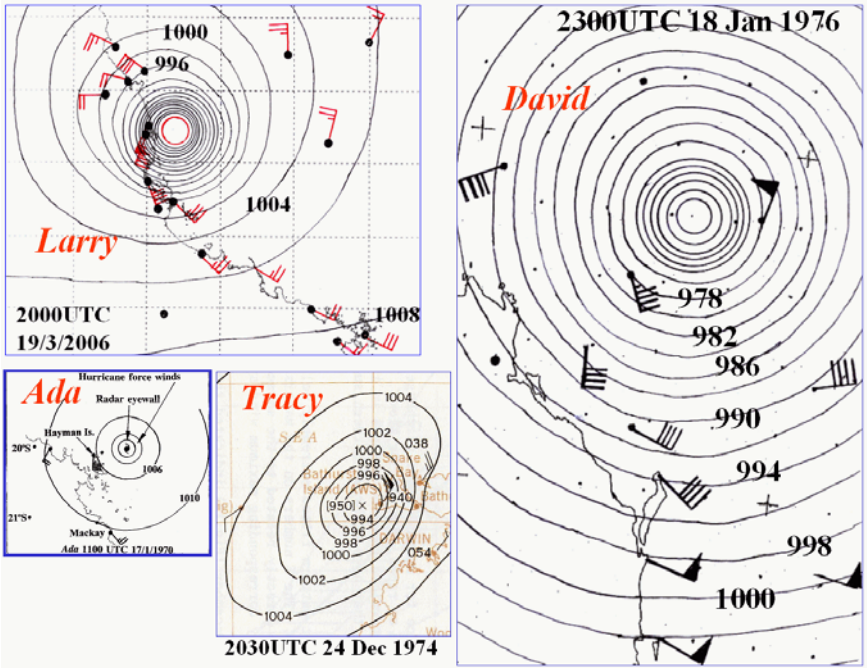


Figure 8. Comparison of the structure of Larry with David, Ada and Tracy all drawn to a similar scale.

Radar Eyewall Convection

Figure 9 shows the location of the strongest convection around the eye and the most likely location of the most intense winds from 2030UTC to 2130UTC 19 March (left frame) and 2200UTC to 2230UTC 19 March 2006 (right frame).

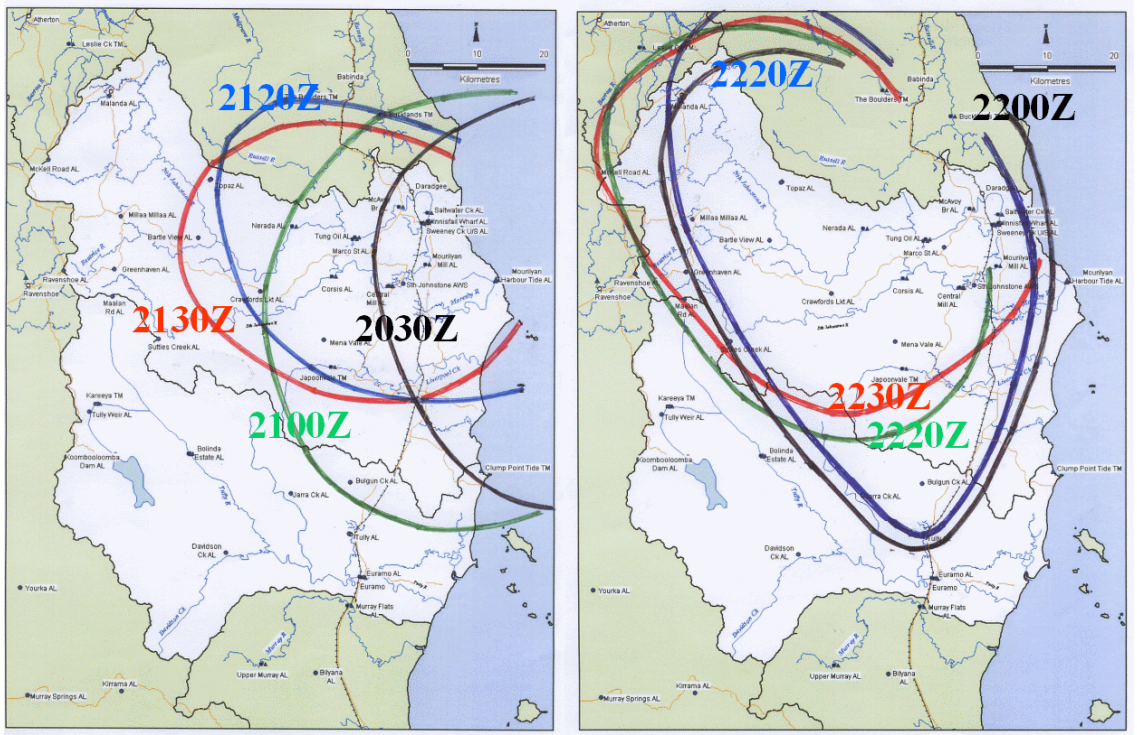


Figure 9. Location of most intense eyewall convection (drawn just inside the line of peak radar reflectivity from Mount Stuart radar) from 2030UTC to 2230UTC 19 March 2006.

Westerly Winds in the Cairns Region

A wind gust of 293.7km/hr (Australian record?) was measured from a Tower on Mount Bellenden Kerr at 2118UTC 19 March. The wind observation was outside the eyewall convection, which was about 10km further south. The tower is located on the eastern side of the mountain peak and about 100 metres below the summit. We need to try and understand these westerly down slope winds, which even in relatively benign situations can produce destructive winds, which tend to reach a maximum at the base of the mountains on the eastern side.

Westerly down slope winds in the Cairns region are notoriously destructive. An example was the so-called tropical Cyclone Agnes in March 1956, which crossed the coast directly over Townsville with a central pressure reading of 960hPa. Agnes had a very large circulation, which after landfall straddled the large mountainous areas south of Cairns. The westerly down slope winds from this cyclone caused more damage at Cairns than the wind damage around the eye at Townsville. Skyrail cableway north of Cairns (see Figure 10) recorded its highest wind speed during Cyclone Larry. A 178 km/h gust was registered at the fourth Tower between its Carvonica base and the first station Red Peak. Tower 4 is at the base of the McAlister Range.

Figure 10 Locations of Skyrail and Mt Bellenden Kerr

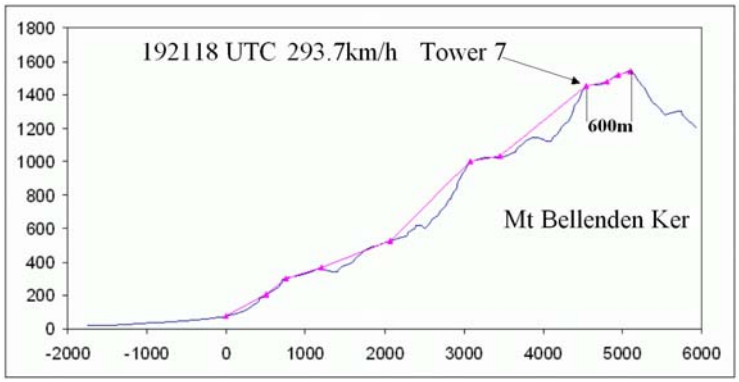


Figure 11. Location of the Tower on Mount Bellenden Kerr with the wind observation.

