Mausam, (1983), **34**, 2, 139-152

551.515.2(267)

A study of the cyclonic storms incident on the different sections of the coast around the Bay of Bengal

D. A. MOOLEY and C. M. MOHILE

Indian Institute of Tropical Meteorology, Pune

(*Received 4 April 1981*)

सार — यह 1877-1980 की अवधि में बंगाल की खाड़ी तट के विभिन्न खण्डों पर आपतित सभी झंझाओं/भीषण झंझाओं का अध्ययन है। इसमें खाड़ीतट, पूर्वी भारत तट और सम्पूर्ण खाड़ीतट के प्रत्येक खंड पर आपतित झंझाओं/भीषण झंझाओं की प्रवृत्ति, उनकी माध्य बारंबारता में परिवर्तन और भीषण झंझाओं एवं झंझाओं के अनुपात में परिवर्तन का परीक्षण किया गया है। बंगलादेश तट पर आपतित झंझाओं की माध्य वार्षिक बारंबारता 1965-80 तक की अवधि में बहुत ही महत्वपूर्ण वृद्धि को प्रदर्शित करती है। आंध्र प्रदेश, बंगलादेश पूर्वी भारत और खाड़ीतटों पर की भीषण झंझाओं के लिए माध्य वार्षिक एवं माध्य मानसूनोत्तर ऋतु बारंबारता उसी अवधि में बहुत महत्वपूर्ण वृद्धि को प्रदर्शित करते हैं। इसमें झंझाओं/ भीषण झंझाओं के आपतन में अतिसार्थक वृद्धि के संभावित कारण भी दिए गए हैं। खाड़ीतट विभिन्न खंडो पर पहुँचने वाली झंझाओं के उद्गम स्थलों को भी ज्ञात किया गया है। खाड़ी के विभिन्न क्षेत्रों पर बनने वाली विभिन्न झंझाओं और उनमें खाड़ी तट के खंडो तक पहुँचने वाली झंझाओं की संख्याओं को भी दर्शाया गया है। एक वर्ष/ऋतु में आए 0, 1, 2, 3 इत्यादि झंझाओं को बारंबारताएं प्वासां प्रायिकता निदर्श के संगत प्राप्त हुई है। अन्ततः इसमें आगामी 50 वर्षों के लिए माध्य वार्षिक बारंबारता का आकलन किया गया है। पुनः इस माध्य का उपयोग करके प्वासाँ प्रायिकता निदर्श के आधार पर 1, 2, 3, 4, इत्यादि झंझाओं की बारंबारता निकाली गई है। ये बारंबारताएं झंझाओं के विनाश से प्रभावित व्यक्तियों को राहत पहुँचाने वाली राशि को व्यवस्था करने या झंझाओं से विनाश वाले क्षेत्रों में उनकी हित के लिए उपयुक्त बीमा योजना बनाने में उपयोगी होंगी।

ABSTRACT. The study covers all the storms/severe storms incident on the different sections of the Bay coast during 1877-1980. The series of storms/severe storms have been examined for trend, changes in mean frequency and changes in the ratio of severe storms to storms incident on each section of the Bay coast, the east India coast and the whole Bay coast. The mean annual frequency of storms incident on Bangladesh coast shows a highly significant increase during the period 1965-80. For the severe storm serie sfor the Andhra Pradesh, the Bangladesh, the east India and the Bay coasts, mean annual and mean post-monsoon season frequency shows a highly significant increase in the same period. Possible causes have been given for the highly significant increase in the incidence of storms/severe storms. Locations of the origin of storms reaching different sections of the Bay coast have been brought out. The number of storms which form over each of the different sectors of the Bay and of these, the numbers which reach each of the sections of the Bay coast have been indicated. The frequency of 0, 1, 2, 3, etc storms in a year/season are found to be consistent with the Poisson probability model. Finally, mean annual frequency has been estimated for the next 50-year period and using this mean, frequencies of 1, 2, 3, 4 etc storms in a year have been worked out on the basis of the Poisson probability model. These frequencies may be useful for planning funds to mitigate the hardship of the people affected by storm havoc or for evolving a suitable insurance scheme for the benefit of the areas liable to storm havoc.

1. Introduction

Cyclonic storms are natural calamities which are as old as Man. Over the sea, they can severely damage a ship or a vessel which gets into its inner core of strong winds. When they strike the coastal belt, they cause considerable destruction due to strong winds, torrential rains and tidal wave. In view of their destructive impact on human society these have been the objects of study for the past few centuries. After gaining some knowledge of these systems, the practice of foretelling these developed on account of the pressing demands of shipping, aviation, industry and Government Departments and efforts continued to be made to improve the art of foretelling. To face these calamities there are three options :

(*i*) To develop method of prediction of these phenomena with requisite accuracy in space and time sufficiently in advance and arrange for quick action to warn the concerned population and to provide facilities as may be necessary to protect the population from the destructive effects of these systems.

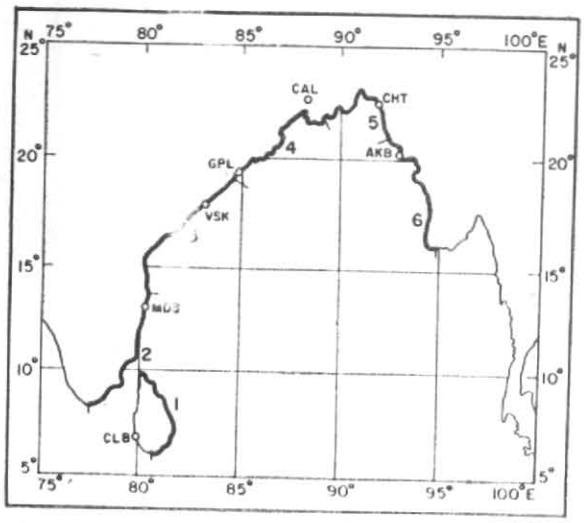


Fig. 1. Map showing different sections of the Bay coast

1 East Sri Lanka	2 Tamil Nadu
3 Andhra Pradesh	4 Orissa-West Bengal
5 Bangladesh	6 Arakan

(*ii*) To study the probabilistic nature of these calamities and use this knowledge in the planning of shelters and requisite funds for mitigating the hardships to the concerned population, or for evolving a suitable insurance scheme to provide cover against storm risk.

(*iii*) To depend on the generosity and sympathy of the unaffected population of the country and on the assistance of the State and the Central Governments after the storm has caused havoc. This involves action only after the event, and by the time sufficient funds are collected, a lot of irreparable damage, physical and mental, is already done to the population. Option (*iii*) does not involve any action on the part of the Meteorological Community. Options (*ii*) and (*iii*) can be pursued simultaneously. The progress and the results achieved under option (*i*) still leave much to be desired by those who have to take action to protect the population. The present study is concerned with option (*ii*)

The storms and depressions in the Bay of Bengal have been studied by several workers (Rai Sircar 1956, 1958, Rao and Jayaraman 1958, Jayaraman 1961, Bhalme 1972, Raghavendra 1973 and Mooley 1980, 1981).

It is proposed to examine the series of cyclonic storms and severe cyclonic storms incident on the different sections of the coast around the Bay of Bengal, for trend and changes in the mean frequency in different periods, for changes in the proportion of storms incident as severe storms, for a suitable probability model and to obtain climatological expectations of the frequencies of the storms which may be useful for planning funds to ameliorate the lot of the people struck by the calamity.

