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A Preliminary Analysis of Convective Windstorm Environments Across Australia

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Abstract

This manuscript documents a preliminary analysis of convective windstorm environments across Australia. It combines radiosonde, reanalysis and severe weather observations to achieve this objective. Severe weather observations across Australia are revealed to have significant issues with stationarity, even when only the past thirty years are considered. Radiosonde and reanalysis observations are shown to agree relatively well for several cities in Australia. In addition, significantly different environments are documented to generate severe wind and tornado events in a sub-tropical environment such as Brisbane compared with a more mid-latitude-like environment such as Perth. The potential to extend this analysis for the remainder of Australia is also briefly discussed.

Introduction

It is now widely acknowledged that convective windstorms are of great importance for the design of structures in sub-tropical regions of the world. This is certainly the case in Australia, were Holmes (2002) has shown that for a range of given locations, convective and synoptically driven wind gusts produce differing exceedance probability curves. It is therefore important that when attempting to understand national wind hazard, an explicit understanding of the meteorological drivers behind measured gust wind speeds are appreciated. The appropriate “tagging” of individual recorded gust events with their meteorological origin then allows statistical analysis of these separated wind climates and reporting of their differing characteristics.

One issue with the methodology outlined above is that exceedance probability curves can only be generated at locations where high fidelity data has been collected over a period of at least 30-50 years. This is relatively rare in Australia with less than 100 (~20%) anemometer stations recording daily gust information for longer than 30 years and less than 50 (~10%) for longer than 50 years. Given the small spatial and temporal scale of convective windstorms, analysis of shorter periods may mean few, if any, convectively driven gusts are embodied in the historical record.

Similar issues arise when attempting to understand tropical cyclone (TC) wind hazard. To overcome this, modellers have developed a range of stochastic simulation techniques that allow the generation of extended (e.g. 10,000 years) synthetic storm event sets upon which standard statistical procedures can then be applied (e.g., Haigh et al., 2013). This approach has the added benefit of providing information on the spatial characteristics of each event. However, for these modelling techniques to faithfully reproduce storm behaviour, and therefore surface level wind signatures, they require detailed information on storm characteristics, behaviour and frequency. As outlined in Harper (2002) there are numerous issues that arise with respect to data quality when building such stochastic models, but sensible handling of these issues, as well as their associated uncertainties, means that useful models can generally be developed.

A similar stochastic modelling approach can (in theory) be used to help build an understanding of convective wind hazard across Australia. However, given the small spatial and temporal scales of these events, it is not only the event characteristics that are uncertain but indeed the actual event occurrence itself. This has been a notable issue when trying to understand climates in well populated areas where people have (to some degree) had the capacity to record severe weather events, but has been almost completely restrictive for more sparsely populated areas of the country in the sense that it has limited our ability to understand severe windstorm climates in these regions.

In order to overcome this lack of event data, instead of explicitly studying the occurrence of severe weather itself, researchers have turned to studying the environments that produce it (e.g., Brooks et al., 2003; Grunwald and Brooks, 2011). This approach is premised upon the understanding that there is a strong relationship between the occurrence of severe weather and the broad scale atmospheric conditions that lead to their development. If these relationships can be built for areas where severe weather observations are reliable, it is hoped that they can be applied to areas where severe weather observations have been historically less reliable, and will allow some understanding of the relative risk of severe weather to be developed.

If this approach is to be applied across a large area, a spatially uniform and reliable measure (or pseudo-measure) of atmospheric conditions is required. Reanalysis databases have previously been used to achieve this and are again used here. Using the estimated spatio-temporal atmospheric conditions within these databases, historic pseudo-soundings can be reconstructed and persistence, or otherwise, of atmospheric conditions conducive to storm development can be analysed.

This paper describes a preliminary assessment of the environments within which severe convective windstorms have historically formed in Australia. It focuses in particular on the data required to undertake this analysis, namely the Bureau of Meteorology Severe Storm Archive (SSA) and the ERA-Interim Reanalysis, and explores the limits to which these data sets should be relied upon. Additionally, a broad scoping analysis of wind-based records (wind gusts, tornadoes) within the SSA is discussed.

