A comparison of the methods used to assess wind hazard in cyclonic regions

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INTRODUCTION

Extreme wind speeds, such as those caused by tropical cyclones, have the potential to cause significant damage to both property and people. An understanding of the likelihood and magnitude of these events, defined as the wind hazard (Holmes, 2015), is necessary to design. Wind hazard calculations underpin the wind loading code used by civil engineers to design structures, but also have uses in other fields: for example, the insurance industry and government planning (Harper, 1999).

Two main methods exist for estimating wind hazard. The first, extreme value analyses, are widely used to estimate the occurrence of extreme wind speeds (e.g. Holmes & Moriarty, 1999; Rajabi & Modarres, 2008; Castellani et al., 2015). Extreme value analyses provide a method to fit historical wind speed observations from one location to a theoretical probability distribution (Palutikof et al., 1999). This distribution can then be extrapolated to estimate the wind speeds for a range of return periods, including those longer than the site's observation record. The second, simulation models, are the more common method of estimating extreme wind speeds for cyclonic regions. These models take into account data about historical cyclones, and use a series of sub-models to generate long records of synthetic cyclone data. Statistical techniques are then applied to these synthetic records to estimate wind hazard.

Extreme value analyses are not commonly applied for estimation of wind hazard in cyclonic regions. Gomes & Vickery (1978) and Cook et al. (2003) have shown that in mixed wind climates, different wind mechanisms should be analysed separately as they have a different underlying probability distribution. Therefore, to perform an extreme value analysis for a site in a cyclonic region, only wind gust data from cyclones is able to be used. Harper (1999) and Holmes (2015) suggest that the data available is not sufficient: the low occurrence and small area of influence of cyclones limits the amount of cyclone data available at individual sites. However Cook et. al. (2003) and Heckert et. al. (1998) both show examples of extreme value analyses in cyclonic regions which perform well in goodness of fit and comparison to other models, with only 30 – 50 years of data. Considering data is available for up to 75 years for many stations in the cyclonic region of Australia, it appears worthwhile to at least investigate an extreme value analysis of this data. Simulation model results can also be compared with extreme value analyses as a form of model validation (Georgiou, 1985).

Within the method of extreme value analyses, there are a number of different types of extreme value analyses. The Gumbel method (GM), Peaks over Threshold method (PoT), and Method of Independent Storms (MIS) are three of the most commonly used approaches. A number of variations and improvements to these methods have also been documented (e.g. Harris, 1996; 1999). Comparison studies at the same site have shown that the extreme wind speed estimates can vary significantly depending on the approach used (An & Pandey, 2005; Holmes & Moriarty, 1999). Therefore, this thesis aims to present a comparison of the different extreme value analyses applied to cyclone gust data at sites around Australia.

METHODOLOGY

Data preparation

Maximum daily wind gust data for 18 sites around Australia was obtained from the Australian Government Bureau of Meteorology (BoM). The sites for analysis were chosen by considering all BoM observation stations within 200 km of the Australian coastline, above the latitude of 30°S. This area includes stations in cyclonic regions C and D and non-cyclonic region B in AS1170.2:2011 (Australian Standards 2011). Stations with less than 30 years of maximum daily gust observations were removed. Figure 1 shows the distribution of sites used in the analysis.

