

FREQUENCIES OF TROPICAL CYCLONES IN THE NORTHEASTERN AUSTRALIAN AREA

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ABSTRACT

A statistical analysis is presented of the frequencies of tropical cyclones in north-eastern Australia. The long-term trends are estimated and the pattern of the times of occurrences of cyclones within each season is investigated.

INTRODUCTION

The tropical cyclone is a significant synoptic component of the summer rainy season over northern Australia. It is an important seasonal determinant; the first occurrence often marks the 'break' of the season. The abundant rainfall received along the path of the storm is of enormous economic benefit to the dry inland areas of the tropics.

In the Australian area, a low pressure system having closed isobars is classed as a tropical cyclone when wind speeds reach or exceed gale force (34 kn). The season in which the cyclones occur extends from about November to April. Broadly speaking, the occurrences are associated with two distinct systems: one off the northwest coast of the continent (Timor Sea and Indian Ocean) and the other off the northeast coast (Gulf of Carpentaria and Coral Sea).

The purpose of this paper is to present a statistical analysis of the number of occurrences per season of tropical cyclones in the eastern system.

DATA

The source of the data is Coleman (1972). This book includes maps of the tracks of all tropical cyclones recorded in the Australian area during the period from November 1909 to June 1969. The boundaries of the study area are fairly well defined by the pattern of occurrences. Tropical cyclones rarely begin north of about 10°S , below 25°S or east of New Caledonia, around 165°E . The western boundary is more arbitrary but examination of the tracks suggests the choice of 135°E . The Gulf of Carpentaria is included in this eastern system because cyclone activity there and in the Coral Sea is closely related. The usual direction of movement of the storms in this system is a curve westwards, southwards and finally southeastwards. The study area and some representative cyclone tracks are shown in Fig 1.

Over the warm tropical seas, air converges into depressions and acquires large amounts of sensible and latent heat. Large-scale divergence is a prevalent feature of the flow patterns in the middle and upper levels of the atmosphere. When the cyclones cross land areas they experience reduced energy input, lose intensity, change

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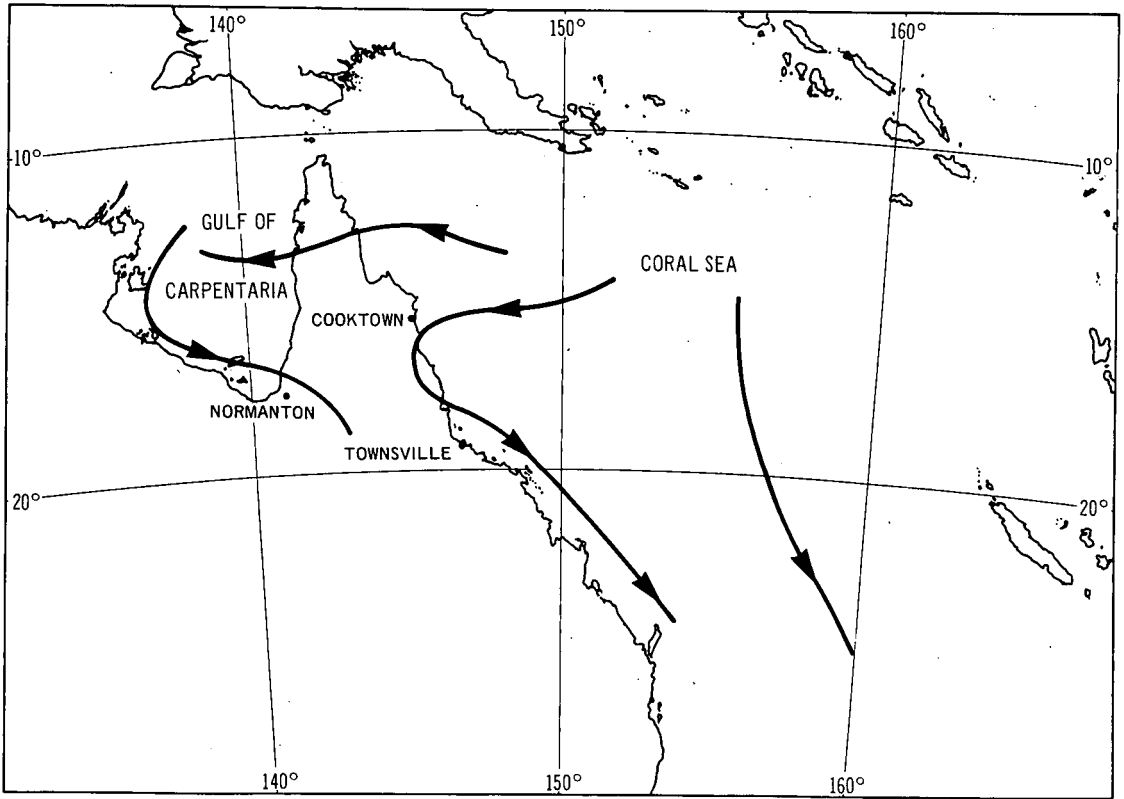