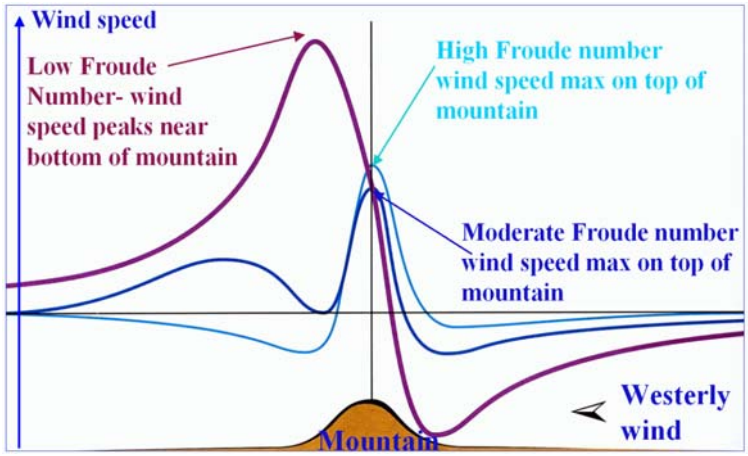


Figure 12. Location of wind maxima in downslope wind situations.

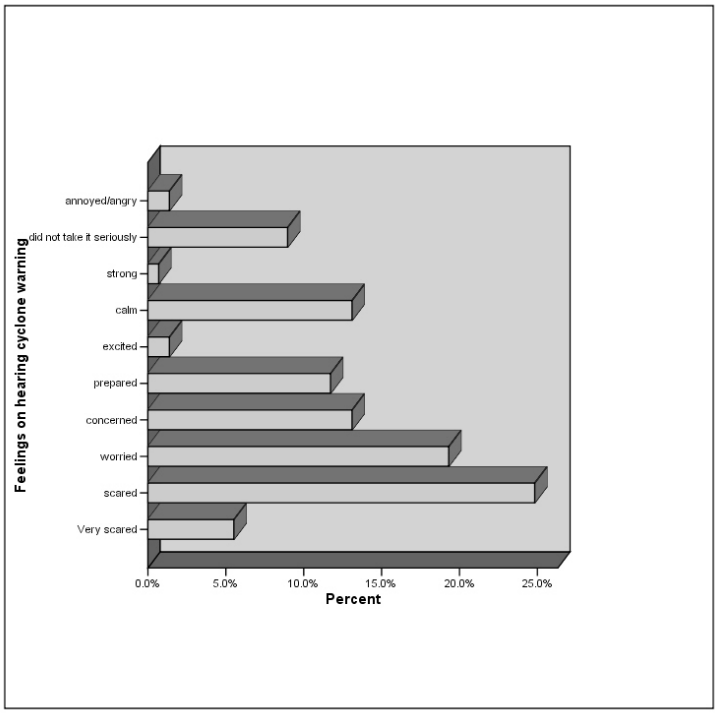
The balance between inertia and buoyancy determines the airflow over a mountain. The Froude Number can express this balance. This number can be written as U/N*h* where U is the wind speed in ms^{-1}, h is the height of the mountain in metres and N is the buoyancy frequency. N increases as the atmosphere becomes more stable. Large Froude numbers occur where there are strong winds, weak stratification and small hills. Large mountains contribute strongly to a low Froude number, which from Figure 12 leads to the wind maximum being located near the base of the mountain.

The Skyrail data indicated strong downslope winds with low Froude numbers. The gust measured near the base of the mountain was 178km/h or 96knots. The strongest winds around Cairns occurred at 9am local time around the time of the Cairns RAWIN flight. Cairns Airport Meteorological Station is not as badly affected by downslope winds as other suburbs closer to the mountains and the maximum wind gust at the airport was 59 knots. The winds from the RAWIN flight were 910hPa 325/42knots, 850hPa 305/43knots, 785hPa 325/39knots and 700hPa 335/50knots. Therefore the Skyrail wind observations represented a strong increase in the ambient winds as it accelerated down the range.

The tower where the Mount Bellenden Kerr wind was measured was located in an area where the wind speed would be rapidly decreasing if the flow conditions were associated with high Froude numbers. Either the peak winds on top of the mountain were significantly greater than 293.7 km/h or there was strong downslope flow down Mount Bellenden Kerr.

Post Disaster Survey (David King)

Following the impact of cyclone Larry on Johnstone Shire and surrounding communities on 20th March, a team of five researchers from the Centre for Disaster Studies carried out a post disaster household survey. The team was led by Dr Douglas Goudie, who has participated in previous post disaster studies. We were also fortunate to have the participation of Dr Dale Dominey-Howes from Macquarie University, and organization as well as participation by Sonia Leonard, the coordinator of the centre. The survey was carried out on a face to face interview basis, beginning on Saturday 25th and concluding on Tuesday March 28th. Eight separate areas/communities were covered – Innisfail Estate, East Innisfail, Flying Fish Point, Coconuts, Kurrimine Beach, South Johnstone, Mourilyan and Babinda. The survey interviewed a representative from 147 participating households that held a total of 471 people at the time the cyclone impacted. The survey indicates a strong pattern of good preparation and protective behaviour, but significantly 82% of respondents had previously experienced a cyclone, principally Winifred that hit Innisfail 20 years ago.



Refining safety weather warnings and community preparedness Role of the media (Douglas Goudie)

'Be prepared. Do everything. "Forget the boy who cried wolf". – Householder from East Innisfail after being battered by Cyclone Larry on 20/4/6.

This summary report from the Centre for Disaster Studies considers the progress of Goudie's post-doctoral work with the Bureau, post impact description of Larry's impact intensity, and focuses on open-ended responses from 150 respondents in Larry's impact zone a week after land fall.

The main focus is the effectiveness of the safety-oriented weather warnings. There is first-hand feedback on the *media, conflicting information, old information, impact times, update frequency and siren use, , There is praise to the Bureau, encouragement to advertise Bureau site, continue Bureau innovation, and detail 'what-to-do' information.*

Goal of safety weather warnings:

Maximise safety and recovery, and minimise loss.

1. There are knowable risks.

2. Help create an aware, informed community,

predisposed to safety-oriented action, as a practice.

3. Provide timely, effective weather warnings

(this is real, this is coming at me,

I need to make safe where I am, or move to somewhere much safer.

I will not travel during the impact period)

4. Provide 'what to do' (action) information,

via reliable sources, web and media delivered.

5. Encourage information-sharing

among friends, neighbours, family.

The cyclone Larry survey underlines that making the threat real remains a core ongoing goal of safety weather warnings.

