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What is the return period of Cyclone Tracy's gust wind speed in Darwin?

Michael Drayton[1]

[1]*Risk Management Solutions Inc., Kaikohe, 0472, New Zealand. michael.drayton@rms.com*

ABSTRACT

Cyclone Tracy's 0.2s gust wind of 60m/s at Darwin airport is by far the highest gust recorded at that location since the instrumented record began in 1959 and is a clear outlier in any extreme value analysis.

Tropical cyclones often pass within a few hundred kilometres of Darwin. We show that extreme value analyses of cyclone winds are sensitive to how daily maximum gusts are attributed to tropical cyclones or other convective activity. Most tropical cyclones affecting Darwin travel from the Northeast to the Southwest. Tracy's direct landfall track was unique in the period of the instrumented wind record. Other similar tracks are recorded earlier in the BoM track database and Murphy (1984). We show how an extreme value analysis can be supplemented by these earlier events and conversely, we show how long return period modelled gusts are sensitive to direct landfall events.

We conclude it is the rare, strong, direct landfall events that dominate return periods critical for design and insurance risk management.

1. Introduction

The images of the destruction in Darwin from Cyclone Tracy are unforgettable. Tracy is regarded as some sort of worst case event. In fact, the highest gust measured by the BoM anemometer at Darwin airport was only 60m/s so it was the quality of building construction in 1974 which led to the devastation on which Tracy's infamy is based. Building codes have of course been overhauled and revised many times since the 1970s and today construction practices in Darwin and the public's awareness of cyclone hazard bear no resemblance to the pre-Tracy era. Nevertheless, Tracy comes up as the benchmark in any risk assessment both from the deterministic view point, i.e. "what would happen in a repeat of Tracy tomorrow?" and the probabilistic, "what is the return period of Cyclone Tracy's gust wind speed in Darwin?". We ask these questions to validate our stochastic tropical cyclone model.

2. Observed wind data

The BoM anemometer at Darwin airport recorded a maximum gust of 60m/s just as the eyewall approached (BoM 1977). The Dines anemograph in use at the time is assumed to have an averaging time of 0.2 seconds.

The Bureau's regular recording of daily maximum wind gusts observations at Darwin (station 14015) began in April 1959 and has continued to the present, with a gap in 1975 during the post-Tracy recovery. The station's metadata describe when instruments were installed and removed although it is ambiguous and multiple instruments may have operated at the same time. For the purposes of this study it is assumed a Dines instrument was in use until 1990 and a Synchrotac anemometer from 1991. A single factor of 1.14 is used to convert between the 3-sec Synchrotac and 0.2-sec Dines observations. This factor is in line with Holmes & Ginger (2012) but does not vary with wind speed as in their table 4. No adjustments are made to the observed winds to standardize terrain conditions. This is consistent with the model output discussed in §5 which includes upwind terrain.

3. Identifying Tropical Cyclone Days for Extreme Value Analyses

Gusts from tropical cyclones must first be separated from the record of all daily maximum gusts before extreme value analyses can be performed. Harper & Mason (2016) and Butler (2015) filtered the maximum gust data by days when a tropical cyclone passed within 300km of the Darwin anemometer (figure 1). Storm size information is not available for all storms in the BoM tropical cyclone track database so it is necessary to use a fixed distance. Butler (2015) notes 300km, coupled with a 17ms^{-1} threshold should exclude low winds not associated with cyclones from being included in the analysis data set. We argue here 300km is too large to separate tropical cyclones from Darwin's high frequency thunderstorms.

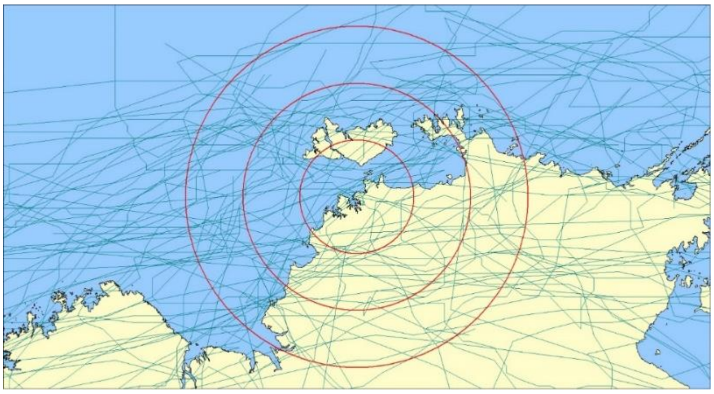

Figure 1. BoM historical cyclone tracks since 1959 over buffers of 100km, 200km and 300km radius around Darwin airport.

