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A Tropical Cyclone Wind Event Data Set for Australia

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Abstract

An overview is presented of the development of a tropical cyclone (TC) wind event dataset for the whole of Australia. This includes the derivation of a 10,000 y synthetic TC climatology and its verification statistics, plus the TC windfield model used to produce wind speed and direction time histories and event statistics at any nominated point. The deterministic verification of the TC windfield model is underpinned by numerous case studies and the statistical verification of the point wind statistics is supported by comparison with several long term AWS sites having good exposure. Comparisons with the AS/NZS 1170.2 design regional wind speeds for Regions B, C and D are presented and discussed, together with ongoing planned event set development.

Introduction

The current AS/NZS 1170.2 regional design wind speed recommendations (Standards Australia 2011, Fig 3.1(A)) derive *inter alia* from the early TC wind data analyses by Gomes and Vickery (1976), combined with complementary work by Dorman (1983) on non-TC winds and with consideration of early TC simulation studies (e.g. Martin 1974, Tryggvason 1979). Additional uncertainty factors F_C and F_D were introduced into the 2002 revision but not supported by any additional analyses.

Since the 1980s there have been many significant developments in knowledge of TC structure and behaviour, remote sensing and data analysis, numerical and statistical modelling techniques, and the potential impacts of long-term climate change on TC wind hazard have been raised (Harper 2013). In addition, the availability of new observational wind and TC parameter datasets, changes in anemometer instrumentation response and analysis, and BoM operational forecasting and analysis procedures, are all compelling reasons for revisiting the Australian TC wind hazard criteria.

The Basis of the Synthetic TC Track Dataset

The historical TC track dataset forming the underlying real climate reference is based on the official Bureau of Meteorology (BoM) historical TC track and estimated intensity data to end-2014 subjected to additional quality assurance by cross-checking and morphing with other SEA-modified TC track data developed for many engineering design studies over the past 20 years (e.g. Harper 1999, 2001, 2002; Harper et al. 2008).

A synthetic statistical TC climate is then constructed by using the historical TC track and intensity data together with a variety of hypothesised relationships. Due to the reduced accuracy of data prior to the satellite era (e.g. Harper and Callaghan 2006), only BoM tracks and estimated intensities from 1969 onwards are used for the model "training", although the full track dataset from 1959 onwards is used in the validation. Except in recent years, the BoM data omits other information essential to the successful modelling of TC wind fields, such as wind speed radii, asymmetries and the like that dictate the distribution of winds around a particular storm and at a particular time in its life-cycle. These additional parameters suited to the Australian region have been developed empirically over many years underpinned by extensive wind and wave calibration studies undertaken for the offshore oil and gas industry in Western Australia (e.g. Harper 2002).

The synthetic track algorithm is a further development of the multiple regression model of James and Mason (2005) that was originally successfully applied to the Queensland coast (e.g. Hardy et al. 2004) and utilises a so-called "Double-Holland" radial surface wind and pressure model (Thompson and Cardone 1996) combined with the recommendations of Harper and Holland (1999) to form a complete parametric model.

This basic framework has been enhanced to include multiple training domains able to be treated separately e.g. regional characteristics, sea and land. Along with Maximum Potential Intensity (e.g. Holland 1997), additional regression variables such as 500 hPa winds, vertical wind shear and relative humidity derived from the NCEP and ECMWF re-analyses have been used in the regression analysis. Significant enhancements to the inner and outer vortex scaling, wind intensity and related variability has improved realism of the surface wind field for an individual TC and also for the total population.

The newly developed TC climatology model covers the whole of Australia (including Cocos (Keeling) and Christmas Islands) and spans 10,000 years at a 3 h temporal fix resolution. It produces very realistic track behaviour, as illustrated in Figure 1, which presents a sample having a period equivalent to that of the source BoM dataset, with colour-coded Mean Sea Level (MSL) Central Pressure deficit (ΔP_o hPa).