Five people interviewed for 4 days in the coastal plains impact zone, starting 5 days after Larry struck. Over 200 people where directly interviewed from `147 households (average of 3.2 persons per HH), representing their families, and reflect the experiences of their neighbours and friends in the impact zone. Many knew they were going through a life-threatening experience. Some only realised that at 3 am, a few hours before impact. But even they had prepared. The researchers hope the warnings, public awareness and preparedness ahead of major impact events will only become more complete as a result of the following responses. The full transcript was sent to the Bureau on 20/4/6 for detailed use.

See outstanding recommendations and Larry tables in Appendix.

Issues profile

- **'Patchy' is good**

Landfall Larry was a *patchy* Category 5. The Bureau already uses the term specifically:

***Patchy:* Occurring irregularly over an area.**
http://www.bom.gov.au/info/wwords/#INTENSITY

Recommendation 1: Language use – Patchy Category 5.

"It was a Category 5 cyclone at landfall, and a patchy Category 5 cyclone over land, perhaps disrupted by Bartle Frere, with areas of highly destructive winds".

This clearly confirms what people saw, and experienced.

- Most residents knew what to do and did it.
- **Zoom scale for local impact places and times.** Destructive winds started at 5 am south of Innisfail and 7 am to the north. Media reports created some confusion or alarm among some residents – what the media was saying from 5 – 9 did not necessarily match their real-time experience.
- **The forecast track map is well appreciated:** "It really did make us take it seriously", but increase the near-land-fall scale and detail.
- There were a couple of **households who used no media**, and had no warning from others, and only learned about the cyclone as it hit. In the extreme event, these are the people we most need to reach.
- Some questioned why such a high surge would be predicted – they were scared enough already.
- The Bureau should do more to promote their web site - particularly how to get into the high impact weather warning areas as threats manifest. 'Please let us know about the Bureau web site'.

Recommendation 2: Bureau to feed back to media

Bureau feeds these survey results out to all media in vulnerable areas.

Rationale:

COAG 2004 principle 7 http://www.dotars.gov.au/localgovt/ndr/nat_disaster_report/naturaldis.pdf :
Reform Commitment 7: develop jointly improved national practices in community awareness, education, and warnings which can be tailored to suit State, Territory and local circumstances.

Further, page 18: The Media:
Media organisations, particularly public and private radio and television organisations, have responsibilities in ensuring that timely and appropriate warnings and advice on disasters is broadcast to communities at the request of relevant authorities. They also have a role to play in educating the community about natural disaster issues.

- 'TV, radio and www all giving different advice'.
- 'Make clear in broadcasts if they are talking about the eye of the cyclone, or which quadrant. Dept of Met needs to have better communication with radio stations, as each one was giving out different information'.
- 'Cyclone Wati – why no information? We had to ring Mackay to get information'.

CYCLONE TESTING STATION
School of Engineering, James Cook University, Townsville

Investigation of structural performance of housing, commercial and light industrial buildings in the Innisfail, Babinda and Kurrimine areas, following Cyclone Larry - Preliminary summary of CTS survey findings

Authors: G. Boughton[1], D. Falck[1], J Ginger[2], D Hayward[3], D Henderson[2], C Leitch[2] and R. Loveridge[4].

This brief document is preliminary and is intended for discussion purposes only.

A formal report will be produced and distributed, following detailed analysis and discussions with related agencies. Scope of the damage investigation did not include infrastructure such as power, communications, sugar mills etc and the survey did not include the tablelands.

Estimation of wind speeds

Tropical Cyclone Larry crossed the coast on 20 March 2006 on a NW track with the eye passing over Innisfail. The eye of Cyclone Larry extended from north of Kurrimine Beach to south of Babinda. A peak gust wind speed of 98 knots was recorded at South Johnstone AWS.

From analysis of simple structures (road signs), the maximum gust wind speeds at 10 m height were in the order of 55 to 65 m/s (~200 to 240 kph), in the area surveyed. This is a preliminary estimate only. Further analysis of data is still required. Cyclone Winfred (1986) had estimated wind gusts in the order of 50 to 55 m/s.

Magnification of wind speeds due to speed up over steep topography did cause an increase in damage to buildings. (Conversely, buildings in the lee or sheltered side of hills suffered minimal damage.)

Performance of buildings

In general, newer housing performed well. Conversely, the majority of major structural damage was associated with older construction (>25 years). Introduction of revised standards for domestic construction in the early 1980s resulting in newer housing being able to withstand higher wind loads. Also, older structures are more likely to have deteriorated components (corrosion, rot, insect attack) leading to a reduction in strength along the critical load path. If the cyclone did not have such a fast forward movement it is likely that structural damage levels, wind driven debris and water ingress would have been

[1] TimberEd, Perth
[2] Cyclone Testing Station, James Cook University, Townsville
[3] Timber Queensland, Brisbane
[4] Australian Building Codes Board, Canberra

far worse. The reduced duration of intense winds also minimised the potential for fatigue failure of metal cladding, fixings and battens.

In some cases of failure of older housing, it was apparent that the house had some upgrading undertaken. For example, a new roof was fitted with new cladding screws but the roof failure occurred at the batten to truss connection which still had only the original nail connection. Some failures had the screw placed between the original nails. For housing in flat exposed areas a 90 mm long Type 17 screw is required along with pre-drilling. Strapping of battens to rafters is an alternative.

House construction since mid 1980s performed well, structurally. This is to be expected due to the newer housing being designed to higher wind speeds. The main source of structural damage to newer construction was from wind driven debris. For a small number of cases, poor detailing led to loss of structural elements. In general, garage doors performed poorly leading to water ingress, internal pressurization and subsequent damage. The loss of flashings, guttering and soffits also contributed to water ingress. Garden sheds performed poorly and added to the wind driven debris.

Even in undamaged buildings there was water ingress through vented gables, roof vents, windows, doors, etc. As observed after Cyclone Vance (Exmouth 1999), some newer houses will need to have plasterboard replaced because of water damage even though there was no structural damage. In older buildings the use of more durable linings meant that even though there may have been structural damage, the linings could be dried out and may not need to be replaced.

Most light industrial buildings surveyed had some form of damage including loss of flashings, roller door failures, cladding loss, and in some cases structural frame failure. Apparent poor detailing of structural connections contributed to failure of some structures. Designers need to assume that a dominant opening (such as roller door failure) will occur, causing a large internal pressure. Poor construction practice and minimal maintenance lead to failure from corrosion of cladding and frame elements.

Typically commercial buildings have large windows (i.e. shop fronts, banks of glass louvers, etc) and roller doors, which are susceptible to failure, increasing the chance of internal pressurization contributing to loss of roof structure. Often attachments (e.g. mechanical services, air-conditioners, etc) were not securely attached causing impact damage to the immediate area and adjacent structures. Water ingress caused significant contents damage.

Preliminary Recommendations:

- For the rebuilding or upgrading of older housing, the complete load path from roofing to foundations, and not just from roof cladding to battens, needs to be addressed. This may not always be feasible so at the very least (pragmatic approach for partial solution) upgrade from roofing to top plates of walls. This includes the rafter to top plate connection and strapping from rafters and ridge plates to ceiling joists and tops of internal walls.