Figure 2 shows the raw BoM daily maximum gusts colour coded by whether or not they occur on a day when a tropical cyclone lies within each buffer.

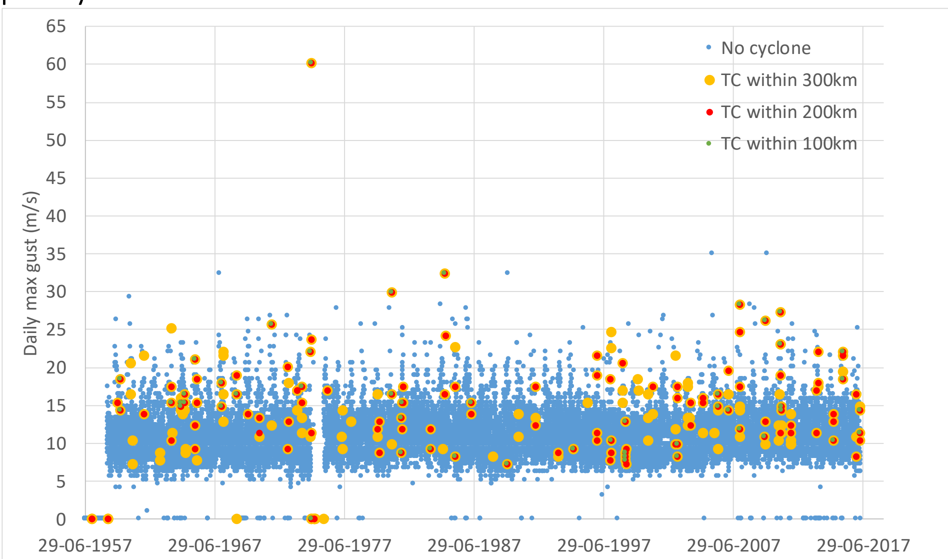

Figure 2. BoM raw daily maximum gust at Darwin.

Cyclone Tracy's gust wind is by far the highest gust in the record. The blue dots are days without a cyclone within 300km. It can be seen many very high winds occur on days without tropical cyclones, highlighting Darwin's mixed wind climate. The other colours show days with storms within 100, 200 or 300km. It can be seen the storm identification is sensitive to the buffer size. Further, closer inspection of some storms which passed close to Darwin showed the maximum gusts at Darwin occurred when the tracks were at the edges of the buffer and not at their closest approach.

While it may be argued a convective downburst some distance from a tropical cyclone is related to, or even caused by the cyclone, the wind field models used by most stochastic risk models involve simple single or double vortex models building on the early work of Holland (1980) to represent the circulation of the storm. Such models cannot capture localized convective activity at distances of ten or more times the radius of maximum winds from the storm centre. It therefore seems inappropriate to use such a large distance threshold for Darwin.

Annual maximum gusts using different buffer sizes are plotted in figure 3. As the buffer size decreases, the slope of the wind speed return period curve steepens at return periods shorter than 10 years.

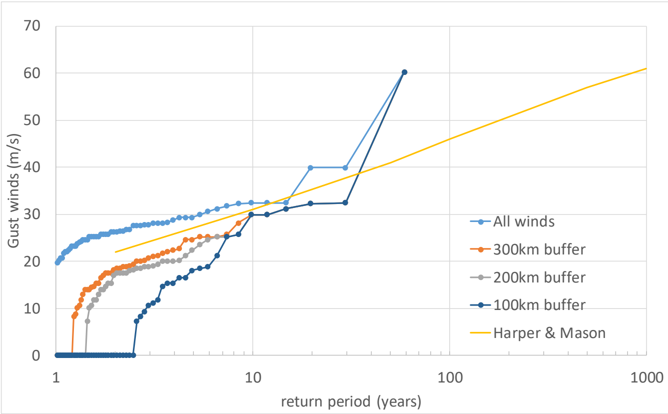

Figure 3 Darwin observed 0.2s gust return periods. The yellow curve is taken manually from Harper & Mason (2016)

4. Cyclone Track Climatology

Most tropical cyclones near Darwin travel in a broadly Northeast to Southwest direction. Many are inland from Darwin having made landfall further north in Arnhem Land and many are offshore running parallel to the coast. Cyclone Tracy's track was unusual in that it turned towards the Southeast and made landfall directly on Darwin.