Fig 1 Map of northeastern Australia showing typical cyclone tracks.

in structure and revert to tropical depressions. Quite often cyclones that have spawned in the Coral Sea cross the Cape York Peninsula and move into the Gulf of Carpentaria. When they reach the water surface again, they may regenerate into tropical cyclones and continue in that form until crossing the coastline once more. Occasionally, cyclones which begin in the Gulf cross the Pacific coast and regenerate.

Coleman plotted the track of each cyclone as a curve joining the points marking the position of the centre at 2300 GMT. Dates are given for the beginning and end of each track. In the study area, no cyclones have been recorded to have begun before about the end of November or after the end of April. The 22 week period up to 30 April is taken to define the cyclone season for the purpose of this analysis. Each season is identified by the year in which it concludes: for example, the period from November 1960 to April 1961 is the 1961 cyclone season. From the information given by Coleman, the week of commencement of each cyclone was extracted. These data are depicted in Fig 2. Figure 3 shows more clearly the numbers of cyclones in each season. A total of 216 tropical cyclones was recorded in the eastern system during the study period.

RELIABILITY OF THE DATA

There are several possible sources of error in the data which must be considered. Inevitably there is uncertainty about the accuracy of the information from which the tracks were plotted. Also the homogeneity of the data may be questioned. The present criterion of defining a disturbance to be a tropical cyclone if it has gale force

