



5th Western Australian State

# COASTAL CONFERENCE 2009

*Whose Coast Is It?  
adapting for the future*

3A:

Climate Change:  
11.45am–12.15pm  
Thursday 8th  
October 2009  
Orion Room

## Analysis of Long-Term Cyclone Track Records for Estimation of Extreme Design Conditions

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### 1. Introduction

The coastline of northern Australia is among the most active cyclone regions in the Southern Hemisphere. The Australian northwest shelf alone receives approximately 10% of the global total of cyclones generated throughout the year. The Australian region for cyclone activity can be defined as the area above  $-24^{\circ}$  latitude, between longitudes of 105 and 160 degrees east (Nicholls, Landesea, and Gill, 1998).

Cyclones create large wind speeds and therefore contribute to extreme wave, current and water level conditions important for the design of ports and maritime structures. While government, federal or state research agencies mostly focus on evaluating the impacts of cyclones on large regional scales, developers and local authorities are often interested to understand the level of risk imposed by extreme climatic conditions on their particular site of interest. Considering the availability of observed or modelled data, it is possible to study the local effects of cyclones and the intensity of cyclone induced winds through statistical analysis of historic cyclone data.

Design wind speeds around Australia can be obtained from Australian Standard HB-212 (2002). In order to provide extreme wind speeds for design purposes, this standard subdivides the Australian coastline and offshore islands into four regions.

This paper is based on three separate studies carried out by GHD on two sites in QLD and one site in WA. Two of the studied sites were located within Region VI and one of the sites was located in Region III, but close to the border of Region II as divided by HB212. The study aimed to provide additional information on the occurrence of extreme cyclone events and the induced wind patterns to complement the information obtained from HB212. Furthermore, while HB212 standard wind speeds are based on analyses of wind speed recordings from various stations around the region, the methodology employed in this study would regenerate a wind sample for each site from the available cyclonic records. This would ensure that the generated sample contained only cyclonic data and was not a combination of two or more different independent distributions.

The studies were conducted for three sites. Site 1 was near Agnes Water and Site 2 near Abbot Point, both

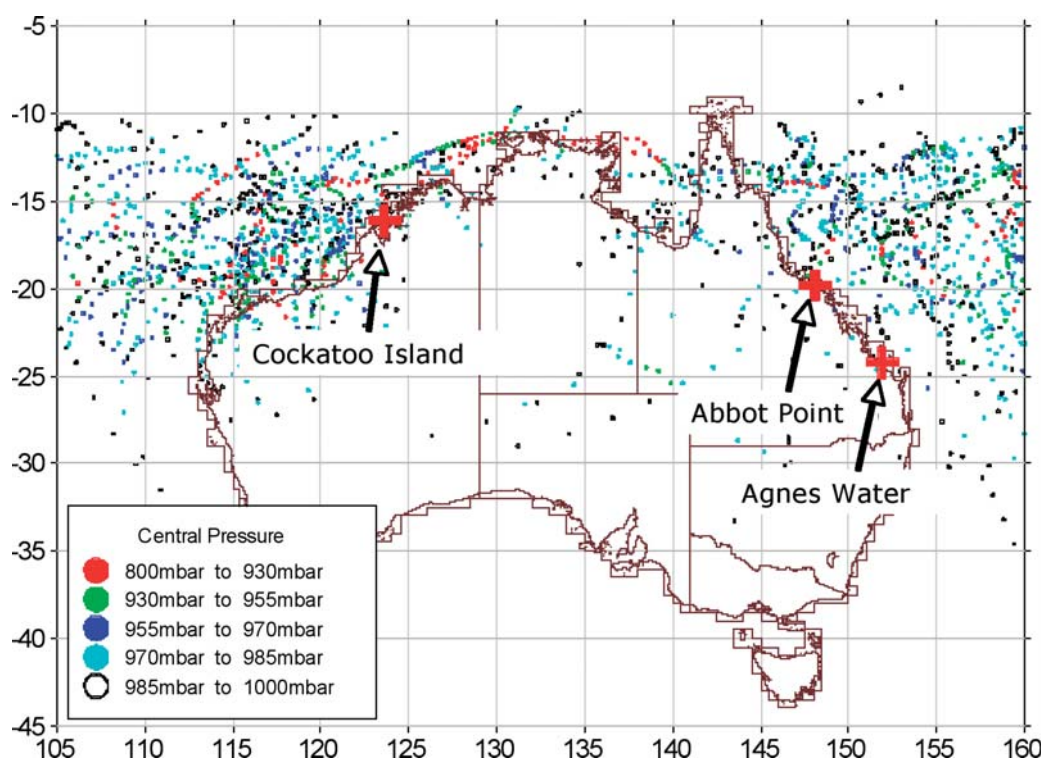
in Queensland. Site 3 was located near Cockatoo Island in the north-west of the Western Australia. The location of the sites is shown in Figure 1.