Methodology

The SSA has been analysed so that dates and times of historic windstorm reports can be extracted. Given there is little confidence in the completeness of the Archive outside of major metropolitan areas, this analysis focuses largely on capital cities. Using these data, relevant atmospheric information is extracted from the ERA-Interim Reanalysis database so that a set of pseudo-soundings can be developed for those times and locations where convective windstorms occurred. These soundings are used to calculate a range of severe weather indices (Kunz, 2007) whose distributions can be studies and compared with those for non-windstorm days.

To ensure the pseudo-soundings developed are broadly representative of actual environmental conditions on the days of storm activity, these soundings are compared with those measured by radiosonde launches at a number of airports around the country. This allows a comparison of relative humidity (RH), temperature and wind conditions up to the 500-mb level.

Brisbane and Perth, are chosen as case studies to exemplify the differing environments that can lead to convective activity in Australia.

Datasets

Bureau of Meteorology Severe Storm Archive (SSA)

In 2012 the Bureau of Meteorology made a nationally aggregated version of their state-based Severe Storm Archives publically available (http://www.bom.gov.au/australia/stormarchive/). The SSA details all reported instances of severe thunderstorm activity and associated hazards either recorded by a weather station or radar, or reported by a Storm Spotter or member of the public. These latter reports draw from historical information in the Bureau's Monthly Weather Reviews or archived newspaper articles. The earliest records in the SSA date back to the 1800s, but given the sparse population and recording systems available at that times, these data are not considered complete.

The SSA documents severe weather ***events*** that produce any of the following ***severe phenomena*** (BoM, 2013):

1. Severe wind gusts
2. Damaging hail
3. Tornado/es
4. Heavy rain
5. Lightning causing injury or death
6. Waterspouts near land
7. Damaging dust devils

A severe weather ***event*** can be comprised of one or more ***severe phenomena*** across a number of locations along a storm path. This most recent definition of severe weather appears to deviate from the historically more prescriptive definitions for severe wind gusts to be those that exceed 90 km/hr (no referencing time given) and for hailstones to exceed 2 cm in size. These prescriptive definitions run through much of the archive.

For this paper only SSA entries between July 1979 and June 2012 (33 meteorological years) classified as either 'wind gusts' or 'tornadoes' are considered explicitly as windstorms – limited information currently exists in the waterspout and dust devils archive so these have been excluded.

Approximately 76% of wind gust records in the SSA are assigned a maximum wind speed, with all tornadoes assigned a Fujita scale rating from 0 to 5. Associated comments suggest that not all wind speeds were recorded and that some have been estimated by damage observations. It is unclear whether tornadoes with an assigned rating of F0 are done so based on reported damage, or if this is the default where little information is available. Associated comments for these records do suggest some attempt has been made to assess reported damages and assign an appropriate damage rating.

Some cleaning of records was required to ensure consistency throughout the SSA and to avoid duplication, but as of the time of writing this has not been rigorously undertaken. The analysis to follow is based upon 5250 wind gust records, 593 tornado records and an aggregated total of 4513 windstorm events.

ERA-Interim Reanalysis database

The ERA-Interim Reanalysis has been used for this study (Berrisford et al., 2011; Dee et al., 2011). Reanalysis is a process by which past observations of the atmosphere, ocean and land surface are quality checked and integrated into present day numerical weather prediction models so that best-estimates of global atmospheric circulations throughout time can be made (Dee et al., 2011). A number of global reanalysis data sets exist, with the ERA-Interim and the NCEP-CFSR being some of the most recent. These differ in assimilation techniques, spatial resolution and temporal duration, but all reanalysis make use of a wide range of observations, including radiosonde, satellite and buoy data. The ERA-Interim was chosen for use in this project due to its utilisation of four-dimensional variational data assimilation which is generally shown to give more realistic assessment of observed conditions (Dee et al. 2011).

The ERA-Interim reanalysis database extends from January 1 1979 to near-present and provides estimates of atmospheric conditions at 6-hour increments. Air temperature, relative humidity, u and v wind components, geopotential height, and sea level pressure were extracted at 50 hPa levels between 1000 hPa and 400 hPa, as well as at the surface (2 m for temperature and 10 m for winds), on a 0.75 degree grid across the country. These data allowed all necessary environmental indices to be calculated.