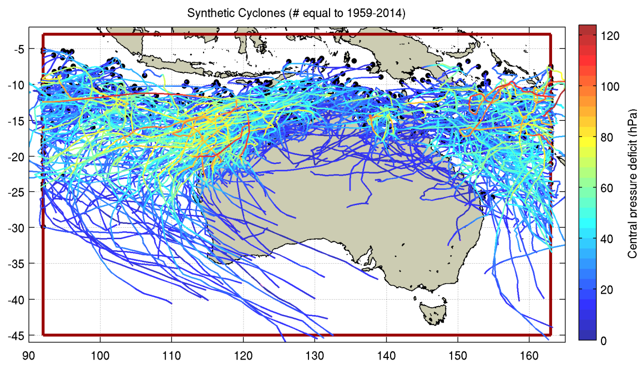

Figure 1 A 55-year sample of synthetic TC tracks from the 10,000 y climatology.

Verification of the Synthetic TC Track Dataset

In addition to the visual similarities, the ensemble of modelled synthetic TC tracks compares well with the observed track parameters to within 90% confidence limits using a bootstrap re-sampling technique. This verification has been undertaken by comparing a number of track parameters including:

- Peak intensity ΔP_o CDF, exceedance and Return Period
- North-South and East-West track speed CDF;
- Speed and Heading CDF and frequency histogram; and
- Duration within a model sub-domain CDF.

Figure 2 provides a whole-of-Australia demonstration of the veracity of the basic TC track model statistics for exceedance frequency and Return Period of maximum intensity. Each graph compares the original historical data parameter statistic (red) to the modelled equivalent (blue), with the thin blue lines representing the modelled 10% and 90% confidence limits based on the 10,000 y sample. In the exceedence plot, not only are the total number of coastal crossing TCs well represented but also the distribution as a function of intensity. The log scale on the Return Period plot emphasises that the distribution tail is an excellent fit to the available data. Similar statistics were produced for many locations with most results falling well within the 90% confidence limits.

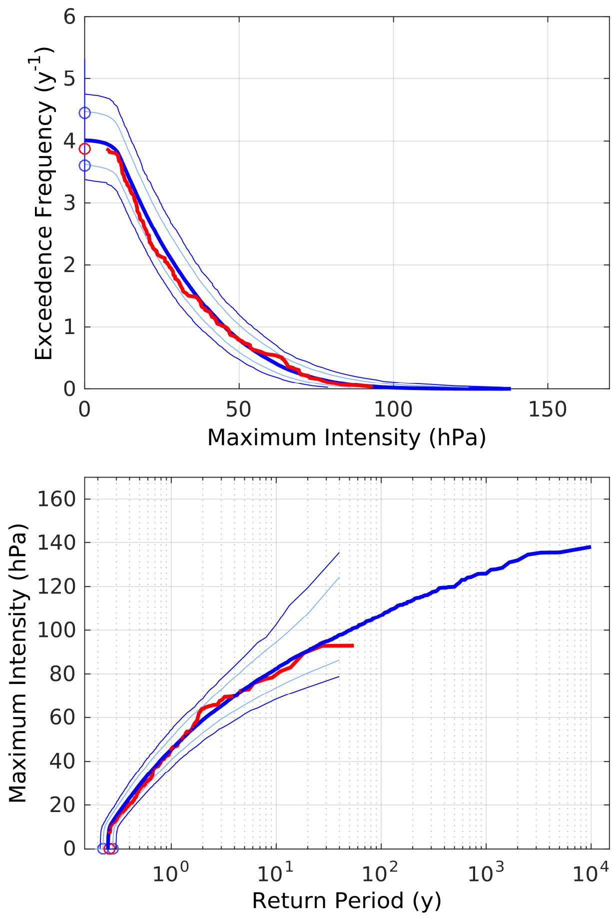

Figure 2 Statistical fits of a variety of track parameters comparing the original historical data (red) and the synthetic track data (blue) for TCs crossing any part of the Australian coastline

