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A statistical study of frequency of depressions/cyclones in the Bay of Bengal

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CONTENTS

1. Introduction

There is a general impression that the total number of annual depressions and cyclones in the Bay of Bengal is decreasing in recent years. This aspect of the subject does not appear to have been studied so far. It was, therefore, felt that it would be of interest to make a detailed statistical study of the frequency of depressions and cyclones in the Bay of Bengal in different years.

The data utilised for study in the paper were compiled by the Investigation and Development Section of the Office of the Deputy Director General of Observatories (Forecasting) and include all depressions for which tracks could be shown.

2. Frequency distribution of depressions/cyclones in the Bay of Bengal

2·1. Table 1 gives the monthly and annual number of depressions/cyclones in the Bay of Bengal for each of the years 1890 to 1955. For the purpose of the total number in each year, no distinction is made between a depression and a cyclone. Tables 2 to 5 summarise these data in the form of monthly, annual and seasonal frequency tables. For each of the months, mean, extremes, median and dispersion values have been worked out. Also, the mean number of depressions in each month as percentage of the annual has been included. Tables 3, 4 and 5 contain frequency distributions for each of the six decades and for the periods—Annual, June–September (Monsoon) and October–November respectively. As in Table 2, means, extremes, and dispersion values are included. We shall briefly refer to the main features of these interesting tables. Fig. 1 shows the annual number of depressions and also the number in the monsoon season.

2·2. The average number of depressions in a year is 12·6, the two months August and September contributing the maximum of 4·3, *i.e.*, a third of the total. September has the highest average of 2·2 with 2·1 in August. The four monsoon months, June to September together account for 57 per cent only of the total and October to December 32 per cent of the annual. The least contribution is 2 per cent from the months January to March,

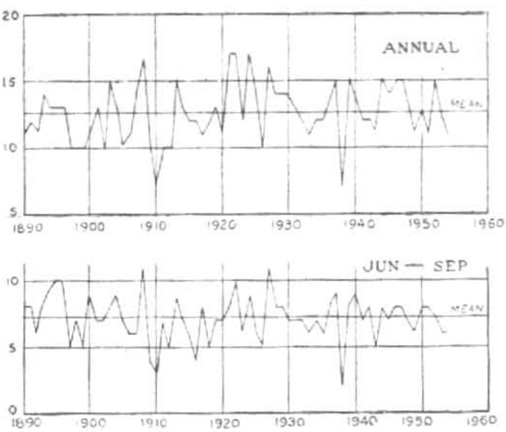

Fig. 1. Number of depressions/cyclones in the Bay of Bengal

February having the lowest average. Depressions during January to March are very rare, 16 only having occurred during a period of 66 years. April-May share only 9 per cent of the total with an average of 1·1.

2·3. The chief depression months are August to October with an average of 2. It is a remarkable fact that there was only one year during the past 66 years when there was no depression in October. The median values indicate that at least 50 per cent of the years had two or more depressions in each of the months July to November. The occurrence of four depressions a month is confined to the months July to November, the frequency being a maximum in August. The highest, 5 in any month, was recorded in September 1891. It is interesting to mention that the highest in any of the months May to December has not exceeded thrice the average for the month. 2 or more depressions may be expected in 50 per cent of the years in each of the months July to November and one or more in the months May, June and December.

2·4. Taking the seasonal totals, we find that the highest number of depressions in June to September is 11 in 1908 and 1927 and the lowest is 2 in 1938. The range is 9. The average is 7 with 64 per cent of the frequency of years being confined to the groups 6 to 8. The highest is about 1·5 times the mean and the lowest about 30 per cent of the mean. The highest and lowest figures for October to December are 7 and 1 respectively with an average of 3·3. 80 per cent of the years had 2 to 4 depressions.

2·5. A study of the annual distribution shows that the highest in any year was 17 and the least 7 giving a range of 10. There were 4 years which had a total of 17, the last occasion being in 1924. In recent years 1938 has recorded the lowest figure of 7. In the entire period of 66 years, there were no years with 8 or 9 depressions. The decade distributions show that the variations are not large. Three quarters of the years had 10 to 14 depressions in a year. Contrary to general impressions frequently expressed, there has been no decrease during the past two decades. The decade averages have been maintained. The frequencies are nearly uniform in the range 10 to 15. The median value is 13, nearly the same as the mean. 95 per cent of the years had more than 10 depressions. The maximum has not exceeded 1·5 times the average and the minimum has not fallen below 50 per cent in any year.

3. Means and variability

3·1. Table 6 gives the means for select periods and seasons. Annual and seasonal means for the decades are given in Tables 3 to 5.

3·2. The lowest of the decade averages for annual in Table 3 is for the decade 1891 to 1900. But when all the years are examined the decade 1909 to 1918 has the lowest average of 11·2, 11 per cent below the average of 1890 to 1950. This decade also contains the year with the lowest number of depressions 7. The highest of the decade averages is 14·5 for the decade 1921 to 1930. This decade includes three of the four years with the highest number of depressions 17. In the first 30 years the means remained below 12, the average being 11·9 while for the next 30-year period the average is 13·4. If the period 1921 to 1930 is excluded the mean for the twenty-year period, 1931 to 1950, works out as 12·8. Thus, only 1921 to 1930 was a period of large excess of depressions, the average excess being 15 per cent of the average for 1890 to 1950.

3·3. The only long period of consecutive years when the average was below 80 per cent of the normal, *i.e.*, less than 10, is for the period 1909 to 1912 with an average of 9·3. Similarly, the highest for any period of more than two consecutive years is for the period 1921 to 1924 and the average is 15·7. The successive four-year averages which include both these periods are given in Table 7. It will be seen that only two of the four-year averages are less than 11 and eleven of the fifteen are in the range 12 to 14.

