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Wind speed measurements of land-falling tropical cyclones using SWIRLnet, a portable anemometer network

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Abstract

Wind speed measurement systems are sparse in the tropical regions of Australia. Given this, tropical cyclone wind speeds impacting communities are seldom measured and often only 'guestimated' by analysing the extent of damage to structures. In an attempt to overcome this dearth of data, a re-locatable network of anemometers to be deployed prior to tropical cyclone landfall is currently being developed. This paper discusses design criteria of the network's tripods and tie down system, proposed deployment of the anemometers, instrumentation and data logging. Preliminary assessment of the anemometer response indicates a reliable system for measuring the spectral component of wind with frequencies of approximately 1 Hz. This system limitation highlights an important difference between the capabilities of modern instrumentation and that of the Dines anemometer (around 0.2 seconds) that was used to develop much of the design criteria within the Australian building code and wind loading standard.

Introduction

Existing wind speed measuring systems are sparse in the tropical regions of Australia. Less than 2% of the peak wind speeds of cyclones making landfall in Australia have crossed where there is a capability to measure them (Harper *et al*, 2008). For example, there is a 200 km gap between Bureau of Meteorology anemometers, where Cyclone Yasi made landfall impacting communities along the coast. The gaps are greater still in lesser populated areas of coastline.

Numerous post disaster damage investigations of communities across Australia have highlighted the difficulties that arise because of the large distances between Bureau anemometers when trying to reliably determining peak wind speeds following a tropical cyclone (Reardon *et al* 1999, Henderson *et al* 2006, Boughton *et al* 2011). These investigations have therefore relied on wind speed estimates derived from back-calculating failure wind loads on bent simple steel structures, such as road signs, referred to as 'windicators' (Ginger *et al* 2007). However, accurate information on peak wind speeds is important for understanding the vulnerability of housing and the effectiveness of current Standards and building regulations. More so, delays in announcing cyclonic wind speeds that impacted affected communities (or differing assessments of estimated wind speed) unfortunately promote complacency in the building sector and public with the over-reporting of wind speeds.

With seed funding from the Queensland Government Dept. of Community Safety, the Cyclone Testing Station (CTS) at James Cook University along with Risk Frontiers at Macquarie University are developing a network of portable anemometers based on the Texas Tech University (TTU) Sticknet system (Schroeder 2012), for the measurement of surface weather conditions during land falling tropical cyclones (TCs). Referencing the system's near real-time transmission of wind speed, direction, temperature, pressure and relative humidity measurements it has been given the acronym SWIRLnet, the Surface Weather Information Relay and Logging Network.

Objectives

The main objectives for developing and deploying the network are: 1) to better quantify surface weather conditions during land-falling tropical cyclones; 2) the dissemination of near real-time community-embedded wind speed information to emergency services; and 3) to provide data that aids assessment of Australian building Codes and Standards in concert with housing and infrastructure damage surveys.

Objectives 2 and 3, although based on the same measurement system, require an understanding of end user requirements in order to provide appropriate and understandable data. The Australian Bureau of Meteorology uses the World Meteorological Organisation (WMO) standard of a 3 second gust, while the Australian National Construction Code and the Australian and New Zealand wind loading standard, AS/NZS 1170.2:2011, use a peak gust having an equivalent moving average time of approximately 0.2 seconds for its wind speed design criteria (Ginger et al 2011).

It is therefore important to understand the capabilities and limitations of the anemometry system with regards to its ability to accurately supply wind speed data that satisfies both these definitions.

SWIRLnet

The initial network consists of six 3.0 m portable instrument towers designed for rapid deployment in the 24-48 hours prior to TC landfall. Each tower is built upon a folding freestanding tripod with an optional guying system to minimise tip deflections during severe winds. The tripods have been designed to resist gust wind speeds of 70 m/s at anemometer height. Proof load testing using a hydraulic loading system to apply a point load at top of mast demonstrated the robustness of the design. Figure 1 shows a tripod setup at the Townsville airport during a trial deployment.