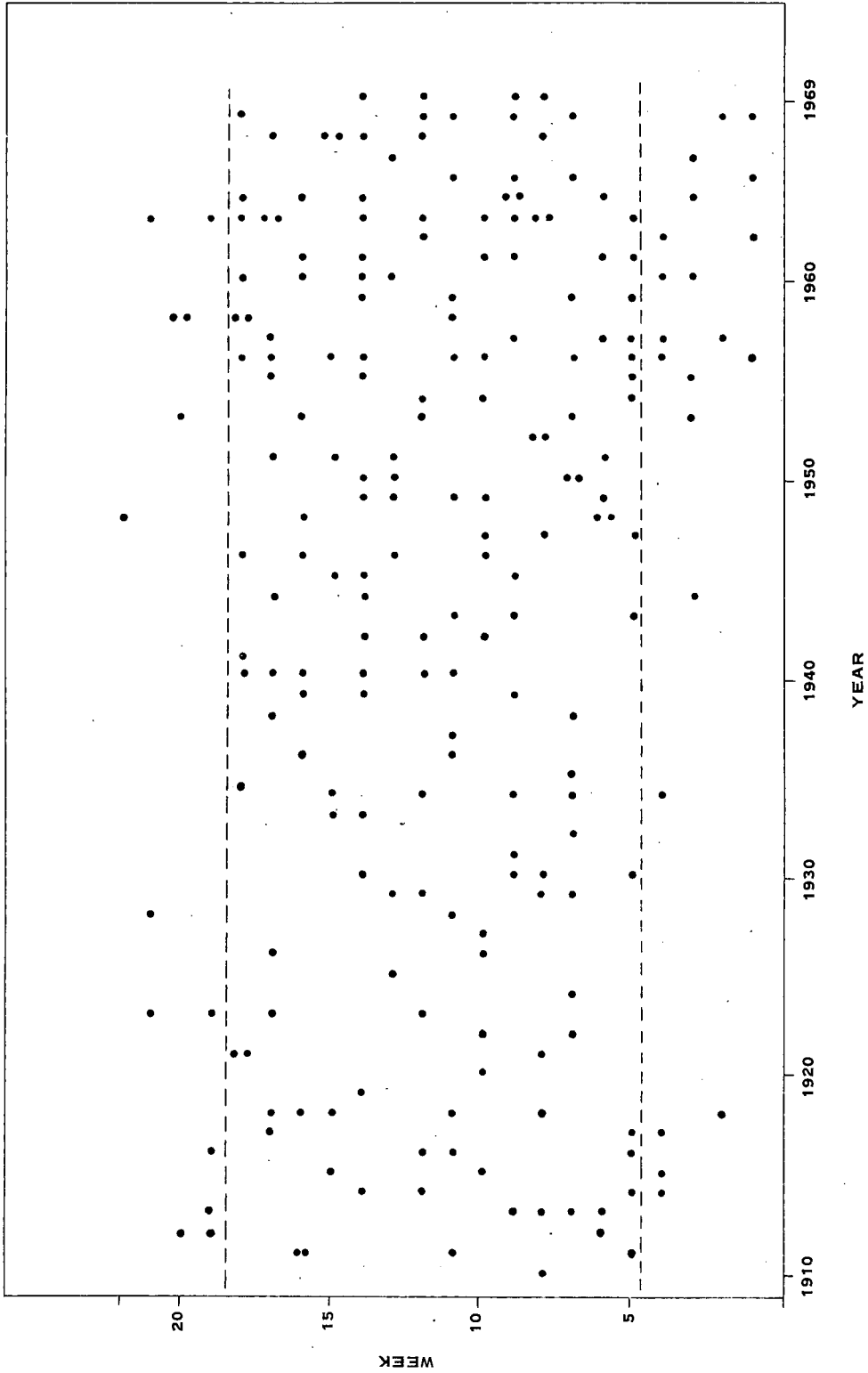


Fig 2 Times of occurrence of tropical cyclones.