2. Data sources

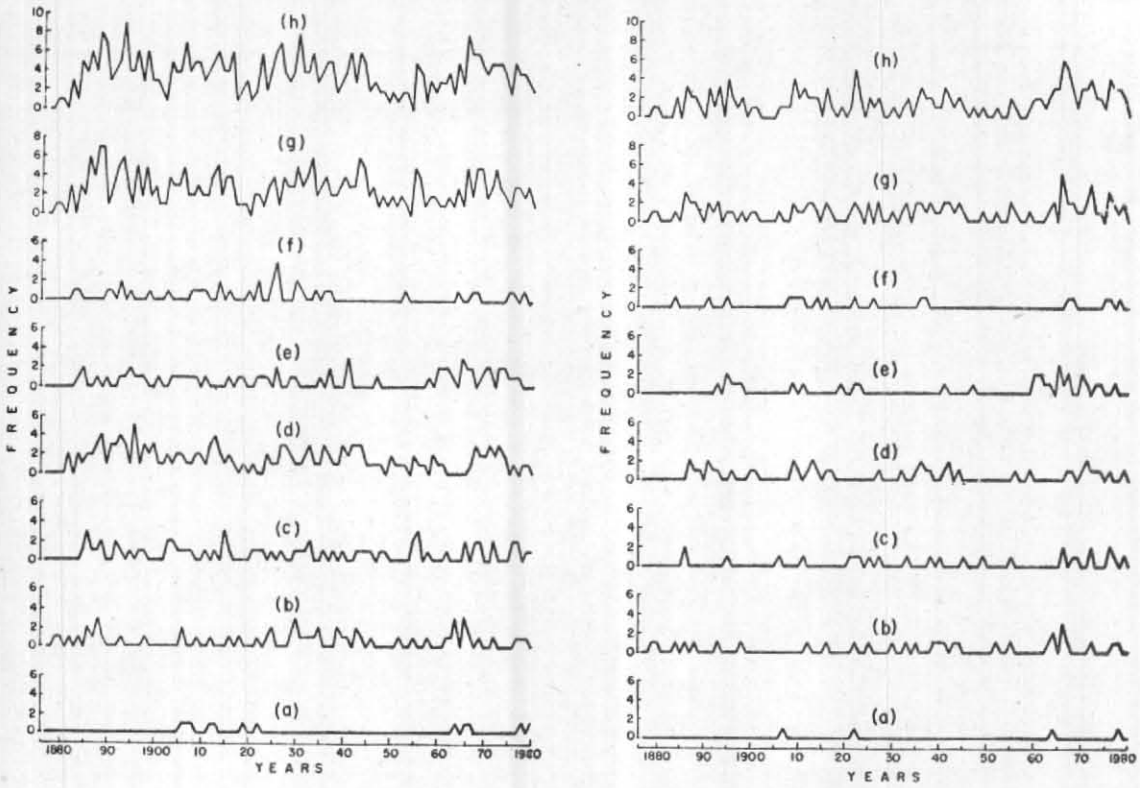
The period considered for this study is 1877-1980 since reliable cyclonic storm data are available only from 1877. The information in respect of storms and severe storms reaching the different sections of the coast around the Bay has been obtained from the India Meteorological Department publication (1979), "*Tracks of storms and depressions over the Bay of Bengal and the Arabian Sea* (1877-1970)" and from the accounts by Das *et al.* (1972, 1973), Alexander *et al.* (1974, 1976, 1977) and Pant *et al.* (1978), for the period 1971-76, and the tracks finalised by the office of the Deputy Director General of Meteorology (Weathet Forecasting), Pune, for the years 1977-79, and from the *Indian Daily Weather Reports* and the *Weather Charts* for 1980. In addition, the accounts for different years given in *India Weather Review* were also consulted.

3. Frequency of storms incident on the different sections of the Bay coast

The total coast considered around the Bay of Bengal and its different sections are shown in Fig. 1. The different sections and their lengths are: only east coast of Sri Lanka (500 km), Tamil Nadu coast (780 km), Andhra Pradesh coast (700 km), Orissa-West Bengal coast (600 km), Bangladesh coast (600 km.), Arakan coast of Burma (650 km). West Bengal and Orissa coasts being small in length have been combined to form one section. These sections together constitute the coast considered around the Bay, which hereafter, will be referred to as the Bay coast. Tamil Nadu, Andhra Pradesh and Orissa-West Bengal coasts together constitute east India coast.

The annual frequency of the cyclonic storms incident on each of the sections of the Bay coast, the east India coast and the Bay coast during the period 1877-1980 is given in Fig. 2 (i). The corresponding frequency for the severe cyclonic storms is given in Fig. 2 (ii).

The incidence of the cyclonic storms/severe cyclonic storms on the different sections of the Bay coast, the east coast of India, and the Bay coast in each of the months, in the summer (April-May), monsoon and the post monsoon seasons and the year during the period 1877-1980 is given in Table 1. It may be mentioned that a storm which crosses the coast at the boundary between two coasts is considered for each of the two



(i) Cyclonic storm (ii) Severe cyclonic storm

Fig. 2. Annual frequency of cyclonic storms reaching coasts of (a) East Sri Lanka, (b) Tamil Nadu, (c) Andhra Pradesh, (d) Orissa-West Bengal, (e) Bangladesh, (f) Arakan, (g) East India, (h) Around Bay

TABLE 1

Incidence of cyclonic storms (severe cyclonic storms) on the different sections of the Bay coast (1877-1980)

S. No.	Coast	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr-May	Jun-Sep	Oct-Dec	Annual
1	East Sri Lanka	1 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (2)	7 (1)	0 (0)	0 (0)	10 (3)	12 (4)
2	Tamil Nadu	3 (0)	0 (0)	2 (2)	1 (0)	7 (4)	0 (0)	0 (0)	0 (0)	0 (0)	6 (1)	27 (17)	12 (7)	8 (4)	0 (0)	45 (25)	58 (31)
3	Andhra Pradesh	1 (1)	0 (0)	0 (0)	1 (0)	6 (3)	4 (0)	1 (0)	1 (0)	5 (3)	27 (7)	20 (12)	2 (0)	7 (3)	11 (3)	49 (19)	68 (26)
4	Orissa-West Bengal	0 (0)	0 (0)	0 (0)	0 (0)	8 (7)	24 (3)	36 (7)	29 (4)	29 (8)	20 (9)	9 (5)	0 (0)	8 (7)	118 (22)	29 (14)	155 (43)
5	Bangladesh	0 (0)	0 (0)	0 (0)	2 (2)	13 (9)	11 (2)	4 (0)	1 (0)	2 (1)	16 (10)	8 (3)	6 (4)	15 (11)	18 (3)	30 (17)	63 (31)
6	Arakan	0 (0)	0 (0)	0 (0)	7 (4)	15 (9)	1 (1)	0 (0)	0 (0)	0 (0)	5 (1)	8 (3)	2 (0)	22 (13)	1 (1)	15 (4)	38 (18)
7	East India	4 (1)	0 (0)	2 (2)	2 (0)	20 (13)	28 (3)	37 (7)	30 (4)	34 (11)	53 (17)	56 (34)	13 (7)	22 (13)	129 (25)	122 (58)	279 (99)
8	Bay	5 (1)	0 (0)	3 (3)	11 (6)	48 (31)	40 (6)	41 (7)	31 (4)	36 (12)	74 (28)	75 (42)	28 (12)	59 (37)	148 (29)	177 (82)	392 (152)

TABLE 2

Number of cyclonic storms (severe cyclonic storms) reaching different sections of the Bay coast in different decades

