SWIRLnet observations during Tropical Cyclones Jasper (2023) and Kirrily (2024)

Matthew S. Mason[1], David J. Henderson[2] and Patrick Driscoll[2]

Matthew S. Mason	David J. Henderson	Patrick Driscoll
The University of Queensland	Cyclone Testing Station, James Cook University	Cyclone Testing Station, James Cook University
matthew.mason@uq.edu.au	david.henderson@jcu.edu.au	patrick.driscoll@jcu.edu.au

ABSTRACT

The 2023/24 tropical cyclone season saw two major storms make landfall on the east coast of Queensland, Tropical Cyclone (TC) Jasper and Tropical Cyclone Kirrily. TC Jasper made landfall near Wujal Wujal in North Queensland as a category 2 storm, while TC Kirrily made landfall just north of Townsville also as a category 2 storm. The Surface Weather Relay and Logging Network (SWIRLnet) was deployed for both events with wind and surface weather information recorded by the ruggedised weather stations that make up the network. Relatively low wind speeds were measured during both events, with the maximum 10-minute mean and 0.2-second gust recorded by the towers (3.2 m elevation) during TC Jasper being 12.7 m/s and 22.4 m/s, and 13.4 m/s and 29.9 m/s for TC Kirrily. Standardising these gusts to 10 m elevation, flat open terrain conditions leads to estimated peak 0.2-second gust values of 26.0 m/s for TC Jasper and 37.6 m/s for TC Kirrily. Both these values are below 55% of the regional wind speed specified in AS/NZS1170.2 for Region C. Analysing the turbulence statistics of the measured data reveals that the tendency for positive skew highlighted by recent observational and wind tunnel studies of hurricane winds in the USA are also present in these data. A close match to the measured skew of 0.5 for hurricane winds at heights and terrain similar to the SWIRLnet towers was observed. This observation suggests that standard wind engineering practice of assuming that turbulence is normally (Gaussian) distributed may be inappropriate and therefore typical peak factors may be an understimation. Noting the relatively low wind speeds observed during these events though, this finding should be treated with some caution.

INTRODUCTION

The Surface Weather Information Relay and Logging Network (SWIRLnet) of portable weather stations was conceptualised in 2012 and first deployed in 2014 during Tropical Cyclone Dylan. The SWIRLnet is a network of six portable weather stations that can be deployed in front of landfalling tropical cyclones to measure the near-surface wind characteristics of these storms. Each station consists of an R.M. Young propellor anemometer that measures wind speed and direction at 10 Hz, a CSL temperature and relative humidity sensor and a shrouded Vaisala pressure sensor that sample 1-min mean data every 10-minutes. Each anemometer is mounted on a tripod at a height of approximately 3.2 m and the temperature and pressure sensors at 1 m elevation. Data are logged locally at the station, with summary data also sent to a server every 10-minutes so they can be displayed on a website in real time for dissemination to the public, emergency services and weather forecasters. SWIRLnet weather stations are deployed out of James Cook University in Townsville using vehicles and trailers by a team of researchers from the Cyclone Testing Station.

Two tropical cyclones made landfall on the east coast of Queensland during the 2023/2024 tropical cyclone season (November – April), Severe Tropical Cyclone (TC) Jasper and Severe TC Kirrily.