3·4. In the decade and other averages for seasonal distribution, similar features are noticed. The highest average of 7·8 for June to September is for the decade 1921 to 1930.

3·5. *Variability*—As measures of variability, extremes, range, standard deviation, mean deviation and coefficient of variability have been included in Tables 2 to 5 for months, seasons, annual etc. The coefficient of variation (%) is least for the months, July to November, the lowest value being 41 per cent for September. August and October have a variability of 50 per cent. It is 30 per cent for October-November combined and only 25 per cent for the monsoon season June-September. Coming to the annual figures we find that the standard deviation varied from 1·5 for 10 years to 2·2 for 20 years, the highest being 2·4. In terms of coefficient of variability, these correspond to 13, 17 and 18 per cent respectively. The value has remained stationary at about 17 per cent. The standard deviation of the annual frequency is 2·2 for the entire period. If we omit the two extreme values of 17 and 7, the range of variation is not large, only 6.

3·6. We will now give the frequency distribution of the variation *d* from year to year for the annual figures. Similar distribution has been worked out for the monsoon period also (Tables 8 and 9). It is seen that the variations from year to year are small. Even a variation of 2 accounts for two-third of the total while 3 covers 4/5th of the frequency. The extreme variations are —8 and +8. For the monsoon period the number has varied from —7 to +6. The variations in the monsoon period are nearly similar to these for annual values.

4. Tests of departure from normality

4·1. Frequency distribution of the annual number of depressions for decades, 30-year periods and for the period 1890 to 1950 are given in Table 3. The entire frequency distribution (1890 to 1950) excepting for the frequency for 7 lies within the range given by mean $\pm$ 2 S.D. In the present case the two limits are 12·6 $\pm$ 2 (2·23), *i.e.*, 17 and 8. For a normal distribution one value in 22 may be expected to lie outside the range $M \pm 2\sigma$. Hence for the series under consideration three such values may be expected though actually there have been so far only 2.

4·2. In testing the normality, two methods are utilised generally. One is to fit a normal curve to the data and test the goodness of fit by χ^2. The other is to calculate functions g_1 and g_2 from the sample moments and test the significance of their departure from the expected values for a normal population. A third method due to Geary uses the ratio of mean deviation to standard deviation.

4·3. The values of g_1 and g_2 etc for different periods are given in Table 10. Both g_1 and g_2 are less than twice the standard errors. In some cases they are even less than the standard error. Hence departure from normality is not significant.

4·4. The results of fitting a normal curve to the frequency distribution are given in Table 11. These results also show that the distribution is not significantly different from normal.

4·5. We will now examine if the frequency of months with different number of depressions follows the normal law (Table 12). It is seen that the frequency distribution of months for January to December is *not* normal while for the other two periods, the frequency distributions are not significantly different from normal.

5. Testing for homogeneity of data and variances

5·1. A test recently developed (David, Hartley and Pearson 1954) for testing lack of homogeneity of data is to calculate the ratio of range (w) to the standard deviation (S) of the sample and find out if w/S exceeds the 5 per cent and 1 per cent values given in the tables. w/S for each decade is already given in Table 3. None of them is significant even at the 5 per cent level. The data may, therefore, be regarded as homogeneous.

Homogeneity of variances—We have calculated mean square estimates of variance (S^2) for decades and it is proposed to test them for homogeneity. $S^2{}_n$ are distributed as $\chi^2\sigma^2{}_n/\nu_k$ with ν_k degrees of freedom. It is desired to test the hypothesis that $\sigma_n{}^2$ have a common though unknown value σ^2. For this purpose the test employed is Bartlett's which is identical with Neyman and Pearson's for equal ν_k.

The statistics is given by

$$M = n\,k \log_e\left(\sum_1^k S^2{}_n/k\right) - n \sum_1^k \log_e S^2{}_n$$

The probability of M's exceeding the observed value is given approximately by χ^2 distribution with k—1 degrees of freedom. M in the present case is 7·417 and degrees of freedom 5. M is not significant. Hence the variances may be regarded as homogeneous.

6. Comparison of means for different periods

6·1. In Sec. 3, we have referred to the means for different periods, decades etc. We will now examine if the means for the different periods differ among themselves and also from the mean for the entire period. In order to find out if the mean for any of the periods is significantly different from the general mean, the following test is utilised.

Let $x_1, x_2 \ldots\ldots x_n$ be the n observations

$$\overline{x_k} = \frac{x_1 + x_2 + \ldots\ldots + x_k}{k}$$

$$\overline{x} = \frac{x_1 + x_2 + \ldots\ldots + x_n}{n} \text{ (overall mean)}$$

$$S^2 = \left\{ \sum_{r=1}^{n} (x_r - \overline{x})^2 \Big/ n \right\} \quad \tau_k = \frac{\overline{x_k} - \overline{x}}{S}$$

It can be shown (Cramer 1946) that the statistic

$$t = \tau_k \left\{ \frac{k\,(n-2)}{n-k-k\,\tau_k^2} \right\}^{\frac{1}{2}}$$

is distributed as Student's t with (n—2) degrees of freedom.

6·2. Table 13 gives for the six decades from 1891, values of t and probability $P(t)$, t being smaller than the observed value.

6·3. The difference between the mean for the decade 1921 to 1930 and the mean for the period 1890 to 1950 is significant at even 1 per cent level of significance. The other five are not significant even at 5 per cent. From normal theory one may expect 1 value in 20 to be outside the 5 per cent value and in the present case it will be 6/20 (=0·3). Hence to test for overall significance, we will apply the P_λ test for combining probabilities. In the present case, P_λ = 14·1404. As a χ^2 with 2 × 6 (=12) degrees of freedom, P_λ is not significant.