S. No.	Coast	1881-90	1891-1900	1901-10	1911-20	1921-30	1931-40	1941-50	1951-60	1961-70	1971-80
1	East Sri Lanka	0	0	3	3	1	0	0	0	3	2
		(0)	(0)	(1)	(0)	(1)	(0)	(0)	(0)	(1)	(1)
2	Tamil Nadu	9	2	3	3	8	9	5	3	10	4
		(3)	(2)	(0)	(2)	(3)	(4)	(3)	(2)	(7)	(3)
3	Andhra Pradesh	8	6	8	6	6	7	6	6	7	8
		(2)	(1)	(1)	(1)	(5)	(3)	(2)	(1)	(4)	(6)
4	Orissa-West Bengal	17	27	15	15	14	18	17	10	9	13
		(4)	(6)	(4)	(6)	(1)	(6)	(4)	(2)	(3)	(7)
5	Bangladesh	5	7	7	4	7	3	4	3	14	9
		(0)	(6)	(1)	(2)	(2)	(0)	(2)	(2)	(12)	(4)
6	Arakan	3	5	4	5	10	4	0	1	3	3
		(1)	(2)	(3)	(3)	(2)	(2)	(0)	(0)	(2)	(3)
7	East India	33	35	26	24	28	33	28	19	26	25
		(9)	(9)	(5)	(9)	(9)	(12)	(9)	(5)	(14)	(16)
8	Bay	41	47	40	36	46	40	32	23	46	39
		(10)	(17)	(10)	(14)	(14)	(14)	(11)	(7)	(29)	(24)

coasts, since it poses almost equal amount of danger to both the coasts. The number of storms/ severe storms reaching east Sri Lanka, Tamil Nadu, Andhra Pradesh and Bangladesh coasts is highest in the post monsoon season (October-December) whereas that for Orissa-West Bengal coast and Arakan coast, is highest in monsoon and summer seasons respectively. When we consider the year as a whole, Orissa-West Bengal has the highest number of storms/severe storms.

Decadewise distribution of the storms/severe storms reaching the different sections of the Bay coast is given in Table 2. The main features of this table are, absence of storms/severe storms reaching east Sri Lanka coast during the decades ending with 1890, 1900, 1940, 1950, 1960, highest number of storms/ severe storms reaching Tamil Nadu coast during the decade 1961-70, a fairly even distribution of storms reaching Andhra Pradesh coast over the different decades, an unusually large number of storms reaching Orissa-West Bengal coast in the decade 1891-1900, an unusally high number of storms/severe storms reaching Bangladesh coast during the decade 1961-70 and practically no storm/ severe storm reaching Arakan coast during the period 1941–60.

4. Trend in the series of storms/severe storms

Cochran (1954) has given a test for linear trend when the variate is distributed according to Poisson probability law. It will be shown in the later section that the number of storms in a year is distributed according to the Poisson probability model. The test statistic for linear trend is :

$$\chi^2 = \frac{[\Sigma (Y_i - \bar{Y})(Z_i - \bar{Z})]^2}{\bar{Y} \Sigma (Z_i - \bar{Z})^2} \quad (1 \text{ d. f.})$$

and it is distributed as Chi-square with 1 d.f. Here Y_i is the number of storms/severe storms in a year or a season and Z_i is the time variable. The test has been applied to the annual and post monsoon series of storms/severe storms for the different sections of the Bay coast and monsoon series of storms/severe storms for Orissa-West Bengal coast. The results are given in Table 3. It is seen from this table that while the annual storm series for Bangladesh coast and the monsoon storm series for Orissa-West Bengal coast show trend significant at 10 per cent level, none of the series shows trend significant at 5 per cent level. However, so far as the severe storm series are concerned, the annual series for Andhra Pradesh coast and the post monsoon series for Bangladesh and east India coasts are showing trend significant at 5 per cent level, and the annual series for Bangladesh and Bay coasts, and the post monsoon series for the Bay coast are showing trend significant at 1 per cent level.

Thom (1960) tested for trend the annual series of tropical storms/hurricanes of southern north Atlantic by fitting linear regression equation to the year number as independent variable and transformed frequency as dependent variable

TABLE 3

Test for linear trend in the series of cyclonic storms/severe cyclonic storms reaching different sections of the Bay coast during the period 1877-1980

Coast	Series	Value of test-statistic, χ^2 (d.f.1)	
		for cyclonic storm	for severe cyclonic storm
East Sri Lanka	Annual	0.92	0.90
Tamil Nadu	Annual	0.25	1.35
Do	Post monsoon	0.38	1.26
Andhra Pradesh	Annual	0.27	4.99*
Do	Post monsoon	0.47	3.75†
Orissa-West Bengal	Annual	2.41	0.06
Do	Monsoon	2.85†	0.20
Bangladesh	Annual	3.10†	7.56**
Do	Post monsoon	1.28	5.36*
Arakan	Annual	0.87	0.01
East India	Annual	0.37	3.69†
Do	Post monsoon	0.61	4.26*
Bay	Annual	0.00	8.83***
Do	Post-monsoon	1.29	7.71**

Note : † Significant at 10%; * Significant at 5%;
** Significant at 1%; *** Significant at .5%.

and then applying the analysis of variance and the F-test. The same method has also been applied to the series of storms/severe storms for the different sections of the Bay coast and it is found that the results given in Table 3 are generally confirmed.

5. Changes in the mean frequency

The period of 104 years (1877-1980) was divided into four equal parts (quarters), P_1 (1877-1902), P_2 (1903-28), P_3 (1929-54), P_4 (1955-80) and two equal parts (halves), P_5 (1877-1928) and P_6 (1929-80). Change in the mean from P_1 to P_2, from P_2 to P_3 and from P_3 to P_4, as well as from P_5 to P_6 was tested by applying the method given by Cochran (1954). Since Mooley (1981) has brought out a significant change in the mean frequency of the severe storms for the Bay coast from the period 1877-1964 (P_7) to the period 1965-80 (P_8) the changes in the mean over these two periods have also been tested for significance. The test statistic is given by

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

where $\bar{Y}_1$ and $\bar{Y}_2$ are the means for the two component periods of n_1 and n_2 years respectively and $\bar{Y}$ is the mean for the whole period. The test statistic is to be referred to Chi-square distribution for 1 d.f. The results of the test for storms and severe storms are given in Table 4.

(A) In respect of the series of the storms, the following significant changes in the mean are noticed :

(*i*) *East Sri Lanka coast, annual frequency* — At one per cent level from the first to the second, from the second to the third quarter; and at five per cent level from the third to the fourth quarter. It may be mentioned that this result is the consequence of the means, 0.0, 0.27, 0.0 and 0.19 for the four quarters of the period.

(*ii*) *For Bangladesh coast, annual frequency* — At 0.5 per cent level, from the third to the fourth quarter, and from the period 1877-1964 to the period 1965-80, the former significance arising as a result of the latter. The trend suggested by the results of section 4 is thus due to the highly significant increase in the mean from the period 1877-1964 to the period 1965-80, the means for the two periods being 0.51 and 1.12 respectively. The highest 16 year mean during the period 1877-1964 was only 0.81, for the period 1893-1908.

(*iii*) *Arakan coast, annual frequency* — At 5 per cent level, from the second to the third quarter, and near 5 per cent level from first half to second half. The means for the four quarters are 0.31, 0.65, 0.27 and 0.23 respectively. Thus, while the means for the first, third and fourth quarter differ little, the mean for the second quarter is significantly higher than that for any of the remaining quarters.

(*iv*) *Bay coast, post monsoon season frequency* : At 0.5 per cent level, from the period 1877-1964 to the period 1965-80.

(B) In respect of the severe storms, the following significant changes in the mean are noted :

(*i*) *Andhra Pradesh coast*

(*a*) *Annual frequency* — At 0.5 per cent level, from the period 1877-1964 to the period 1965-80 ; the means for the two periods are 0.18 and 0.62 respectively. The highest 16-year mean during the period 1877-1964 was only 0.37 for the period 1918-33. Thus the significance in trend brought out by Table 3 is due to the marked increase in the mean during the period 1965—80.

