Reassessment of wind hazard in the current climate

W. C. Arthur[1], C. M. Thomas[1], L. A. Sanabria[1] and R. P. Cechet[1]

[1]*Risk and Impact Analysis Group, Geoscience Australia, Canberra, Australia,*
craig.arthur@ga.gov.au

1 INTRODUCTION

In this study, we have applied statistical models to develop a spatially specific understanding of wind hazard arising from tropical cyclones (TCs), synoptic storms and thunderstorms. It is important to separate the peak wind gusts into these components because wind multipliers, as detailed in AS/NZS 1170.2 [1] (hereafter referred to as the Standard), affect these components differently. In particular, the topographic multiplier for thunderstorm downbursts is significantly reduced compared to synoptic winds, due to the markedly different vertical profile of winds in thunderstorm downbursts [2]. The return period wind speeds of the three individual components are combined to produce a revised estimate of severe wind hazard across the continent.

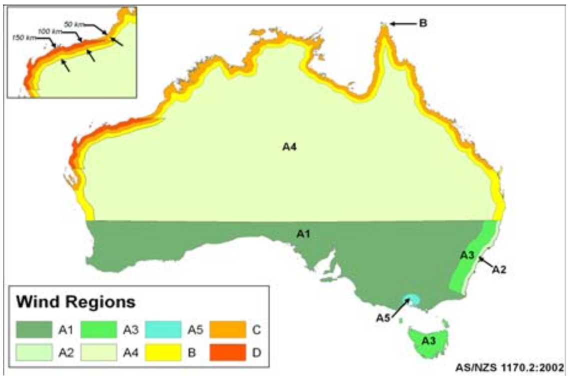

Fig. 1: Wind regions as defined in AS/NZS 1170.2:2002. Regions C and D represent the cyclonic regions. Along with region B, these regions are each 50 km wide.

For previous wind risk studies, we have used the regional design wind speeds (Fig. 1), as defined in the Standard, as an estimate of the wind hazard. The regional wind speeds used in the Standard were determined from analysis of observations of daily maximum gust wind speeds. As this is a design standard, there are additional conservatism factors included in the specification of regional wind speeds for Regions C and D to accommodate the uncertainty in the estimated return period wind speeds in these areas. The aim of this study is to develop techniques that can be used to evaluate severe wind hazard and risk under future climate scenarios.

2 TROPICAL CYCLONES

The historical record of TC events in the Australian region represents approximately 100 years of activity – which is too short a record to evaluate the wind speeds at long return periods. To overcome this shortfall in data, severe wind hazard due to TCs is modelled using Geoscience Australia’s Tropical Cyclone Risk Model (TCRM), a statistical-parametric model of tropical cyclone behaviour. We use the Bureau of Meteorology’s (BoM) best-track dataset [3] as input to generate a synthetic catalogue of TC tracks representing 50,000 years of TC activity. A parametric wind field is fitted to each of the synthetic tracks, the resulting wind fields aggregated, and a Generalized Extreme Value (GEV) distribution is fitted to the modelled wind speeds at each point over the area of interest. The location, scale and shape parameters of the GEV distribution are estimated using the method of L-moments [4].

The cyclonic wind hazard estimated using TCRM qualitatively matches the existing Standard well (Fig. 2) over tropical areas. Peak hazard levels along the northwest coastline are generally within a few $m.s^{-1}$ of the regional wind speeds specified in the Standard. Landfall decay is modelled using a parameterisation based on data from the USA [5], resulting in slower decay over the interior. At higher latitudes along the west coast (poleward of 30°S), TCRM significantly over-estimates the level of hazard. The linear boundary-layer model employed assumes the translational speed of the TC is much less than the tangential wind speed, which breaks down as the TCs accelerate across southwest Australia.