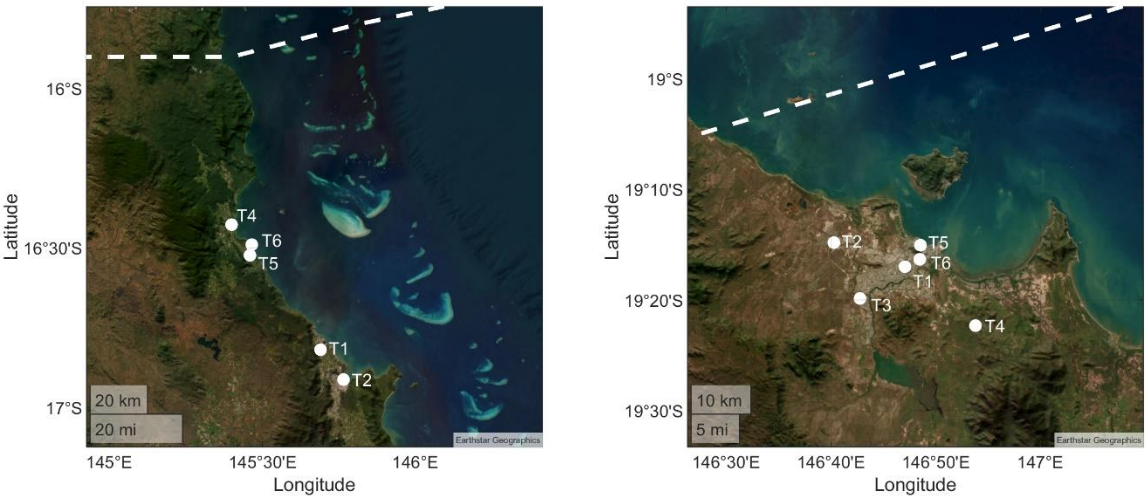
Severe TC Jasper formed in the Coral Sea on 5 December 2023, intensifying within a few days to a category 5 system. Jasper lost intensity as it moved westard towards the Queensland coast, only to reintensity as it neared the coast. The storm made landfall as a category 2 system at around 8 pm on 13 December near the town of Wujual Wujal about 60 km northwest of Port Douglas and 120 km northwest of Cairns. At landfall the cyclone had a central pressure of 985 hPa, a radius to maximum winds of approximately 46 km, gale force winds (>17 m/s) estimated to extend out to 185 km to the southeast of the storm and storm force winds (>25 m/s) out to 83 km (Bureau of Meteorology, 2024). After landfall, TC Jasper decayed quickly, but then stalled, causing widespread flooding through the region.

Severe TC Kirrily formed in the Coral Sea on 24 January 2024. It intensified quickly to a category 3 storm, but weakened as it approached the coast. TC Kirrily made landfall 30-40 km northwest of Townsville as a category 2 system at about 10 pm on January 25. At landfall, TC Kirrily had a central pressure of 989 hPa and a radius to maximum winds of approximately 26 km (Bureau of Meteorology, 2024). This meant parts of Townsville experienced passage of the southern part of the eye. Following landfall TC Kirrily moved inland and decayed quickly but remained an ex-tropical low moving through western Queensland for more than a week causing widespread heavy rain and flooding.

The SWIRLnet was deployed and captured near-surface wind measurements during both TC Jasper and Kirrily. This paper briefly describes these two deployments, the wind data captured, and presents standardised peak gust estimates for each tower, and an analysis of turbulence measured at these sites.

DEPLOYMENTS

Five towers were deployed during TC Jasper, Figure 1(a). The sixth tower (T3) had communications issues so was unable to be successfully deployed. Two towers (T1, T2) were located in Cairns, with T1 located on an oval on the JCU campus and T2 near the Cairns hospital. Towers T5 and T6 were deployed in park land in Port Douglas, with T6 nestled between several rows of housing and T5 in a field on the western edge of the town. T4 was set up on a property in Newell, about 10 km northwest of Port Douglas, which sits about 750 inland from the coastline. T4 was the closest tower to the landfall location, but was still about 50 km south of this location. T1 had relatively uniform open terrain in all directions, but all other sites had a mix of open to suburban terrain that varied for different wind directions.



(a) Tropical Cyclone Jasper

(b) Tropcial Cyclone Kirrily

Figure 1. Tower deployment and cyclone track (dashed line) location information for (a) Tropical Cyclone Jasper and (b) Tropical Cyclone Kirrily.

In total nine towers were deployed for TC Kirrily. Given the forecast landfall location was in the vicinity of Townsville, it was decided to deploy all towers throughout the city so that winds across different parts of the city could be mapped, Figure 1 (b). Three additional towers/anemometers to the regular six were also deployed during TC Kirrily to test their integration with the existing network and the performance of different acquisition and instrument choices. Despite this, only results from the six regular towers are discussed here. Tower 4 (T4) was deployed in a relatively open lot of land near a small development, but all other towers were located in parks embedded in suburban areas of the city. As such, T4 is considered relatively open terrain for most directions (particularly for northerly directions), with all other sites likely being close to suburban terrain, but with varying upwind fetches of housing for different directions.

