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Tropical cyclone impacts on the Western Australian coast

John Holmes[1]
[1]JDH Consulting, PO Box 269, Mentone VIC, 3194; john.holmes@jdhconsult.com

ABSTRACT

This paper reviews the numbers of tropical cyclones in the southern Indian Ocean, and the land-falling cyclones that have impacted the Pilbara and Gascoyne coastlines of Western Australia in the last 50 years, with particular emphasis on those of Category 4 strength and above since 1970. It shows reductions in impacts of severe cyclones on that coastline in the two most recent decades. However, there have been a significant number of land-falling severe storms north of 20°S, suggesting an extension of the northern boundary of Region D in AS/NZS 1170.2 is warranted.

1. Introduction

The Pilbara coastline of northwestern Western Australia (WA) is known to be affected by the most frequent and strongest tropical cyclones in the Australian region. A 50-kilometre wide strip between 20° S (just north of Port Hedland) and 25° S (just south of Carnarvon) has been designated as 'Region D' in the Australian/New Zealand Standard for wind actions, AS/NZS 1170.2 (Standards Australia, 2011). This Region incorporates the northern part of the Gascoyne coast, as well as the Pilbara coast. The design wind speeds for buildings and other structures in this Region are the highest in Australia, and are higher than any other parts of northern Australia.

Although the permanent population density in Region D is low, the economic significance is very high, with liquid natural gas (LNG) plants at the Burrup Peninsula near Karratha, at Onslow, and on Barrow Island. Iron ore is exported from Port Hedland and Cape Preston, and there is a nascent eco-tourism industry on the Ningaloo Reef, near Exmouth.

2. Exposure of the WA coastline to tropical cyclones

The website of the Bureau of Meteorology (BoM) enables 'filtering' of tracks to those that occurred within defined dates, and within distances of 50 to 500 kilometres of a location in a list, (http://www.bom.gov.au/cyclone/history/tracks/index.shtml). Figure 1 shows the tracks of all 133 tropical cyclones that had some part of their tracks within a radius of 500 kilometres from Port Hedland, in the forty-nine-year period from seasons 1969/70 to 2017/18. These tracks include the vast majority of those that impacted the coastline of Western Australia during that period. Many of the storms shown did not cross the coastline, and all strength categories of storms are included. Generally the storms track from north-east to the south-west in the latitudes from 10 to 22°S. If they continue over the ocean beyond 22°S, they tend to recurve to a more southerly track.

Figure 1, being limited to storms with tracks within a radius of 500 kilometres of Port Hedland, and to the period up to 2018, does not include all storms that made landfall on the WA coast during the 1970-2000 period. However, another BoM web page allows access to reports of all significant tropical cyclones that occurred in the Australian Region during the fifty-year period:

http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/history/past-tropical-cyclones/

Other useful sources are the websites: 'severeweatheraustralia.com' and 'wikipedia.org'.

