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Deployment of the Surface Weather Information Relay and Logging Network (SWIRLnet) during Tropical Cyclone Ita (2014)

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Abstract

The Surface Weather Information Relay and Logging Network (SWIRLnet) of portable anemometers were deployed and recorded surface weather conditions in Cooktown and Port Douglas during the landfall of Tropical Cyclone Ita in North Queensland on 11 April, 2014. The peak recorded 3 second and 0.2 second gusts at 3.2 m elevation were 36 m/s and 28 m/s respectively, in the Cooktown region. Converting these speeds to open terrain, z = 10 m values, a 0.2 second gust of around 40 m/s is estimated. Based on AS/NZS1170.2, this suggests Cooktown experienced a gust wind speed with a return period of 25-50 years. Following the event a damage survey was undertaken in Cooktown with limited damage observed to engineered structures, as would be expected given the wind speeds recorded.

Introduction

Tropical Cyclone (TC) Ita formed in the South Pacific Ocean on 1 April, 2014 and made landfall on the Queensland coast on 11 April as a category 4 (Australian scale) storm. Prior to landfall it passed over the Solomon Islands and Papua New Guinea causing significant damage to homes and infrastructure, primarily through flash flooding. 22 people were killed and tens of thousands displaced in the Solomon Islands capital, Honiara (OCHA, 2014).

TC Ita intensified to a category 5 systems as it moved south-west towards the Queensland coast, but weakened prior to making landfall near Cape Flattery 55 km north of Cooktown (Figure 1).

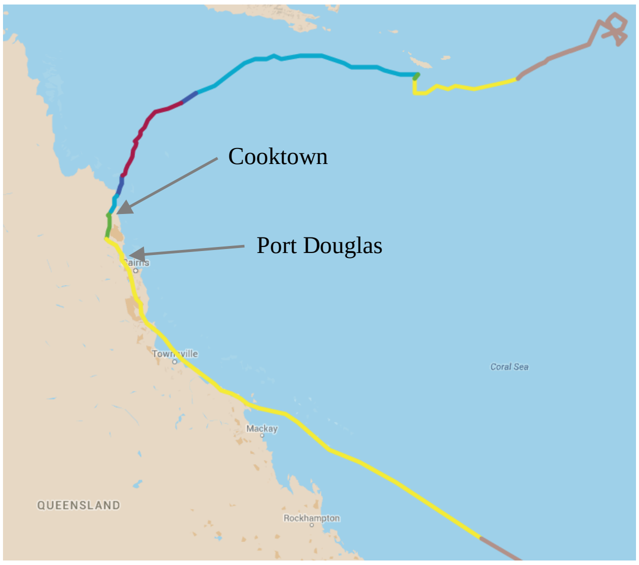


Figure 1. TC Ita track and intensity map (data courtesy BoM).

The storm tracked south along the coastline (making several coast crossings), until it moved offshore around Airlie Beach as a category 1 system on 13 April. Over the following days TC Ita underwent extra-tropical transition and generated strong winds and heavy rainfall as it passed over New Zealand. Despite the intensity of TC Ita at landfall, minimal damage to buildings (in Australia) was reported with the insured loss to structures estimated at only $8.4 Million AUD. Damage to agricultural crops were, however, more significant, with total losses estimated at around $1.1 Billion AUD (Impact Forecasting, 2014).

The SWIRLnet (Henderson et al., 2013) was deployed during TC Ita with three towers positioned in the Cooktown region, approximately 55 km south of the landfall location, and the remaining three in Port Douglas. Each tower recorded wind speed and direction at a height of 3.2 m as well as temperature, pressure and relative humidity. Towers were transported by road from Townsville and deployed in Cooktown on 10 April with data logged for 90 hours. Towers deployed in Port Douglas were positioned on 11 April and their data logged for 31 hours. The three members of the Cyclone Testing Station (CTS) deployment team remained in Port Douglas during the storm passage before collecting towers and returning to Cooktown to retrieve the remaining towers and undertake a local damage assessment.