6·4. We will apply the analysis of variance to test for the homogeneity of the six decade means (Table 14). This analysis would generally support taking the different means as homogeneous.

6·5. We have studied the significance of the difference between the mean of a sub-period and the mean for the entire period. We will now examine the significance of the differences between means of different periods. The test utilised for the purpose is t-test. If $\bar{x}$ and $\bar{y}$ are the two means each based on n observations, then

$$t = \frac{(\bar{x}-\bar{y})}{\left[\left\{\dfrac{\sum_{i=1}^{n}(x_i-\bar{x})^2+\sum_{i=1}^{n}(y_i-\bar{y})^2}{n(n-1)}\right\}\right]^{\frac{1}{2}}}$$

	Mean	S^2
(i) 1890-1922	12·09	5·460
1923-1955	13·03	3·803

$t = 1\cdot78$ (not significant at 5 per cent)

	Mean	S^2
(ii) (a) 1890-1911	11·73	4·874
(b) 1912-1933	13·09	5·134
(c) 1934-1955	12·86	4·028

	t	Significant
(b)—(a)	2·03	No
(c)—(a)	1·77	No
(b)—(c)	0·35	No

6·6. The analysis of variance is given in Table 15.

6·7. We may conclude from the above analysis that the means are not significantly different from the mean of the entire period or among themselves.

7. Analysis of trend

7·1. We will now examine the series for trend. In the first instance we will try linear trend ($Y=a+bT$) for the periods 1890–1920 and 1921–1950. The equations are —

(i) 1890–1920 (1890 is taken as the origin)

Denoting the year T from 1890 as 0, 1891 as 1,... and the frequency by Y, we have

$$Y-12 = -\cdot1613-0\cdot002016\,(T-15)$$

(ii) 1921–1950

$$Y-12 = 1\cdot367-0\cdot0645\,(T-15)$$

The regression coefficients are not significant.

7·2. We will now examine for trend in some detail for the entire series from 1890 to 1950. The method followed will be the fitting of orthogonal polynomials to the data.

7·3. The results of fitting the first four polynomials are given in Table 16.

7·4. It is seen that the first polynomial accounts for about 5·5 per cent and the later polynomials each account for less than 1 per cent. *The total contribution to the variance from the fourth degree polynomial is only of the order of 8 per cent.*

7·5. The above detailed analysis clearly indicates that there is no trend in the series. We will analyse now the variations between months and between years. For this purpose, January to December and June to September groupings will be examined (Tables 17 and 18). Table 17 shows that variations between months are significant which may also be seen from the table of monthly averages (Table 2). Between years it is, however, not significant.

Tables 17 and 18 show that variations from year to year are not significant. In the case of June to September even variations between months are not significant.

8. Inter-correlations between months and seasons

Frequently questions are raised if the number of depressions in any month or season gives indication of the succeeding month(s) and season(s) respectively. We have, therefore, worked out the inter-correlations between months and seasons and these are given in Tables 19, 20 and 21.

Table 19 shows that excepting the inter-C.C. between April and May *none* of them is significant. The significant association although not high would suggest that if there are no depressions in April, May may have some depressions.

None of the C.Cs. in Tables 20 and 21 is significant. One may conclude that the number of depressions in any month (excepting April–May) is no index of the number in the succeeding months. Similar results hold for the two seasons, monsoon and October—November.

9. Periodicity

9·1. The method followed for analysing periodicity of the series of depressions and cyclones is mainly Schuster's periodogram analysis.

9·2. If $x_1, x_2 \ldots\ldots x_n$ represent the number of depressions in each of the years $1, 2, \ldots\ldots n$ respectively and T is the period for which we are testing the series, then we calculate the quantities,

$$A(T) = \frac{2}{N'} \sum_{t=1}^{T} y_t \cos \frac{2\pi t}{T}$$

$$B(T) = \frac{2}{N'} \sum_{t=1}^{T} y_t \sin \frac{2\pi t}{T}$$

N' is so chosen that it is equal to the largest multiple of T in N. $N' = p.T$, where p is an integer. If $R(T)$ denotes the amplitude of the periodogram corresponding to the period T, then

$$R^2(T) = A^2(T) + B^2(T)$$

9·3. The probability that R^2 exceeds $4\sigma^2 K/N$, where σ is the standard deviation of the population, is e^{-K}. As σ^2 is to be estimated from the sample, the correct test to be applied should be based on the distribution of R^2/S^2 where S^2 is an estimate of the standard deviation as calculated from the sample. If $g = R^2/2S^2$, it may be shown (Fisher 1929) that the probability P of g exceeding a given value is

$$P = (1-g)^{n-1} = (1-2K/N)^{(N-3)/2}$$

n is the total number of periods and equal to $\frac{1}{2}(N-1)$ when N is odd with suitable adjustment for even values. As it is usual to choose the highest value of the intensity for testing significance, the above test should be modified. If $R^2_{\text{max.}}$ is the largest intensity then the probability P that $g = R^2_{\text{max.}}/2S^2$ exceeds a given value was derived by Fisher (1929) and is

$$P = n(1-g)^{n-1} - \frac{n(n-1)}{2}(1-2g)^{n-1} + \cdots + (-1)^{m-1}\, {}_nC_m\, (1-mg)^{n-1}$$

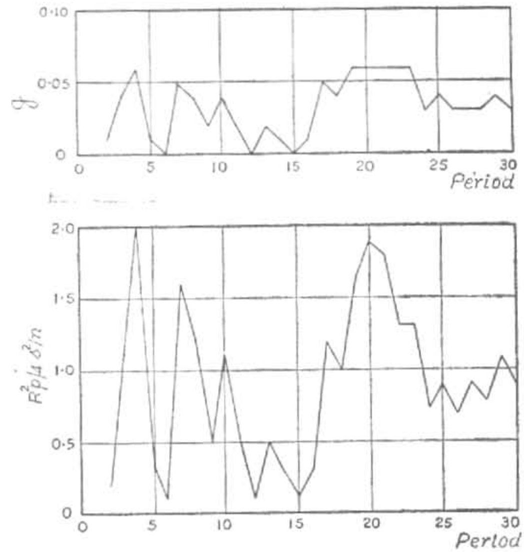

Fig. 2. Periodogram analysis

m is the greatest integer less than $1/g$ and n has the same meaning as before.