WIND MEASUREMENTS

Approximately 1.5 days of measured wind data are shown in Figure 2 for TC Jasper and Figure 3 for TC Kirrily for each of the operational towers. The 10-minute mean velocity, $u_{600,Obs}$, peak 0.2-second gust over the preceding 10-minute period, $u_{0.2,600,Obs}$, and 10-minute mean wind direction time histories are show for each tower in these figures. All plots except for T6 during TC Jasper and T4 during TC Kirrily are based on the 10 Hz measurements, with the mean being for a 10-minute block, and the peak gust determined using a 0.2-second moving average filter on the raw data. For the two exceptions, the 10 Hz data files had been corrupted so the plots of $u_{0.2,600,Obs}$ were developed using the real-time summary data and multiplying the peak 3-second gust data recorded in those files by a constant 3-second to 0.2-second gust duration adjustment factor of 1.12 (Holmes and Ginger, 2012). Table 1 summarises these data and lists the maximum $u_{600,Obs}$ and $u_{0.2,600,Obs}$ recorded at each tower for each TC. Table 1 also lists coresponding estimates of mean, $u_{600,Std}$, and peak gust, $u_{0.2,600,Std}$, values when standardised to flat open terrain (z_0 = 0.02 m) conditions and an elevation of z = 10 m. Standardisation of observations has followed the approach detailed in Mason (2017).

T4 measured the highest mean velocities during TC Jasper at around the time of lanfall (20:00) on 13 December. While it was the closest station to the landfall location (though still 50 km away), the smoother terrain around the site compared with nearby sites (e.g. T5, T6) also contributed to this observation. The maximum gust was recorded at T5, with a marginally higher measured gust of 22.7 m/s over the 22.4 m/s measured at T4. Standardising these gusts it is found that a maximum estimated peak gust of 26 m/s was experienced at any of the tower sites. This value is just below 40% of the maximum regional wind speed specified for Region C in AS/NZS1170.2 (Standards Australia, 2021), so unsurprisingly significant wind damage was not widely reported.

Table 1. Maximum observed and standardised wind measurements (units: m/s). *signifies that the 0.2-second gust was estimated based on 3-second gust data.

Cyclone	Tower	$u_{600,Obs}$	$u_{0.2,600,Obs}$	$u_{600,Std}$	$u_{0.2,600,Std}$
Jasper	T1	5.7	15.2	11.0	17.9
	T2	5.3	4.8	16.5	16.4
	T4	12.7	22.4	16.6	26.0
	T5	7.9	22.7	14.3	25.0
	T6	3.7	14.6*	10.8	18.6*
Kirrily	T1	9.5	24.3	15.9	26.8
	T2	9.8	19.4	15.1	23.6
	T3	8.8	20.4	15.5	24.8
	T4	13.4	29.9*	22.7	37.6*
	T5	7.2	18.3	14.4	22.6
	T6	7.7	19.7	14.6	24.5