While the Bureau of Meteorology continues to build on their network of fixed Automatic Weather Stations (AWS) around the country, the density of towers is still relatively low—particularly in sparsely populated regions. The aim of developing and deploying the SWIRLnet, therefore, is to facilitate the capture of greater detail on the surface weather conditions (primarily wind) during landfalling tropical cyclones than what can be captured by the dedicated AWS network alone. In a general sense, this information can be used in near-real-time by disaster response agencies to help estimate potential impacts during events as well as providing greater confidence in estimates of wind speeds experienced by impacted communities. From a wind engineering perspective, these data will enable characterisation of the turbulent wind fields in the very near-surface region during tropical cyclone landfall and provide much needed validation for wind field models used for risk assessment.

This paper outlines the deployment and observations made by the SWIRLnet during Tropical Cyclone Ita. A brief overview of the instrumentation is provided in the following section with further detail on individual tower deployment sites, including the potential influence of surrounding terrain and topography, following this. Recorded wind data is then discussed along with the procedure employed for normalising observational data to standard 10 m open terrain measurements. A brief overview of the structural damage survey undertaken in Cooktown is also provided.

Instrumentation

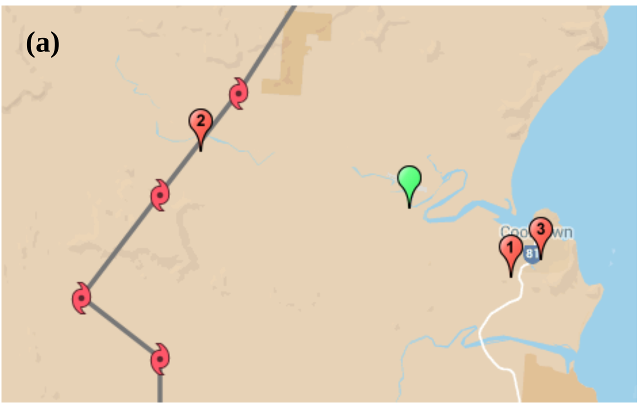
The SWIRLnet is made up of six 3.2 m towers capable of surviving gust wind speeds up to 90 m/s (Figure 2). Each tower is equipped with a marine rated R.M. Young propeller anemometer for measuring wind speed and direction. They also have a shrouded CSL temperature and relative humidity sensor and a Vaisala pressure probe located about 1 m from the ground. All wind data is logged at 10 Hz with all other variables logged as 1-minute averages every 10 minutes. All data is stored locally on the tower, with 10-minute summary data for each atmospheric variable sent over the 3G network to a virtual server at James Cook University (JCU) every 10 minutes. Campbell Scientific software is used to manage the acquisition and logging procedures.

Figure 2. SWIRLnet tower with foot and central anchors shown.

Tower Locations

Deployment locations for the three towers in the Cooktown area are shown in Figure 3a, with the TC track and Cooktown Airport AWS site also indicated. Towers 1 and 3 were embedded in the suburban area of Cooktown, while tower 2 was located in a relatively open field 20 km to the WNW of the town. The slope at each site was small enough not to significantly influence recorded wind speeds, but for towers 1 and 3 hills to the south and east may have influenced upwind flow when winds were from these directions. Fortuitously the eye made a direct passage over tower 2, and passed within 20 km of towers 1 and 3.

Figure 3b shows the deployment locations in Port Douglas. Again all towers are on flat land so will not have experienced topographic amplification. Tower 4 is located on a vacant suburban block and observations were, unfortunately, significantly influenced by nearby trees. Towers 5 and 6 were located in more rural areas and are essentially considered ‘open’. The TC travelled southward and to within 10 km to the west of all towers.



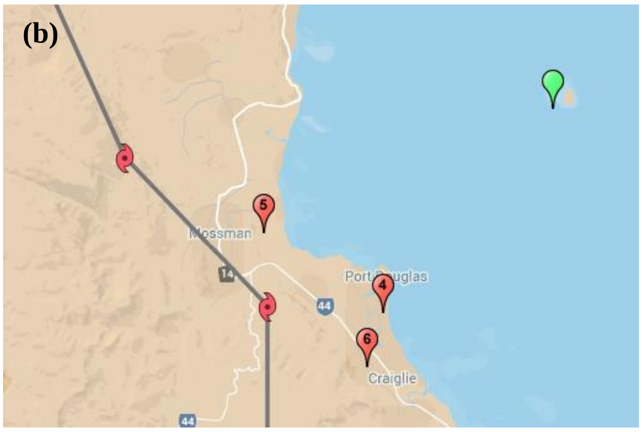


Figure 3. SWIRLnet and BoM AWS tower locations in (a) Cooktown and (b) Port Douglas. Numbered red symbols indicate SWIRLnet towers and green symbols indicate BoM AWS stations; Cooktown Airport in (a) and Low Isles in (b).