Figure 4 shows the full record of BoM historical tracks passing within 100km of Darwin. Three other tracks make landfall in a similar direction to Tracy: 1915, 1937 and 1954, all before regular wind observations began. Murphy (1984) has descriptions of these events and a similar event in 1897. They stand out for their damage in Darwin. Murphy cites a wind observation of 158 km/h and pressure of 982hPa in Darwin for 1937. A lower pressure (960hPa) was recorded in 1897 but no wind estimate is available. The 1937 gust is therefore either the second or third highest gust from a tropical cyclone since 1897 and possibly since 1827, the earliest entry in Murphy's record. Using this information we can tentatively extend the historical wind speed return period plot.

Figure 5 shows the post-1959 historical observations supplemented with the 1937 gust as the second highest and Tracy's gust as the highest in 120 years. We have assumed the unknown gusts for 1897 and 1915 are both higher than the rest of the instrumented record and fall in the gap in the plot. Tracy remains a clear outlier.

Figure 4. BoM historical tracks passing within 100km of Darwin with 1915, 1937, 1954 and Tracy in black

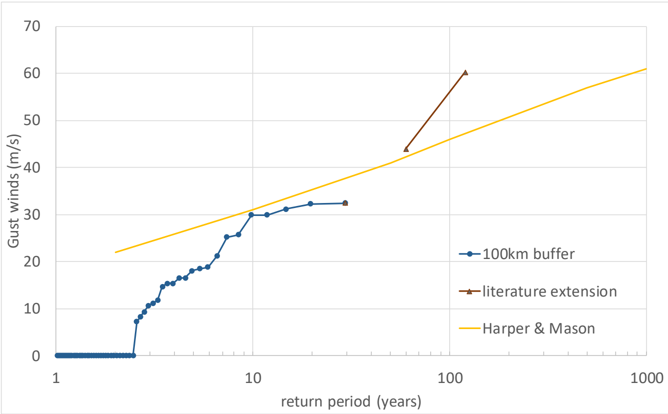

Figure 5. Darwin 0.2s gust return periods supplemented by data from Murphy (1984)

5. Stochastic Model

RMS has developed a stochastic model of tropical cyclones for Australia to allow insurers to assess their risk to wind losses. A full description of the model is outside the scope of this paper although a brief overview is available online at
http://forms2.rms.com/rs/729-DJX-565/images/RMS_Australia_CycloneModel_DatasheetFinal.pdf

The model consists of tens of thousands of synthetic tracks and their associated wind fields. The tracks are generated using a random walk process similar to that of Hall & Jewson (2007). Landfall intensity distributions are specified based on analyses of historical pressure data. For the Northern Territory, the historical record is considered complete from 1960 although only landfalling pressures from 1980 are used to specify the landfall intensities of storms along the coast from Northern Arnhem Land to the Northern Kimberly. The most extreme landfall pressure is derived via maximum potential intensity considerations, e.g. Holland (1997). Storms fill over land and may reintensify if they cross back out to sea.

Gust wind speeds are computed along the life of each track. For each point of interest, terrain is considered in eight upwind directions and the maximum 3-second gust wind speed is stored for each event.

For insured loss calculations the winds are converted to repair costs through vulnerability functions and then the financial consequences for building owners, insurers and reinsurers can be quantified.

In this paper we stop with the wind hazard and concentrate on the model output for Darwin. Wind speed return periods can be computed from the peak gusts from each event, see figure 6.