(*b*) *Post monsoon season frequency* — At one per cent level, from the period 1877-1964 to the period 1965-80.

(*ii*) *Bangladesh coast, annual frequency* — At 0.5 per cent level, from the third quarter to the fourth quarter and from the period 1877-1964 to the period 1965-80

TABLE 4

Test for significant change in the mean annual frequency of cyclonic storms/severe cyclonic storms reaching the different sections of the Bay coast

Coast	Season	Period From	Period To	Test statistic (cyclonic storm) χ^2 (1d.f.)	Test statistic (severe cyclonic storm) χ^2 (1d.f.)
East Sri Lanka	Annual	P_1	P_2	7.00**	2.00
		P_2	P_3	7.00**	2.00
		P_3	P_4	5.00*	2.00
		P_5	P_6	0.33	0.00
		P_7	P_8	2.97†	0.28
Tamil Nadu	Annual	P_1	P_2	0.39	0.82
		P_2	P_3	2.79†	1.92
		P_3	P_4	0.26	0.20
		P_5	P_6	2.48	2.61
		P_7	P_8	0.00	1.23
Tamil Nadu	Post monsoon	P_1	P_2	0.89	1.00
		P_2	P_3	1.80	1.00
		P_3	P_4	0.04	1.00
		P_5	P_6	1.80	1.96
		P_7	P_8	0.20	1.43
Andhra Pradesh	Annual	P_1	P_2	0.76	1.60
		P_2	P_3	0.76	0.33
		P_3	P_4	1.40	2.25
		P_5	P_6	0.06	1.38
		P_7	P_8	1.41	10.64***
Andhra Pradesh	Post monsoon	P_1	P_2	0.18	1.29
		P_2	P_3	0.04	0.11
		P_3	P_4	0.04	1.33
		P_5	P_6	0.51	1.32
		P_7	P_8	0.95	6.72**
Orissa-West Bengal	Annual	P_1	P_2	0·58	0.05
		P_2	P_3	0.05	0.00
		P_3	P_4	2.06	0.18
		P_5	P_6	1.45	0.02
		P_7	P_8	0.40	2.05
Orissa-West Bengal	Monsoon	P_1	P_2	0.55	0.09
		P_2	P_3	0.14	0.11
		P_3	P_4	3.77†	0.82
Orissa-West Bengal		P_5	P_6	1.66	0.00
		P_7	P_8	1.73	2.39
Bangla-desh	Annual	P_1	P_2	0.14	0.09
		P_2	P_3	1.50	1.29
		P_3	P_4	8.26***	12.80***
		P_5	P_6	0.78	2.61
		P_7	P_8	8.42***	12.96***
Arakan	Annual	P_1	P_2	3.24†	2.27
		P_2	P_3	4.17*	3.60†
		P_3	P_4	0.08	1.29
		P_5	P_6	3.79†	0.89
		P_7	P_8	0.14	2.12
East India	Annual	P_1	P_2	0.11	0.00
		P_2	P_3	0.18	0.09
		P_3	P_4	0.35	2.12
		P_5	P_6	0.00	2.27
		P_7	P_8	0.03	10.75***
East India	Post monsoon	P_1	P_2	0.16	0.00
		P_2	P_3	0·44	0.36
		P_3	P_4	0.37	1.78
		P_5	P_6	1.18	3.38†
		P_7	P_8	3.29†	8.64***
Bay	Annual	P_1	P_2	0.98	0.55
		P_2	P_3	1.65	1.29
		P_3	P_4	1.02	11.91***
		P_5	P_6	0.16	2.63
		P_7	P_8	2.24	23.61***
Bay	Post monsoon	P_1	P_2	0.29	0.00
		P_2	P_3	0.78	0.03
		P_3	P_4	3.52†	8.00***
		P_5	P_6	0.28	3.95*
		P_7	P_8	8.22***	16.78***

Note 1 : P_1=1877-1902; P_2=1903-1928; P_3=1929-1954; P_4=1955-1980; P_5=1877-1928; P_6=1929-1980; P_7=1877-1964; P_8=1965-1980.

Note 2: † Significant at 10%; * Significant at 5%; ** Significant at 1%; *** Significant at .5%.

the former significance being due to the latter. The means for the two periods 1877-1964 and 1965-80, are 0.22 and 0.75 respectively. The highest 16-year mean during the period 1877-1964 was only 0.37 for the periods 1883-98 and 1947-62. The significant trend brought out by Table 3 is due to the highly significant increase in the mean during the period 1965-80.

(iii) East India coast

(*a*) *Annual frequency* — At 0.5 per cent level, from the period 1877-1964 to the period 1965-80, the means for the two periods being 0.82 and 1.69 respectively. The highest 16-year mean during the period 1877-1964 was only 1.31 for the period 1930-45. The trend suggested by Table 3 is due to the highly significant increase in the mean during the period 1965-80.

(*b*) *Post monsoon season frequency* — At 0.5 per cent level, from the period 1877-1964 to the period 1965-80.

(iv) Bay coast

(*a*) *Annual frequency* — At 0.5 per cent level, from the period 1877-1964 to the period 1965-80. The means for the two periods are 1.22 and 2.81 respectively. The highest 16-year mean during the period 1877-1964 was only 1.81 for the period 1908-23. The significant trend seen in Table 3 is due to the highly significant increase in the mean during the period 1965-80.

(*b*) *Post monsoon season frequency* — At 0.5 per cent level, from the period 1877-1964 to the period 1965-80.

TABLE 5

Ratio of severe cyclonic storms/cyclonic storms reaching different sections of the Bay coast during different periods

Coast	Periods	No. of storms	Ratio of severe storms to storms
East Sri Lanka	1877-1902	0	—
	1903-1928	7	0.29
	1929-1954	0	—
	1955-1980	5	0.40
	1877-1964	8	0.37
	1965-1980	4	0.25
	1877-1980	12	0.33
Tamil Nadu	1877-1902	13	0.54
	1903-1928	10	0.40
	1929-1954	19	0.47
	1955-1980	16	0.69
	1877-1964	49	0.49
	1965-1980	9	0.78
	1877-1980	58	0.53
Andhra Pradesh	1877-1902	14	0.21
	1903-1928	19	0.37
	1929-1954	14	0.36
	1955-1980	21	0.52
	1877-1964	54	0.30
	1965-1980	14	0.71
	1877-1980	68	0.38
Orissa-West Bengal	1877-1902	46	0.24
	1903-1928	39	0.26
	1929-1954	41	0.24
	1955-1980	29	0.41
	1877-1964	134	0.25
	1965-1980	21	0.48
	1877-1980	155	0.28
Bangladesh	1877-1902	13	0.46
	1903-1928	15	0.33
	1929-1954	9	0.22
	1955-1980	26	0.69
	1877-1964	45	0.42
	1965-1980	18	0.67
	1877-1980	63	0.49
Arakan	1877-1902	8	0.37
	1903-1928	17	0.47
	1929-1954	7	0.29
	1955-1980	6	0.83
	1877-1964	33	0.39
	1965-1980	5	1.00
	1877-1980	38	0.47
East India	1877-1902	72	0.29
	1903-1928	68	0.31
	1929-1954	73	0.32
	1955-1980	66	0.52
	1877-1964	235	0.31
	1965-1980	44	0.61
	1877-1980	279	0.35
Bay	1877-1902	93	0.32
	1903-1928	107	0.34
	1929-1954	89	0.30
	1955-1980	103	0.57
	1877-1964	321	0.33
	1965-1980	71	0.63
	1877-1980	392	0.39

It can thus be inferred from this analysis that the incidence of the storms and the severe storms on the Bangladesh coast during the year and of the storms on the Bay coast during the post monsoon season was at a much higher level during the period 1965-80 than during any preceding 16-year period prior to 1965 and that similar situation holds in respect of the incidence of the severe storms on Andhra Pradesh, the east India and the Bay coasts during the year as well as during the post monsoon season.