*In this paper, initially the data employed in the studies are described and a brief description of the empirical wind field model adopted to regenerate cyclone wind speeds is given. Study methodology, including statistical analysis of cyclone tracks and estimation of extreme conditions are presented in the following chapters. Finally, the study results are summarised and the estimated design wind speeds are compared with suggested wind speeds from HB 212.*

## 2. Cyclone Data

Historical cyclone data utilised in the studies was sourced from The Joint Typhoon Warning Center (JTWC) Tropical Cyclone internet database. Tropical cyclone best-tracks contain 6-hourly tropical cyclone wind and position data (Chu, Sampson, Levine, & Fukada, 2002). The positions and cyclone intensities provided in this archive are from post-storm analysis of recorded and observed storm data. The JTWC database consists of records dating back to 1945. Most of the older records lack intensity information and therefore cannot be utilised in statistical analysis of extreme conditions. Available records since 1989 however provide additional parameters including maximum sustained wind speed and/or minimum sea level pressure. Selected cyclone data pertaining to the Australian Region consisted of 5177 six-hour records including tropical storm events. The data is shown on Figure 1.

**Figure 1. Location of the studied sites as well as historic cyclones tracks around Australia for the period between 1989 and 2008. Figure clearly demonstrates the large population of cyclones around Australia.**



## 3. Modelling of Wind Field

Cyclone wind fields can be generally established utilising three different methods. The first method is based on the analysis of recorded cyclone data and weather charts. This method is not practical when analysing a large number of historic cyclone records. The second method is to compute wind fields employing a numerical atmospheric model (Thompson & Cardone, 1996). As the third method and in the simplest form, it is possible to estimate cyclone wind fields based on the gradient between the atmospheric pressure at the centre of a cyclone and the ambient pressure (Holland, 1980).

In this study and to simplify the calculation procedures, all estimations were based on the Bret-X model (Bretschneider, 1990). The model is based on the following mathematical form for the pressure profile:

Equation (1)

$$\frac{P_r - P_0}{P_N - P_0} = \frac{(r/R)^2}{1 + (r/R)^2}$$

Where  $P_r$  is pressure (mbar) at radius  $r$ ,  $P_0$  is the cyclone central pressure and  $P_N$  is the ambient pressure.  $R$  is the radius of maximum cyclostrophic wind speed.

The maximum gradient wind speed ( $V_g$ ) can be estimated from:

Equation (2)

$$V_g = -\left(\frac{1}{2}fR\right) + \sqrt{\left(\frac{1}{2}fR\right)^2 + V_C^2}$$

And Equation (3)

$$V_C = \sqrt{\frac{1}{\rho_{air}} \max\left[\frac{r dp}{dr}\right]} = K_1 \sqrt{P_N - P_0}$$

Where  $f$  is the Coriolis parameter,  $V_C$  is the maximum cyclostrophic wind speed,  $\rho_{air}$  is air density,  $dp/dr$  is pressure gradient and  $K_1$  is a constant equals to 13.26 (when velocity is in knots and pressure is mbar).