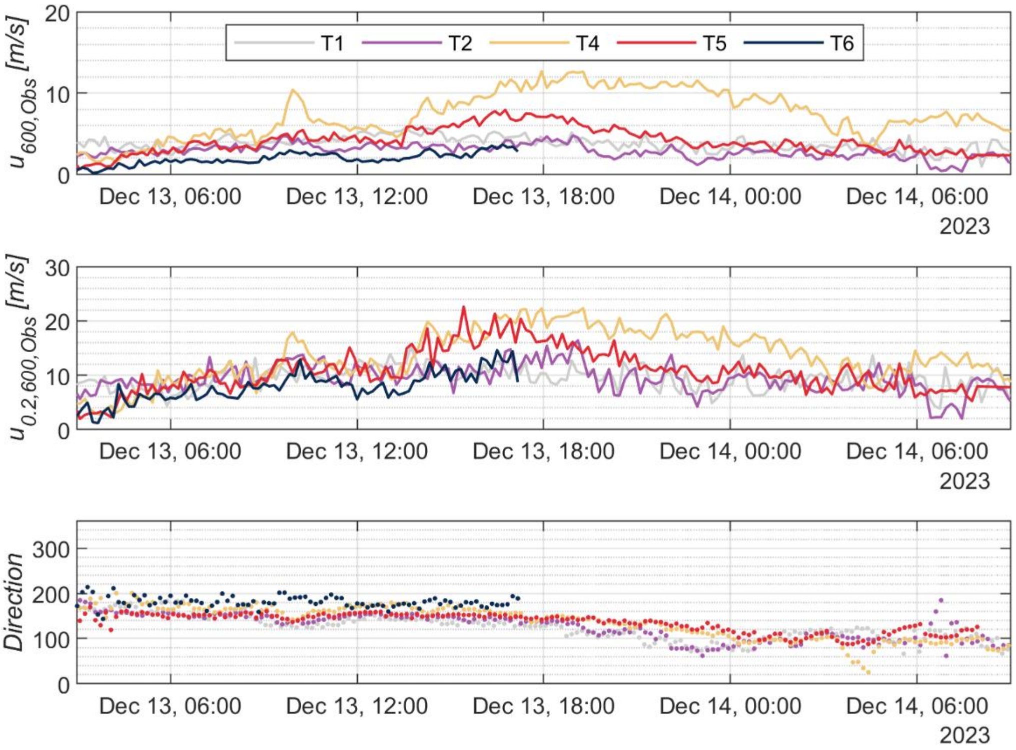


Figure 2. Wind measurements during Tropical Cyclone Jasper.

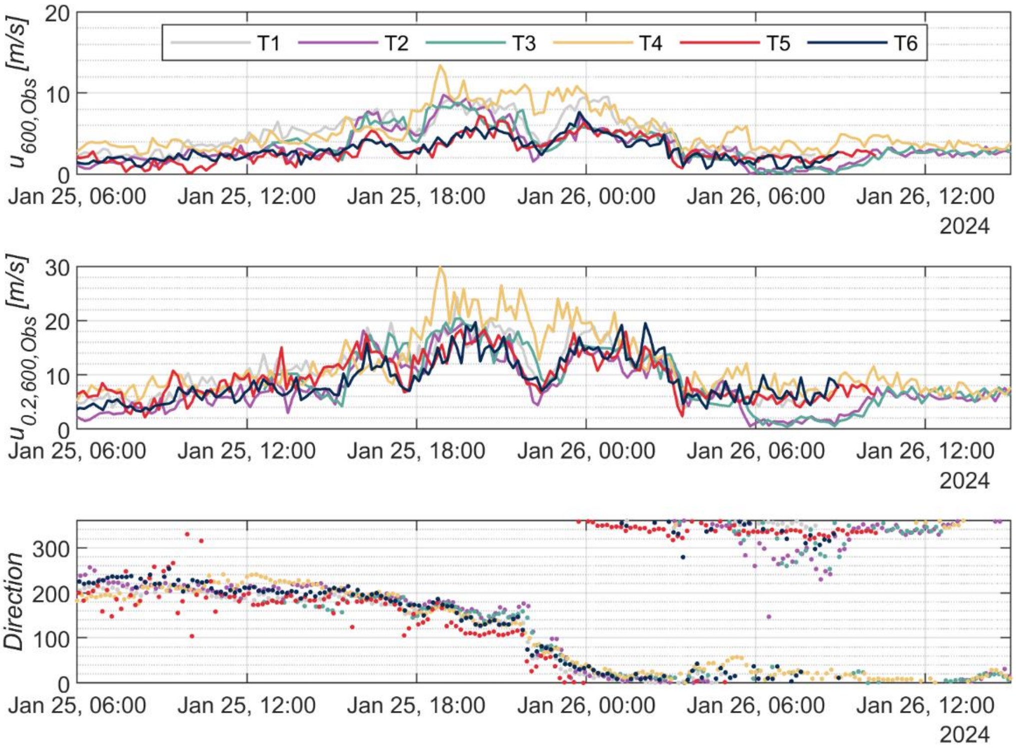


Figure 3. Wind measurements during Tropical Cyclone Kirrily.

