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Increase in annual frequency of the severe cyclonic storms of the Bay after 1964 — Possible causes

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ABSTRACT. The series of annual frequency of severe cyclonic storms which struck the coast around the Bay of Bengal during the period 1877-1977 has been examined to find out if any significant change has occurred in the mean frequency. It is observed that while the series for the period is homogeneous, a highly significant increase in the mean annual frequency has occurred after 1964. The larger annual mean frequency may be due to better facilities of detection of severe storms and/or meteorological conditions over the Bay being more frequently favourable for intensification of storms into severe storms. An estimate of the mean annual frequency is made for the next 50-year period and the frequency distribution on the basis of this mean is given for the period, utilising the Poisson probability model which has shown good fit to past data.

1. Introduction

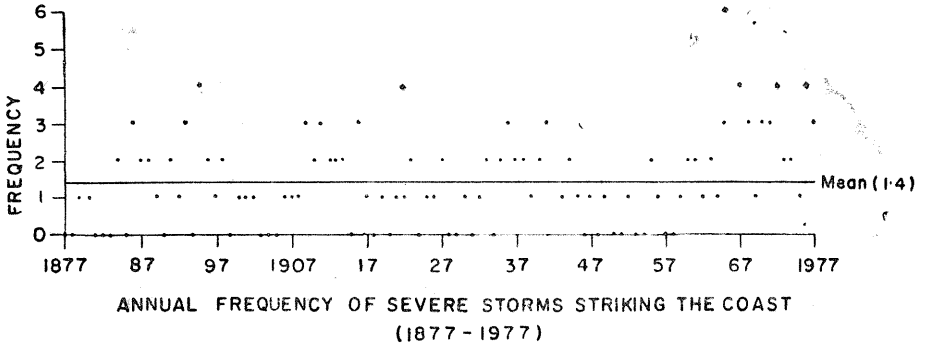
Severe cyclonic storms are natural calamities for the coastal districts struck by them. Enormous damage to property, loss of life and dislocation in the means of communication result from extremely strong winds, phenomenal rains and tidal waves. In this study, it is proposed to examine the long series of the severe cyclonic storms of the Bay of Bengal which struck the coast to find out if there has been any significant change in the mean frequency of these systems.

2. Data

All the severe cyclonic storms which struck the east coast of Sri Lanka, east coast of India, Bangla Desh coast and Arakan coast of Burma during the period 1877-1977 have been considered. Hereafter, this coast around the Bay would be referred to as the coast. Data in respect of the severe storms which struck the coast have been collected from the tracks of Storms and Depressions over the Bay of Bengal and the Arabian Sea published by the India Meteorological Department (1964) for the period 1877-1960, the supplement to this publication for the period 1961-70, articles in the *Indian Journal of Meteorology, Hydrology and Geophyics* giving accounts of storms and depressions by Das *et al.* (1972, 1973); Alexander *et al.* (1974, 1976, 1977) and Pant *et al.* (1978), for the period 1971-76. Information for 1977 was extracted from the account of storms and depressions prepared by the office of the Deputy Director General of Meteorology (Weather Forecasting), Pune.

2. Scrutiny of data

Fig. 1 shows the annual frequency of the severe storms from the Bay which struck the coast. A careful examination of this figure suggests that during ihe period 1877-1964, the variation in the annual frequency is generally small. However, thereafter, the frequency appears to have increased appreciably during the period 1965-77. Table 1 gives the means for the periods 1877-1977, 1877-1964, 1965-1977, successive 13-year periods commencing from 1877 and for the period 1886-98 which had the highest mean for a 13-year period prior to 1965. It is seen that the mean for 1965-77 is much higher than the highest mean for a 13-year period prior to 1965. Before any statistical test is applied to find out if any significant change in the level of the mean has



ANNUAL FREQUENCY OF SEVERE STORMS STRIKING THE COAST
(1877 - 1977)

Fig. 1

TABLE 1

Mean annual frequency of severe storms which struck the coast during different periods