- Regular inspection of structural elements (including in the roof space) to look for signs of deterioration (e.g. corrosion, rot, etc). Certainly after an event of the magnitude of Cyclone Larry, critical components in the tie-down system need to be inspected to check their continued performance in future tropical cyclones.
- Education of builders and building certifiers (to ensure correct tie down). This should especially target builders and certifiers brought in from outside the Cyclone zone as part of the reconstruction effort.
- Education of builders and designers for correct classification of site topography and implementation of the required construction details.
- Education of designers of industrial buildings in the correct application of the local pressure factors and internal pressure coefficients in the wind loading standard, AS/NZS 1170.2.

Further Liaisons

- Johnstone Shire Council – assistance with education of builders, certifiers, owners.
- Exchange of survey and data analysis with Geoscience Australia.
- Wind speed estimation analysis with Bureau of Meteorology, Systems Engineering Australia, Geoscience Australia, JDH Consulting, Mullins Consulting, etc.

Acknowledgements

In conducting this investigation we acknowledge the support and assistance of the Dept of Emergency Services, Dept Public Works, Dept of Housing and Local Government, Australian Building Codes Board, Insurance Australia Group, Timber Queensland, Bluescope Steel and Emergency Management Australia.

The authors are very grateful to the residents who generously assisted this study by volunteering information, answering questions and on occasions inviting the authors into their houses to inspect damage.

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Geoscience Australia (Bob Cechet)

Geoscience Australia has deployed 3 teams to travel to the affected areas to survey the damage and to assess the social and economic impact.

The investigation of the damage caused by Cyclone Larry to buildings and infrastructure is being carried out in collaboration with James Cook University, Curtin University and the Insurance Australia Group. GA has been asked as a member of the "Operations Recovery Industries Action Group" to provide research into understanding the economic losses associated with the impact of this event on the primary industry of the area.

GA and the Queensland Dept. of Primary Industries and Fisheries (PDIF) are conducting field surveys to assess the extent of damage to agricultural areas affected by Tropical Cyclone Larry. This work will involve validating post-disaster remote sensing imagery and surveying growers on the loss of productivity resulting from the cyclone. The data collected from the field surveys will provide detailed estimates of direct economic losses to the agricultural industry that will be used to assess the long-term impact on the regional economy and provide information to assist policy decisions for recovery.

What information is being collected?

Small teams from Geoscience Australia and its partners are using equipment such as GPS (Global Positioning System) units, digital cameras and handheld computers to record information about properties, such as construction type, building materials, number of floors, and damage sustained.

Photos of the buildings are a complementary way of recording these important details. High-resolution satellite data is being used to determine some properties of buildings such as roof size and distance to nearest building. Satellite imagery is also being used to assess the extent of cropping and crop damage in the region.

In addition, other GA teams are seeking supplementary information from primary producers about the impacts on their economic activities and their plans for recovery.

Estimation of wind speeds (local and regional)

The role of local steep topography in the central and suburban regions of Innisfail with regard to "local damage of a line or cluster of structures" was of particular significance where winds from two directions (SW & NNE) were experienced before and following the passage of the cyclone eye.

The "local" magnitude of the wind speed on the ridges is magnified by the speed-up over steep topography. There was a noticeable increase in damage to buildings on topographic ridges (Innisfail CBD, Southeast Innisfail & suburbs of Hudson and Belvedere) . Buildings on the sheltered side of hills that suffered minimal damage when the wind initially was from the SW were affected when the cyclone eye passed and they were exposed to damaging winds from the NNE.

The wind multipliers defined in Aust/NZ Wind Loading Standard (AS/NZS 1170.2) can numerically describe the site wind exposure and speed modifications.

These multipliers give quantitative measures of local wind conditions relative to the regional wind speed (defined as open, level terrain at a 10 m height) at each location.

The three wind multipliers are the terrain/height multiplier (M_z), the shielding multiplier (M_s) and a topographic (also called hill-shape) multiplier (M_h).

Geoscience Australia will be deriving these wind multipliers for a significant part of the impact zone of Cyclone Larry as input to our structural vulnerability model which estimates the direct economic loss for a given site wind speed.

Analysis of satellite imagery

ACRES, a business unit of Geoscience Australia, is acquiring and analysing satellite imagery over the cyclone affected area of far North Queensland. The ACRES archive contains pre-cyclone imagery of LANDSAT-5 and 7 acquired in October and November 2005, RADARSAT and ERS-2 imagery acquired in the last five years.

ACRES also maintains a daily archive of coarse resolution MODIS (250m spatial resolution) and NOAA-AVHRR (1km) imagery of Australia.

So far ACRES have acquired two post-cyclone RADARSAT images acquired on 21 March and 25 March (10m resolution). ACRES also purchased one ENVISAT (radar) image from European Space Agency and has requested SPOT5 image acquisition over Innisfail through Raytheon, ASTER imagery through a Japanese agency (ERSDAC) and IRS image acquisition (through Indian Space Agency). Pre- and post-cyclone RADARSAT imagery acquired through ACRES have been distributed to key agencies within Queensland government and other Commonwealth government agencies free of cost.

Satellite imagery held in ACRES archive can be viewed from - http://acres.ga.gov.au/intro.html.

The RADARSAT imagery clearly shows the damage to banana plantations but details of other crops are not evident from this imagery and access to optical imagery would be very useful to identify different crop types in this area. ACRES staff are currently ground-truthing their crop detection algorithms in the cyclone affected area in order to obtain accurate estimates of crop types and extent of damage through remote sensing data analysis techniques.