9·4. Table 22 gives the values of intensities by Schuster's periodogram analysis corresponding to periods of 2 to 30 years. The periodogram is shown in Fig. 2. Values of g have also been entered in the table. There are three peak values. The first is of 4 years, the second for 7 years and the third for 20 years. As the minimum value of K for significance at 5 per cent level is 2·996 and as all the values of the periodogram intensity are less than 2·1, one may safely conclude from the analysis that there is no periodicity in the series.

10. Independence of successive observations

10.1. If $x_1, x_2 \ldots\ldots\ldots x_n$ are n observations, a method for testing the independence of successive observations is to test the significance of the ratio of the mean square successive differences to the variance.

$$\delta^2 = \sum_{r=1}^{n-1} \frac{(x_{r+1} - x_r)^2}{n-1}$$

$$S^2 = \sum_{r=1}^{n} \frac{(x_r - \bar{x})^2}{n}$$

$$d = \sum_{r=1}^{n-1} |x_{r+1} - x_r|/n$$

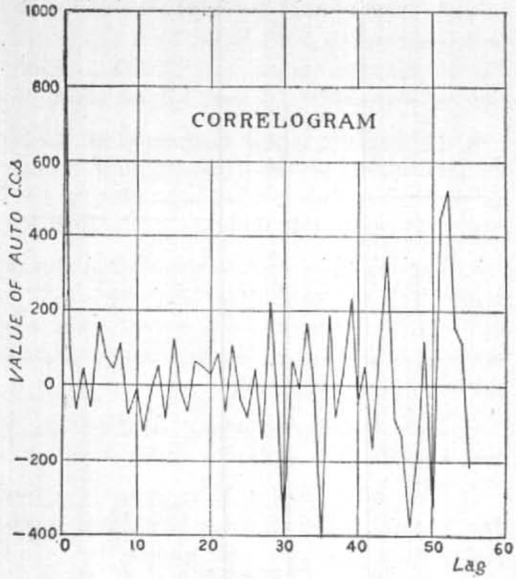

Fig. 3

10·2. A table of significance levels of δ^2/S^2 known as Neumann Ratio is available (Hart 1942). Use of d/S also in place of δ^2/S^2 has been suggested (Kamat 1953). Values of δ^2/S^2 and d/S for different periods are given in Table 23.

10·3. A sequence of variates $x_1, x_2 \ldots x_n$ is said to be a random series or to satisfy the condition of randomness, if $x_1, x_2, \ldots x_n$ are independently distributed with the same distribution. A non-parametric test for randomness developed by Wald-Wolfowitz (1943) is to test the statistic

$$R = \sum_{t=1}^{n-1} x_t \, x_{t+1} + x_n \, x_1$$

For large values of n, $[R - E(R)]/\sigma_R$ is normally distributed. In the present series (1891-1950), R=61, $E(R)$=1780, and $\sigma_R = 38\cdot65$.

$$\text{Therefore,} \quad \frac{R - E\,(R)}{\sigma_R} = 1\cdot12$$

and is not significant. The series may be regarded as random.

10·4. Table 24 gives the auto-correlation coefficients for lags from 1 to 55. For testing their significance, the only detailed tables available are those by Anderson (1942). These tables are based on the circular definition of auto-covariance but this is not a serious objection when n is large. Based on these tables we find one only of the 55 auto-correlation coefficients as significant at 1 per cent though some of the values particularly after 40th lag are significant at 5 per cent. As the value of n is small for lags after 40, it may be inferred that the auto-correlation coefficients are not significant. The definition of r_s is

$$r_s = \left[\sum_{t=1}^{n-s} x_t \, x_{t+s} - \frac{\sum_1^{n-s} x_t \sum_1^{n-s} x_{t+s}}{n-s} \right] \times \left[\sum_1^{n-s} x^2_t - \frac{\left(\sum_1^{n-s} x_t \right)^2}{n-s} \right]^{-\frac{1}{2}} \times \left[\sum_1^{n-s} x^2_{t+s} - \frac{\left(\sum_1^{n-s} x_{t+s} \right)^2}{n-s} \right]^{-\frac{1}{2}}$$

The correlogram which is a plot of the values of auto-correlation coefficients is shown in Fig. 3.

10·5. When the various possible periodicities are investigated an estimate of the spectrum $f(\omega)$ of the periodogram is required.

$$f\,(\omega) = \frac{1}{n} \left\{ \left(\sum_1^n x_r \cos \omega r \right)^2 + \left(\sum_1^n x_r \sin \omega r \right)^2 \right\}$$

$$= \sum_{-n}^{+n} \left\{ \left(1 - \frac{|s|}{n} \right) C_s \cos \omega s \right\}$$

As calculation of this complete expression involves considerable labour, a first estimate of the spectrum is obtained by Bartlett's method.

$$f_B\,(\omega) = \sum_{-p}^{+p} \left(1 - \frac{|s|}{p} \right) C_s \cos \omega s$$

We have taken $p = 15$ in the present instance. Values of $f_B\,(\omega)$ are given in Table 25.