Wind Field Observations

3 Metre Observations

As an example of tower output, recorded data for SWIRLnet tower 2 are shown in Figure 4. The 10 minute mean (V_{600}), 3 second (V_3) and 0.2 second ($V_{0.2}$) gust data are shown. For clarity, the blue and red shaded regions show the range of gust (V_3, $V_{0.2}$) data, with V_{600} shown as a solid blue line. All wind data is block-averaged based on recorded 10 Hz data. For the wind direction plot (middle), 10 minute averaged wind direction is shown as a solid blue line, with 3 second averaged directions shown as points. Gust factors (lower plot) are shown for 0.2 and 3 second gusts referenced to a 10 minute mean.

As shown in Figure 3a, the TC eye made a direct passage over tower 2. This is reflected in Figure 4 with a 180 degree shift in wind direction as well as a lull in wind speed as the eye passed. Two peaks in wind speed were recorded, one prior to eye passage and the second following it. While a change in wind direction was still recorded at towers 1 and 3 (not shown), given their location to the left (in storm coordinates) and outside of the eye, they did not experience the full 180 degree wind shift or lull in wind speed. The Port Douglas towers were closer to the TC track and tower 5 records displayed a large wind shift and a drop in wind speed, suggesting it caught the outer edge of the eye. Recordings at towers 4 and 6 were stopped prior to the full TC passage and only recorded the front-side winds, so no conclusive remarks about whether they experienced a direct eye passage can be made.

The maximum recorded V_{600}, V_3 and $V_{0.2}$ for all towers, as well as minimum recorded central pressure, are given in Table 1. Tower 2 recorded the maximum mean (V600) wind speed while towers 3 and 1 recorded the maximum 3- (27.7 m/s) and 0.2-second (36.3 m/s) gusts, respectively. Based on the discussion in Henderson et al. (2013) the anemometer response may not be adequate to accurately provide $V_{0.2}$ values, but they are included here nonetheless as they represent the averaging period embodied in the Australia/New Zealand wind loading standards.

Despite the separation between towers in Cooktown, similar wind speeds were recorded at each site. In all these cases maximum gusts were recorded when the storm was well north (25-45 km) of the anemometer and outside the estimated radius to maximum winds (8 km). Maximum mean winds for towers 1 and 3 also occurred when the storm was north of those sites (approx. 25 km), but tower 2 recorded its maximum as the front side of the eye was passing over. Given the TC was rapidly decaying as it moved south, the observation of maxima when the storm was farther from the tower, but associated with a lower central pressure than when it made its closest passage, is not entirely unexpected. All maxima recorded in Port Douglas occurred when the storm was more than 70 km north and category 2 or stronger.