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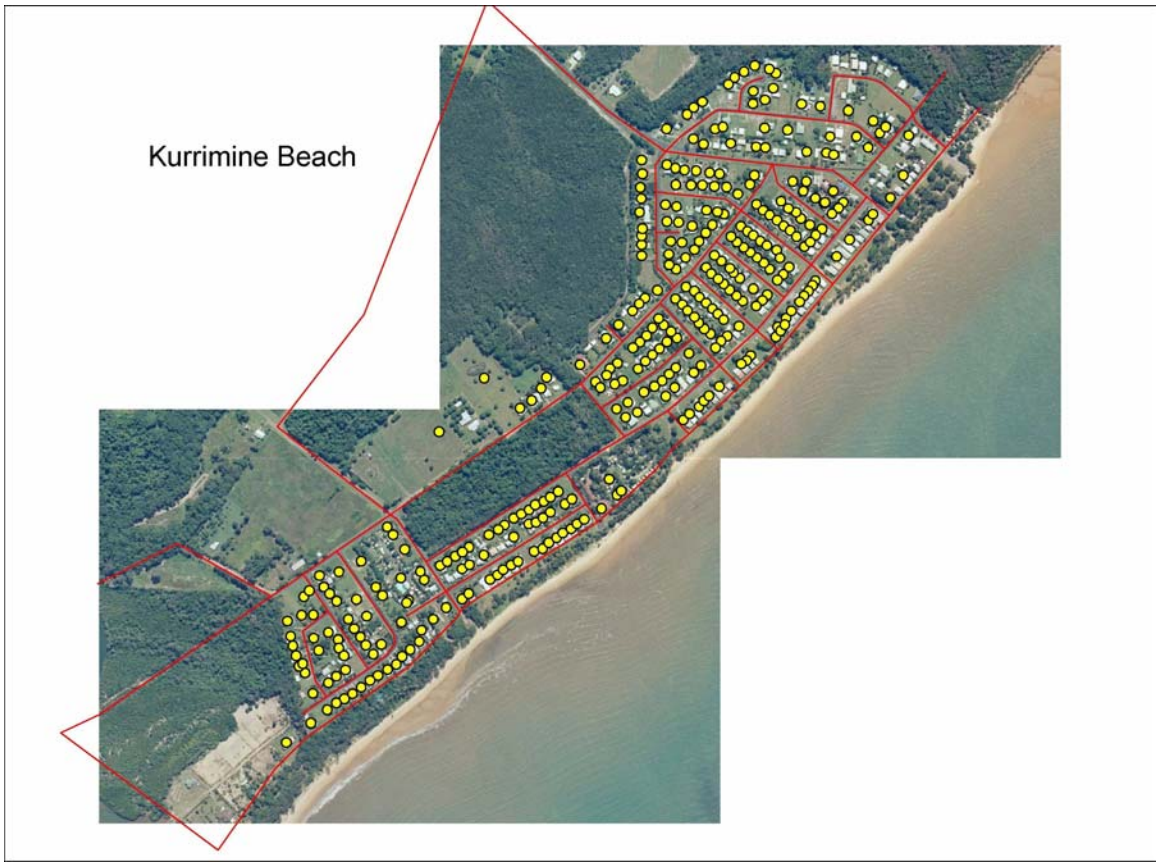
The following images were provided by Geoscience Australia:


25/03/2006


LARRYS TAKE AWAY
WE HATE LARRY!
27/03/2006


28/03/2006


Kurrimine Beach

Dr Bruce Harper

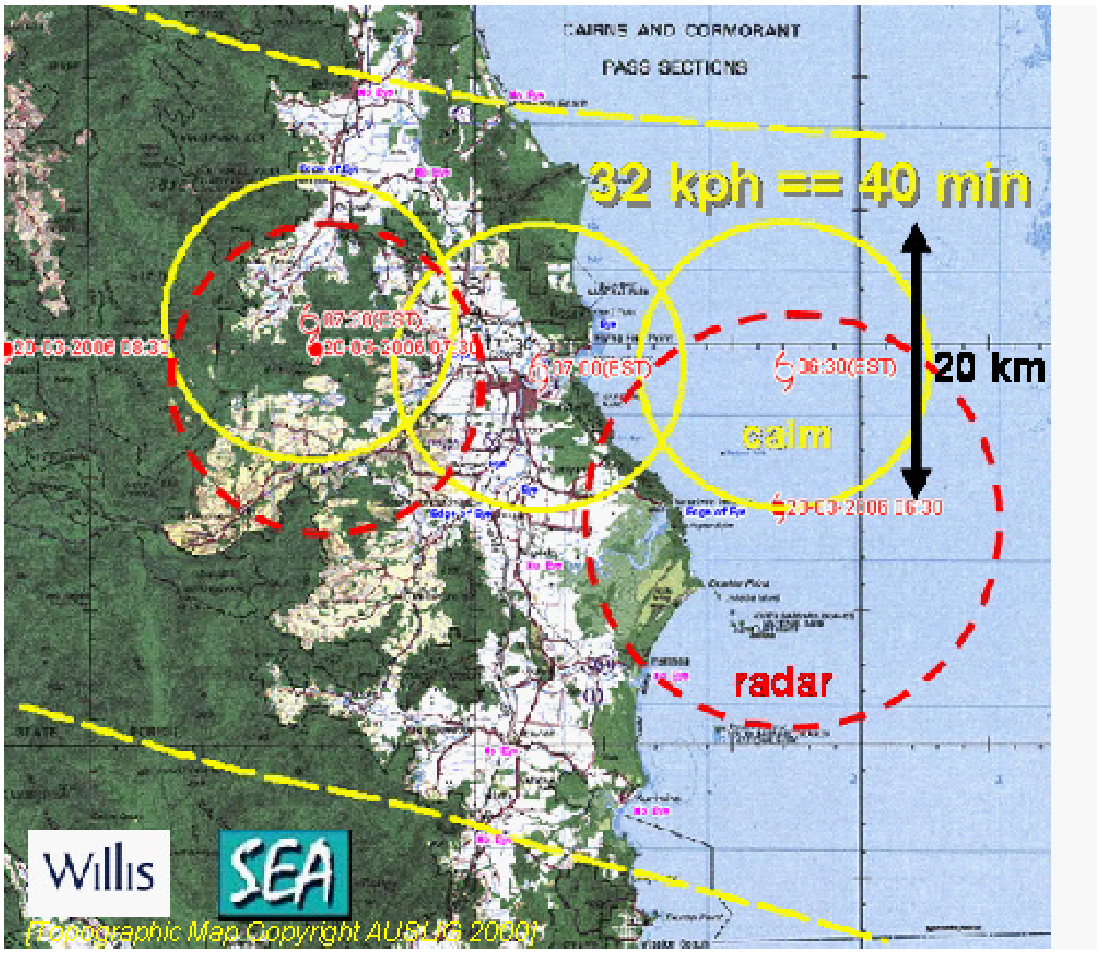
Systems Engineering Australia Pty Ltd (SEA)
In association with Willis Reinsurance Australia Ltd (Willis)

Sponsored by Willis, Dr Harper reported that he was amongst the first of the impact assessment groups to inspect and survey the Innisfail area. He arrived midday Wednesday 22nd March and visited all of the major townships over the following two and a half days. His overall impressions were that, while damage to older and/or exposed housing across the region was extensive, newer homes remained largely intact. Commercial buildings in Innisfail and Babinda that were most affected were also predominantly of older construction, with debris damage to roofs also being a factor. Vegetation damage was extensive and severe along the coast between Mission Beach in the south and Flying Fish Point in the north. Damage to low tension power distribution networks was also extensive. Babinda in the north appeared to have suffered disproportionate wind damage relative to its displacement from the centre, which Dr Harper attributed likely to topographic funnelling of downslope westerly winds. On recovering the barograph from Babinda P.O. on 23rd March, he observed significant pressure fluctuations were evident near its minimum station pressure of 964.5 hPa. The speed of storm movement and possible shielding by vegetation were also identified as factors that may have acted to reduce the overall building damage across the region.