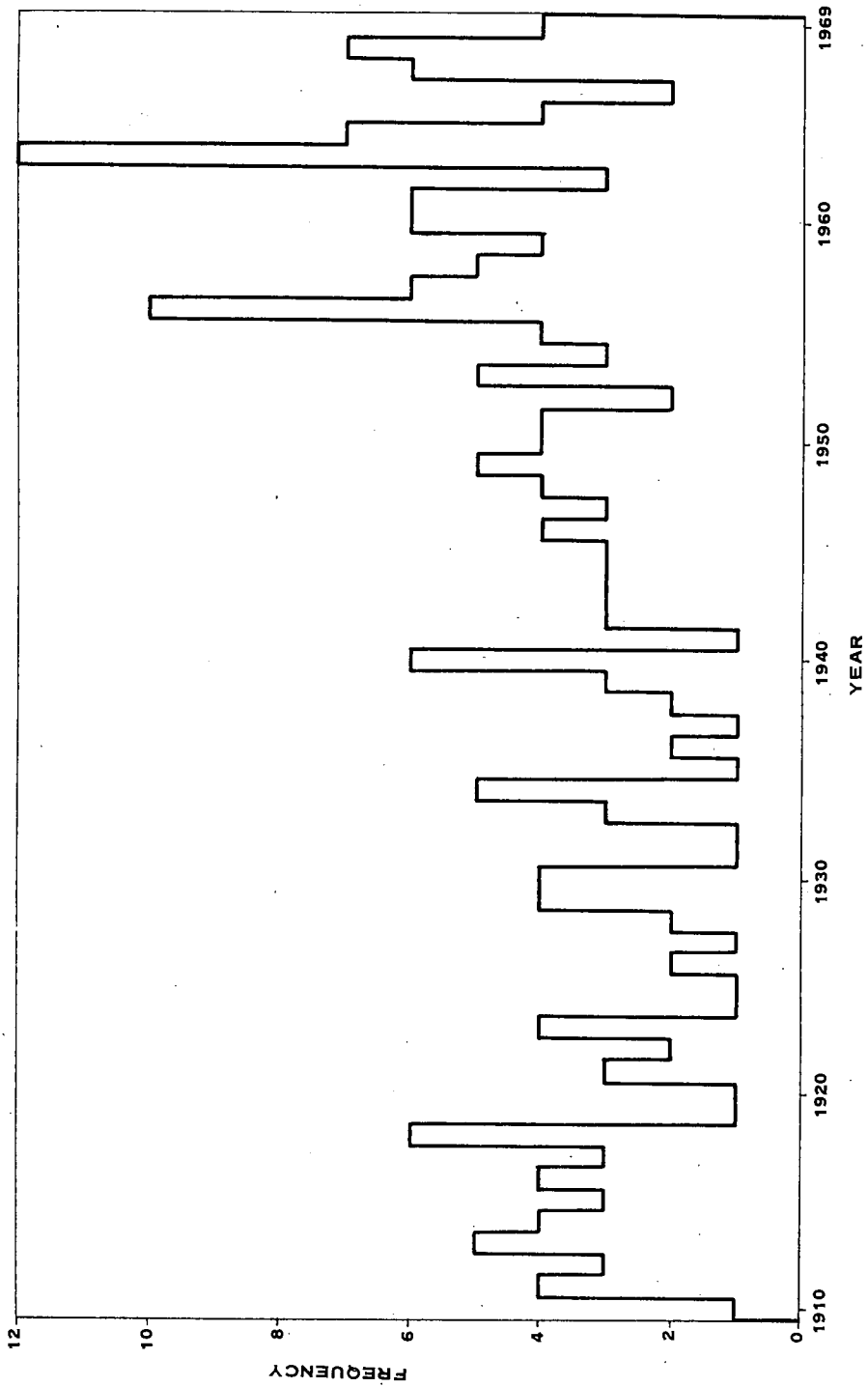


Fig 3 Numbers of cyclones in each season.

winds was introduced comparatively recently, in 1956. Moreover, during the study period there have been considerable improvements in the detection and tracking of cyclones. These points are now considered in more detail.

The date on which any particular low pressure system was designated a tropical cyclone may have been rather arbitrary, especially before the current definition of a tropical cyclone was introduced. The date it was declassified may also have been doubtful. For this reason, the week of the season in which the cyclone was reported to have begun was used rather than the day.

Early this century much of the study area was sparsely populated, the observational network was still developing, and information about weather conditions at sea was scant. With time, great improvements were achieved and much more information is available about the more recent cyclones. Cyclone surveillance increased markedly during the Second World War, but the most dramatic improvements have occurred during the last fifteen years. Radar and satellite pictures enable the early identification and continuous tracking of tropical cyclones. It is to be expected that cyclones which were away from well-travelled shipping lanes and outside the meteorological observation network once went unnoticed but would now be detected. Therefore it is possible that the increased frequency of recorded cyclones is in part due to these more sophisticated observational facilities.

To some extent an increase due to detection capability may be offset by more careful attention to meteorological detail; the tracks of some early cyclones begin far inland - nowadays such storms would not be regarded as tropical cyclones unless they had developed the appropriate intensity and structure at sea. Also it is possible that before 1956 depressions with surface winds less than 34 kn might have been classified as tropical cyclones.

These aspects of the collection of the data cast doubts on its reliability and usefulness. A check on its validity can be made by comparing the observed cyclone frequencies with rainfall registration.

Many stations in the area have reliable records of rainfall throughout the study period. Cyclones cause much rain in the immediate vicinity. But the meteorological conditions which favour cyclone activity, for example the southerly movement of the inter-tropical convergence zone, also favour a general increase in rainfall. In fact in the study area most of the rain recorded for a rainfall season (September through August) is received during the cyclone season (Stewart 1973). If the cyclone data is reliable, it is to be expected that in seasons in which many cyclones were recorded rainfall registrations were high. The curve of the registrations per rainfall year from 1910 to 1966 for Cooktown is shown in Fig 4; the cyclone frequencies of Fig 3 have been superimposed. The two series show the same trends: high values at the beginning of the period, lower values from about 1920 to 1940 and increasing values into the mid-1960s. The peaks and troughs in the series tend to coincide. For these data, the Spearman rank correlation coefficient for the common period of 57 years is $r = 0.360$ and the statistic $t = r (55/(1-r^2))^{1/2} = 2.87$ is significant at the 1% level when compared with the t_{55} distribution. Most of the east coast stations in the area also show significant correlation between rainfall year registration and cyclone frequency. For example, in the central part of the coast where cyclonic activity is less, but still important, Townsville has $r = 0.274$, which is significant at the 5% level. To the west, however, Normanton on the Gulf of Carpentaria does not have significant correlation between rainfall and overall seasonal cyclone frequencies. But that area is not greatly affected by the rain influences active along the east coast (Stewart 1973) and if rainfall registrations are compared with the frequencies of cyclones in the Gulf, the correlation is significant.