Wind measurements for TC Kirrily at all towers except T4 show a distinct rise in velocity leading up to landfall (22:00 on Jan 25), a dip in velocity as the eye moved over the towers and then a secondary increase in winds as the back side of the eyewall passed. T4 shows something similar, but without the distinct dip in velocity associated with the eye of the storm. This occurred because T4 was the furthest tower from the storm track and appears to have been outside of the central eye. For all towers, winds were strongest prior to the eye passage, with T4 measuring the highest mean (13.4 m/s) and peak gust (29.9 m/s) wind speeds. Despite the greater distance from the cyclone track, the more open terrain at T4 than the other suburban sites will have contributed to the heigher winds being recorded here. There were also some dynamical storm features that saw a region of high winds persist to the south of the eye in the region of T4 during landfall that also contributed to this observation. Standardising the measured gust at T4 leads to a value of $u_{0.2,600,Std}$ = 37.6 m/s, which corresponds to approximately 55% of the maximum Region C regional wind speed, so again the absence of widespread wind damage for this event was expected.

ANALYSIS OF TURBULENCE

Turbulence can be analysed in a range of different ways. The focus of this brief analysis is on the third statistical moment of turbulence, skewness. Skewness is a measure of the asymmetry of the distibution of fluctuating velocities about their mean. That is, if one has a time series of velocity fluctuations that are normally (Gaussian) distributed about a mean velocity, then the mean and median will coincide and a skewness value of 0 will result. However, if the distribution of fluctuations is non-Gaussian, then either the right (positive) or left (negative) tails of the distribution will be longer and there will be a greater probability of exceedences in that direction. If it were the case that TC (or any other event) winds are non-Gaussian, some of the assumptions made in wind engineering may be misplaced. Recent research by Fernandez-Caban and Masters (2017) (hereafter FCM17) has shown that for wind measurements during several hurricances, turbulent fluctuations near the ground do in fact show non-Gaussian characteristics, with a positive skew consistently measured. They show this skew to decrease with distance from the ground and also with decrease in surface roughness and attribute its presence to an increasing presence of sweeps (i.e. small packets of downward momentum) in the flow field.

To investigate whether such skewness also exists in the TC Jasper and Kirrily wind measurements, Figure 4 shows the measured skewness for 10-minute blocks of data plot against their mean wind speed. Shown also on the figure is the expected skewness for a Gaussian distribution and the mean measured skewness for hurricane measurements at 5 m elevation and mean wind speeds between 5 and 15 m/s, divided into suburban (FCM17-B) and open (FCM17-C) terrain categories, as reported by FCM17.

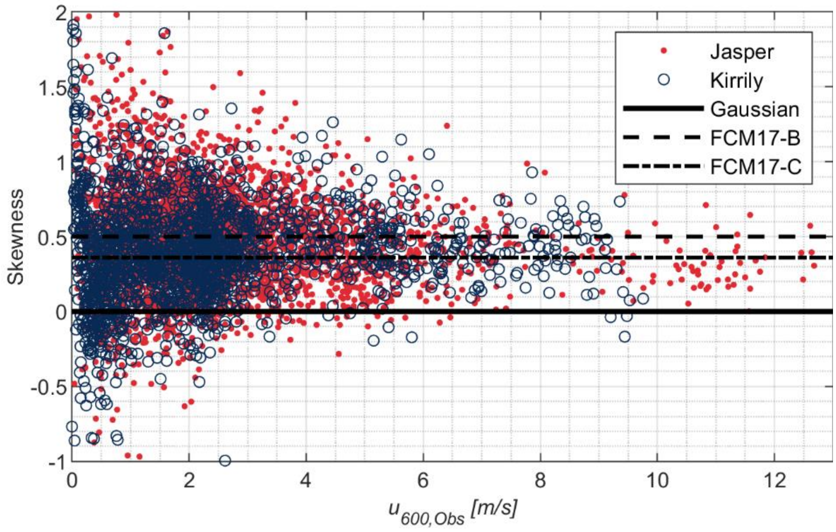


Figure 4. Measured skewness of turbulent fluctuations.