3 THUNDERSTORMS

There is little knowledge of the spatial distribution of thunderstorm wind hazard. The distribution of thunder-days (days on which thunder is heard) and lightning flash rate have been used to estimate the frequency of thunderstorms across Australia [6, 7]. Holmes [8] has investigated the effect of separation by storm type (i.e. thunderstorm or synoptic storm) for the capital cities. To our knowledge, the intensity of wind gusts (and the resulting return period wind speeds) attributable to thunderstorms has not been spatially estimated across the country.

The assessment of thunderstorm wind hazard is based on observational data from BoM anemometers and the corresponding coded weather descriptions from BoM stations to identify those wind gusts that were likely produced by thunderstorms. Using a peaks-over-threshold approach [9], Generalized Pareto Distributions (GPDs) are fitted to the observational data from each station. To produce a spatial representation of the hazard from thunderstorms, we interpolated the parameters of the fitted GPDs across the country, and then calculated return period wind speeds from these interpolated parameters. This technique provides little spatial texture (Fig. 2), but loosely resembles the distribution of thunder-day observations [6], with increased hazard across the eastern and northern parts of the continent.

4 SYNOPTIC STORMS

Synoptic storms are those wind events that cannot be classified as tropical cyclones or thunderstorms. The existing understanding of wind hazard in Regions A1 – A5 is based on observed wind speeds at a limited number of observing stations around Australia and New Zealand. The model used here follows the technique proposed by Holmes and Moriarty [10] which allows the wind hazard from thunderstorm downbursts and synoptic storms to be evaluated separately.

A peaks-over-threshold approach is also used for evaluating severe wind hazard from synoptic storms [9], but here the method is adapted to utilise gridded output from regional climate models. Daily maximum mean wind speed values were extracted from CCAM[1] [11] and convoluted with a distribution of gust factors (ratio of peak gust to mean wind speed) based on observational data to provide a synthetic record of daily maximum gust wind speeds [12]. As with the thunderstorm observations, the synthetic records were fitted to a GPD.

For the majority of the continent, the return period wind speeds are well estimated (Fig. 2). Higher hazard levels are observed across the southern parts of the continent compared to areas across the north. This is as expected, with synoptic storms dominating the weather patterns over the southern states. There is significant spatial variability (for example over southern Western Australia), which we attribute to the use of regional climate model output as the underlying data source for this model. Over elevated terrain (especially over southeast Australia), the return wind speeds are reduced relative to the wind hazard over lower terrain, in contrast with detailed studies of the effect of mountain slopes on wind speeds [13].

5 RESULTS

It is necessary to combine the estimates of the individual hazards from thunderstorms, tropical cyclones and synoptic winds to form an estimate of the combined hazard. This is achieved by using a probabilistic formula which computes the return period of the combined wind hazard at a particular exceedance level in terms of the return periods of each of the constituent wind hazards at that level, as described by Eq. 1:

$$t_{comb}(w) = \left[1 - \left(1 - \frac{1}{t_c(w)}\right)\left(1 - \frac{1}{t_s(w)}\right)\left(1 - \frac{1}{t_t(w)}\right)\right]^{-1} \qquad \text{(Eq. 1)}$$

where $t_{comb}(w)$ is the return period of the combined wind at an exceedance level w, and $t_c(w)$, $t_s(w)$ and $t_t(w)$ are the return periods of the cyclonic, synoptic and thunderstorm winds at that

---

[1] CCAM – Conformal-Cubic Atmospheric Model

level. Eq. 1 can be inverted to provide a combined exceedance level w for a specified return period t.

Fig. 2 presents the combined 500-year return period gust wind speed. Highest hazard levels are found along the northwest coastline, consistent with the expected impact of intense tropical cyclones. Lowest hazard levels are found across the interior of the continent.