The radius to maximum wind *Rmax* is the principal scale parameter of a TC that determines the distribution of wind speeds around the centre and, over its lifetime, establishes the peak wind swath. As the observed record of radius to maximum wind in Australia is very limited, extra datasets derived from various studies (e.g. Harper (2002) for North West Shelf; GHD (2013) for Gulf of Carpentaria etc.) have been considered together with the large US dataset of aerial reconnaissance of hurricanes analysed by Willoughby and Rahn (2004). Figure 3 compares the US data (small blue dots being all data and open blue dots being < 18°N) with the limited Australian data (red) on a background of a 1000 sample of the synthetic TC climate (background grey). It shows that the model data is a fair representation of the latitudinally-stratified US data and is supported by the limited Australian data.

Wind Model Verification

Verification of the synthetic track and wind field model has then been achieved by:

- Modelling each of the approximately 90,000 TCs in the 10,000 y simulated TC climate for the whole of Australia using an enhanced Double-Holland model;
- Retaining the maximum mean winds (V_{600}) for each storm on a regular 5 km grid;
- Choosing a range of reliable measurement sites for statistical comparisons;
- Ranking each modelled TC event's maximum V_{600} wind and estimated peak $V_{0.2}$ gust to assign Return Periods (or Average Recurrence Intervals) of exceedance;
- Comparing the modelled winds with the available deemed reliable measured wind data.

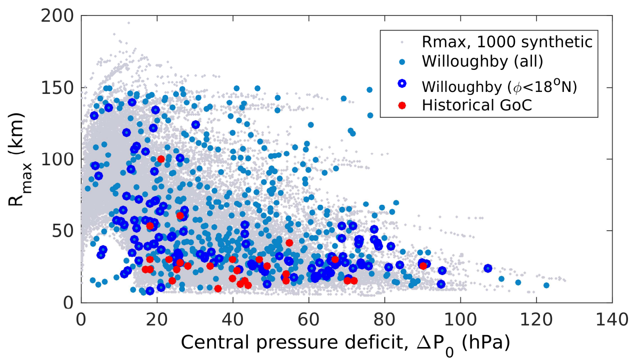

Figure 3 Analysis of synthetic TC intensity and radius to maximum wind.

Based on verification with reliable offshore Automatic Weather Stations (AWS), the simulated winds from these model TCs are deemed representative of a "Terrain Category 0" or Tcat 0, which has a roughness height one order of magnitude smaller than the smoothest Tcat 1 terrain in AS/NZS 1170.2 (i.e. z0=0.0002). This assumption is consistent with the WMO-sponsored findings of Harper et al. (2010) for TC winds in the open ocean environment. The transition from Tcat 1 to Tcat 0 is made by applying the ESDU (2002) boundary layer assumptions, which are sufficiently compatible with AS/NZS 1170.2 for these purposes.

The modelled mean wind speeds were then converted to the equivalent wind gust that is used in AS/NZS 1170.2 (recently re-defined to be the 0.2 s wind gust within a 10 min period, $V_{0.2,600}$) and also to be representative of Tcat 2 (the +10m AGL standard reference terrain category on flat country for structural design).

The BoM now operates a network of AWS across Australia that routinely measure the 10 min mean wind (V_{600}) each 10 min and the peak 3 s (moving average) wind gust in each 10 min period ($V_{3,600}$). Unfortunately this homogeneous dataset has only become available since the mid-1990s when new "Synchrotac" 3-cup anemometers and associated sampling and averaging equipment was gradually installed, replacing the earlier “Dines” pitot-static anemographs at all of the long-term measurement sites and updating earlier AWS at many offshore island and reef sites that had unfortunately proven unreliable since the 1980s. At some airports, this sampling is typically increased to include the peak 1 min wind gust in each 10 min period ($V_{60,600}$) and the peak 3 s gust within each 1 min ($V_{3,60}$).