Figure 1. Tripod with anemometer deployed at Townsville airport. Note folded tripods in rack on trailer

Anchoring is required on each of the tower leg footpads and beneath the central mast. This is achieved by driving star pickets through each of the footpads and connecting the central mast to either a short bored pier concrete anchor block or a driven ground screw (Figure 2). Trial deployments suggest erection time for each tower is from 20 minutes at a permanent concrete anchor site to 50 minutes for a screw in ground anchor installation.

The development of this system is based on extending the 2.2 m anemometer height of the TTU Sticknets. The added height will add to the design and operational complexity of the tripods, including tie down, and doesn't allow the tripod to be purchased "off the shelf". The benefit of the increased height is that the anemometer is at a typical eaves height for single storey houses and corresponds with the lower bound for information provided in the Australian wind loading standard.

Figure 2. Ground screw anchors

Deployment

During deployments tower location will be based on a series of predetermined anchor points located in parks and sporting fields along the tropical Queensland coast-line. Where considered of value, towers will also be erected opportunistically using the screw in ground anchors. The selection of predetermined sites is primarily aimed at gaining measurements of wind speeds impacting communities (built environment) as opposed to positioning the anemometers to ensure measurement of the maximum wind speeds within a given storm. Positioning decisions will be made in consultation with Bureau forecasters and local councils.

Instrumentation

Each tower is equipped with a marine rated R.M. Young propeller anemometer, a Vaisala pressure transducer, and a CSL shrouded temperature and relative humidity sensor. Data is sampled and logged locally at 10 Hz to an on-board memory card, with 3G telemetry of summary data, e.g. peak 3 second gust and 10 minute mean, to a central server every 10 minutes.

To conserve battery life, the 3G data modem and pressure transducer are powered down for eight minutes out of the ten. A five day battery life is achieved via this power management. It does however mean that all communications are nominally one way, such that the towers can transmit and listen for data successfully received verification but cannot be re-programmed or polled remotely.

Anemometer response

In order to understand the performance of anemometers a set of wind tunnel experiments were conducted to compare the spectral response of these instruments with that of a Cobra Probe. In these tests the anemometer was positioned in the JCU wind tunnel with the cobra probe positioned at the same height but laterally displaced by 300 mm. The anemometer and Cobra Probe were sampled at 10 Hz and 156.3 Hz respectively.

Figure 3 displays the spectral densities for the anemometer and Cobra Probe where the instrument centre line mean velocity was 11 m/s. The turbulence intensity at instrument height was approximately 0.14. Instrument response is comparable in the low frequency range, but departs beyond 0.7 Hz. It is hypothesised that the experimental set up may play some role in this deviation. For instance the large size of the anemometer propeller (180 mm diameter) meant there was some change in mean and turbulent characteristics over the wind area influencing measurements. This was not the case for the much smaller Cobra probe and consequentially some of the high frequency fluctuations measured by this instrument were effectively damped across the anemometer propeller. Additionally, an increase in spectral density was shown to occur at frequencies beyond 3 Hz. This is believed to be a result of aliasing of the non-filtered signal and further work will include the use of post-processing low-pass filters to 'clean' these records. Similar results were found when comparing spectra for experiments with different wind speeds.