Period	Mean	Period	Mean
1877-1977	1.40	1916-1928	1.23
1877-1964	1.16	1929-1941	1.46
1965-1977	3.00	1942-1954	0.62
1877-1889	0.92	1952-1964	1.00
1890-1902	1.38	1886-1998	1.77
1903-1915	1.31		

taken place, it may be appropriate to examine whether the event of severe cyclonic storm striking the coast is random. This can be done by applying Mann-Kendall rank statistic test for randomness against trend to the series of time intervals between successive severe storms striking the coast. The time interval series was obtained from the days of striking the coast. The test has been applied to (*i*) the whole series of 140 terms, (*ii*) the series obtained from the 102 severe storms during the period 1877-1964, (*iii*) three equal components of series

TABLE 2

Results of Mann-Kendall rank statistic test for randomness against trend applied to the series of time interval between successive severe storms striking the coast

S. No.	Period covered by series	No. of terms	Test statistic (T)	Limits beyond which T is significant at 5% level
1	1877-1977	140	−0.125*	±0.112
2	1877-1964	101	0.067	±0.132
3	1965-1977	38	0.081	±0.222
4	First half of series at S. No. 2	51	−0.070	±0.189
5	Second half of series at S. No. 2	50	0.059	±0.191
6	First one-third of at S. No. 2	34	−0.011	±0.236
7	Second one-third of series at S. No. 2	34	0.216	±0.236
8	Last one-third of series at S. No. 2	33	0.191	±0.239

*Value significant at 5 per cent level

TABLE 3

Fit of the Poisson distribution to Y, the number of severe storms striking the coast in a year (1877-1964)

Y	f_0	f_p
0	28	27.58
1	29	32.00
2	22	18.57
3	7	7.18
4	2	2.08
$\geqslant 5$	0	0.59

Variance test : Chi-square goodness-of-fit test :

Test statistic, $\chi_{87}^2 = 80.3$ Test statistic $\chi^2 = 1.09$ (d.f.3)

$P(\chi^2 > 80.3) = 0.67$ (d.f.87) $P(\chi^2 > 1.09) = 0.77$ (d.f.3)

Note : f_0 is observed frequency and f_p is frequency on Poisson hypothesis.

obtained from the severe storms during the period 1877-1964, (*iv*) the series obtained from the severe storms of the period 1965-77. The results of these tests are indicated in Table 2. It can be seen from this table that the whole series is indicating trend significant at 5 per cent level, but neither the series for the period 1877-1964 nor any of its three equal components is showing any significant trend. The series for the period 1965-77 is also not indicating any trend. Thus the event of severe storm striking the coast can be generally taken to be random. The trend suggested for the whole series appears to be due to the higher mean during the period 1965-77.

3. Probability distribution

The random variable under consideration is the number of severe storms striking the coast in a year. Since two successive events of the coast being struck by severe storm are widely separated they could be taken as independent of each other. The low probability of the event would suggest that Poisson distribution may be a good fit to the number of events in a year. Poisson model has been fitted to the data for the period 1877-1964 and the the fit has been tested by the variance test suggested by Cochran (1964) and the Chi-square goodness-of-fit test. The results are given in Table 3. The test statistic for the variance test is :

$$\chi_{n-1}^2 = \frac{n \Sigma Y_i^2}{\Sigma Y_i} - \Sigma Y_i$$

where, n is the number of years of data, Y is the random variable, *viz.*, the number of severe storms striking the coast in a year. χ_{n-1}^2 is to be referred to Chi-square table for n-1 degrees of freedom to test its significance at the prefixed level. It is seen from Table 3 that the fit of the Poisson probability model is very good.