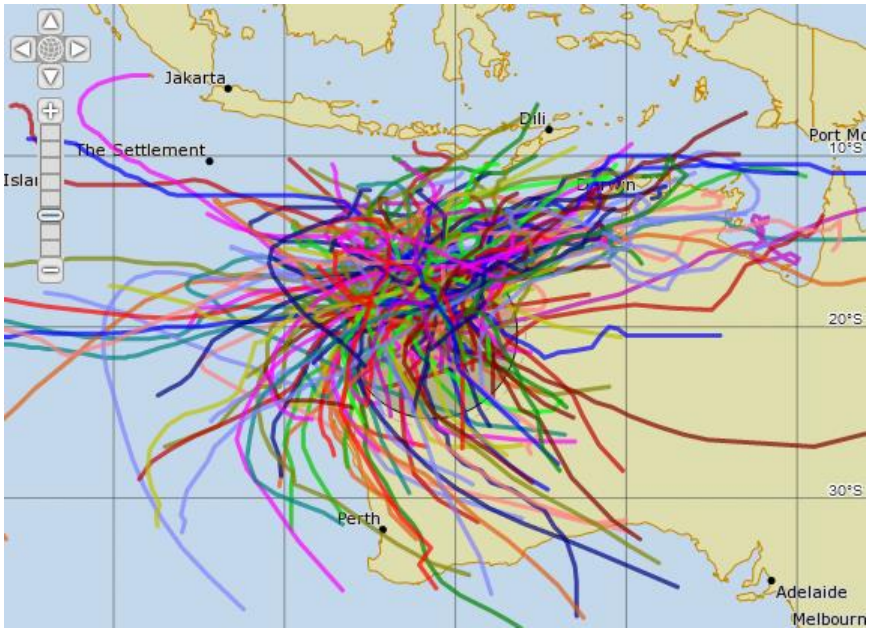

Figure 1. Cyclones with tracks within 500km from Port Hedland, 1969-2018

A rigorous search, using the above sources, identified a total of 104 tropical cyclones that made landfall somewhere along the coastline of WA during the fifty summer seasons from 1970 to 2020. Of those, 28 had estimated central pressures of 950hPa or less, and can be classified as damaging events. 82 storms produced recorded gusts greater than 20 m/s at one or more of the BoM anemometer stations within Region D. 53 cyclones of all categories made landfall on the coastline of Region D, about half the total that impacted all parts of the coastline of WA during that period. 15 damaging cyclones (central pressure $\leq$ 950 hPa) impacted on the Region D coastline during 1970-2020, with the remaining 13 making landfall in Region C. Further statistics on these events are discussed in the following sections.

3. Land-falling statistics

3.1 Impacts by latitude

Figure 2 shows the number of storms impacting the entire coast of WA with a central pressure of 950 hPa or less, over the last fifty years, with the latitude at landfall shown. The wind regions, as defined in AS/NZS 1170.2 are also shown.

Of the 28 impacts shown in Figure 2, 13 cyclones made landfall in Region C. Of those, 6 were estimated by the BoM to have had a central pressure of 930hPa or less at landfall, and all except one impacted at latitudes less than 20°S. In fact, the strip between 19° and 20°, currently in Region C, has experienced more impacts than all the 1° intervals between 21° and 25°, which are currently in Region D. This suggests that consideration should be given to extending the boundary of Region D further north by 1 to 2°, and that the more southerly Gascoyne coast (23°S to 25°S) should be re-designated as Region C.

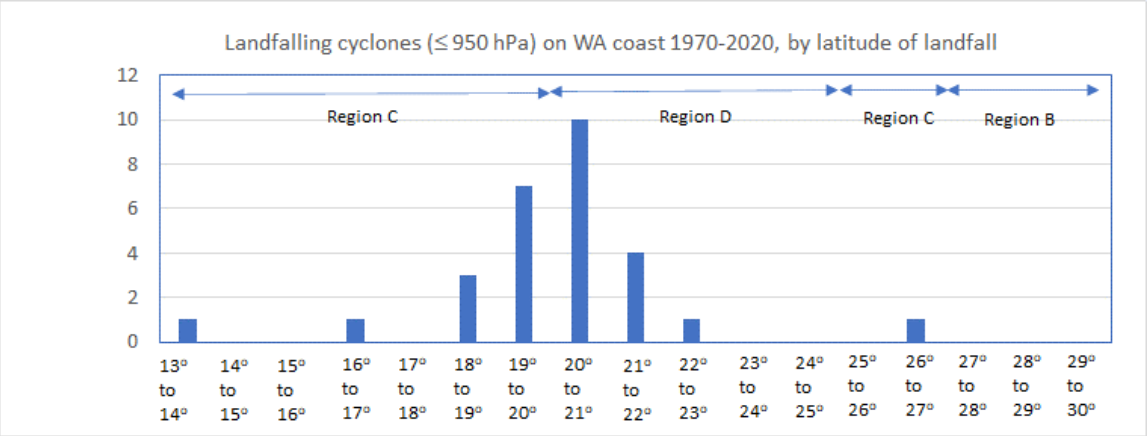

Figure 2. Land-falling severe cyclones on the entire WA coastline, 1970-2020

Table 1 lists the severe cyclones that made landfall on the coastline of Region D since season 1970-1. It shows that the Pardoo to Onslow strip of coastline (20.0°S – 21.5° S) has experienced nearly all the impacts of very severe cyclones on Region D in that period. Of the list in Table 1, 'Vance', 'George', 'Olwyn', and 'Damien' resulted in structural damage that were subjects of technical reports by the Cyclone Testing Station of James Cook University (Reardon *et al*., 1999; Boughton and Falck, 2007; Boughton *et al*., 2015; Boughton and Falck, 2020)