10·6. This smoothing process which is due to Bartlett may be expected to show the prominent periods. It is interesting to observe that there are no peaks at all in this case. There appear to be no prominent periods, a result which supports the periodogram analysis of the preceding section.

11. Summary

The main results of the study are summarised below—

1. Tables have been given showing the monthly, seasonal and annual means together with extremes, range, variability and median values. Frequency distributions for each of the six decades for seasons and annual have also been included.

2. The annual average is 12·6 with the median value 13. 50 % of the years had more than 2 depressions in each of the months July to November with one each in May, June and December. The highest average is 2·2 for September. The largest number of depressions in any year (17) has not exceeded 1·5 times the average. The lowest number of depressions has not fallen to (7) less than half the average.

3. Averages and standard deviations for each year up to 1955 have been calculated. The standard deviation is 2·2 with a coefficient of variability of only 17 per cent.

4. The highest decade average of 14·5 is for the period 1921 to 1930. The highest average for more than two consecutive years is 15·7 (1921-24) and the lowest 9·3 (1909-12).

5. Variations in the total number of annual depressions are small. The extremes are —8 and +8. A difference of 3 covers about 80 per cent of the years. Similar results hold for the monsoon season also.

6. The annual frequency distribution is not significantly different from normal.

7. The data form a homogeneous series. The variances for decades have been tested and form a homogeneous group.

8. The means for different periods are not significantly different either among themselves or from the mean for the entire period.

9. There is no trend in the series. This indicates clearly that there have been no changes in recent years.

10. The series is not auto-correlated.

11. There is no periodicity in the series.

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TABLE 1

Monthly and annual number of depressions/cyclones in the Bay of Bengal

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun-Sep	Oct-Nov	Annual
1890					1	1	2	3	2	2			8	2	11
1891					1			3	5	1	2		8	3	12
1892						1	2	1	2	3	1	1	6	4	11
1893				1	2	1	1	3	3	2	1		8	3	14
1894				1		2	3	1	3	3			9	3	13
1895				1		2	2	3	3	1		1	10	1	13
1896						2	3	4	1		2	1	10	2	13
1897					1	1	1	1	2	2		2	5	2	10
1898					1	1	2	2	2	1	1		7	2	10
1899				1				3	2	3	1		5	4	10
1900						2	3	3	1	2			9	2	11
1901					1	2	2	2	1	2	2	1	7	4	13
1902					1	1	1	2	3	2			7	2	10
1903					1	1	3	2	2	2	3	1	8	5	15
1904					1	3	1	2	3	1	2		9	3	13
1905					1	1	2	1	3	1		1	7	1	10
1906	1					2	2	1	1	1	1	2	6	2	11
1907			1		2	2		3	1	2	2	1	6	4	14
1908					1	2	1	4	4	2	2	1	11	4	17
1909					2	1			3	2	1	1	4	3	10
1910				1			1	1	1	1	2		3	3	7
1911				1		2		3	2	2			7	2	10
1912							1	2	2	3		2	5	3	10
1913						2	3	2	2	3	2	1	9	5	15
1914					2	2	2	1	2	1	2	1	7	3	13
1915						1		2	3	2	3	1	6	5	12
1916					1	2		1	1	4	3		4	7	12
1917					1	3	1	2	2	1	1		8	2	11
1918	1				1		2	1	2	2	2	1	5	4	12
1919						1	2	3	1	1	3	2	7	4	13
1920				1		1	2	2	2	2	1		7	3	11
1921	1			1	1	2	2	1	3	4	1	1	8	5	17
1922				1		2	3	1	4	1	4	1	10	5	17

NOTE—All depressions and cyclones which have found a place in the *India Weather Review* (Annual Summaries) have been taken into account. From 1921 dates of tracks have been utilised

TABLE 1 (*contd*)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun-Sep	Oct-Nov	Annual
1923	1			1	1		1	3	2	1	1	1	6	2	12
1924			1	1	1	1	2	4	2	3	2		9	5	17
1925				1	1	1	2	2	1	2	3	1	6	5	14
1926					1	1		2	2	2	1	1	5	3	10
1927					2	1	4	4	2	2	1		11	3	16
1928			1		1	1	2	2	3	2	1	1	8	3	14
1929	1				1	2	2	4		2	2		8	4	14
1930					2	2	3		2	1	3	1	7	4	14
1931					1		1	4	2	4		1	7	4	13
1932					1	1	3	1	2	2	2		7	4	12
1933					1	1		2	3	1	2	1	6	3	11
1934	1			1		1	2	2	2	1	2		7	3	12
1935				1		1	2	1	2	2	2	1	6	4	12
1936				1	1	2	2	2	2	1	1	2	8	2	14
1937				2		1	3	1	4	1	2	1	9	3	15
1938			1		1			1	1	1	2		2	3	7
1939	1			1			2	3	3	2	2	1	8	4	15
1940					1	2	1	4	2	1	2	1	9	3	14
1941					1	1	2	2	2	1	2	1	7	3	12
1942				1		1	3	2	2	2	1		8	3	12
1943					2		3	1	1	3	1		5	4	11
1944		1			1	1	4	2	1	3	2		8	5	15
1945	1			1			3	1	3	1	2	2	7	3	14
1946							3	3	2	3	2	2	8	5	15
1947		1		1		2	2	2	2	2	1	2	8	3	15
1948	1			1	1	1	2	2	2	3			7	3	13
1949				1	2	1	1	1	3	2			6	2	11
1950				1	1	2	2	1	3	1	1	1	8	2	13
1951						2	3	3		1	1	1	8	2	11
1952					1	1	3	2	1	4	2	1	7	6	15
1953	1			1		2		2	2	2	2		6	4	12
1954					1		1	2	3	2		2	6	2	11
1955					2	2		1	3	4	1	1	6	5	14