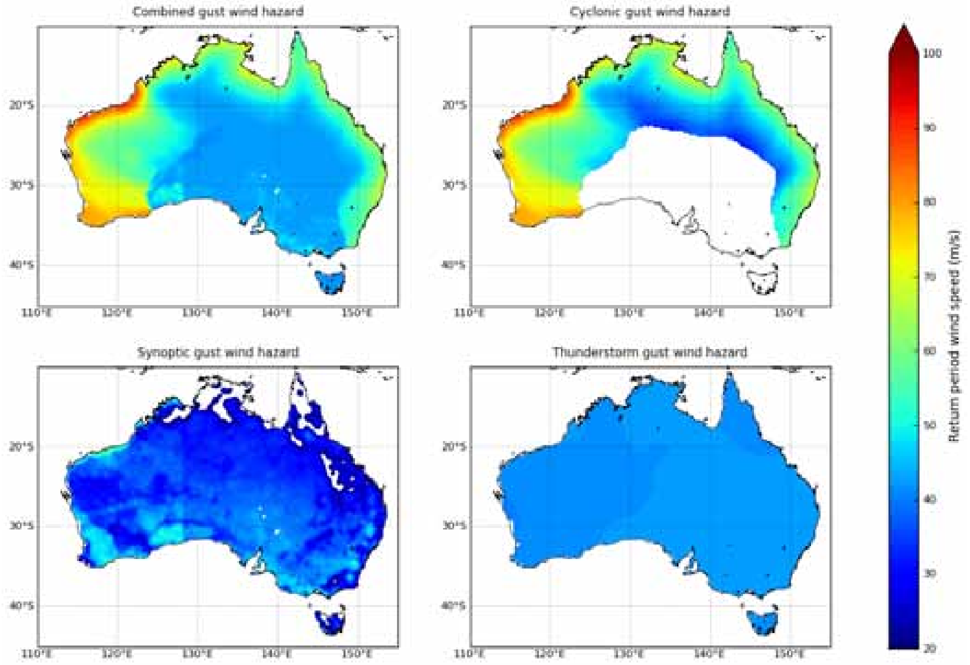

Fig. 2. *Combined 500-year return period wind gust hazard for Australia (top left), comprised of gust wind hazard arising from tropical cyclones (top right), synoptic storms (bottom left) and thunderstorms (bottom right).*

At longer return periods (greater than 500 years), the difference between the cyclonic wind hazard and synoptic and thunderstorm hazards becomes evident over the southwest part of the continent. This is likely due to the relatively poor performance of the tropical cyclone model at high latitudes where tropical cyclones would be expected to be weakening or transitioning to extra-tropical cyclones (i.e. transitioning to synoptic storms).

Significant differences between this revised estimate of wind hazard and the existing regional wind speeds specified in the Standard are clear over the western half of the continent (Fig. 3). The largest differences arise near the boundaries of the existing Regions B, C and D, especially in the north and west of the country. Refinement of the landfall decay model will necessarily improve the performance of the tropical cyclone model in this area. Over the interior, there is minimal difference, giving confidence that the initial thunderstorm and synoptic wind hazard estimates are reasonably robust.

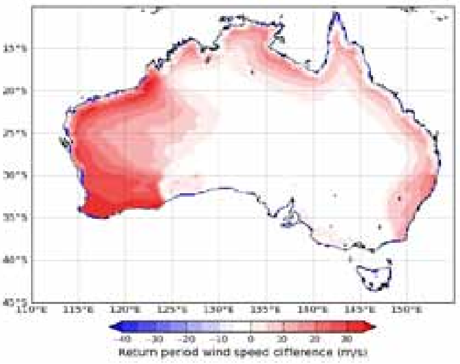

Fig. 3. Difference between revised estimate of combined 500-year return period wind gust hazard and the existing Regional Wind Speeds specified in the Standard. Positive values indicate the revised estimate is higher than the Regional Wind Speed.