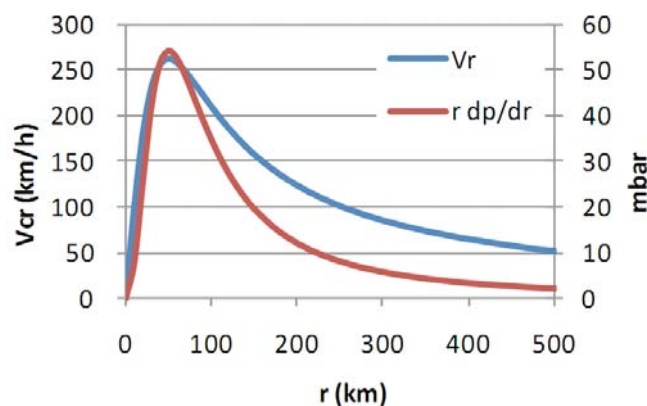
Cyclostrophic wind speeds at the required range of radial distances ( $V_{Cr}$ ) can be estimated from:

Equation (4)

$$V_{Cr} = V_C \sqrt{\frac{2(r/R)}{1 + (r/R)^2}}$$

A sample radial distribution of cyclone velocities for conditions recorded during cyclone Vance (1999) is shown in Figure 2. Vance is one of the strongest recorded cyclones crossing Australia mainland and was reported to create gust wind speeds of more than 280km/hour.

**Figure 2. Radial distribution of cyclostrophic wind speed and pressure gradient variation for Cyclone Vance (1999) with 910mbar central pressure, 50km radius of maximum wind at 12° latitude.**

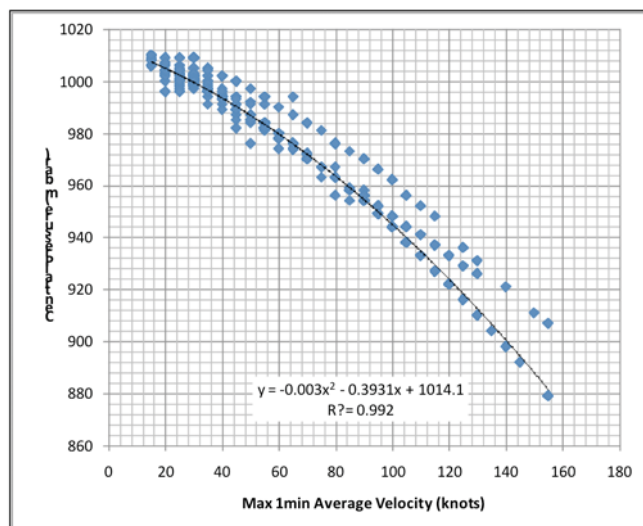


## 4. Generation of Wind Sample

### 4.1 Missing Pressure Data

As many of the records only included the maximum sustained wind speeds, a second order polynomial equation was established between the available central pressure and maximum wind speed data (As shown in Figure 3). The equation was then used to estimate the central pressure where missing. The polynomial form agrees with the general expressions available to estimate maximum wind speed from central pressure.

**Figure 3. A second order polynomial equation was established to estimate missing central pressure data. The polynomial form agrees with the general expressions available to estimate maximum wind speed from central pressure.**



### 4.2 Analysis of Proximities

A computer script was developed to sort the available cyclone events in the order of their distance from the studied sites. Each best-track cyclone record describes a 6 hour event. It can be reasonably assumed that the number of 6 hour events directly corresponds to the number of extreme wind conditions (with the same 6 hour duration) experienced at that site.

In order to provide a better understanding of cyclone probability for each site, intensity and geographical frequency distribution of the cyclone records were established. The results are shown in Table 1, Table 2 and Table 3. It is important to note that these tables show the number of 6 hour events and not the number of cyclones.

### 4.3 Estimating Wind Velocity at Sites

Based on the Bret-X model and for each 6-hour cyclone record, wind velocity expected at the site (at the distance between the site and the cyclone centre) was estimated. The search radius was limited to 600 km, beyond which, wind speeds impacting the area of interest should drop to relatively small values.