NOTE—All depressions and cyclones which have found a place in the *India Weather Review* (Annual Summaries) have been taken into account. From 1921 dates of tracks have been utilised

TABLE 2

Frequency distribution — Monthly

1890—1950 (61 years)

No. of depressions/ cyclones	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	52	59	57	37	23	12	10	2	1	1	12	25	
1	9	2	4	24	30	27	12	19	12	22	18	28	
2					8	20	24	21	29	25	24	8	
3						2	13	12	15	10	6		
4							2	7	3	3	1		
5									1				
Total	9	2	4	24	46	73	107	125	132	114	88	44	768
Mean	·1	0	·1	·4	·7	1·2	1·7	2·1	2·2	1·9	1·4	·7	12·6
% of annual	1·2	·2	·5	3·2	6·0	9·5	14·0	16·3	17·1	15·1	11·4	5·6	
Median	0	0	0	0	1	1	2	2	2	2	2	1	
Highest	1	1	1	2	2	3	4	4	5	4	4	2	
Year	1948	1947 1944	1938	1953	1949	1904 1917	1927 1944	1940	1891	1931	1922	1954	
Ratio of highest to average	6·7	33	14	5	2·7	2·5	2·2	1·9	2·3	2·1	2·9	2·9	
Standard deviation	0·37	0·18	0·79	0·53	0·65	0·79	1·07	1·06	0·88	0·89	0·97	0·68	
Coefficient of variability(%)	247	600	357	133	87	66	61	52	41	48	67	94	
Mean deviation	0·25	0·06	0·13	0·49	0·57	0·65	0·87	0·82	0·68	0·67	0·84	0·59	

Percentage of annual frequency in the different seasons

January—March	2	October—December	23
April—May	9	June—October	72
June—July	24	July—October	62
July—August	30	September—October	32
August—September	33	July—September	47
June—September	57	June—November	83
October—November	26	July—November	74

TABLE 3
Frequency distribution — Annual

No. of depressions	1891–1900	1901–1910	1911–1920	1921–1930	1931–1940	1941–1950	1890–1920	1921–1950	1890–1950
7		1			1		1	1	2
8									
9									
10	3	3	2	1			8	1	9
11	2	1	2		1	2	6	3	9
12	1		3	1	3	2	4	6	10
13	3	2	2		1	2	7	3	10
14	1	1		4	2	1	2	7	9
15		1	1		2	3	2	5	7
16				1				1	1
17		1		3			1	3	4
Mean	11·7	12·0	11·9	14·5	12·5	13·1	11·8	13·4	12·6
Median	11·5	12	12	14	12·5	13	12	14	13
Highest	14	17	15	17	15	15	17	17	17
Year							1908	1921, 22,24	
Lowest	10	7	10	10	7	11	7	7	7
Year							1910	1938	
S.D.(*S*)	1·5	2·9	1·5	2·3	2·4	1·6	2·0	2·2	2·23
w/*S*	2·7	3·4	3·3	3·0	3·4	2·5	5·0	4·5	4·5
Mean deviation	1·3	2·4	1·1	1·8	1·7	1·3	1·59	1·74	1·79
M.d./*S*	·9	·8	·73	·8	·7	·8	·79	·78	·80
Coefficient of variation(%)							17	16	17

$S^2_{max.}/S^2_{min.}=3\cdot88$

TABLE 4
Frequency distribution — June-September

No. of depressions	1891–1900	1901–1910	1911–1920	1921–1930	1931–1940	1941–1950	1890–1950
2					1		1
3		1					1
4		1	1				2
5	2		2	1		1	6
6	1	2	1	2	2	1	9
7	1	3	4	1	3	3	15
8	2	1	1	3	2	5	15
9	2	1	1	1	2		7
10	2			1			3
11		1		1			2
Mean	7·7	6·8	6·5	7·8	6·9	7·2	7·16
Median	8	7	7	8	7	7·5	7
Highest	10	11	9	11	9	8	11
Lowest	5	3	4	5	2	5	2
S.D.(*S*)	1·9	2·3	1·5	1·9	2·0	1·0	1·79
Mean deviation							1·26
Coefficient of variation(%)							25
% frequency in groups 6—8							64
w/*S* (Range/S.D.)	2·6	3·5	3·3	3·2	3·5	3·0	5·0

$S^2_{max.}/S^2_{min.}=5$

TABLE 5

Frequency distribution — October-November

No. of depressions	1891–1900	1901–1910	1911–1920	1921–1930	1931–1940	1941–1950	1890–1950
1	1	1					2
2	4	2	2	1	1	2	13
3	3	3	3	3	5	5	22
4	2	3	2	2	4	1	14
5		1	2	4		2	9
6							
7			1				1
Mean	2·6	3·1	3·8	3·9	3·3	3·3	3·31
% of annual							26·2
Standard deviation	·97	1·20	1·55	1·15	·68	1·06	1·16
Coefficient of variability(%)							35
Mean deviation							0·97
Median	2·5	3	3·5	3·5	3	3	3
Highest	4	5	7	5	4	5	7
w/S	3	3·3	3·3	2·6	3·0	2·9	5·2

$S^2_{max.}/S^2_{min.} = 5{\cdot}2$

TABLE 6

Means for different periods

Period	Annual	Jun–Sep	Oct–Dec	Period	Annual	Jun–Sep	Oct–Dec
(1) *20-year period*				(4) *50-year period*			
1891-1910	11·85	7·25	3·5	1891-1940	12·52	7·14	4·06
1911-1930	13·20	7·15	4·6				
1931-1950	12·80	7·05	4·1	(5) *60-year period*			
(2) *30-year period*				1891-1950	12·62	7·15	4·07
1891-1920	11·87	7·00	3·87	(6) 1890-1950 (61 years)	12·59	7·15	4·03
1921-1950	13·37	7·30	4·27				
(3) *40-year period*				(7) 1890-1955 (66 years)	12·56	7·12	4·09
1891-1930	12·53	7·20	4·05				