Besides the importance of precision in wind measurement it is essential that the dataset is sufficiently long to enable reliable estimation of the exceedance probability so that it can be compared with the synthetically modelled winds. Unfortunately, some of the longer marine-exposed wind records derive from un-instrumented observations at lighthouses, typically located on steep complex terrain. These data are unfortunately not ideal for the types of analyses needed here.

Meanwhile, land-based observations are typically more complex to interpret due to variations in surface roughness with direction, topographic influences from hills or escarpments, and often significant changes in their surrounds over time due to urban or industrial development. Combined with changes in instrumentation and procedures it can make interpretation of such data highly uncertain. Accordingly, although no single AWS might demonstrate verification of the modelled winds at a specific point, it can be done reliably in a regional manner.

A total of 29 AWS sites across northern Australia were used for verification of the model. The majority of these (23) are in Queensland, with 3 each in NT and WA. Where available, the AWS high resolution gust data in strong wind conditions (e.g. $V_{60,600}$ and $V_{3,60}$) was used to help adjust the full historical wind data record at a site to “standard exposure” of +10m Tcat 2. The resulting gust factors provided an estimate of the turbulence intensity at the various sites and, by implication, the surface roughness and the associated Tcat exposure in 22.5° azimuths. The model-data comparisons required a detailed examination of each specific situation, with allowance being made to account for:

- Directional roughness exposure
- Topographic influences
- Multiple site shifts over time
- Data gaps (especially for the offshore sites)
- Changes in instrumentation

Peak gust conversions were applied to all data that is post-Dines (e.g. Synchrotac or other as noted in the site-specific BoM metadata) using the advice of Holmes and Ginger (2012) to obtain a $V_{0.2,600}$ equivalent wind gust speed. The minimum wind speed retained was 5 ms^{-1} and the data filtered to limit the sample to periods when there was a TC within 300 km of the site at the time, retaining only the single peak wind for each such event. Both BoM “HC” synoptic and “HM” mean winds have been used, together with the “DC” peak daily gusts.

Figure 4 provides a sample of site-specific modelled and measured winds around Australia, each converted to Tcat 2 exposure at +10 m AGL in flat open country (i.e. Mt=Mh=Ms=1). The model verification (blue lines) is that represented by the matching of the mean wind speeds (blue symbols) whereas the modelled gust (red line) is obtained by a theoretical adjustment of the modelled mean based on equilibrium boundary layer turbulence theory. In many cases this also agrees well with the measured gust data (red symbols), although several airport sites showed likely local bluff body effects that appear to contaminate the peak gust record. The regionally-relevant AS/NZS 1170.2 V_R design curve is also shown on each graph for comparison.

Finally, Figure 5 presents a whole-of-Australia contour map of the $V_{0.2,600}$ peak gust for the 100 y Return Period. This well represents the known regions of significant TC occurrences and shows realistic latitudinal variations and coastal attenuation characteristics. In addition to Return Period analyses, the dataset can be interrogated at any location to extract complete time histories of TC wind speed and direction useful for detailed studies of structural loading fatigue, dynamic response and the like.