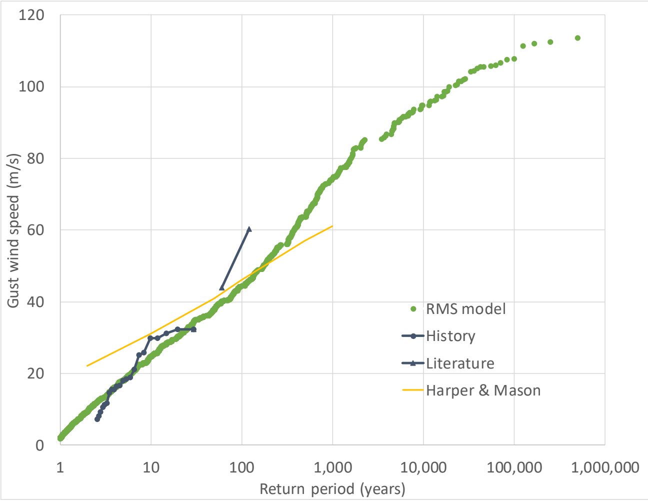

Figure 6. Darwin airport 0.2-second gust wind speed return periods from history, i.e. 100km buffer on BoM observations supplemented by Murphy (1984), and the RMS stochastic model. The yellow curve is taken manually from Harper & Mason (2016).

The RMS modelled gust wind-speed return period curve lines up very well against cyclone day observations filtered by a 100-km radius. The shape of the model curve is far from linear. It appears linear up to beyond 100 years and then increases faster before starting to plateau off at extremely long return periods.

Manual inspection revealed that most, but not all, of the highest gust winds, at the longest return periods, come from intense synthetic events making direct landfall on the coastal gates close to Darwin. To demonstrate the sensitivity of the modelled results we removed all modelled storms making landfall on the gate closest to Darwin and regenerated the curve with the remaining storms. Figure 7 shows how the upward bend in the gust return period plot beyond approximately 100 years becomes far less pronounced when these storms are removed.

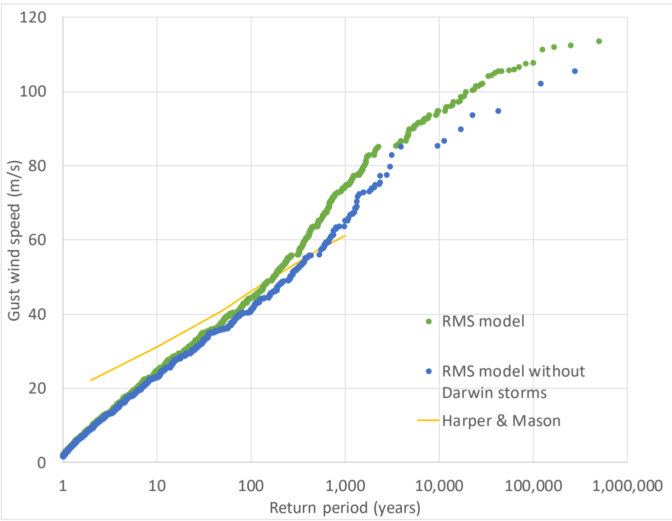

Figure 7. RMS modelled 0.2-second gust winds at Darwin airport with and without direct landfalls within approx. 50km of Darwin.

Direct landfalls close to Darwin are not common, most storms affecting Darwin make landfall elsewhere or remain offshore. Further, most storms making direct landfall are not particularly intense so the short return period end of the curve is not sensitive to storms with tracks like that of

CY Tracy. At long return periods it is the very rare combination of a very strong storm with a track like Tracy that produces very high winds at Darwin. The curve must plateau off at the physical limit of the strongest possible storm (considerably stronger than Tracy) on a track that takes its eyewall over the anemometer location. Cook & Nicholls (2009) put forward a similar physical argument even if their quantitative output was strongly criticised by Harper et al. (2012)

Based on the RMS stochastic model output, CY Tracy's 0.2 sec gust of 60m/s has a return period of approximately 600 years, slightly shorter than the approximately 1000 years inferred by Harper & Mason (2016) and Butler (2015).

6. Conclusions

Estimates of long return period gust wind speeds, for design or risk management purposes, are unavoidably uncertain when based on a limited historical record. Extrapolation from a purely statistical extreme value analysis requires assumptions about the distribution to use and is sensitive to how the observations are separated by phenomenon in a mixed wind climate.

Cyclone Tracy is the only cyclone in the record of instrumented wind observations to make a direct landfall close to Darwin. As an outlier it is hard to use.

The RMS stochastic model is well calibrated against the observed record in Darwin and its extrapolation beyond the observed record, to return periods of interest for design and risk management purposes, makes physical sense. We therefore recommend stochastic models of tropical cyclones continue to at least guide estimation of long return period winds in the cyclone-affected parts of Australia.

RMS estimates the return period of Cyclone Tracy's gust wind in Darwin to be 600 years.

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