For all estimations, a radius of maximum wind speed of 50 km and forward speed of 20 km/h were assumed. Both numbers are the approximate average values based on a study carried out on a large number of cyclones from Atlantic Ocean (Walsh & Wright, 2005). Air density was assumed to be constant and the ambient pressure was assumed to be 1013mbar, approximately equal to annual mean sea level pressure in the northern regions of Australia.

**Table 1. Cyclone data distribution for Site 1, Agnes Water (1989 to 2008)**

Proximity (km)	Cyclone Category						Total
	TS	1	2	3	4	5	
600	52	27	10	2	1		92
400	27	10	3	1			41
200	4	2	1				7
100	1						1
50							
<b>Total</b>	<b>84</b>	<b>39</b>	<b>14</b>	<b>3</b>	<b>1</b>		<b>141</b>

**Table 2. Cyclone data distribution for Site 2, Abbot Point (1989 to 2008)**

Proximity (km)	Cyclone Category						Total
	TS	1	2	3	4	5	
600	124	45	33	16	15	3	236
400	78	21	11	7	4	2	123
200	13	4	2	1	1		21
100	1	2	2		1		6
50		1					1
<b>Total</b>	<b>216</b>	<b>73</b>	<b>48</b>	<b>24</b>	<b>21</b>	<b>5</b>	<b>387</b>

**Table 3. Cyclone data distribution for Site 3, Cockatoo Island (1989 to 2008)**

Proximity (km)	Cyclone Category						Total
	TS	1	2	3	4	5	
400	240	44	46	21	33	14	398
300	168	31	41	19	18	8	285
200	34	4			2	1	41
100	9	1					10
50	2						2
<b>Total</b>	<b>453</b>	<b>80</b>	<b>87</b>	<b>40</b>	<b>53</b>	<b>23</b>	<b>736</b>

The velocities were then converted into 10min average wind speed at 10m (V<sub>10</sub>) using the equation provided by (Bretschneider, 1990) for the Western Pacific Ocean:

$$\text{Equation (5)} \quad V_{10} = 0.82 U_{RV}$$

Where  $U_{RV}$  is the radial gradient velocity corrected for the forward motion speed of the cyclone.

The frequency distribution of various wind speed bins was then established for each site, which provided the number of recorded wind speed events for that site. The results, as shown in Table 4, were later utilised in the extreme analysis exercise to predict long-term extreme wind speeds.

## 5. Extreme Analysis

Generated wind speed frequency data was utilised to estimate extreme wind speeds for the sites. Data was reduced based on the Peak Over Threshold method (POT). Fisher and Tippet II (FT-II) distribution was employed to fit the generated wind speed samples. FT-II is the same probability distribution form adopted in HB212 (Holmes & Weller, 2002).

Extreme wind speeds estimated for the three studied sites are listed in Table 5. The 10min average wind speeds are converted to 3s gust speeds based on the equation described in CEM (2002). Estimated extreme wind speeds for the three sites are plotted in Figure 4.

**Table 4. Frequency distribution of cyclonic wind speed at all three sites based on statistical analysis of historic cyclone records (1989–2008)**

V10 (km/hour)	Site 1	Site 2	Site 3
<30 or (blank)	104	249	432
30–40	23	76	150
40–50	5	32	76
50–60	5	11	40
60–70	2	7	17
70–80	2	2	12
80–90		4	5
90–100		2	2
110–120		1	1
120–130		2	1
>130		1	
<b>Grand Total</b>	<b>141</b>	<b>387</b>	<b>736</b>