Table 1. Strongest cyclones impacting Region D since 1970-71

Name	**Date**	**central pressure at landfall (hPa)**	**Location**	**Latitude (° S)**
George	March 2007	902	east of Port Hedland	20.1
Orson	April 1989	911	Cape Preston	21.0
Joan	December 1975	915	west of Port Hedland	20.4
Sheila	February 1971	925	Roebourne	20.5
Trixie	February 1975	925	Mardie	21.2
Olivia	April 1996	925	Mardie	21.1
Vance	March 1999	925	Exmouth	22.4
Dean	February 1980	930	Port Hedland	20.2
Kirsty	March 1996	935	Pardoo	20.1
Lua	March 2012	935	Pardoo	20.0
Bobby	February 1995	940	Onslow	21.5
John	December 1999	940	Whim Creek	20.7
Jane	January 1983	947	Pardoo	20.1
Christine	December 2013	948	Roebourne	20.7
Connie	January 1987	950	Port Hedland	20.3
Olwyn	March 2015	955	Exmouth - Carnarvon	*
Damien	February 2020	955	Karratha	20.9

* 'Olwyn' travelled along the Gascoyne coast, finally making landfall at Shark Bay (26.4°)

Table 2 shows the most severe cyclones that made landfall on Region C in Western Australia. As shown in Figure 1, and Table 2, there have been many impacts on the coastline between 19°S – 20° S, a strip that is presently in Region C. This stretch of the Pilbara (the 'Eighty Mile Beach') is relatively unpopulated, but it is the proposed site of a A$47 billion Asian Renewable Energy Hub (AREH) with 26,000 MW of solar panels and wind turbines: https://asianrehub.com/

On the other hand, only one severe tropical cyclone ('Olwyn') affected the north-south orientated Gascoyne coast and the town of Carnarvon during 1970-2020; three much weaker storms: Beryl (1973 – 1002hP at landfall), Alistair (2001 – 998hPa) and Nicholas (2008 – 980hPa) made landfall on the Gascoyne coast in that period doing little damage.

Table 2. Strongest cyclones impacting Region C of WA since 1970-71

Name	Date	central pressure at landfall (hPa)	Location	Latitude (° S)
Amy	January 1980	911	west of Wallal Downs	19.9
Chris	February 2002	915	west of Wallal Downs	19.9
Laurence	December 2009	929	Mandora	19.4
Enid	February 1980	930	Wallal Downs	19.8
Annette	December 1994	930	Mandora	19.7
Rosita	April 2000	930	Broome	18.3
Sam	December 2000	935	Nita Downs	18.8
Fay	March 2004	935	Wallal Downs	19.8
Hazel	March 1979	936	Denham (Shark Bay)	26.1
Elsie	February 1987	940	Mandora	19.6
Ingrid	March 2005	940	Cape Londonderry	13.9
Chloe	April 1995	945	Kimberley coast	16.4
Sally	December 1971	950	Broome	18.3

3.1 Impacts by decade

The number of impacting storms with central pressures at landfall less than 950hPa and 930 hPa respectively are shown in Figures 3 and 4 on a decadal basis.

There is no clear overall trend with time up to 2010 in Figure 3, but there have been fewer severe cyclones impacting Region D since 2000, and none with a central pressure ≤ 930hPa since Cyclone 'George' in 2007. The latter trend may be associated with the Indian Ocean Dipole (IOD), which has had more periods of positive values since 2000, resulting in cooler waters off Western Australia. However, longer-term climate change effects cannot be discounted.