TABLE 7

1893–1896	13·1	1913–1916	13·0	1933–1936	12·3
1897–1900	10·3	1917–1920	12·3	1937–1940	12·7
1901–1904	12·7	1921–1924	15·7	1941–1944	12·5
1905–1908	13·0	1925–1928	13·5	1945–1948	14·3
1909–1912	9·3	1929–1932	13·1	1949–1952	12·5

TABLE 8

d	1891–1920	1921–1950	1891–1950	d	1891–1920	1920–1950	1890–1950
—8	1	1	2	1	5	3	8
—7	0	0	0	2	1	2	3
—6	0	1	0	3	4	0	4
—5	0	1	1	4	0	1	1
—4	0	1	1	5	2	1	3
—3	4	1	5	6	0	2	2
—2	3	4	7	7	0	0	0
—1	4	6	10	8	0	1	1
0	6	6	12				

If x_n is the number of depressions in year n, then $d = x_n - x_{n-1}$

TABLE 11

Fitting of normal curve to the frequency distribution

No. of depressions	Observed frequency	Expected frequency	$\frac{(\text{Obs.—Exp.})^2}{\text{Exp.}}$
7	2	2·04	0
8	0	3·03	3·03
9	0	5·58	5·58
10	9	8·43	0·24
11	9	10·45	0·20
12	10	10·64	0·04
13	10	8·89	0·14
14	9	6·09	1·39
15	7	3·43	3·71
16	1	1·58	0·22
17	4	0·67	16·55
		Total	31·10

$\chi^2 = 31 \cdot 10$ with D.F. 60 is *not* significant showing that the fit is not good

TABLE 9

		Annual			Monsoon		
		1890–1920	1920–1950	1890–1950	1890–1920	1920–1950	1890–1950
(*i*)	$d = 0$	6	6	12	4	4	8
	% of total	20	20	20	13	13	13
(*ii*)	$\vert d \vert \leqslant 2$	19	21	40	22	21	43
	% of total	63	70	67	73	70	72
(*iii*)	$\vert d \vert \leqslant 3$	27	22	49	23	26	49
	% of total	90	73	82	77	87	82
(*iv*)	$\vert d \vert \leqslant 4$	28	24	52	28	27	55
	% of total	90	80	85	93	90	92

TABLE 10

Period	g_1	S.E. of g_1	Col. 2 / Col. 3	g_2	S.E. of g_2	Col. 5 / Col. 6
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1890–1920	0·2900	0·4205	0·69	0·7552	0·8208	·92
1921–1950	0·5595	0·4269	1·3	1·0160	0·8237	1·2
1890–1950	—0·0581	0·3063	·19	0·0011	0·6039	·002

TABLE 12

No. of depressions	Frequency of No. of months Jan–Dec	Jun–Sep	Jun–Nov
0	291	25	38
1	207	70	110
2	159	94	143
3	58	42	58
4	16	12	16
5	1	1	1
n(No. of months)	732	244	366
Total	768	437	639
Mean (m_1)	1·05	1·79	1·75
S.D.	1·07	1·03	1·00
Mean deviation	0·8623	0·8211	0·7826
Mean deviation / S.D.	0·8059	0·7972	0·7826
g_1	·7819	·2229	·2354
S.E. (g_1)	·0903	·1559	·1273
g_2	—·1190	—·1997	—·1523
S.E. (g_2)	·1805	·3105	·2544

TABLE 13

Mean (1890—1950)=12·59, S=2·23, n—2=59

Decade	t	P (t)	Significant at 5 per cent
1891–1900	—1·395	·08333	No
1901–1910	—1·0753	·20615	No
1911–1920	—1·0753	·14115	No
1921–1930	3·146	·99871	Yes
1931–1940	—0·1388	·44480	No
1941–1950	0·7917	·78651	No

TABLE 14

10-year period

Variation due to	S. S.	D. F.	M. S.	F
Between periods	55·28	5	11·06	2·48
Residual	240·90	54	4·46	
Total	296·18	59		

F is just significant at 5% but not at 1%

TABLE 15

11-year period

Variation due to	S. S.	D. F.	M. S.	F
Between periods	26·44	5	5·288	
Residual	291·82	60	4·864	
Total	318·26	65		1·0872

F is not significant

TABLE 16

Progressive analysis of variance

Degrees of freedom Regression A	Residual B	Residual $1-R^2$ C	Whole regression R^2 D	Last variate E	F Whole regression B.D./A.C.	t^2 Last variate B.E./C	
0	60	1·0000					
1	59	0·9445	0·0555	0·0555	3·4669	3·4669	Not significant
2	58	0·9398	0·0602	0·0047	1·8576	0·2901	
3	57	0·9311	0·0689	0·0087	1·4060	0·5326	
4	56	0·9184	0·0816	0·0127	1.2439	0·7744	

TABLE 17

January to December

Variation due to	S.S.	D.F.	M.S.	F
Between months	389·62	11	35·42	54·49
Between years	24·90	60	0·410	0·63
Residual	427·71	660	0·65	
Total	842·23	731		

TABLE 19

C. C. between any month and the succeeding month (January — May)

January—February	—·08
February—March	—·05
March—April	—·08
April—May	—·35

TABLE 18

June to September

Variations due to	S.S.	D.F.	M.S.	F
Between months	4·11	3	1·37	1·19
Between years	48·09	60	0·80	0·70
Residual	206·14	180	1·15	
Total	258·34	243		