These comparisons between cyclone frequencies and rainfall suggest that the cyclone frequency data may be more reliable than anticipated. Perhaps the various sources of error do not strongly influence the data or, more probably, they tend to cancel one another out.

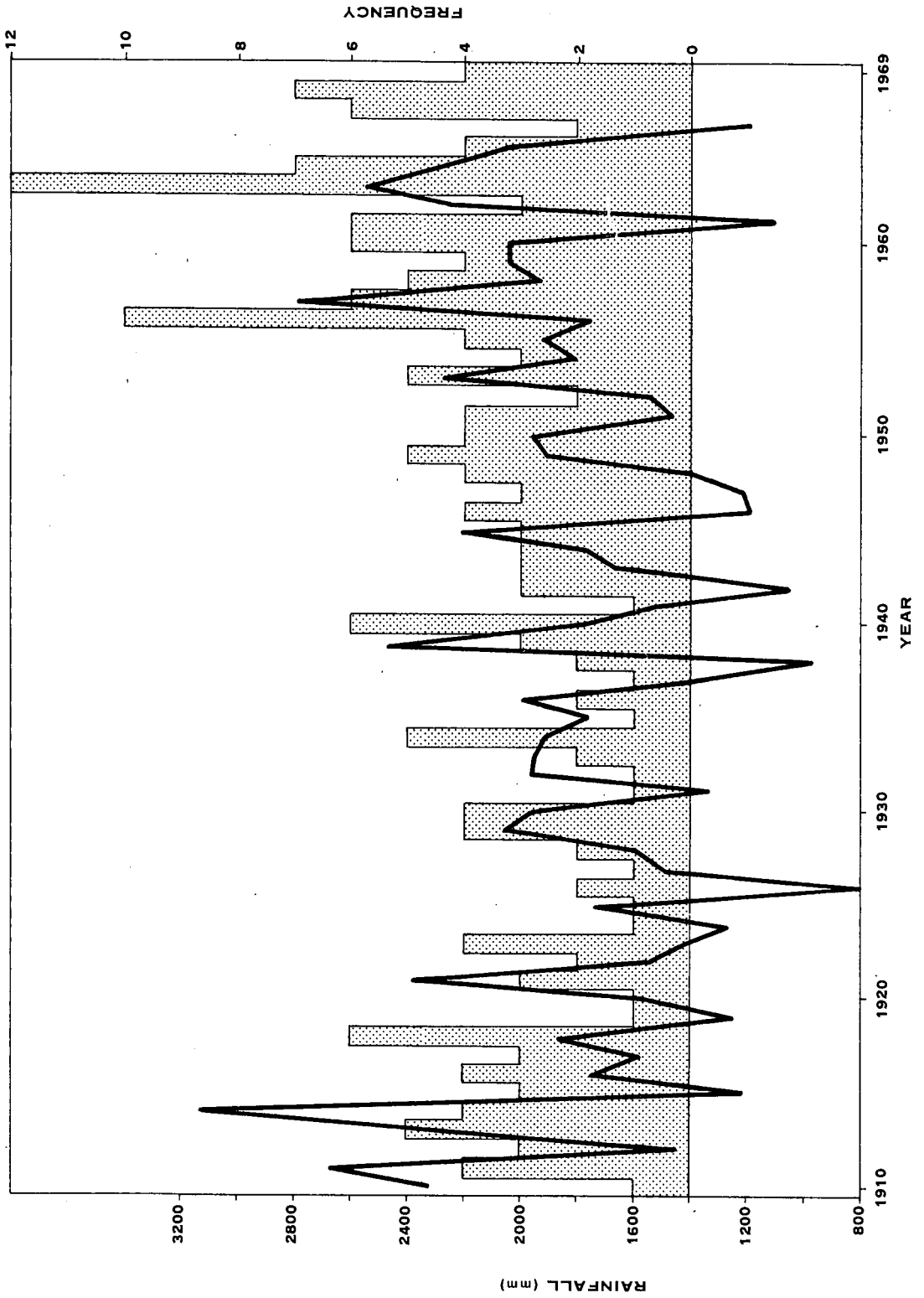


Fig 4 Seasonal rainfall totals and cyclone frequencies for Cooktown.