4. Testing significance of change in the level of the mean

Cochran (*loc. cit.*) has given the test statistic for testing the significance of the change in the level of the mean when the variable is distributed according to Poisson probability model. It n is the total period of the record, n_1 and n_2 are its two component periods ($n_1 + n_2 = n$) and $\bar{y}$, $\bar{y}_1$ and $\bar{y}_2$ are the means based on n, n_1 and n_2 years of data, then according to Cochran (*loc. cit.*) the significance of the change in the level of the mean after n_1 years can be tested by the following test statistic :

$$\chi^2 = \frac{n_1 n_2 (\bar{y}_1 - \bar{y}_2)^2}{(n_1 + n_2)\bar{y}} \quad \text{d.f. 1}$$

χ^2 has to be referred to Chi-square tables for 1 degree of freedom (d.f. 1).

The changes in the level of the mean (*i*) from the period 1877-1920 to the period 1921-64, (*ii*) from 1877-1926 to 1927-77, (*iii*) from 1952-64. to 1965-67 and (*iv*) from 1877-1964 to 1965-77, were tested for significance. The results are given in Table 4. It is seen from this table that the changes in the mean annual frequency of the severe storms striking the coast from 1952-64 to 1965-77, and from 1877-1964 to 1965-77, are highly significant. Thus after 1964 the mean appears to have changed in a highly significant way. As no trend is observed during the period 1965-77, it appears that the mean slipped up significantly after 1964.

TABLE 4

Change in the level of the mean frequency of severe storms striking the coast

Total period	Mean for total period ($\bar{y}$)	Sub-period	Mean for sub-period ($\bar{y}_1$)	Remaining period	Mean for remaining period ($\bar{y}_2$)	χ^2, (d.f.1) test statistic
1877-1964	1.16	1877-1920	1.18	1921-64	1.14	0.03
1877-1977	1.40	1877-1926	1.22	1927-77	1.57	2.21
1952-1977	2.00	1952-1964	1.00	1965-77	3.00	13.00
1877-1977	1.4	1877-1964	1.16	1965-77	3.00	21.76

Note : χ^2 exceeding 3.84 is significant at 5 per cent level, and exceeding 7.88 is significant at 1 per cent level.

TABLE 5

Mean annual frequency of storms which formed over the Bay, efficiency of intensification of storms into severe storms over the Bay, and the ratio, severe storms/storms which struck the coast for different periods

Period	Mean annual storm frequency	Efficiency of intensification	Severe storms/storms which struck the coast
1877-1977	4.49	0.37	0.40
1877-1964	4.35	0.33	0.35
1965-77	5.38	0.63	0.66
1877-89	3.77	0.26	0.31
1890-1902	4.31	0.34	0.36
1903-1915	4.92	0.30	0.30
1916-28	4.69	0.31	0.36
1929-41	5.38	0.34	0.39
1942-54	3.54	0.28	0.28
1952-64	3.46	0.47	0.43
1886-98	5.69	0.32	0.35
1924-36	5.69	0.22	0.25
1932-44	5.46	0.38	0.47

5. Examination of storm frequency

The larger number of severe storms striking the coast during the period 1965-77 could be due to (*i*) the larger number of storms combined with normal efficiency of intensification into severe storms or (*ii*) approximately normal frequency of storms combined with higher than normal efficiency of intensification. To resolve this matter, information was obtained in respect of the mean frequency of storms which formed over the Bay, efficiency of intensification of storms into severe storms over the Bay, and the ratio, severe storms/storms which struck the coast, for 1877-1977, 1877-1964, 1965-77, for successive 13-year periods commencing from 1877, 1952-64, and three 13-years periods prior to 1965 for which the mean annual frequency of severe storms exceeded that for the period 1965-77. It is seen that prior to 1965, there were some 13-year periods when the number of storms which formed over the Bay exceeded that during the period 1965-77. Applying the test for the change in the level of the mean frequency of storms after 1964, *i.e.*, from the period 1877-1964 to the period 1965-77, as suggested by Cochran (*loc. cit.*) we get the test statistic, $\chi^2 = 2.68$ (d. f. 1) which shows that the increase in the mean frequency of storms is not significant even at 10 per cent level. The mean efficiency of intensification of storms into severe storms for the period 1877-1964 is 0.33 and generally lies between the limits 0.33 ± 0.10 for all the 13-year periods except for the period 1965-77 for which there is a sharp increase to 0.63. The ratio, severe storms/storms which struck the coast is 0.35 for the period 1877-1964, and