6. Proportion of storms reaching the coast as severe storms

From the preceding section, it is noticed that both for the east India and the Bay coasts, there is a very highly significant increase in the mean annual frequency of the severe storms from the period 1877-1964 to the period 1965-80, but in respect of the storms there is no significant change in the mean over these periods. This means that a much higher percentage of storms reached the coast as severe storms during the period 1965-80. The ratio of severe storms/storms reaching the different sections of the Bay coast, for the periods, 1877-1902, 1903-1928, 1929-1954, 1955-1980, 1877-1964, 1965-1980, and 1877-1980 has been worked out and the same is given in Table 5. In addition, the number of storms reaching the different sections of the Bay coast is given in this table. The following salient points are noted from the table :

(*i*) A high stability of the ratio during the different periods prior to 1965 and a sharp increase by 90 to 110 per cent during the period 1965-80 for the east India and the Bay coasts.

(*ii*) Fairly stable ratios during periods prior to 1965 and increase by 60 to 100 per cent during the period 1965-80 for Tamil Nadu, Andhra Pradesh and Orissa-West Bengal coasts.

(*iii*) Lesser stability of the ratios during periods prior to 1965 and increase of 60 to 100 per cent from the period 1877-1964 to 1965-1980 for Bangladesh and Arakan coasts.

(*iv*) While east Sri Lanka coast shows relatively small variations of the ratio over the different periods, no storms reached this coast during the periods 1877-1902 and 1929-1954.

From the period 1877-1964 of the record of the cyclonic storms, the highest 16-year period ratio of severe storms to storms reaching Tamil Nadu, Andhra Pradesh, Orissa-West Bengal, Bangladesh, Arakan, east India and the Bay coasts has been obtained, subject to the condition that the number of storms during the period is not less than 10. This restriction had to be imposed since with a smaller value of the number of cyclonic storms, the ratio becomes unstable, resulting in a

TABLE 6

Highest 16-year period ratio of severe storms/storms reaching coast during the period 1877-1964, and ratio for the period 1965-80

Coast	Highest ratio	16-year period		Period 1965-80	
		Years	No. of storms	Ratio	No. of storms
(1)	(2)	(3)	(4)	(5)	(6)
Tamil Nadu	0.60	1935-50	10	0.78	9
Andhra Pradesh	0.60	1918-33	10	0.71	14
Orissa-West Bengal	0.43	1908-23	21	0.47	21
Bangladesh	0.60	1886-1901	10	0.67	18
Arakan	0.70	1908-23	10	1.00	5
East India	0.44	1908-23	36	0.61	44
Bay	0.49	1908-23	59	0.63	71

high random ratio. Table 6 gives these ratios and the ratios for the period 1965-80. Comparing these highest 16-year period ratios from the period prior to 1965 with those for the period 1965-80, it is seen that the latter ratios are higher than the former ratios for each of the coasts. The amount by which the ratios for 1965-80 are higher than the highest from the period 1877-1964 varies from about 15 to 40 per cent. The increase in the ratio after 1964 is in general due to the significant increase in the incidence of the severe storms without any corresponding increase in the incidence of the storms except in the case of Bangladesh coast. In the case of Bangladesh, while the mean annual frequency of storms doubled, that of severe storms trebled during the period 1965-80 from its mean value for the period 1877-1964 and hence the ratio of severe storms to storms increased during the period 1965-80.

The increased incidence of the severe cyclonic storms during the period 1965-80 could be due to two reasons. The first reason may be better aids for efficient detection through satellite pictures, radars and improved coastal network of observatories which became available during this period. The second reason may be more frequent coincidence of the synoptic situations which lead to intensification of storms into severe storms. Variability is observed in the ratio as well as in the frequency of the severe cyclonic storms for 16-year periods from the record prior to 1965 when better side for efficient detection of severe storms were absent. The storm intensity from the satellite picture configurations and radar pictures is estimated over the Indian area on the basis of empirical relationship which apparently is derived from data from elsewhere. It is possible that the empirical relationship used may not hold adequately for the Indian area. According to Gray (1979), the relationship between satellite cloud configurations and storm intensity is quite complex and significant difficulties in intensity estimation can occur in individual situations. Arnold (1977) has brought out cases from West Pacific in which difficulties arose in intensity estimation and he has stated that for proper estimation of storm intensity from the satellite cloud pictures adequate interpretation experience is necessary. We have not come across any study of the Bay cyclonic storms which brings out the discrepancies in the intensity estimation from satellite pictures and the intensity estimation from the conventional wind data. Such a study in respect of the cases of Bay storms for which both the conventional wind data and the satellite cloud pictures are available is essential for evaluation of the techniques of the estimation of the storm intensity from the satellite pictures. The protagonist of the method of estimation of storm intensity by satellite cloud configurations might say that in the past period (*i.e.*, prior to 1965) some severe storms over the Bay might have been missed in the absence of satellite pictures. If this argument is accepted, the question arises, why only severe storms should be missed and not storms also? It has been seen that there is no significant increase in the annual frequency of the storms incident on the Bay coast after 1964.

Finally, taking into account the facts that the empirical relationship used in the estimation of storm intensity may not possibly hold adequately for the Indian area, significant difficulties have been encountered in intensity estimation apparently even in area for which empirical relationship has been developed, and there is no significant increase in the annual frequency of storms incident on the Bay coasts after 1964, it does not appear possible to conclude that better storm detection aids is the only reason for increase in the annual frequency of severe Bay storms after 1964. The second reason deserves to be considered and looked into.

7. Locations of origin of storms reaching different sections of the Bay coast

It is of interest to know where the storms which ultimately reach a particular coast originate over the Bay. To bring this out, Fig. 3 has been prepared. It gives for each of the sections of the Bay coast, the locations of origin over the Bay of the storms which later reached these coasts. Since storm tracks show variation from one season to another, Fig. 3 has been prepared for specific seasons. The main features of the storms reaching the different sections of the Bay coast as brought out by this figure can be summarised as follows :

(a) *East Sri Lanka coast (Oct-Dec)* — Storms are mostly formed over the area 6-9° N and 82-92° E.