STOCHASTIC MODEL

The term 'stochastic point process' is used to describe a random process whose realisations consist of a series of events occurring at points in time or space. An example of the use of point process models to describe a series of physical events is the analysis of earthquake occurrences by Vere-Jones (1970). Other examples and most of the theory used here can be found in Cox and Lewis (1966) and Lewis (1972). The generation of a cyclone (or, in practice, its identification) is considered as a point event and the series of cyclone occurrences as a random process in time; although the series could be treated (with much more difficulty) as a multivariate point process if factors such as position and pressure were also considered.

A simple model for the series of cyclone occurrences is obtained by assuming that, within each season, cyclones occur completely at random; that is, the series is taken to be a realisation of a Poisson process. Let N_i be the number of cyclones occurring in the i th season, where $i = 1, 2, \dots, n$. For this data, the number of seasons, n is 60. Let the parameter λ be the expected number of cyclones per season. The random variables N_i , $i = 1, 2, \dots, n$ are assumed to be independent, each having a Poisson distribution with mean λ . Then the probability of k cyclones occurring in the i th season is

$$\text{Prob } (N_i = k) = \frac{\lambda^k e^{-\lambda}}{k!}, \quad k = 0, 1, 2, \dots \quad \dots 1$$

For a homogeneous Poisson process, the parameter λ is constant. In the cyclone data there is an obvious trend in the frequencies so a more appropriate model would be a time-dependent Poisson process in which λ is a function $\lambda(i)$ of the season. In this new model, the numbers of cyclones in different seasons are still statistically independent.

A further property of a Poisson process is that the intervals between events are independent and identically distributed, each having an exponential distribution with parameter λ .

A stochastic model of this kind is used as a framework for the statistical investigation of the data. However, it must be stressed that the model is purely descriptive and is not suggested as a model for the physical processes producing tropical cyclones.

SEASONAL CYCLONE FREQUENCIES

The trend in the seasonal frequencies which is evident from Fig 3 is studied first. Regression analysis is used to investigate how the parameter $\lambda(i)$ varies with the season.

If the number of cyclones in the i th season, N_i , has a Poisson distribution with mean $\lambda(i)$, then its variance is also $\lambda(i)$. But constant variance is assumed for regression analysis so a variance stabilising transformation should be applied to the data. The transformation

$$y_i = \sqrt{(N_i + 3/8)} \quad \dots 2$$

was used because Anscombe (1948) showed that

$$E(y_i) \approx \sqrt{(\lambda(i) + 3/8)} \text{ and } \text{var } (y_i) \approx \frac{1}{4}. \quad \dots 3$$

Table 1 summarises the results of regression analysis of the variables y_i against the independent variable i .

Table 1 Results of regression analysis of the variables y_i against the independent variable i

Estimated straight line	$y = 1.4917 + 0.0142i$			
Estimated quadratic	$y = 1.8533 - 0.0208i + 0.0006i^2$			
ANALYSIS OF VARIANCE				
Variation	d.f.	s.s.	m.s.	var. ratio
Due to constant	1	222.212		
Due to slope	1	3.623	3.623	16.59 †
Error	58	12.665	0.218	
Due to straight line	2	225.835		
Due to squared term	1	1.420	1.420	7.20 †
Error	57	11.245	0.197	
Total	60	238.5		

† The variance ratios 16.59 and 7.20 are respectively significant at the 0.1% level compared with the $F_{1,58}$ distribution and at the 1% level compared with the $F_{1,57}$ distribution.

From the analysis of variance, it can be seen that the variance ratio for the slope of the straight line is 16.59, which is highly significant, indicating that the slope is non-zero. Similarly, the coefficient of the squared term in the quadratic is significantly non-zero. When a cubic equation is fitted a non-significant result is obtained. Therefore the trend in the y_i 's is adequately expressed by the quadratic. In terms of the N_i 's the trend is estimated by

$$N = (1.8533 - 0.0208i + 0.0006i^2)^2 - 0.375 \quad \dots 4$$

Notice that the two estimates of the variance of the y_i 's, namely 0.218 and 0.197, compare favourably with the theoretical value of 0.25 for a Poisson process. An investigation of the residuals

$$e_i = y_i - 1.8533 + 0.0208i - 0.0006i^2 \quad \dots 5$$

shows no indication of departure from normality of the underlying distribution (a tacit assumption made in the analysis of variance). Neither is there evidence that successive residuals are not independent; the Durbin and Watson (1951) statistic

$$d = \frac{\sum_{i=2}^{60} (e_i - e_{i-1})^2}{\sum_{i=1}^{60} e_i^2} = 1.94 \quad \dots 6$$

is not significant.