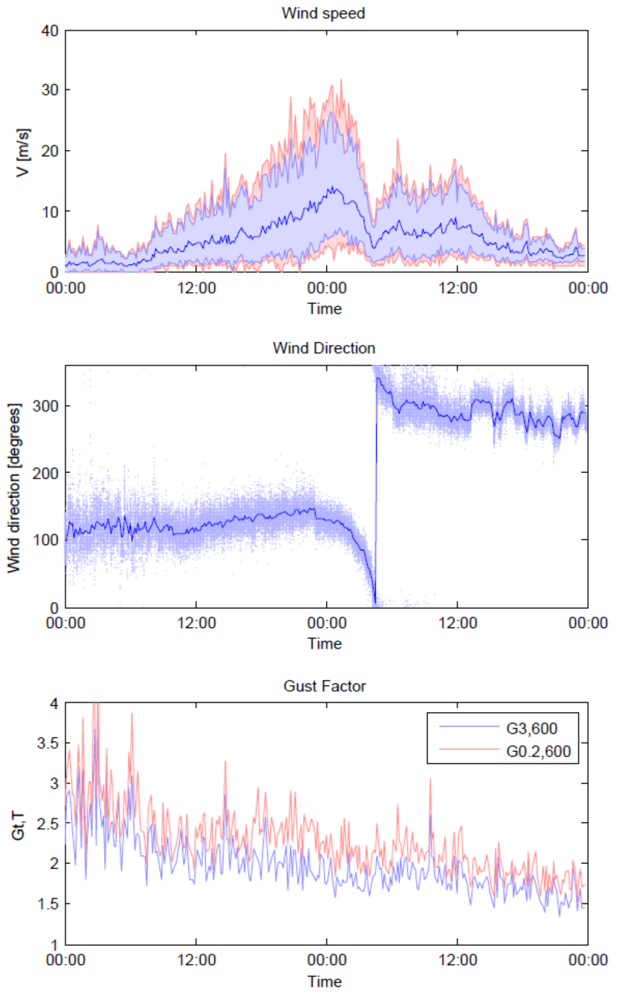


Figure 4. Wind speed, direction and gust factor plots for SWIRLnet tower 2. Plots begin at 00:00 on April 11, 2014 (local time).

Tower	Observation (z = 3.2 m)			
	V_{600} [m/s]	V_3 [m/s]	$V_{0.2}$ [m/s]	Pressure [hPa]
1	13.0	27.4	36.3	984
2	13.8	26.4	32.3	974
3	12.9	27.7	33.8	982
4	4.0	10.6	13.2	993
5	10.7	16.3	19.6	992
6	7.6	16.1	17.6	993

Table 1. Maximum recorded wind speed and minimum surface pressures at each of the SWIRLnet towers. Towers 1-3 are located at Cooktown and towers 4-6 are at Port Douglas.

Gust Factors

Averaged gust factors, $G_{t,T}$, for each of the towers are given in Table 2. Averaging in each instance was over the 4 hour period prior to the storm passage when wind speeds were highest. In Cooktown the suburban surroundings of towers 1 and 3 are reflected in higher gust factors than seen for the more exposed tower 2. Similar gust factors to tower 2 are seen at towers 5 and 6 in Port Douglas, reflecting the similar rural/semi-rural surrounds of each site. Tower 4 shows much higher factors than other sites, which is believed to be caused by a ‘wall’ of tall trees (>10 m tall) shielding the anemometer. These factors are therefore considered site specific but do highlight the highly turbulent nature of winds that load structures within an urban roughness canopy.

Tower	Observation (z = 3.2 m)	
	$G_{3,600}$	$G_{0.2,600}$
1	2.07	2.59
2	1.85	2.26
3	2.23	2.98
4	3.43	4.33
5	1.70	1.92
6	1.97	2.23

Table 2. Averaged gust factors, $G_{t,T}$ (t is the gust averaging period and T is the mean averaging period), for the 4 hour block prior to storm passage at each site.

For comparison, calculated $G_{0.2,600}$ values for terrain category 2 and 3 for elevations <5 m, are 1.73 and 2.0 respectively, when using turbulence intensity values provided in AS/NZS1170.2 and a peak factor of 3.7. These are low when compared with average $G_{0.2,600}$ SWIRLnet observations (Table 2).

Viewing gust factor time histories for each tower, e.g. Figure 4 (lower), some wind speed dependence was observed, but in general this stabilised once V_{600} exceeded approximately 8-10 m/s. Considering only these data, a distinct relationship between turbulence intensity and gust factor ($G_{3,600}$) is evident (Figure 5). This observation is theoretically intuitive and has previously been shown for 10 m observations during several US hurricanes (Masters et al., 2010). The magnitude of gust factors observed here are greater than those reported by Masters et al. (2010), but this is linked to higher measured turbulence intensities and the general trend (shown for their Hurricane Rita observations) is similar.