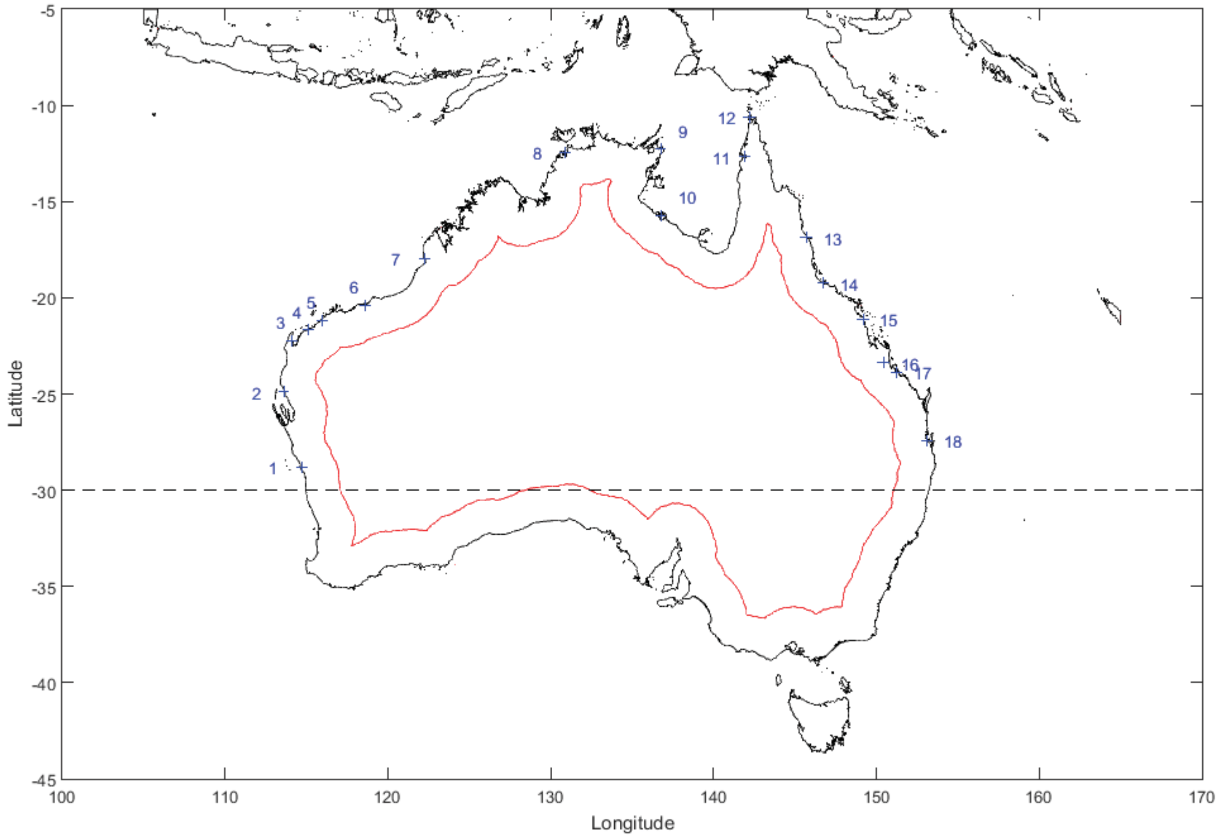

Figure 1: Locations of the Bureau of Meteorology observation stations used in the analysis. The red line shows the 200km buffer used to select stations. Names of stations can be found on the abacus of Figure 2.

Corrections were applied to the wind gust data to standardise it according to the World Meteorological Organisation (WMO) guidelines. The recommended guidelines for overland wind gust measurements are an exposure of level, open terrain at 10 m above the ground, with a gust duration of 3 seconds (World Meteorological Organisation, 2008). The terrain in all directions surrounding each observation station was inspected using Google Earth. When the terrain in any cardinal direction was not open and level, the terrain/height multipliers found in AS1170.2:2011 were used to account for this. Over the observation period of many BoM stations, the anemometer type has been changed from Dines to 3-cup Synchrotac. Correction factors derived by Holmes & Ginger (2012) were applied to wind gusts recorded by Dines anemometers to convert them to equivalent 3 second gusts.

Wind gusts recorded during cyclones were selected by creating a list of ‘cyclone days’ for each site. This was done using cyclone track data from the International Best Track Archive for Climate Stewardship (IBTrACS) cyclone database (National Oceanic and Atmospheric Administration, 2014). For the length of the site’s observation period, a day was considered a ‘cyclone day’ when a cyclone track was recorded within a 500 km radius of the station. The choice of a cyclone radius of 500 km was justified by inspecting the radii data on historical cyclones in Australia and performing a sensitivity analysis. The maximum daily wind gust recorded on ‘cyclone days’ was extracted to create a list of wind gusts from cyclones for each site. To ensure independence of the data, the serial numbers of the cyclones were compared and only the maximum daily gust for each cyclone was retained in the list.