TIME OF OCCURRENCE OF CYCLONES

If the time-dependent Poisson process is taken as a model of cyclone occurrences, it follows that, for the i th season, the times between successive cyclones and the time from some point at the beginning of the season to the occurrence of the first cyclone would all be mutually independent, identically distributed events, exponentially distributed with parameter $\lambda(i)$. Therefore if this simple model is appropriate,

one would expect cyclones to be spread evenly throughout each season, but the intervals between them to be greater where $\lambda(i)$ is small (say from 1920 to 1940) and smaller when $\lambda(i)$ increases. However, inspection of Fig 2 shows that this effect is not pronounced. Instead, when $\lambda(i)$ is small the first cyclone occurred much later in the season than when $\lambda(i)$ was large but the intervals between subsequent cyclones in a season do not vary greatly.

In fact, the Spearman rank correlation coefficient between the number N_i of cyclones and the week t_i of occurrence of the first cyclone (counted from the week beginning 29 November) is $r = 0.535$, which is significant at the 0.1% level.

If the gaps between successive cyclones are studied in order (but leaving out the long gaps from the last cyclone in one season to the first of the next season), there is no evidence of lack of independence. The first order serial correlation coefficient is $\tilde{\rho}_1 = -0.02$, which is not significant when $\tilde{\rho}_1 \sqrt{n} = 0.25$ is compared with the standard normal distribution $N(0,1)$ (see Lewis 1972).

In Fig 2, the gaps between cyclones appear to be somewhat longer when there were few cyclones in the season than when there were more. For instance, the average gap length up to 1940 was 3.82 weeks (with standard deviation of 3.25 weeks) while after 1940 the average was 2.84 weeks (with standard deviation of 2.36 weeks). However, this trend is not as marked as most of the other effects observed. Thus the test statistic u (see page 47 of Cox and Lewis (1966)), which approximately has the $N(0,1)$ distribution if there is no trend in the gaps, has the observed value of 2.16, which is significant at the 5% level but not at the 1% level.

SUMMARY

In a statistical analysis of the frequency of tropical cyclones in northeastern Australia, the most obvious feature is that from 1910 to 1969 cyclone numbers initially decreased and then increased. It is interesting to compare this with the results of Russell (1971). He modelled hurricane occurrences on the Texas coast by a periodic Poisson process and estimated a period of about 33 years using data for over 150 years.

There is also a seasonal effect in the occurrence of tropical cyclones. In bad seasons the first one is likely to occur near the beginning of the season and the gaps between successive ones are short but at random. In less severe seasons, the first cyclone occurs later. However, in any season cyclones are much more likely to occur during the middle, from the beginning of January to the end of March, than at either end of the season.

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REFERENCES

- Ancombe, F.J. 1948. The transformation of Poisson, binomial and negative-binomial data. *Biometrika*, 35, 246-254.
- Coleman, F. 1972. *Frequencies, tracks and intensities of tropical cyclones in the Australian region, November 1909 to June 1969*. Bur. Met. Australia.
- Cox, D.R. and Lewis, P.A.W. 1966. *The Statistical Analysis of Series of Events*. Methuen, London.
- Durbin, J. and Watson, G.S. 1951. Testing for serial correlation in least squares regression II. *Biometrika*, 38, 159-178.

Lewis, P.A.W. 1972. Recent results in the statistical analysis of univariate point processes. *Stochastic Point Processes: Statistical Analysis, Theory and Applications*. Ed. P.A.W. Lewis. Wiley, New York.

Russell, L.B. 1971. Probability distributions for hurricane effects. *J. Waterways, Harbors and Coastal Engineering Division, Proc. Amer. Soc. Civil Engineers*, 97, No. WW1, 139-154.

Stewart, J. 1973. Rainfall in northern Queensland (1870-1970): trend and expectation. Ph.D. Thesis, Department of Geography, James Cook University of North Queensland.

Vere-Jones, D. 1970. Stochastic models for earthquake occurrence. *Jl R. statist. Soc. (B)*, 32, 1-62.