6 SUMMARY AND CONCLUSIONS

We have presented a revised estimate of wind hazard across the Australian continent, utilising statistical models of wind hazard to develop a spatial understanding of the return period wind speeds due to synoptic storms, tropical cyclones and thunderstorms. The techniques used for evaluating severe wind hazard from TCs and synoptic storms can be easily adapted to provide estimates of these hazards under future climate conditions. We have not been able to develop a robust technique for evaluating thunderstorm wind hazard that is sufficiently independent of the observational data to permit evaluation of future climate severe wind hazard, and research continues in this area.

The resulting maps of wind hazard are, in many areas of the country, in good agreement on the magnitude and spatial distribution of wind hazard. Notable areas of exception are the southwest corner, where our approach indicates higher wind hazard (arising from the passage of decaying tropical cyclones), and the northwest coastline, where the rate of decay of landfalling tropical cyclones results in differences in return period wind speed. Both of these discrepancies arise due to an acknowledged shortcoming of the modelling technique used, and highlight another area requiring further research.

7 ACKNOWLEDGEMENTS

This work was undertaken as part of the National Wind Risk Assessment, a collaborative project between Geoscience Australia and the Department of Climate Change and Energy Efficiency. We are also grateful to CSIRO Marine and Atmospheric Research for providing CCAM data, and the BoM for providing observational data and tropical cyclone best track data.

8 REFERENCES

[1] AS/NZS 1170.2, "Standards Australia/Standards New Zealand - Structural design actions, Part 2: Wind actions," Standards Australia, Australian Standards/New Zealand Standards 2002.

[2] M. S. Mason, G. S. Wood, and D. F. Fletcher, "Numerical simulation of downburst winds," *Journal of Wind Engineering and Industrial Aerodynamics,* vol. 97, pp. 523-539, 2009.

[3] Y. Kuleshov, R. Fawcett, L. Qi, B. Trewin, D. Jones, J. McBride, and H. Ramsay, "Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean," *Journal of Geophysical Research,* vol. 115, p. 9, 2010.

[4] J. R. M. Hosking, "L-moments: Analysis and Estimation of Distributions using Linear Combinations of Order Statistics," *Journal of the Royal Statistical Society,* vol. 52, pp. 105-124, 1990.

[5] P. J. Vickery and L. A. Twisdale, "Wind-Field and Filling Models for Hurricane Wind-Speed Predictions," *Journal of Structural Engineering,* vol. 121, pp. 1700-1709, 1995.

[6] Y. Kuleshov, G. de Hoedt, W. Wright, and A. Brewster, "Thunderstorm distribution and frequency in Australia," *Australian Meteorological Magazine,* vol. 51, pp. 145-154, 2002.

[7] Y. Kuleshov, D. Mackerras, and M. Darveniza, "Spatial distribution and frequency of lightning activity and lightning flash density maps for Australia," *Journal of Geophysical Research,* vol. 111, p. 14, 2006.

[8] J. D. Holmes, "A re-analysis of recorded extreme wind speeds in Region A," *Australian Journal of Structural Engineering,* vol. 4, 2002.

[9] L. A. Sanabria and R. P. Cechet, "A Statistical Model of Severe Winds," Geoscience Australia, Canberra Geocat 65052, 2007.

[10] J. D. Holmes and W. W. Moriarty, "Application of the generalized Pareto distribution to extreme value analysis in wind engineering," *Journal of Wind Engineering and Industrial Aerodynamics,* vol. 83, pp. 1-10, 1999.

[11] J. McGregor and M. R. Dix, "An Updated Description of the Conformal-Cubic Atmospheric Model " in *High Resolution Numerical Modelling of the Atmosphere and Ocean* K. Hamilton and W. Ohfuchi, Eds. New York: Springer 2008, pp. 51-75.

[12] L. A. Sanabria and R. P. Cechet, "Severe Wind Hazard Assessment using Monte Carlo Simulation," *Environmental Modeling and Assessment,* vol. 15, pp. 147-154, 2010.

[13] J. D. Holmes, *Wind Loading of Structures*, 2 ed.: Taylor and Francis, 2007.