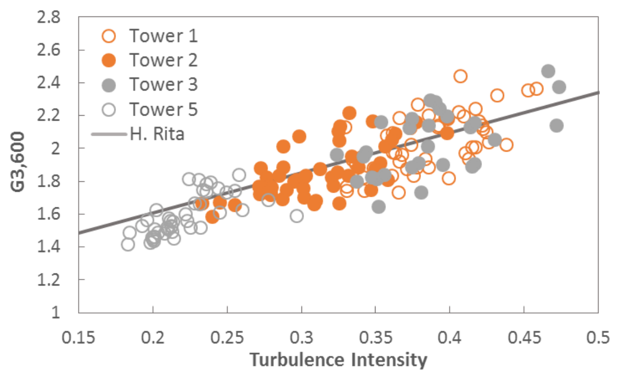


Figure 5. Relationship between measured gust factors ($G_{3,600}$) and turbulence intensity.

Wind Speed Conversion

To enable comparison between towers sited in differing terrain (and AS/NZS1170.2), all records have been converted to equivalent open terrain (z_0 = 0.02 m), z = 10 m values. Given all sites were relatively free from localised topographic amplification, no adjustment has been made for this, despite some lee effects (as discussed earlier) potentially influencing observations. Surface roughness was averaged over an upwind distance of approximately 500 m in all directions and an equivalent terrain/height multiplier estimated based on the approach outlined in AS/NZS1170.2. These values were used to convert maximum wind speeds to equivalent open terrain values (Table 3). Similar conversions were applied to BoM observations at Cape Flattery (landfall location) and Cooktown Airport AWS.

The maximum converted 0.2s gust in Cooktown were approximately 40 m/s, with values around 20 m/s measured in Port Douglas. Closer to the landfall position the Cape Flattery AWS recorded a 3 second gust of 44 m/s, which if converted to a 0.2 second gust would be closer to 50 m/s. Cape Flattery is thought to have experienced close to the maximum over-land winds (mainland), and these represent a 25-50 year return period gust for a point location in region C. Winds in Cooktown were more likely equivalent to something approximating 20 year return period gusts.

Tower	Adjusted velocity (z_0=0.02m, z=10m)		
	V_{600} [m/s]	$V_{3,600}$ [m/s]	$V_{0.2,600}$ [m/s]
1	18	32	41
2	19	30	36
3	19	31	40
4	6	12	15
5	14	18	22
6	11	18	20
Cape Flattery	32	44	-
Cooktown	25	36	-

Table 3. Open terrain, z = 10 m converted maximum wind speeds for all SWIRLnet towers as well as Cape Flattery and Cooktown Airport AWS stations.

Damage Survey - Summary

The Queensland SES reported approximately 200 houses and buildings from the Cooktown and surrounding areas suffering damage. A large proportion of these were a result of tree fall. On retrieving the anemometers, the CTS conducted an overview damage survey of Cooktown. Only a handful of major structural failures associated with wind loads were observed. One of these was a pre-1980s house that lost its roof and was located adjacent to Tower 1. The battens and rafters were only nailed (not strapped or screwed). Rot of the timber and corrosion of fixings was also observed. Similar observations were made of an old commercial property (Figure 6) and a pre-1980s highset house.

For contemporary construction, damage from wind (excluding from falling trees) was observed to be caused by loss of flashings, guttering and other attachments (Figure 7). Some residents also reported damage from wind driven water ingress.

Conclusions

Six relocatable SWIRLnet anemometer towers were deployed to investigate winds associated with Cyclone Ita impacting on Cooktown and Port Douglas. The SWIRLnet system functioned well with data being transmitted via 3G to a virtual machine at JCU and successfully logged locally at each tower.

A maximum 0.2 second gust wind speed of 36.3 m/s was measured at Cooktown and just below 20 m/s in Port Douglas. The high gust factors measured at each tower highlight the truly turbulent nature of winds that load structures within an urban roughness canopy. Given these gust factors were larger than those embodied in AS/NZS1170.2, further research appears to be required to gain insight into the true nature of wind loading during these events.

The damage survey undertaken in Cooktown suggests that the small number of observed house and buildings failures were due to older construction methods predating current requirements. There was minimal observed structural failures of current housing construction, as would be expected given the measured wind speeds. However, issues of poor performance of flashings, doors and awnings, did exacerbate wind driven rain ingress and add to the discomfort of those sheltering inside.

Acknowledgments

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Figure 6. Loss of roof from older property. Cladding had been replaced but no retrofits or upgrading of batten to rafter connections observed.

Figure 7. Failed (a) gutter and (b) flashings on modern community shelter

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