Based on his inspections and analysis of the radar and AWS data, Dr Harper concluded that *Larry* may have undergone significant deformation as it crossed the coast, perhaps associated with local topographic factors and its relatively fast forward speed. His accrued eyewitness reports of the timing and location of the 20 km diameter calm do not agree with the radar eye locations, which suggest that the +4000 m radar storm core may have been larger and displaced approximately 10km further south at the time of coast crossing (refer figure). As noted by Callaghan, subsequent radar images showed significant distortions and Harper suggested a possible later realignment with the surface calm, which may have led to increased winds around that time. He argued that this potential "tilting" of the storm warm core might in turn explain the relatively high recorded central pressure at landfall of around 960 hPa and the flatness of the available MSL pressure readings between Coquette Point, Innisfail, South Johnstone and also Babinda. He also noted that the recorded mean wind speeds (V_{600}) from Lucinda through South Johnstone to Green Island were of a very similar magnitude (45 to 50 m/s only as highlighted by Mason/AMC) and that this also suggested a very unusual pressure/wind structure. High gustiness of the winds at South Johnston AWS near the peak ($G_{3,600}$ up to 2.2) were also noted as either evidence of structural instability or also possible topographic effects from the nearby Basilisk Range to the south of the AWS site. He noted that preliminary estimates of upper and lower bounds of regional gust wind speeds derived from street sign data that had been collected by JCU/CTS, Boughton, Holmes and Mullins indicated a possible range of peak V_3 winds at standard exposure of between (conservatively) 50 and 65 m/s, which compared well with the peak measured AWS wind gust of 50.5 m/s. Mechanical testing of selected signs was still needed to refine these estimates. The reported 82 m/s point-sampled gust from the CSIRO's Bellenden Ker tower (elev 1400m) was examined but is expected to reduce to a standard exposure wind similar to these values. In Dr Harper's view all of this data indicated that *Larry* was a high Category 3 or a low Category 4 storm at landfall. Dr Harper also contributed comments from Dr John Holmes (JDH Consulting) whose opinion was that peak wind gusts at standard exposure were likely to have been in the range of 50 to 60 m/s only.

Dr Harper also reported on storm tide impacts, noting that the excellent network of EPA storm tide gauges clearly indicated that the peak surge was near Clump Point and Bingil Bay, leading to HAT being exceeded by about 0.7m, with wave setup and runup impacts above that level. This agreed with his field inspections but he also noted that the overall impact on beaches across the region was relatively minor, possibly because of the neap tides and the very short period of surge action. He also reported on some preliminary storm tide simulations using MMUSURGE (in association with AMC – Australian Maritime College). Based on these initial runs it was expected that the recorded storm surge would ultimately be well modelled by a shrinking and weakening storm structure as it approached the coast. The intensity range was likely to be middle to low Category 4 at that time.

In closing, Dr Harper indicated that more storm tide and wave modelling was planned in association with AMC and Willis and that this would yield a modelled wind swath for the region, which would be made available to assist other investigators. Work would also continue with Willis and JCU/CTS on investigating building performance during *Larry*.



Deduced outer swath of significant structural damage, inner surface calms and radar eye positions at indicated times (EST).

Environmental Protection Agency (David Robinson)

On Monday 20 March 2006 severe tropical cyclone Larry crossed the Queensland coast near Innisfail. The Bureau of Meteorology had issued Top Priority cyclone advices for coastal communities between Cape Tribulation and Ingham.

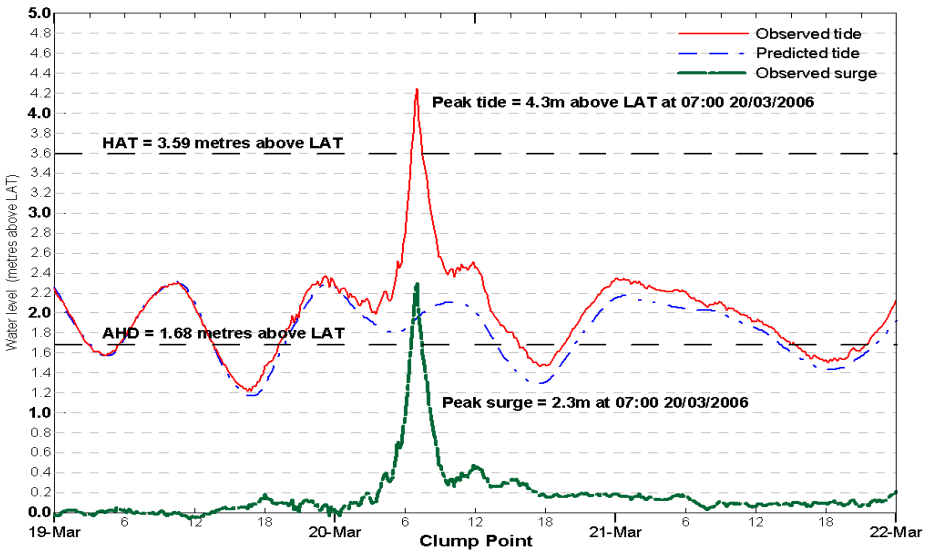
- Forecast as Category 5 cyclone prior to crossing with predicted central pressure of 915hPa.
- Large significant wave heights recorded at a number of north Queensland locations.
- 2.3m storm surge recorded at Clump Point.
- Reports of only minor erosion damage to beaches.
- Storm tide flooding recorded in the Clump Point-Mission Beach area.

Fact Sheet on TC Larry is available to download at
http://www.epa.qld.gov.au/publications/p01863aa.pdf/Tropical_cyclone_Larry.pdf

Nearest wave recorders were at Cairns and Townsville.
For this event, tide data was obtained from the
Townsville, Lucinda, Cardwell, Clump Point, Mourilyan
and Cairns gauges (see www.epa.qld.gov.au/tides for site details).
Plots of the records from these sites are shown in figures 6–11 of the TC Larry Fact Sheet.
An initial report and photographs from the joint EPA/BoM coastal inspections of the week of 27 March is available on request.

Recorded surge heights

Site	Date & time	Surge (m)	Exceeded HAT
Townsville	20/03/2006 10:00	0.77	No
Lucinda	20/03/2006 08:00	0.86	No
Cardwell	20/03/2006 08:10	1.76	Equal
Clump Point	20/03/2006 07:00	2.30	Yes
Mourilyan	20/03/2006 07:30	1.34	No
Cairns	20/03/2006 09:00	0.51	No



Kurrimine Beach

Bureau of Meteorology (Peter Otto)

The Bureau of Meteorology conducted a comprehensive survey of a wide area of damage over a period of two and a half weeks. This survey involved:

- Ground based damage assessment (in association with Engineers from Geoscience Australia and specialists from the EPAs Coastal Services Unit).
- Helicopter-based reconnaissance of the coast from Cairns to Bedarra Island, and inland to the tablelands.
- Accessing meteorological data from other agencies (e.g. Ravenshoe wind-farm, CSIRO site at Bellenden Ker)
- Surveying members of the community, with particular emphasis on speaking to mature and well-educated community service workers/volunteers who experienced the eye of the cyclone. Pressure readings, anecdotes and details of structural damage were recorded.