Figure 4 shows considerable scatter at low mean wind speeds, but a reasonable convergence as velocities increase above about 5 m/s. Looking at data beyond this value for both TCs a clear preference for positive skew is evident. Noting that the strongest mean winds during TC Jasper were observed at T4, which was broadly classified as open terrain, a similar order of positive skew to that shown for FCM17-C is seen. Slightly higher skewness values are observed for TC Kirrily.

Another way to consider the skewness of these data is through an analysis of gust and peak factors. Figure 5 shows the 0.2-second gust, 10-minute (600-second) mean, gust factors, $G_{0.2,600,Obs}$ plot against the turbulence intensity, *Iu*, for each of the recorded 10-minute blocks. The gradiant of a line going through $G = 1$ on this plot represents the peak factor, *g*, typically used in wind engineering. AS/NZS1170.2 specifies the use of $g = 3.4$. Lines representing peak factors of 3.4, 3.7 and 4.0 are shown for reference. The threshold level of *Iu* for terrain categories 2 and 3 (roughly encompassing the observed data) are also shown. Inspecting data for mean velocities greater than 5 m/s, it is seen that $g = 3.4$ lies below the majority of observed data points. In fact, when dividing the data into those below the terrain category 3 threshold, it is found that 62%, 36% and 17% lie above the $g = 3.4$, 3.7 and 4.0 lines, respectively. For the data points above terrain category 3, these percentages increase to 80%, 60% and 36% respectively. This observation supports the findings of FCM17 that increasing surface roughness leads to greater skewness and also shows that the current approach of assuming $g = 3.4$ may underestimate actual peak gusts, particularly for higher terrain categories.

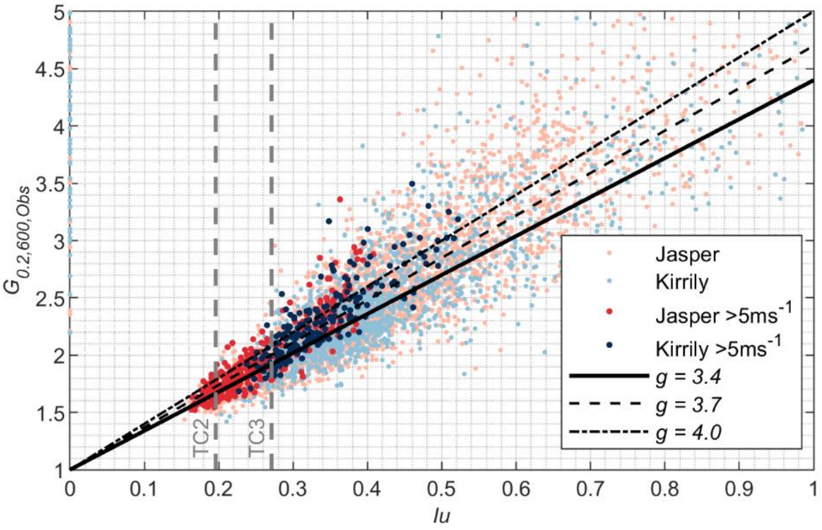


Figure 5. Measured relationship between turbulence intensity, *Iu*, and gust factors, $G_{0.2,600,Obs}$.

REFERENCES

Bureau of Meteorology, “Database of past tropical cyclones tracks”, Accessed on 11 June, 2024.

Fernandez-Caban, P.L. and Masters, F.J., “Near surface wind longitudinal velocity positively skews with increasing aerodynamic roughness length”, *Journal of Wind Engineering & Industrial Aerodynamics*, 169, 94-105, 2017.

Holmes, J.D. and Ginger, J.D., "The gust wind speed duration in AS/NZS1170.2", *Australian Journal of Structural Engineering*, 13, 3, 2012.

Mason, M.S., "Tropical Cyclone Debbie (2017): Conversion of measured wind speeds", Technical Note 201701, The University of Queensland Wind Research Laboratory, August, 2017.