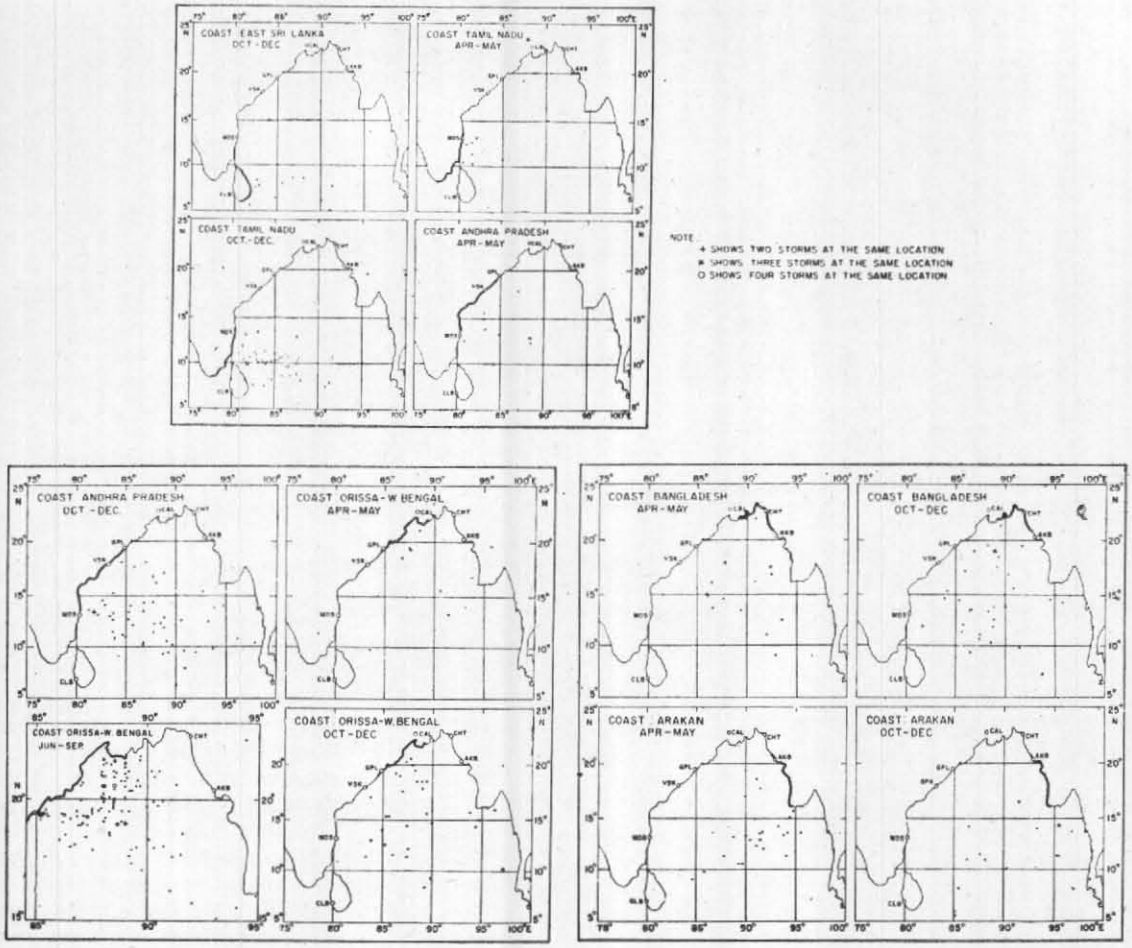


Fig. 3. Locations of origin of storms reaching the different coasts around Bay in different periods
Note : † shows two storms at the same location, *shows three storms at the same location,
O shows four storms at the same location

(b) *Tamil Nadu coast*

Apr-May — Stormsare mostly formed in the area 10-13° N and 80-85° E.

Oct-Dec — Most of the storms are formed over the area 7-13.5°N and 80-92° E.

(c) *Andhra Pradesh*

Apr-May — Storms formed mostly over the area 12-16° N and 80-85° E.

Oct-Dec — The scatter of locations of formation of storms covers a large portion of the Bay.

(d) *Orissa-West Bengal*

Apr-May — The scatter covers a wide area of the Bay.

Jun-Sep — The scatter covers north and adjoining central Bay.

Oct-Dec — The scatter covers a large portion of the Bay.

(e) *Bangladesh*

Apr-May — The scatter mostly covers central Bay between 85° and 94° E.

Oct-Dec — The scatter covers most of the Bay north of 10° N

(f) *Arakan*

Apr-May — The scatter is mostly confined to the area 10-16° N and 82-96° E.

Oct-Dec — The scatter mostly covers the area 10-17° N and 86-97° E.

8. Storms forming over different sectors of the Bay and reaching different sections of the Bay coast

The climatological information in respect of the number of storms forming over each of the different sectors of the Bay and the numbers

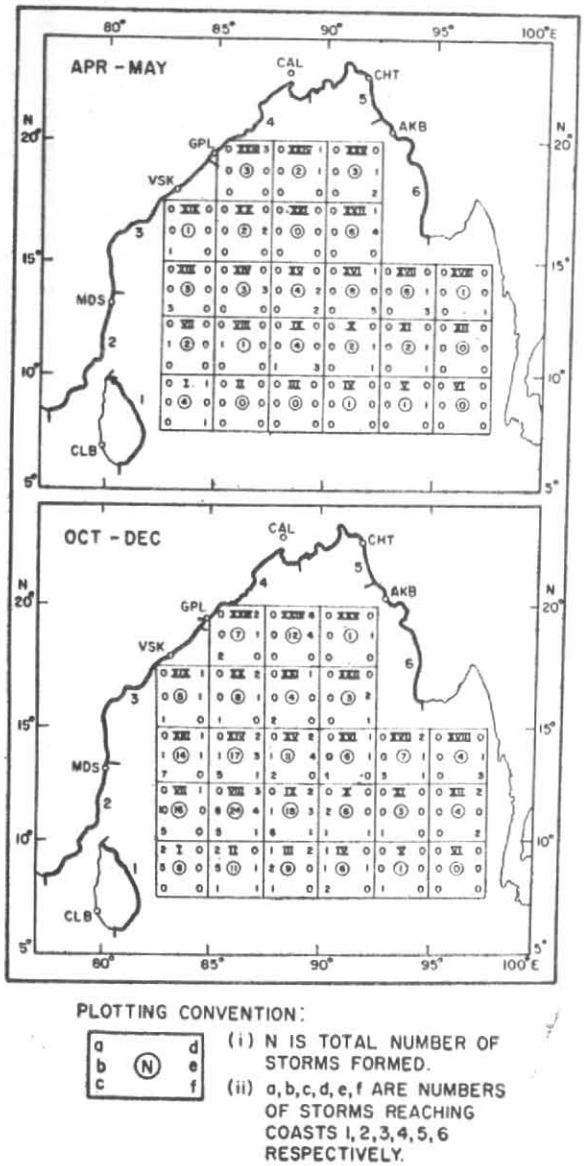


Fig. 4. Storms forming over over different sectors of Bay (I-XXV) and reaching different coasts (1 to 6)

from amongst them reaching the different sections of the Bay coast is useful to various user interests. The same has been compiled in Fig. 4, for specific seasons, *viz.*, post monsoon season (October December) and summer (April-May). The Bay sectors are generally 2.5° Lat. × 2.5° Long. The sector number is given in Roman figure at the top of each sector. The total number of storms which formed over each sector is given by the number within the circle. The number of storms reaching east Sri Lanka, Tamil Nadu and Andhra Pradesh coasts are given in the left portion of the sector from top to bottom respectively, and those reaching Orissa-West Bengal, Bangladesh and Arakan coasts are given in the right portion of the sector from top to bottom respectively. The difference between the total number of storms which formed over a sector and the total number of storms which reached the coasts gives the number of storms which dissipated over the Bay. The main points noticed from Fig. 4 are :

(a) *During April-May* — The highest number (8) of storms formed in Sector XVI : Of these, one reached Orissa-West Bengal coast, five reached Arakan coast, and two dissipated over the Bay.

(b) *During October-December* — The highest number (24) of storms formed in sector VIII : Of these, none reached east Sri Lanka coast, 8 reached Tamil Nadu coast, 5 reached Andhra Pradesh coast, 3 reached Orissa-West Bengal coast, 4 reached Bangladesh coast, one reached Arakan coast and 3 dissipated over the Bay.

9. Probability model for cyclonic storms

As the interval between two successive storms reaching the coast is quite large, these events, *viz.*, storms reaching the coast, could be considered as independent of each other. The probability of a storm reaching the coast on a day is extremely low. In these circumstances, Poisson distribution may show good fit to the number of storms reaching the coast in a specific period of time. The test of variance for Poisson distribution as suggested by Cochran (1954) has been applied to the number of storms reaching the Bay coast, the east India coast and the different sections of the Bay coast in specific periods (year or season).