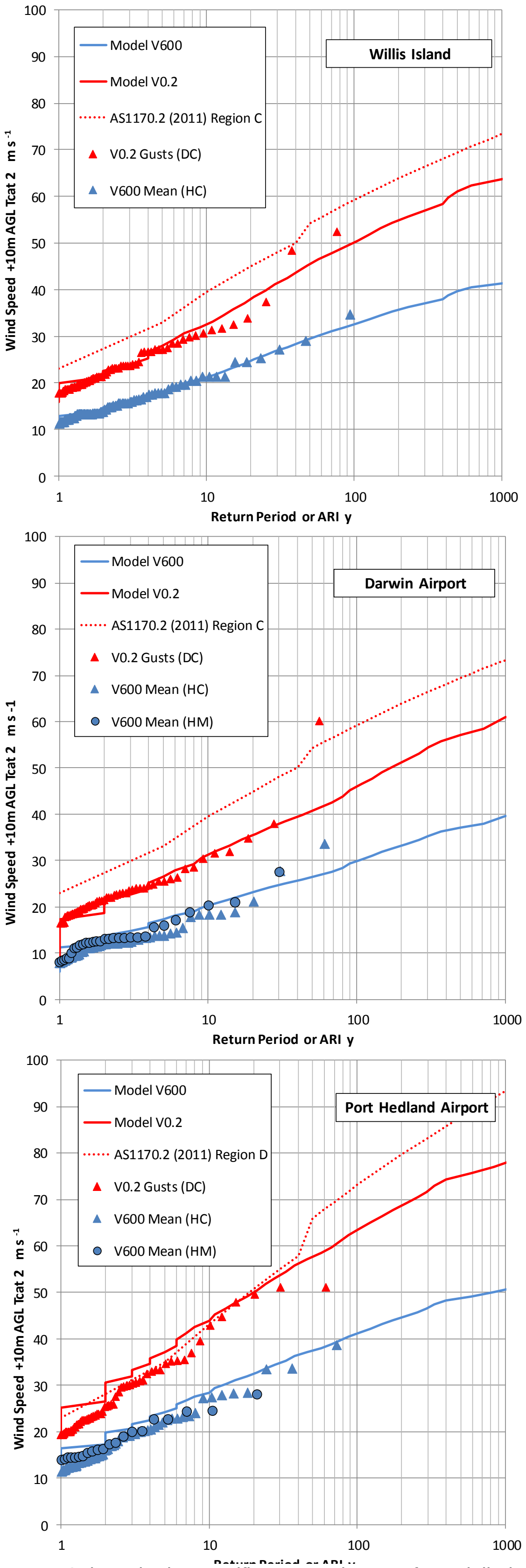

Figure 4 Selected site-specific comparisons of modelled and measured wind data across Australia; blue indicates mean V_{600} winds and red is $V_{0.2,600}$ peak gusts, adjusted to +10m Tcat 2.

Conclusions

The foregoing comparisons of modelled and measured (terrain adjusted) winds indicates that the synthetic TC track and wind field model is producing spatially consistent estimates of the mean wind exceedance over wide areas that match well statistically to the better exposed and longer term reliable BoM AWS sites. The theoretically estimated peak gust wind speeds also compare well with the more reliable sites.

Work is continuing on further refinement of the methodology to potentially represent ENSO variability and extension well beyond 50,000 y in order to obtain smoother spatial variation. A number of other AWS sites are also yet to be assessed in detail.

There are significant reductions in regional design wind speed derived from this dataset compared with the present AS/NZS 1170.2 Regions B and C criteria, although Region D are more similar. If adopted, the authors recommend managing this risk transition by introducing an additional design factor (e.g. M_i) that would specifically target the value of inspection and certification. Monitoring the impact of more rigorous inspection over time would then enable this design factor to be reduced.

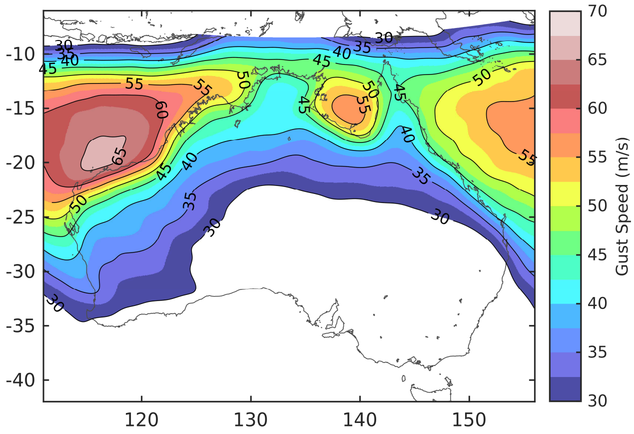

Figure 5 Synthetic TC wind $V_{0.2,600}$ +10m Tcat 2 gust speeds across Australia for the 100 y Return Period.

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