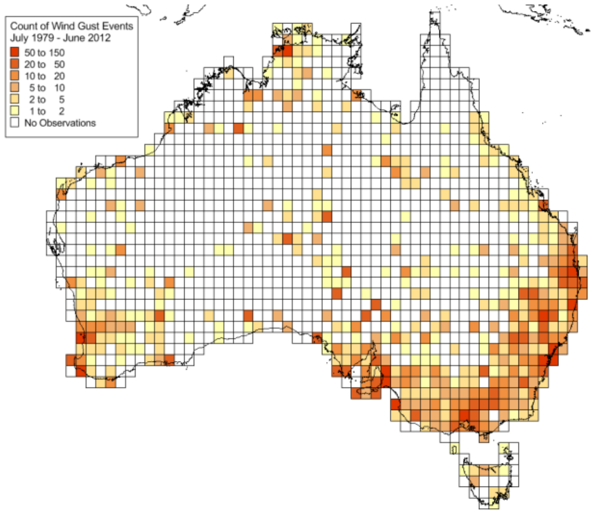
Bureau of Meteorology Radiosonde data

Bureau of Meteorology Radiosonde data were obtained for several locations used by the ECMWF for ingestion into their reanalysis modelling. Duration of records varied for individual sites, but Perth radiosonde data has been available since the beginning of the ERA-Interim time period (i.e., January 1979), while Brisbane radiosonde data was only available since February 2000. Radiosondes are launched four times per day and provide measurements of temperature, moisture and wind speed for various levels from the surface into the lower stratosphere.

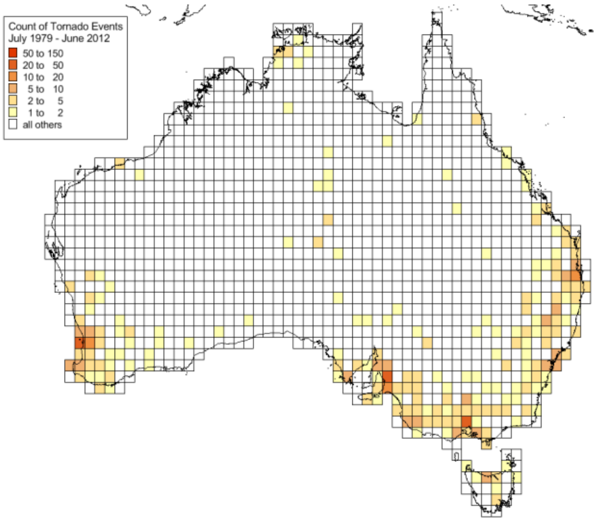
Preliminary regional windstorm climatology

Analysis of the SSA

A recent paper by Allen et al (2011) analysed a cleaned subset of the SSA (2003 – 2010) for all hazards on a national level. The present analysis found similar trends for wind data. Figure 1a shows the spatial distribution of wind event counts (i.e., those events reporting one or more severe wind gusts) within the SSA (July 1979 – June 2012) when binned into 0.75 degree grid cells across the country. Figure 1b shows the same for tornado reports. As expected, the largest number of reports cluster around population areas, with all capital city areas recording both wind gust and tornado generating events. It is clear however, that vast areas of the country have no records despite there being no meteorological justification for their absence.



(a) Count of wind gust observations, July 1979-June 2012.



(b) Count of tornado observations, July 1979-June 2012.

Figure 1. Observation count for events reporting one or more (a) severe wind gusts, and (b) tornadoes between July 1979 and June 2012.

Despite the increased number of reported events in and near major cities, it is evident that changes in monitoring and recording practices also influence record counts. This means that it may not be possible to reliably use event counts for all years in the SSA, even within our post-1978 sample, to develop an understanding of event frequency. To understand this, event counts were aggregated for cells considered representative of each capital city and plot with respect to the meteorological year (July – June) within which they occurred. Figure 2 shows these data for Brisbane. Running a change point analysis on this plot shows a potential point of dislocation around 1989, with an additional abrupt change around 2001. Similar observations were noted in most cities, with the late 1980s, early 1990s and the early 2000s generally being points of potential change. Based on these analyses, periods of stationarity were chosen. In the case of Brisbane, the period from 1989 onwards was deemed “stationary”.