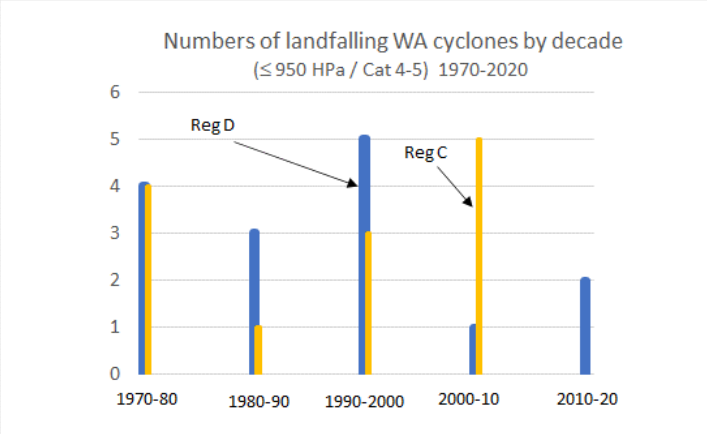

Figure 3. Trends by decade in severe land-falling tropical cyclones (≤ 950hPa)

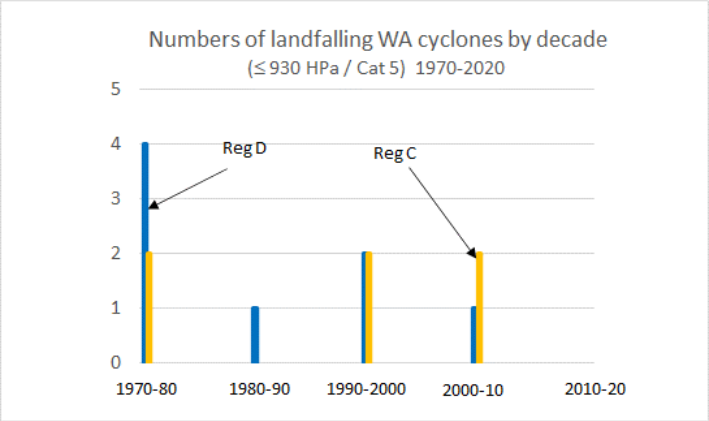

Figure 4. Trends by decade in severe land-falling tropical cyclones (≤ 930hPa) (none occurred in 2010-20)

4. Expected impacts assuming a Poisson distribution

The appropriate probability distribution for a variable that can only take integer values, such as the number of very severe tropical cyclones impacting 1000 kilometres of Region D coastline per decade, is the Poisson Distribution, for which the probability mass function can be written:

$$p_X(x) = \lambda^x . \frac{exp(-\lambda)}{x!} \quad (1)$$

where x is the number of events, and λ is the average number (not necessarily an integer value).

The use of a Poisson distribution assumes that the numbers of landfalling cyclones in successive decades are statistically independent events. This is a reasonable assumption for decadal numbers, noting that Callaghan and Power (2011) found that even "interannual variability in landfall frequency is well simulated as a Poisson process".

The previous section indicates that the average rate of impacts per decade on the Region D coastline, by tropical cyclones with central pressures of 930hPa or less, over the last fifty years is 1.6. Then taking λ as 1.6, Equation (1) can be used to determine the probability of getting x Category 4 impacts per decade, with x equal to 0, 1, 2, 3, 4 etc. These calculations are tabulated in Table 3.

Table 3. Calculations from Eq. (1) with λ = 1.6

x	$p_X(x)$
0	0.202
1	0.323
2	0.258
3	0.138
4	0.055
5	0.018

From Table 3, the probability of no tropical cyclones, with central pressure of 930hPa or less, impacting the Region D coast in a decade (as has occurred in the decade 2010-2020), when the average rate, λ, is 1.6, is 0.202 – i.e. there is a 20% chance of that occurring, a fairly high probability. The chance of a decade having four such events in a decade, as occurred in 1970-1980, is 5.5%, also a reasonably high value.

Of course the Poisson model as outlined above, assumes a stationary climate – i.e. without long-term trends such as those that might be occuring due to global warming. However, as discussed in the

previous section, there are no clear multi-decadal trends at present for increasing numbers of severe tropical cyclones impacting the WA coastline, as have occurred, or are predicted to occur in other parts of the world (e.g. Holland and Bruyere, 2014; Knutson *et al*., 2020; Holmes, 2020).

4. Conclusions

- The current boundaries of Region D in AS/NZS 1170.2 should be reviewed based on the locations of impacts along the coastline of severe damaging cyclones.
- Carnarvon and the Gascoyne coast should be located in Region C, not Region D.
- Based on the number of observed impacts of severe storms north of 20°S, consideration should be given to extending the northern boundary of Region D to the north by 1 or 2 degrees.
- There have been fewer land-falling severe storms in the most recent two decades but it is too early to attribute this to long-term climate change.

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