Some key findings during this period include:

- At least 4 hours of consistent satellite-based cyclone intensity estimates of low Category 5 immediately prior to impact
- Clear satellite evidence of eye wall meso-vortices
- The observation of a 294 km/hr gust at Bellinden Ker (elevation approximately 1450m[5]).
- The partial destruction of a 6 year old, $500K home at Garner's Beach, which insurance engineers have determined experienced 80m/s winds. They also proposed that the home would have suffered complete failure if it had been exposed to these winds for another 30 minutes.
- Anecdotal evidence from a University Professor who survived the notorious 1999 Sydney-Hobart and Montegue Island yacht races (70 and 80 knot mean winds respectively) that TC Larry's winds were far worse (though follow up questioning is needed to determine his position during both races).
- A wooden stake of over 1/2 a metre in length skewered through a coconut palm.

[5] Some quick calculations have been done that cast doubt upon whether or not this wind strength is applicable at a height of 10m, however this is a very complicated field of research and more work on this question is essential.

- Unconfirmed reports of a measured gust of 315 km/hr at Jappoonvale on what are believed to be quality instruments.
- Evidence of tornadic touchdown at Herberton (accompanied by a witness report).
- Gusts of 185 km/hr at the Ravenshoe wind farm (an excellent site that seems to be well away from topographically induced lee influences).
- Still to be confirmed storm tide measurements of 4-4.5 metres above the tide at the time of crossing, with large boulders and concrete slabs clearly thrown metres inland, and in some cases dozens of metres.
- Some snapped coconut palms at Kurrimine Beach, with many green coconuts torn off their parent trees (consistent with wind gusts of up to 171 knots[6])
- 1 report of an eye pressure of 915 hPa at south Innisfail from a coast-guard volunteer
- 1 report of an eye pressure of 925 hPa at south Innisfail from another coast-guard volunteer
- 1 report of an eye pressure of 920 hPa at the seaside town of "the Coconuts" from a Kindergarten head-mistress (with an impressive character reference from a principal of a nearby school who also is the father of a senior Bureau of Meteorology staff member).
- A report of a 910 hPa pressure reading at Innisfail and an as yet vague report of 900-920 hPa at the old Nerada tea plantation on the Palmerston Highway (the latter report obviously needs to be followed up).
- An as yet vague report of the pressure at Jappoonvale being "25 hPa higher than the eye pressure the Bureau of Meteorology had in their warnings" between 7 and 8am (that forecast eye pressure figure was 915 hPa).
- Two separate reports of pressures of 940 hPa at Silkwood (not in the eye).

Of these data, the most objective is clearly the storm tide and the pressure readings, particularly at Silkwood. Whilst it could be argued that the pressure reports from the eye (albeit from demonstrably responsible and community minded people) could be influenced by the forecast eye pressures, this same argument cannot be used against the readings outside the eye at Silkwood and Jappoonvale.

A lot of work is still required. The accounts of the witnesses need to be scrutinised, their instruments need to be calibrated and checked (not only at standard air pressures but also at low pressures).

Clearly more time is needed to thoroughly and responsibly assess the true nature of this very important tropical cyclone.

The use of damage to infer wind speeds:

The comprehensive survey clearly showed that some areas were worse affected than others.

A limited set of road signs along the Bruce Highway were analysed to infer the presumably perpendicular component of wind to the sign. However such an analysis poses the following important questions:

[6] Guard and Lander, *The Saffir-Simpson Tropical Cyclone Scale for the Tropical Pacific.*

- The signs studied were in a small subset of the damage area (along the Bruce Highway, and predominantly to the south of Innisfail)
- The Bruce Highway faces north/south, and so the road signs would only measure southerly or northerly wind components. However the survey showed that easterly winds in areas along the beach and at Silkwood and Jappoonvale were probably the strongest winds during impact.
- Once any structure has bent over due to stress at a certain speed, it can no longer indicate that winds have reached any higher level as it is slipstreaming these winds.

Studies of housing damage may yield a more comprehensive impression of the wind field over an area, however there are many variables that might influence the ability of a home to withstand a cyclone, namely:

- Shelter from other structures and trees
- The honesty of the builder
- How many builders (particularly owner builders) would have built their home above specifications

Finally, and very importantly, the damage signature over an area is intrinsically linked to the duration of the extreme winds. With cyclone Larry moving at over 25 km/hr, it is very likely the most extreme winds only lasted 10-20 minutes. This will greatly influence the amount of debris that becomes airborne, and in-turn the amount of airborne debris has a profound effect on the amount of damage done. Therefore mental comparisons to previous and usually longer-lived events in different areas with different building standards is not ideal. The pressure data derived from credible concerned citizens, along with the well-established satellite intensity estimation techniques and storm tide measurements are arguably the most objective data available for this system. Nevertheless cautious and thorough appraisal of these preliminary data is essential before public statements are made on the strength of this very important cyclone.

Aerial photograph showing extensive environmental damage at Etty Bay

Coastal erosion and Storm Tide aftermath at Cowley Beach


Wooden stake driven through a coconut palm at Silkwood

Bureau's Automatic Weather Station at South Johnstone near Innsifail

Vegetation damage adjacent to the Automatic Weather Station

APPENDIX: Survey statistics relating directly to the Bureau and the Media (Douglas Goudie and David King)

Information Source During Cyclone Warning Period

Info source on Sunday	Count	Col %
Radio	38	25.9%
TV	26	17.7%
Friends & Relatives	5	3.4%
BoM website	19	12.9%
Local Authorities	1	.7%
Multiple sources	31	21.1%
TV & radio	27	18.4%
Total	147	100.0%

Use of Tracking and Forecast Maps

	Used tracking map		Total	
Usefulness of Forecast map	Yes	No	Count	Col %
	Count	Count		
Yes very	19	27	46	32.6%
Yes	27	20	47	33.3%
Not much	1	4	5	3.5%
Did not see it	2	41	43	30.5%
Total	49	92	141	100.0%

Expectation of Storm Surge and Local Impact by Location

	Expectation of Storm Surge on Coast			Total	Expectation of surge impact at this Location			Total
Location	Yes	No	maybe		Yes	No	maybe	
Innisfail Estate	20	9	1	30	12	17	1	30
East Innisfail	26	6		32	8	24		32
Flying Fish Point	3	1		4	3	1		4
Coconuts	9	2		11	9	2		11
Kurrimine		1		1		1		1
Mourilyan	14	9		23	4	19		23
South Johnstone	9	8		17	1	15	1	17
Babinda	13	15		28	1	27		28
Total	94	51	1	146	38	106	2	146

Time that People Became Concerned About Larry and Time of Commencing Preparations in Response to the Cyclone Warning