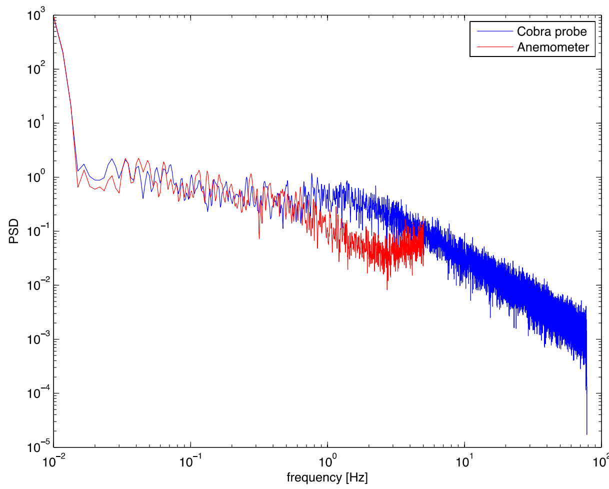

Figure 3. Spectral densities for Cobra probe and Propeller anemometer

Colocation of 3 m with 10 m AWS

A 3 m tripod was deployed to the Townsville Airport (Figure 1) and erected approximately 40 m from the Bureau of Meteorology's 10 m 3-cup Automatic Weather Station. The close proximity of the 3 m and 10 m towers, and siting of both in open terrain, does allow the collected wind speed data to be compared with specifications in the Australian wind loading standard AS/NZS1170.2. To do this, two ten hour periods have been extracted from the SWIRLnet 10 Hz time series and analysed alongside the 1-minute summary data provided by the Bureau for their cup anemometer. Using these data the elevation/terrain multiplier (Mz,cat) specified in AS/NZS1170.2 could be compared against the range of multipliers calculated from acquired data. To avoid any gust correlation or time offset issues, the gust relevant Mz,cat value specified in the wind standard has been converted to a 10 minute mean equivalent using the corresponding turbulence intensities (0.196 at 3 m, 0.183 at 10 m) and peak factor (3.7) also specified in the standard. For the acquired tower data, 120 10-minute mean ratios, U3/U10, were calculated by dividing the 3 m tower wind speed (U3) by the corresponding 10 m tower mean wind speed (U10). Figure 4 shows data plotted with respect to the mean wind speed at the 3 m tower and broken into the two 10-hour epochs.

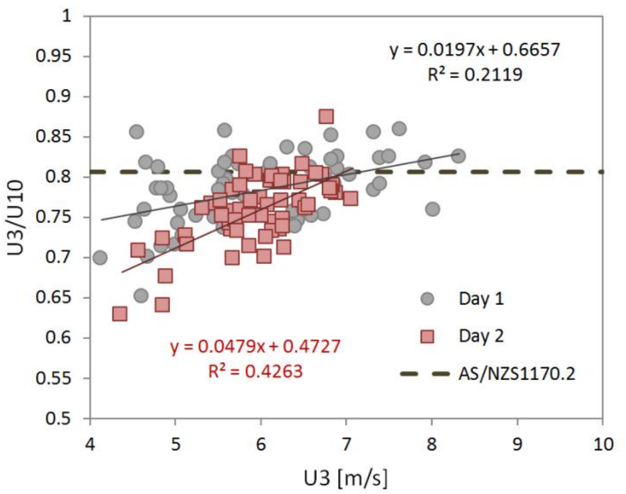

Figure 4. 10-minute mean ratios (U3/U10) used as pseudo terrain/height multipliers calculated using the 3 m tower observations and co-located Bureau AWS data.

Although the low wind speeds mean it would not be prudent to make any firm statements about the wind standard's ability to perform at 'design level' wind speeds, it does appear that the AS/NZS1170.2 derived value of 0.81 is exceeded by 20% of 10-minute records. These occur almost exclusively on day 1. Further research is required to determine the cause of this, but it is hypothesised that the higher fluctuations in mean 10-minute wind speed on that day could play a role as well as slight difference in mean wind directions. It is also interesting to note that at low wind speeds, an increasing trend in U3/U10 is evident as wind speeds increase.

Ongoing work

To date, the tripods have not been deployed or tested during a severe weather event. To continue verification and validation of the system, SWIRLnet is being used during this cyclone offseason to investigate effects on mean and gust wind speeds within simple terrain changes due to typical open parks in housing suburbs. The grid of time synced measurements will allow exploration of statistical and numerical methods for utilising tower point observations to generate spatial wind fields. Tower use in the "off-season" also allows refinement of deployment procedures for the cyclone season.

A refined study comparing the propeller anemometer with the Cobra probe and a 3-D sonic anemometer needs to be undertaken in the wind tunnel to better understand the instrument capacities. The study will investigate the influence of a range of mean wind speeds and turbulence intensities.

This is a long term project for the Cyclone Testing Station. Anyone who feels that they can make a contribution to the success of the project is welcome to contact us.

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