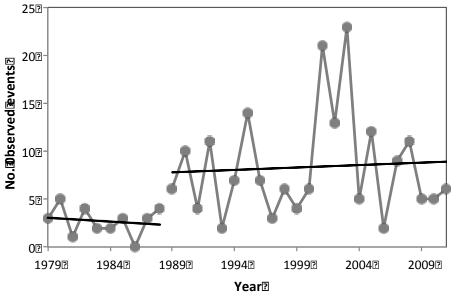


Figure 2. Number of observed wind events (gusts + tornado) reported in the greater Brisbane region.

It is generally believed that severe windstorms are warm-season phenomena. This is shown to be true for Brisbane (Figure 3) with the period between October and January, generating around 80% of records. For Perth however, a different result is obtained, with the same proportion of records reported in the months between May and September. In both cities the distribution of wind gusts and tornadoes follow that of the combined populations, but the percentage of wind events that generate tornadoes is greater in Perth, 35%, than in Brisbane, 13%. This observation raises an important point that must be borne in mind when interpreting storm environments, indices, or even when analysing split wind climate data, and that is convective windstorms are not all the same. Initiation of events in warm, moist climates (i.e. Brisbane) require significant surface heating to force vertical lifting within an environment. In contrast, in the southern part of the country, the periodic return of large southern ocean lows and their associated frontal system provide this impetus. Whether the lifting mechanism has an appreciable impact on the structure of the resulting convective outflow is, however, still largely unknown.

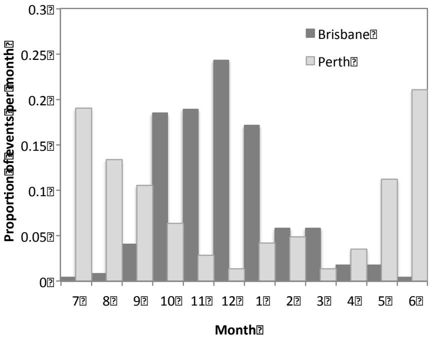


Figure 3. Distribution of monthly wind event (gusts + tornado) counts in Brisbane and Perth.

Although there is uncertainty around the intensity metrics provided in the SSA, their inclusion does allow regional analysis of relative convective storm intensity. Following what is now common practice in severe storm analysis, gust and tornado events are classified as either severe or significant severe. The thresholds chosen for delineating between these two categories was a gust of 65 knots, or a tornado with a Fujita Scale rating of F2. Anything greater than or equal to these values was classified as significant severe. Table 1 shows the relative proportion of events in Brisbane and Perth with each classification.

	Wind gusts		**Tornadoes**	
	Severe	**Sig. Sev.**	**Severe**	**Sig. Sev.**
Brisbane	88%	12%	93%	7%
Perth	87%	13%	93%	7%

Table 1. Proportion of wind gusts and tornado events within severe and significant severe categories for Brisbane and Perth.

Similar results are shown for both wind gusts and tornadoes in both areas. The similarity in proportions for wind gusts is, perhaps expected given the similar exceedance probability of 65 knots in the wind loading standard. The similarity for tornadoes is a little more surprising given the genesis mechanisms of warm and cool season tornadoes is thought to differ. Comparing the relative proportion of tornadoes with a similarly classified population of US tornadoes (Simmons and Sutter, 2011), it appears, at least for these two cities, that the 7% of reports greater than or equal to F2 is less than the roughly 20% observed by those authors.

Comparing reanalysis and radiosonde data

ERA-Interim and radiosonde data were compared at three different levels: 500 mb, 700 mb and 900 mb and for three different parameters: wind, temperature and pressure. Reanalysis data is available every six hours since January 1, 1979. A radiosonde observation was assigned to a reanalysis observation whenever it occurred within three hours of the reanalysis time. Occasionally radiosondes reported non-standard millibar levels (e.g., 882 mb). If no observation was provided at the 500-mb, 700-mb or 900-mb level, but an observation was provided at a level within 25-mb of these levels, it was utilized for comparison.