**Table 5. Extreme 3S gust wind speeds (m/s)**

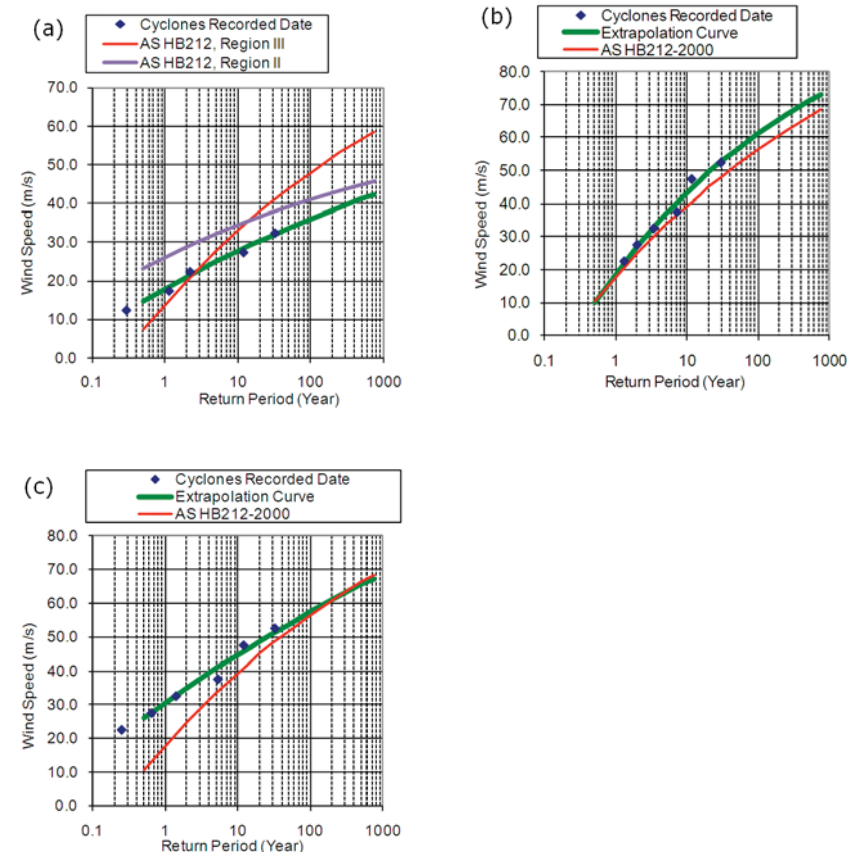
Return Period (Years)	Site 1	Site 2	Site 3
5	25	37	41
10	28	43	45
15	29	47	47
20	30	49	49
30	32	53	51
50	34	57	54
100	36	61	57
250	39	67	62
500	41	71	65

## 6. Conclusion and Discussion

In Site 1, the results underestimated the wind speed for larger return periods. This could be due to contribution of other extreme weather conditions not included in this study. In site 2, the results closely matched winds speeds from HB212 Region IV and in Site 3, results showed similar extreme conditions for the larger return periods, while overestimating the lower return periods.

While inconsistencies were found in the results, some patterns can be linked to the frequency distributions shown in Table 4. Firstly, the extreme wind speeds for large return periods are -higher in Site 2 than Site 3. Reviewing the frequency distribution of the cyclone records, it is noticed that there are a greater number of events reported for Site 3. It is clear, however, that individual large wind speed events were more frequently recorded around Site 2. Cyclone data also reveals that, while a larger number of cyclones were recorded in the vicinity of Site 3, closer proximities were experienced in Site 2, resulting in larger wind speeds. The, larger number of cyclones around Site 3 resulted in frequent wind speeds of about 60 to 80 km/hour, thus larger extreme conditions are experienced for lower return periods.

**Figure 4. Comparison of the study results with HB212. (a) the results for site 1, the results underestimated the wind speed; (b) in site 2, the results closely matched winds speeds from HB212; (c) while results were producing similar extreme conditions for larger return period, the lower return periods were higher.**



Overall, considering the difference in approaches employed in this study and in preparation of extreme wind speeds using HB212, it can be stated that the difference in the final results is not significant. Not to be forgotten, some of the differences may also be attributed to the inherent inaccuracies of the methods employed in this study. These include selection of the wind model, conversion between sustained winds and surface wind as well as parameters assumed in the estimations.

## 7. Further Studies

Considering the availability of data and faster computer systems, it would be beneficial to perform a similar study for a gridded area across Australian active cyclonic region and generate contour plots of extreme winds for various return periods.

## 8. References

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