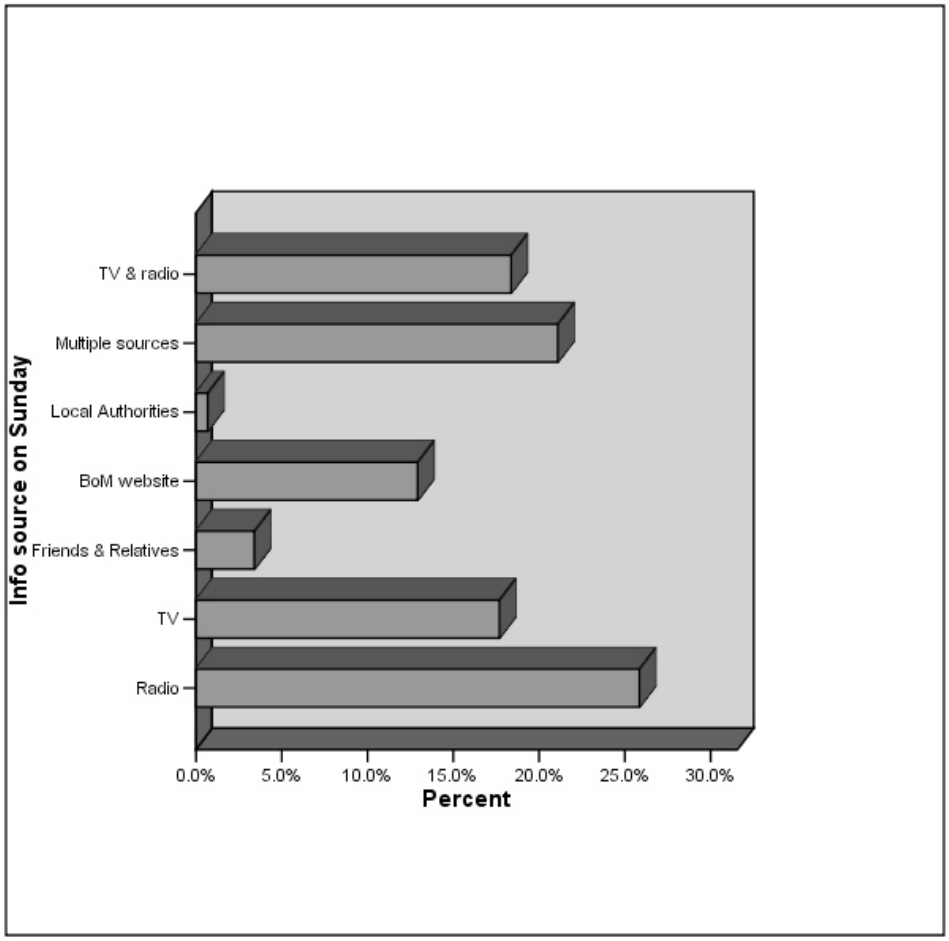
Time became concerned about Larry	**Count**	**Col %**
Before Saturday	5	3.5%
Saturday	14	9.8%
Sunday before 9	5	3.5%
Sunday 9-1	19	13.3%
Sunday 1-5	27	18.9%
Sunday 5-8	8	5.6%
Sunday after 8	8	5.6%
Monday am	54	37.8%
Not concerned	3	2.1%
Total	143	100.0%
Time of beginning preparations		
Before Saturday	16	11.0%
Saturday	30	20.7%
Sunday before 9	3	2.1%
Sunday 9-1	22	15.2%
Sunday 1-5	41	28.3%
Sunday 5-8	11	7.6%
Sunday after 8	10	6.9%
none made	12	8.3%
Total	145	100.0%

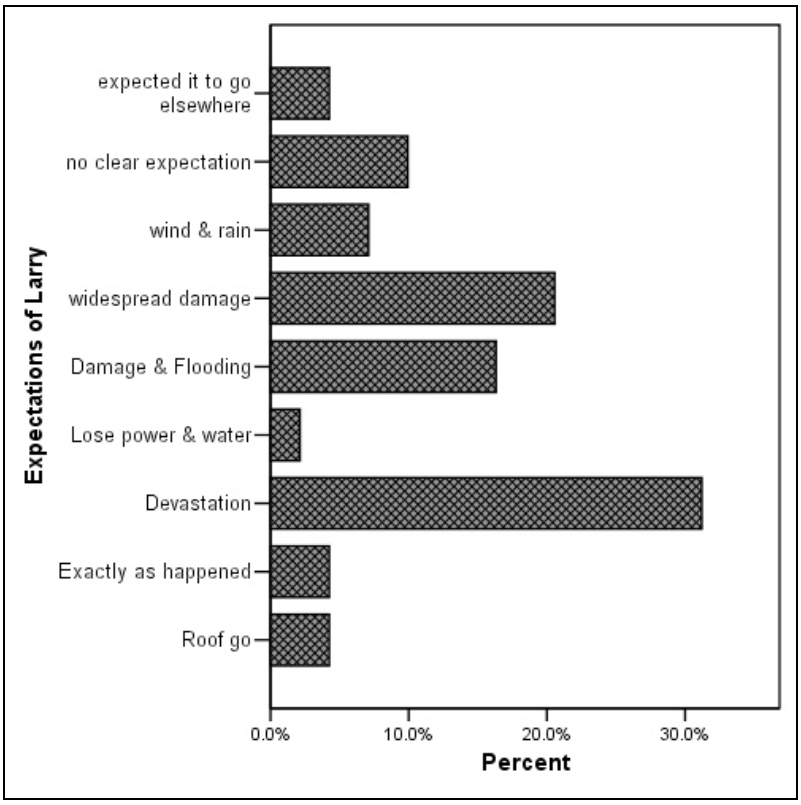
Place and Actions in Sheltering During Cyclone Larry's Passage

Actions to shelter	Count	Col %
evacuate	17	11.6%
shelter in central room	31	21.2%
mattresses	13	8.9%
under table	2	1.4%
shelter in bathroom/laundry	16	11.0%
lounge	14	9.6%
shelter in bedroom	8	5.5%
kitchen	2	1.4%
under house room	12	8.2%
anywhere/moved about	28	19.2%
in car/garage	3	2.1%
Total	146	100.0%

Bureau of Meteorology Advice and Warnings

Rating of BoM cyclone advice	Count	Col %
spot on	18	12.2%
reliable	47	32.0%
could be more frequent near landfall	13	8.8%
more prominent/louder	10	6.8%
okay/pretty good	44	29.9%
missed/didn't hear them	5	3.4%
contradictory messages	6	4.1%
exact locations impacted	3	2.0%
NESB	1	.7%
Total	147	100.0%
Were the BoM messages Useful		
Yes	133	91.7%
No	12	8.3%
Total	145	100.0%
Were They Easy to Understand		
Yes	141	98.6%
No	2	1.4%
Total	143	100.0%
Were They Too Technical		
Yes	13	9.1%
No	130	90.9%
Total	143	100.0%
Were They Frequent Enough		
Yes	105	73.4%
No	38	26.6%
Total	143	100.0%
Rating of BoM messages		
excellent	17	13.2%
good	31	24.0%
Okay	22	17.1%
poor	3	2.3%
Make them more regular	39	30.2%
media exaggerated	2	1.6%
no access to radio/power loss	3	2.3%
needed more info	11	8.5%
siren frightening	1	.8%
Total	129	100.0%


Info source on Sunday
TV & radio
Multiple sources
Local Authorities
BoM website
Friends & Relatives
TV
Radio
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%
Percent


Expectations of Larry
expected it to go elsewhere
no clear expectation
wind & rain
widespread damage
Damage & Flooding
Lose power & water
Devastation
Exactly as happened
Roof go
0.0%
10.0%
20.0%
30.0%
Percent