Biases and mean absolute errors (MAE) were calculated between the radiosonde and reanalysis data. In general, as would be expected given the conservative nature of reanalysis data, low biases were typically seen when the radiosondes reported high measurements, and high biases were typically seen when the radiosondes yielded low measurements. This is also to be expected given that a radiosonde represents a single point measurement, while the reanalysis is averaged over a 0.75° grid. From a modelling perspective what this means is that when deriving environmental indices based on reanalysis data, lower values of, for example, shear and CAPE will be calculated. When averaged over all measurements, biases and mean absolute errors were relatively modest, as shown in Table 2.

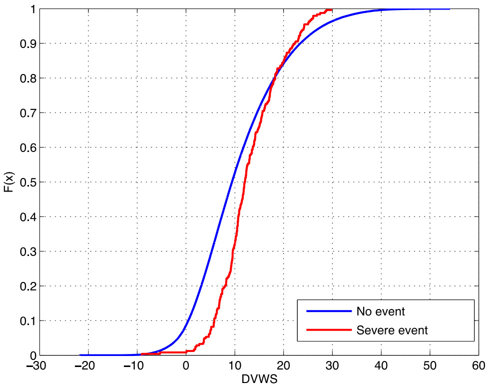
Parameter	Perth (MAE)	Perth (Bias)	Bris. (MAE)	Bris. (Bias)
500 mb RH (%)	8.8	+3.7	8.4	+3.8
700 mb RH (%)	8.8	-1.1	9.2	+1.4
900 mb RH (%)	9.3	+4.3	10.6	+3.9
500 mb Wind (km h^{-1})	6.1	+0.5	5.9	-1.8
700 mb Wind (km h^{-1})	5.4	-0.5	5.1	-1.4
900 mb Wind (km h^{-1})	6.3	+0.1	6.2	+1.1
500 mb T (°C)	0.6	+0.1	0.5	-0.2
700 mb T (°C)	0.6	0.0	0.6	-0.3
900 mb T (°C)	1.0	-0.5	0.7	-0.1

Table 2. Perth and Brisbane radiosonde-reanalysis biases for 500-mb, 700-mb and 900-mb levels for relative humidity, total wind and temperature, respectively.

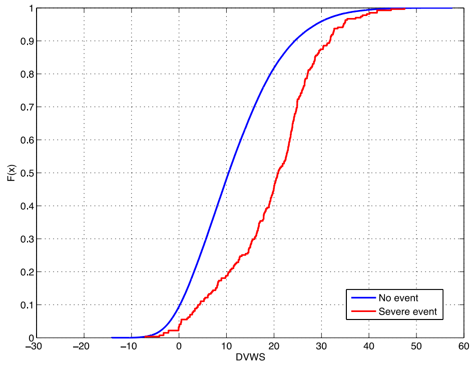
Severe Weather indices

Preliminary work has been carried out looking at the relative performance of a range of severe weather indices to estimate the probability of severe windstorm occurrence. The most common approach for estimating the likelihood of severe storm occurrence based on raw radiosonde data or their pseudo-sounding reanalysis counterparts is to use the joint probability, or a covariate threshold based on a measure of convective available potential energy (CAPE) and a measure of deep layer shear within the atmosphere. This is expected to be a reasonable approach for estimating windstorm likelihood in Brisbane, but is expected to perform poorly, or at the least require differing thresholds when attempting to estimate storm occurrence in Perth.

To exemplify why this is the case, Figure 4 shows a plot of the cumulative distribution functions of non-windstorm event (gust + tornado) and windstorm event environments with respect to deep vertical wind shear (DVWS), for Brisbane and Perth. It is evident that even though the distribution for non-event cases are similar between the two cities, there is a marked difference in the shear required to generate windstorms in the two regions. Given the differing origin of these storms discussed earlier, this is not unexpected, but it does mean that a varied identification or modelling approach will be required to accurately identify environments conducive to storm development in different parts of the country.



(a) Brisbane



(b) Perth

Figure 4. Cumulative distribution functions for windstorm occurrence and non-occurrence in (a) Brisbane and (b) Perth with respect to DVWS.

Conclusions

Different synoptic environments drive severe weather events in Brisbane and Perth. Future work will involve examining what characterizes synoptic environments generating severe weather in other major Australian cities, with a final goal being to characterize severe weather environments across the country.

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