Extreme value analyses

Three extreme value analyses were performed on the data: the Gumbel method (GM), the Peaks over Threshold method (PoT) and the Method of Independent Storms (MIS). Descriptions of these methods can be found in Palutikof et al. (1999), An & Pandey (2005) and Holmes (2015). The GM was performed using the traditional annual maxima approach, with a modification to account for years where there were no cyclones in the vicinity of the site. Plotting positions were calculated by considering the annual maxima of the entire dataset, but only the cyclone values were used to estimate the Type 1 Generalised Extreme Value (GEV) distribution.

The PoT method was performed as described by Palutikof et al. (1999). Fitting of the GPD distribution was done using MatLab’s inbuilt maximum likelihood estimator for the Generalised Pareto Distribution. A threshold of 18 m/s was chosen and implemented for all sites. This threshold was chosen to ensure all stations had more than 10 values included in the analysis.

The MIS applied in this study was modified from Palutikof et al. (1999) to account for the fact that a continuous wind record was not used. This meant that the original up-crossing and down-crossing approach was not required. The maxima of independent storms were simply taken as the maximum value from each cyclone. The data were then fitted to the Type 1 GEV distribution. A fit was also made to the GEV distribution, using MatLab’s inbuilt maximum likelihood estimator for the GEV distribution.

RESULTS AND DISCUSSION

Figure 2 shows the 500 year return period wind gust speeds predicted by the different extreme value analyses for the 18 sites. The regional wind speeds specified by AS1170.2:2011 for design are also shown.

The MIS method fitted to the GEV distribution gives very high wind speed estimates relative to the other values. At Site 5, this is also true for the PoT method. Inspection of the individual site wind hazard plot (see an example in Figure 3 for Site 6, Carnarvon Airport) shows the reason for this: for most stations, a Type 2 extreme value distribution has been fitted to the data. The wind speeds estimated by this distribution increase rapidly with increasing return period, giving very high estimates outside the range of return periods of the data.

The finding that the Type 2 distribution best fits the data is interesting because very few studies have found this result for extreme value analyses of wind speeds. In a study of non-cyclonic sites in Australia, Holmes (2002) found some sites did fit the Type 2 distribution. However, in these instances the shape parameter was changed to zero, effectively constraining the distribution to a Type 1 distribution. Holmes' (2002) reasoning for this was that an unbounded wind estimate does not make physical sense, as there is a limit on how intense a wind speed can get. The same argument can be made in this instance: the wind speeds estimated for some cases are above 200 m/s, which is completely unrealistic.

For the other extreme value analyses, the range of 500 year wind gust speeds predicted by the different methods range from 2 to 29 m/s. The variability between the methods appears to be related to the number of cyclones at the location, but this was not consistent for all sites. No method consistently provides an upper or lower bound estimate.

Another observation from the extreme value analyses is that for all sites, some estimates are greater than the design wind speeds specified in AS1170.2. While this appears concerning at first, it can be explained by considering that the design wind speeds have been developed using datasets from a number of sites, rather than just one. This highlights one key issue with performing an extreme value analysis at a single location: some sites may have a recording period which experiences higher wind speeds than will be typical for that site in the long term, and vice versa. This leads to differences in wind speed estimation between sites which, geographically and physically, should have similar wind hazard. Adopting an approach similar to AS1170.2, where the analysis results are smoothed spatially, may therefore lead to better estimates of extreme wind speeds.