TABLE 6

Expected frequency distribution (number of years) of severe storms striking the coast during the next 50 years (1978-2027 A. D.) on the assumption of (A) mean being maintained at the plateau level, *viz.*, 3.0 per year (B) mean falling to 2.1 from the present level of 3.0 per year

No. of severe storms striking the coast	Frequency (A)	Frequency (B)	(A)—(B)
0	3	6	—3
1	7	13	—6
2	11	13	—2
3	11	10	1
4	8	5	3
5	5	2	3
⩾6	4	1	3

generally lies between 0.35 ± 0.10 for all the 13-year periods except for the period 1965-77 for which there has been a sharp increase to 0.66. Thus, after 1964, a much higher percentage of the cyclonic storms appears to have intensified into severe storms. Satellite cloud pictures became available on a routine basis from about the same time. During the course of the last 15-20 years, the network of coastal observatories has improved. Storm detection radars became available at some of the coastal stations after 1970. Satellite pictures, better network of coastal observatories and storm detection radars contributed to more efficient detection of severe cyclonic storms. However, estimation of storm intensity from satellite picture configurations and radar pictures is based on empirical relationship. Gray (1979) has mentioned that the relationship between satellite cloudiness configurations and intensity is quite complex and significant difficulties in intensity determination can occur in individual situations and Arnold (1977) has documented these cases for the west Pacific, and that for proper estimation of storm intensity from the satellite pictures adequate interpretation experience is essential. In view of this, it is felt that only a fraction of the increase in severe storm frequency after 1964 can be attributed to better detection of severe storms by satellite pictures. It is seen from the records for the period prior to 1965 when improved network of coastal observatories, satellite and radar pictures were not available, there were periods when higher percentage of storms intensified into severe storms, suggesting meteorological conditions over the Bay being more often favourable for storm intensification during these periods. Thus more often favourable meteorological conditions over the Bay also contributes to higher percentage of storms intensifying into severe storms. Better severe storm detection resulting from the additional facilities, and more often favourable meteorological situations over the Bay appear to be the two factors which have resulted in higher frequency of severe storms during the period 1965-77. Apportionment of the contribution by these two factors is very difficult.

6. Climatological outlook

The mean frequency of severe storms striking the coast was fairly stable during the long period of 1877-1964. However, it sharply rose up to a plateau after 1964 and maintained itself at the plateau level during the period 1965-77. The question of great concern is, will the mean be maintained at the plateau level for long? If the mean is to maintain itself at the plateau level for a long time, like 50 years, then in the next 50 years the number of years with 0, 1, 2, etc. severe storms striking the coast would be approximately as shown in Table 6, on the basis of the Poisson distribution. It is difficult to expect that mean would remain at the plateau level for as long a period as 50 years. Considering the period 1877-1964, the highest 20-year mean slightly exceeds 1.5, whereas the highest 30-year, 40-year and 50-year means are around 1.4. It is felt that a 50 per cent increase due to better detection of severe storms from the use of satellite and radar pictures over and above the highest 50-year mean of 1.4 before 1965 could be considered quite rational. On this basis, the mean for the next 50-year period could be estimated as 2.1. With this mean, the annual frequency distribution that could be expected in the next 50-year period (1978-2027 AD) would be as indicated in Table 6.

7. Conclusion

In the long record of the severe Bay storms which struck the coast during the period 1877-1977, the mean annual frequency of the

severe storms striking the coast has slipped up significantly after 1964. The large annual mean appears to be due to better facilities of detection of severe storms and meteorological conditions over the Bay being more often favourable for intensification of storms into severe storms.

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