While applying the test, the series of cyclonic storms considered are, annual and post monsoon for Tamil Nadu, Andhra Pradesh, east India and the Bay coasts, annual for Bangladesh for the two periods 1877-1964 and 1877-1980 in view of the significant change in the mean after 1964, and for annual and monsoon for Orissa-West Bengal coast. Other series have not been considered in view of the low mean annual frequency.

The test statistic is given by :

$$\chi_v^2 = \frac{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}{m}$$

where v, the number of degrees of freedom is $(n-1)$, m, the parameter of the Poisson distribution, is $\frac{1}{n}\sum_{i=1}^{n} Y_i$, *i.e.*, $\bar{Y}$, and Y_i is the number of storms reaching the coast in i^{th} year.

TABLE 7

Results of the variance test for application of Poisson distribution to the number of storms reaching the different sections of the Bay coast during the year/sections

Coast	Season	Period	Value of test criterion χ^2	d.f.
Tamil Nadu	Annual	1877-1980	110.55	103
Do	Post monsoon	1877-1980	95.98	103
Andhra Pradesh	Annual	1877-1980	100.24	103
Do	Post monsoon	1877-1980	97.45	103
Orissa-West Bengal	Annual	1877-1980	91.25	103
Do	Monsoon	1877-1980	97.05	103
Bangladesh	Annual	1877-1980	103.73	103
Do	Annual	1877-1964	82.11	87
East India	Annual	1877-1980	109.04	103
Do	Post monsoon	1877-1980	111.57	103
Bay	Annual	1877-1980	100.94	103
Do	Post monsoon	1877-1980	106.80	103
Do	Post monsoon	1877-1964	84.00	87

For Poisson distribution, mean = variance $= m$. Thus,

$$\chi_v^2 = \frac{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}{\bar{Y}}$$

$$= \frac{\sum_{i=1}^{n} Y_i^2}{\bar{Y}} - n\bar{Y}$$

$$i.e., \quad \chi_v^2 = \frac{n \sum_{i=1}^{n} Y_i^2}{\sum_{i=1}^{n} Y_i} - \sum_{i=1}^{n} Y_i$$

In this form, this is also referred to as Thom's (1957, 1966) criterion for adequacy of the Poisson distribution.

The results of the variance test for Poisson distribution for storms are given in Table 7. The test statistic is not significant at 5 per cent level in any of the cases considered. The significant change in the mean annual frequency for Bangladesh and in the mean post monsoon season frequency of storms, in the relatively small period of 1965-80, has not vitiated the applicability of the Poisson distribution for the period 1877-1980. However, from the value of the test statistic it is noticed that the fit for the period 1877-1964 is slightly better. Thus the results of the variance test are consistent with the hypothesis that the number of storms reaching coast in a year/season is Poisson-distributed.

Chi-square test for fit of the Poisson distribution has also been applied in the cases for which the variance test has been applied. The results are given in Table 8. These are consistent with the hypothesis of the Poisson distribution.

Thus both the tests show that number of storms incident on Tamil Nadu, Andhra Pradesh, Orissa-West Bengal, Bangladesh, east India and the Bay coasts in a year is distributied in accordance with the Poisson probability model.

10. Climatological expectation of storm frequency for the next 50-year period

It has been seen in the preceding section that the number of storms incident on the coast in a year follows Poisson probability model. The model can be used to obtain the probabilities of 0, 1, 2, 3 etc storms in a year and these can be used for planning and risk insurance purposes.

From the consideration of stability, it is essential that planning funds for taking suitable action to reduce the sufferings of the people due to havoc resulting from a rare phenomenon like cyclonic storms is done on a long-term basis, say for 50-year period. For this purpose, the best estimate of the mean annual frequency of storms is necessary for the next 50 years. In the case of storms, except for those reaching Bangladesh coast, the mean annual frequency for the period 1965-80 is not significantly different from that for the period 1877-1964; hence, the next 50-year mean annual frequency of storms for coasts other than Bangladesh has been estimated by giving equal weightage to the means for the periods 1877-1964 and 1965-80. Thus, in relative terms more weightage has been given to the most recent short period of 16 years. In the case of Bangladesh coast for which the mean annual storm frequency has increased significantly from the period 1877-1964 to the period 1965-80, two estimates have been obtained for the purpose of comparison and selection. The first one is obtained by giving equal weightage to the means for the most recent 16-year period and for the preceding 88-year period, and this comes out to be 0.81. The second one is obtained by the following formula.

TABLE 8

Fit of Poisson distribution to the number of storms reaching the different sections of the coast around Bay (Chi-square test)

Season	Period	No. of storms in a year/ season	Obs. freq.	Frequency on Poisson hypothesis	χ^2 (d.f.) (Test statistic)
		Tamil Nadu			
Annual	1877-1980	0	60	59.54	0.16
		1	34	33.21	(1)
		2	6	9.26	
		3	4	1.72	
		⩾4	0	0.27	
		Tamil Nadu			
Post monsoon	1877-1980	0	66	67.47	0.54
		1	32	29.19	(1)
		2	5	6.32	
		3	1	0.91	
		⩾4	0	0.11	
		Andhra Pradesh			
Annual	1877-1980	0	54	54.08	0.02
		1	35	35.36	(2)
		2	12	11.56	
		3	3	2.52	
		⩾4	0	0.47	
		Andhra Pradesh			
Post monsoon	1877-1980	0	64	64.93	0.11
		1	32	30.59	(1)
		2	7	7.21	
		3	1	1.13	
		⩾4	0	0.15	
		Orissa-West Bengal			
Annual	1877-1980	0	22	23.43	3.36
		1	36	34.92	(3)
		2	24	26.02	
		3	18	12.93	
		⩾4	4	6.70	
		Orissa-West Bengal			
Monsoon	1877-1980	0	30	33.44	3.35
		1	45	37.94	(3)
		2	17	21.53	
		3	10	8.14	
		⩾4	2	2.95	
		Bangladesh			
Annual	1877-1980	0	58	56.75	0.71
		1	31	34.38	(1)
		2	13	10.41	
		3	2	2.10	
		⩾4	0	00.36	
		Bangladesh			
Annual	1877-1964	0	52	52.77	0.06
		1	28	26.99	(1)
		2	7	6.90	
		3	1	1.18	
		⩾4	0	0.11	
		East India			
Annual	1877 1980	0	8	7.11	3.22
		1	20	19.08	(5)
		2	24	25.59	
		3	23	22.88	
		4	11	15.35	
		5	12	8.23	
		6	4	3.68	
		⩾7	2	2.03	
		East India			
Post monsoon	1877-1980	0	35	32.18	1.87
		1	32	37.75	(3)
		2	26	22.14	
		3	8	8.66	
		⩾4	3	3.27	
		Bay			
Annual	1877-1980	0	4	2.40	3.74
		1	9	9.04	(6)
		2	15	17.04	
		3	17	21.41	
		4	24	20.18	
		5	16	15.21	
		6	12	9.56	
		7	3	5.15	
		⩾8	4	3.44	
		Bay			
Post monsoon	1877-1980	0	20	18.96	0.67
		1	30	32.27	(4)
		2	30	27.46	
		3	14	15.58	
		4	6	6.63	
		⩾5	4	3.90	
		Bay			
Post monsoon	1877-1964	0	19	18.76	0.48
		1	27	29.00	(3)
		2	25	22.41	
		3	11	11.54	
		4	4	4.46	
		⩾5	2	1.83	

TABLE 9

Estimates of the mean annual storm frequency for the next 50-year period (1981-2030), highest 50-year mean from 1877-1964 and mean of the highest and the lowest 50-year means from 1877-1964

Coast	Estimate for next 50-year period	Highest 50-year mean from 1877-1964	Mean of highest and lowest 50-year means from 1877-1964
East Sri Lanka	0.17	0.14	0.09
Tamil Nadu	0.53	0.64	0.58
Andhra Pradesh	0.74	0.76	0.65
Orissa-West Bengal	1.41	1.84	1.54
Bangladesh	0.84	0.62	0.54
Arakan	0.34	0.58	0.40
East India	2.71	2.81	2.78
Bay	4.05	4.40	3.91

TABLE 10

Frequency distribution of cyclonic storms reaching different coasts during the next 50-year period (1981-2030 A.D.)