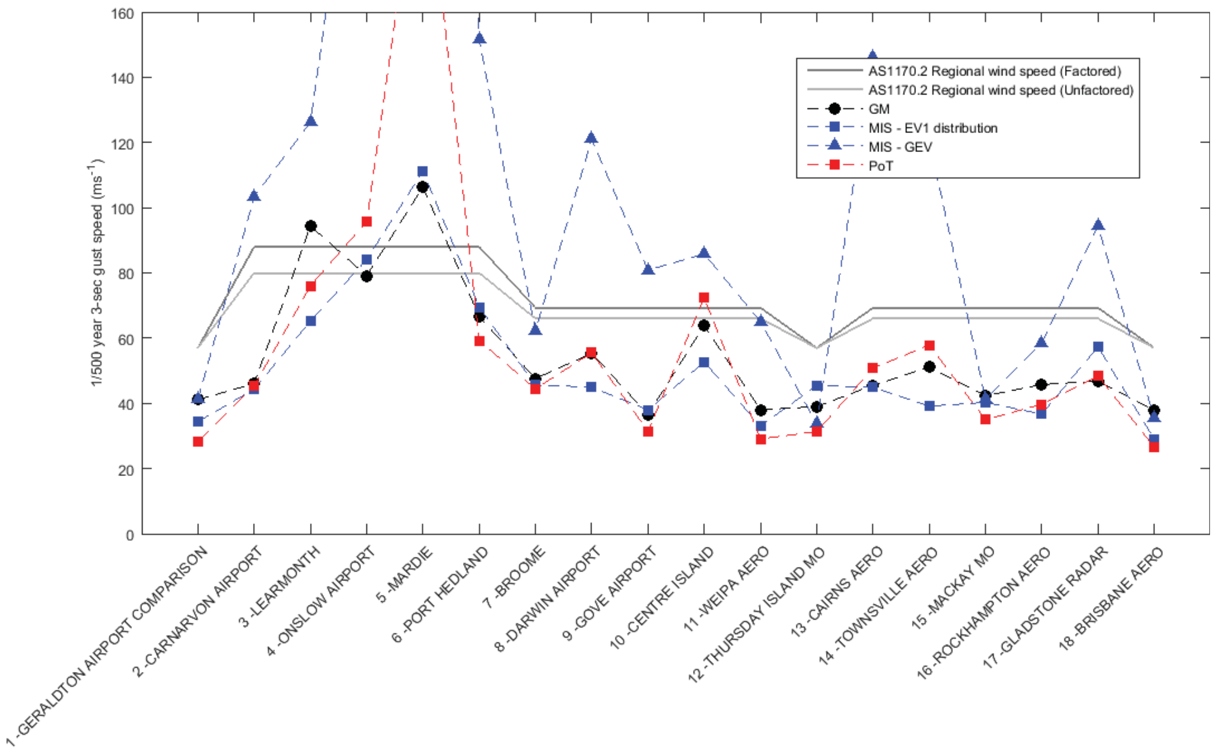

Figure 2: 500 year return period 3-sec wind gust speeds predicted by different extreme value analyses.

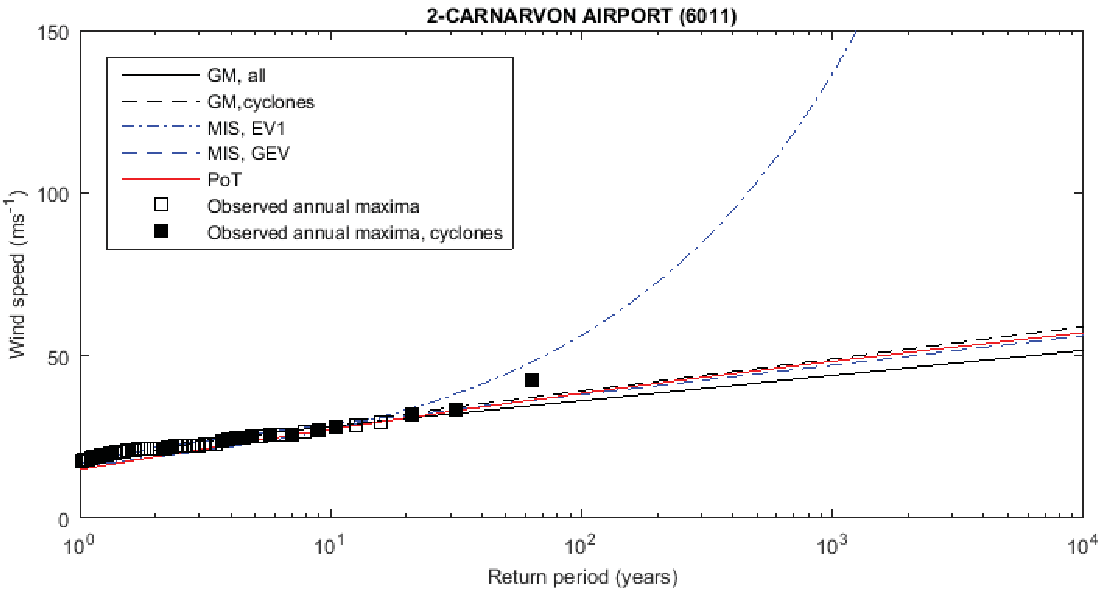

Figure 3: An example wind hazard plot for Site 2, Carnarvon Airport, showing the different extreme value analyses.