TABLE 21

C. C. between monsoon season (June—September) and October—November

1891—1920	—0·26
1921—1950	0·18
1891—1950	0·07

TABLE 20

Inter C. Cs. between months (May to December)

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
May		·0631	—·1552	—·0594	—·0815	·1131	—·026	—·2177
Jun			·0790	·0121	—·0462	—·1784	·0532	—·0247
Jul				—·0669	—·1273	0	·1140	·0682
Aug					—·1095	—·0418	—·0450	—·1002
Sep						—·1388	—·0704	·0452
Oct							—·2246	—·1415
Nov								·1147

TABLE 22

Period (years)	R_p^2	mp	$R_p^2/(4\sigma^2/N)$	$R_p^2/(4S^2/N)$	g
2	0·0625	64	0·2097	0·2045	·00639
3	0·3669	63	1·2309	1·1674	·03706
4	0·6114	64	2·0510	2·0007	·06252
5	0·0918	65	0·3080	0 3057	·00941
6	0·0311	60	0·1043	0·0922	·00319
7	0·5003	63	1·6783	1·5918	·05054
8	0·3783	64	1·2690	1·2379	·03868
9	0·1700	63	0·5703	0·5409	·01717
10	0·3637	60	1·2201	1·0783	·03594
11	0·2004	55	0·6723	0·5279	·01920
12	0·0504	60	0·1691	0·1494	·00498
13	0·1621	65	0·5438	0·5398	·01661
14	0·0883	56	0·2962	0·2602	·00831
15	0·0457	60	0·1533	0·1355	·00452
16	0·0947	64	0·3177	0·3099	·00968
17	0·4953	51	1·6615	1·1586	·04544
18	0·3713	54	1·2456	0·9639	·03570
19	0·5770	57	1·9356	1·5873	·05569
20	0·6515	60	2·1855	1·9315	·06438
21	0·5542	63	1·8591	1·7633	·05598
22	0·6021	44	2·0198	1·2662	·05756
23	0·5709	46	1·9151	1·3103	·05698
24	0·2870	48	0·9628	0·7220	·03008
25	0·3904	50	1·3096	0·8841	·03536
26	0·3989	52	1·0027	0·7264	·02793
27	0·3299	54	1·1067	0·8564	·03172
28	0·3095	56	1·0382	0·8160	·02974
29	0·3886	58	1·3036	1·0858	·03744
30	0·3162	60	1·0607	0·9374	·03125

$R_p^2 = A_p^2 + B_p^2$; mp=No. of observations used in working out R_p. σ (standard deviation) is based on all the observations—65. S.—S. D. based on the actual number of observations used in R_p. $g = R_p^2 / 2S^2$.

5% significant values: $R_p^2/(4\sigma^2/N) = 2{\cdot}996$ $g = 0{\cdot}095$ ($n = 30$).

TABLE 23

	1891—1910	1911—1930	1931—1950	1890—1920	1921—1950
δ^2	7·842	9·895	9·053	6·533	9·931
S^2	4·97	5·16	3·76	3·89	4·77
δ^2/S^2	1·58	1·92	2·41	1·68	2·08
d	2·050	2·200	1·900	1·871	2·133
S	2·229	2·272	1·939	1·972	2·184
d/S	0·92	0·97	0·98	0·95	0·98

Significant values :—		$n=20$	$n=30$
	5% δ^2/S^2	1·368	1·4672
	5% d/S	1·41	1·35

None of the values of δ^2/S^2 and d/S is significant even at 5 per cent level. The series may be regarded as independant.

TABLE 24
Correlation coefficients

s	$(n-s)C_s$	r_s	s	$(n-s)C_s$	r_s
1	+32	+0·1045	29	−6	−0·0332
2	−21	−0·0686	30	−65	−0·3625
3	+16	+0·0539	31	+11	+0·0666
4	−18	−0·0598	32	−2	−0·0126
5	+52	+0·1758	33	+23	+0·1667
6	+23	+0·0769	34	−1	−0·0080
7	+15	+0·0504	35	−47	−0·4068
8	+34	+0·1170	36	+21	+0·1852
9	−22	−0·0770	37	−9	−0·0825
10	−4	−0·0143	38	+3	+0·0289
11	−34	−0·1226	39	+24	+0·2315
12	−5	−0·0180	40	−5	−0·0487
13	+13	+0·0478	41	+5	+0·0497
14	−26	−0·0967	42	−16	−0·1669
15	+32	+0·1197	43	+12	+0·1264
16	−4	−0·0153	44	+32	+0·3439
17	−19	−0·0762	45	−7	−0·0856
18	+15	+0·0629	46	−10	−0·1308
19	+13	+0·0566	47	−23	−0·3800
20	+25	+0·1111	48	−11	−0·1976
21	+18	+0·0876	49	+5	+0·1221
22	−13	−0·0651	50	−10	−0·2687
23	+22	+0·1136	51	+16	+0·4444
24	−7	−0·0367	52	+14	+0·4746
25	−18	−0·0947	53	+4	+0·1466
26	+8	+0·0416	54	+3	+0·1186
27	−28	−0·1454	55	−5	−0·2179
28	+41	+0·2238			

TABLE 25

ω (degrees)	f_B (ω)	ω (degrees)	f_B (ω)
6·0	6·8104	28·0	3·3981
9·0	6·8346	30·0	3·2645
12·0	6·3484	32·7	3·2946
15·0	5·8906	36·0	3·6439
18·0	5·2951	40·0	4·4237
20·0	4·8440	45·0	5·5849
24·0	3·9965	48·0	6·1787
26·0	3·6495	51·0	6·5874
26·5	3·5095	54·0	7·1543
27·0	3·5101	57·0	6·7260
27·69	3·4295	60·0	6·5081