Coast	Frequency of different numbers of storms in a year									
	0	1	2	3	4	5	6	7	8	9
Tamil Nadu	29	16	4	1						
Andhra Pradesh	24	18	7	2						
Orissa-West Bengal	12	17	12	6	2	1				
Bangladesh	22	18	8	2						
East India	3	9	12	11	7	4	2	1		
Bay	1	4	7	10	10	8	5	3	2	1

NOTE : Computed frequencies are rounded to the nearest integer.

Estimated mean =

$$\frac{\text{Highest 50-yr mean during 1877-1964}}{\text{Highest 16-yr mean during 1877-1964}} \times \text{Mean for 1965-80.}$$

$$= \frac{0.62}{0.81} \times 1.12 = 0.84$$

The second estimate which is slightly higher that the first estimate is preferred since the period in which the mean annual frequency has significantly increased is given more weightage. Table 9 gives the mean annual frequency estimated for the next 50-year period along with the highest 50-year mean from the period 1877-1964 and the mean of the highest and lowest 50-year means from the period 1877-1964, for comparison. It is noticed from this table that the estimated 50-year mean is fairly close to the mean of highest and lowest 50-year means, and generally lower than the highest 50-year mean except in the case of Bangladesh coast. This is what one would expect in view of the fact that the mean for Bangladesh for the recent 16-year period is much higher than the highest 16-year mean from the period 1877-1964.

Utilising these means, frequencies of 0, 1, 2, 3 etc storms reaching Tamil Nadu, Andhra Pradesh, Orissa-West Bengal, Bangladesh, east India and the Bay coasts are computed on the basis of the Poisson distribution. These are given in Table 10. If the corresponding probabilities are required, these may be obtained by dividing frequencies by 50.

11. Conclusions

The following conclusions can be drawn in respect of the storms/severe storms reaching the different coasts.

(*i*) Highly significant increase in the mean annual frequency of storms during the period 1965-80 for Bangladesh coast and significant increase during the period 1903-1928 for Arakan coast, and highly significant increase in post monsoon season frequency of storms during the period 1965-80 for the Bay coast have occurred. In respect of the severe storms, highly significant increase in the mean annual frequency for Andhra Pradesh, Bangladesh, east India and the Bay coasts and in the mean post monsoon season frequency for Andhra Pradesh, east India and the Bay coasts, has occurred during the period 1965-80. For Bangladesh, while the mean annual frequency of storms doubled, that of severe storms trebled during the period 1965-80 from their mean values during the period 1877-1964.

(*ii*) Better aids, like satellite cloud pictures, radars and improved coastal network of observatories, and more frequent coincidence of the synoptic conditions favourable for intensification of storms appear to be two possible reasons for the post-1964 increase in the frequency of severe storms incident on the Bay coast.

(*iii*) The annual frequencies of 0, 1, 2, 3. 4 etc, storms in a year/season for the different sections of the Bay coast are consistent with the Poisson probability model.

(*iv*) The estimated annual frequencies of 1, 2, 3, 4 etc, storms computed for the different coasts from the estimated next 50-year mean frequency on the basis of the Poisson model could be used for planning funds for mitigating the hardships of the people struck by the calamity. These could also be considered for evolving a suitable insurance policy against storm risks.

Acknowledgements

The authors are grateful to the Director for the facilities to pursue the study, and the Deputy Director General (Weather Forecasting) for the facilities to collect required information in respect of storms from the record. They would also like to convey thanks to Miss J. S. Pethkar and Miss V. M. Nirkhe for their assistance in tabulation and plotting of data and to Mrs. S. P. Lakade for typing the manuscript.

References

Alexander, G., George, C.A. and Jambunathan, R., 1974, Cyclones and depressions of 1973 — Bay of Bengal and Arabian Sea, *Indian J. Met. Geophys.*, **25**, pp. 347-362.

Alexander, G., Bhaskar Rao, N.S. and Jambunathan, R., 1976, Cyclones and depressions of 1974 – Bay of Bengal and Arabian Sea, *Indian J. Met. Hydrol. Geophys.*, **27**, pp. 113-126.

Alexander, Srinivasan, G. V. and Jambunathan, R., 1977, Cyclones and depressions of 1975 — Bay of Bengal and Arabian Sea, *Indian J. Met. Hydrol. Geophys.*, **28**, pp. 3-20.

Arnold, C.P., 1977, Tropical cyclone cloud and intensity relationships, *Atmos. Sci., Paper* 277, Colorado State Univ. Ft. Collins, Colo, 154 pp.

Bhalme, H.N., 1972, Trends and quasi-biennial oscillation in cyclonic disturbances, *Indian J. Met. Geophys.*, **23**, pp. 355-358.

Cochran, W.G., 1954, Some methods for strengthening the common Chi-square tests, *Biometrics*, Biometric Society of U.S.A. **10**, pp. 417-451.

Das, P.K., George, C.A. and Jambunathan, R., 1972, Cyclones and depressions of 1971—Bay of Bengal and Arabian Sea, *Indian J. Met. Geophys.*, **23**, pp. 453-466.

Das, P.K., George, C.A., Jambunathan, R., 1973, Cyclones and depressions of 1972 — Bay of Bengal and Arabian Sea, *Indian J. Met. Geophys.*, **24**, pp. 327-344.

Gray, M.W., 1979, Tropical cyclone intensity determination through upper tropospheric aircraft reconnaissance, *Bull. Amer. Met. Soc.*, **60**, 9, pp. 1969-74.

India Meteorological Department, 1979, *Tracks of Storms and Depressions over the Bay of Bengal and the Arabian Sea* (1877-1970).

Jayaraman, S., 1961, Tests of randomness of occurrence of depressions/storms in Bay of Bengal, *Indian J. Met. Geophys.*, **12**, pp. 529-530.

Mooley, D.A., 1980, Severe cyclonic storms in the Bay of Bengal 1877-1977, *Mon. Weath. Rev.*, Washington, **108**, pp. 1647-1655.

Mooley, D.A., 1981, Increase in annual frequency of the severe cyclonic storms of the Bay after 1964—Possible Causes, *Mausam*, **32**, pp. 35-40.

Pant, P.S., Srinivasan, V. and Jambunathan, R., 1978, Cyclones and depressions in the Indian Seas in 1976, *Indian J. Met. Hydrol. Geophys.*, **29**, pp. 613-628.

Raghavendra, V.K., 1973, A statistical analysis of the number of tropical storms and depressions in the Bay of Bengal during 1890-1969, *Indian J. Met. Geophys.*, **24**, pp. 125-130.

Rai Sircar, N.C., 1956, A climatological study of storms and depressions in the Bay of Bengal, *Indian J. Met. Geophys.*, **7**, pp. 157-160.

Rai Sircar, N.C., 1958, A climatological study of storms and depressions in the Bay of Bengal, Mem. India Met. Dep., **30**, Part 5.

Rao, K.N. and Jayaraman, S., 1958, Frequency of depressions and cyclones, *Indian J. Met. Geophys.*, **9**, pp. 233-250.

Thom, H.C.S., 1960, The distribution of annual storm frequency, *J. Geophys. Res.*, **65**, pp. 213-222.

Thom, H.C.S., 1966, Some methods of climatological analysis, Tech. Note No. 81, WMO No. 199, pp. 1-53.