CONCLUSIONS

This thesis has presented data showing a comparison of the different methods used to assess wind hazard, for 18 sites in the cyclonic region of Australia. The following conclusions were obtained from the results:

- There is a large variability between different extreme value estimates with different methods, and this increases with increasing return period.
- Fitting the data to a GEV distribution results in a Type 2 distribution for most sites, and correspondingly leads to unrealistic estimates of gust wind speeds at long return periods.
- Some extreme value analyses result in wind speed estimates that are higher than the design wind speeds found in AS1170.2. This is because the analysis only considered a single point in space, and is not necessarily indicative that the AS1170.2 values are too low.

These results highlight the variable nature of estimating extreme wind speeds for long return periods. Different analyses can lead to vastly different results, and therefore estimations should always be made in a context of uncertainty.

REFERENCES

Y. An & M.D. Pandey (2005), *A comparison of the methods of extreme wind speed estimation*, Journal of Wind Engineering and Industrial Aerodynamics, 93: 535 – 545.

F. Castellani, A. Garinei, L. Terzi, D. Astolfi (2015), *Applied statistics for extreme wind estimate*, Wind Energy, 18: 613 – 624.

N.J. Cook, R.I. Harris, & R. Whiting (2003), *Extreme wind speeds in mixed climates revisited*, Journal of Wind Engineering and Industrial Aerodynamics, 91: 403 – 422.

P.N. Georgiou (1986), *Design wind speeds in tropical cyclone-prone regions*, PhD thesis, The University of Western Ontario, London.

L. Gomes & B.J. Vickery (1978), *Extreme wind speeds in mixed wind climates*, Journal of Industrial Aerodynamics, 2: 331 – 344.

B.A. Harper (1999), *Numerical modelling of extreme tropical cyclone winds*, Journal of Wind Engineering and Industrial Aerodynamics, 83: 35 – 47.

R.I. Harris (1996), *Gumbel re-visited: a new look at extreme value statistics applied to wind speeds*, Journal of Wind Engineering and Industrial Aerodynamics, 1: 1 – 22.

R.I. Harris (1999), *Improvements to the "Method of Independent Storms"*, Journal of Wind Engineering, 80: 1 – 30.

N.A. Heckert, E. Simiu, T. Whalen (1998), *Estimates of Hurricane Wind Speeds by "Peaks Over Threshold" Method*, Journal of Structural Engineering, 124: 445 – 449.

J.D. Holmes (2015), *Wind Loading of Structures*, 3rd edn., CRC Press, Boca Raton.

J.D. Holmes & J.D. Ginger (2012), *The gust wind speed duration in AS/NZS 1170.2*, Australian Journal of Structural Engineering, 13: 207 – 218.

J.D. Holmes & W.W. Moriarty (1999), *Application of the generalized Pareto distribution to extreme value analysis in wind engineering*, Journal of Wind Engineering and Industrial Aerodynamics, 83: 1-10.

National Oceanic and Atmospheric Administration (2014), *IBTrACS-WMO All Storms data*, csv file, accessed 15 July 2015.

J.P. Palutikof, B.B. Brabson, D.H. Lister & S.T. Adcock (1999), *A review of methods to calculate extreme wind speeds*, Meteorological Applications, 6: 119 – 132.

M.R. Rajabi & R. Modarres (2008), *Extreme value frequency analysis of wind data from Isfahan, Iran*, Journal of Wind Engineering and Industrial Aerodynamics, 96: 78 – 82.

Standards Australia 2011, *Structural design actions Part 2: Wind Actions*, AS/NZS 1170.2:2011.