MAUSAM, 51, 3 (July 2000), 225 - 230

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# Origin and movement of cyclonic storms in the Bay of Bengal

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*(Received 8 June 1998, Modified 29 March 2000)*

**सार** - इस शोध पत्र में 1891 से 1997 के दौरान आए चक्रवातीय तूफानों की अवस्थितियों के आँकड़ों का उपयोग करते हुए, खाड़ी में तट से लगभग 500 कि.मी. की दूरी पर अवस्थित तूफान द्वारा किसी स्थान अथवा राज्य में पहुँचकर टकराने अथवा प्रभावित करने की संभावना का अध्ययन करने का प्रयास किया गया है। इस बात का पता चला है कि अक्तूबर और नवंबर के महीनों में तमिलनाडु तट को प्रभावित करने वाले तूफानों के बनने की संभावित अवस्थिति 9.3° उत्तर / 85.0° पूर्व, मई और अक्तूबर के महीनों में आंध्रप्रदेश को प्रभावित करने वाले तूफानों की अवस्थिति लगभग 11.5° उत्तर / 87.0° पूर्व एवं मई और अक्तूबर में उड़ीसा को प्रभावित करने वाले तूफानों की संभावित अवस्थिति 16.0° उत्तर / 89.5° पूर्व है। पश्चिमी बंगाल को प्रभावित करने वाले मई में बनने वाले तूफानों का स्थान लगभग 14.8° उत्तर / 88.6° पूर्व और अक्तूबर में बनने वालों का स्थान 17.0° उत्तर / 88.8° पूर्व है। यह भी देखा गया है कि उत्तर मानसून ऋतु के बाद के महीनों ( अक्तूबर - दिसंबर ) के दौरान आने वाले तूफानों के मार्ग वर्षा ऋतु में खाड़ी में पहले आए तूफानों के मार्ग पर निर्भर करते हैं। बंगाल की खाडी में तूफान की माध्य दिशा खाड़ी में पहले आए तुफान के समाश्रयण समीकरण की माध्य दिशा पर आधारित है।

**ABSTRACT.** Using 1891- 1997 data of cyclonic storm positions an attempt is made to study probability of a storm located at about 500 kms in the Bay from the coast to strike or threaten a given station or a given state. It is found that probable location of formation of storms affecting Tamil Nadu coast is 9. 3° N/85.0°E in the month of October and November, for the storms affecting Andhra Pradesh is around 11. 5° N/87. 0° E in May and October and for the storms affecting Orissa is 16. 0° N/89. 5° E in May and October. The storms affecting West Bengal have their origin around 14. 8 °N/88. 6°E in May and 17. 0 °N/88. 8°E in October. It is also found that the track of a given storm during post monsoon months (October-December) depends on the track of the earlier storm formed in the same season over Bay. Mean direction of storm over the Bay of Bengal is estimated based on the mean direction of the storm formed earlier in the Bay by a regression equation.

**Key words** – Storm, Probable location, Striking probability, Threatening Probability.

## 1. Introduction

Cyclonic storms (Depressions, Cyclonic storms and Severe cyclonic storms) affect east coast of India every year and cause a huge loss of life and property. The origin of formation of cyclonic storms varies from season to season and month to month. Ganesan *et a.l* (1994 b) found that in April the storms form in lower latitude around Andaman sea, in May the area of origin shifts northward and in the month of October storms mostly originate over southwest and central Bay. In November storms form further south and in December near the equator. Ganesan *et al*. (1994 a) calculated the probability of a latitude strip being affected by cyclonic systems. Muthuchami (1997) found that the storms formed south of 10° N and west of 90° E in the month of April will cross over the Tamil Nadu coast and storms formed east of 90° E during this month move along a parabolic path and affect mostly Bangladesh and Myanmar coasts. Sen and Pillai (1993) concluded that the zones over the Head Bay continue to have maximum frequency However, considering the maritime zones of each state, largest number of storms are found to have crossed Andhra Pradesh. De and Joshi (1995) found that nearly 1/3 of all the storms in the north Indian Ocean occurred in the area bounded by 87.5°E/ 92.5°E, 17.5°N/ 22.5°N while rest 2/3 occurred elsewhere.

In this paper an attempt is made to locate the most probable position of formation of storms which affect various coastal states of India. The striking probability and threatening probability of a storm which is at a mean distance of around 500 km from a state have been analyzed. Further the mean direction of movement of storms in the post monsoon season have been estimated based on mean direction of movement of the storm formed earlier in the same season.

## 2. Data used and methodology

The relevant data for this paper have been collected from India Meteorological Department (1972) the "tracks of storms and depressions over the Bay of Bengal and

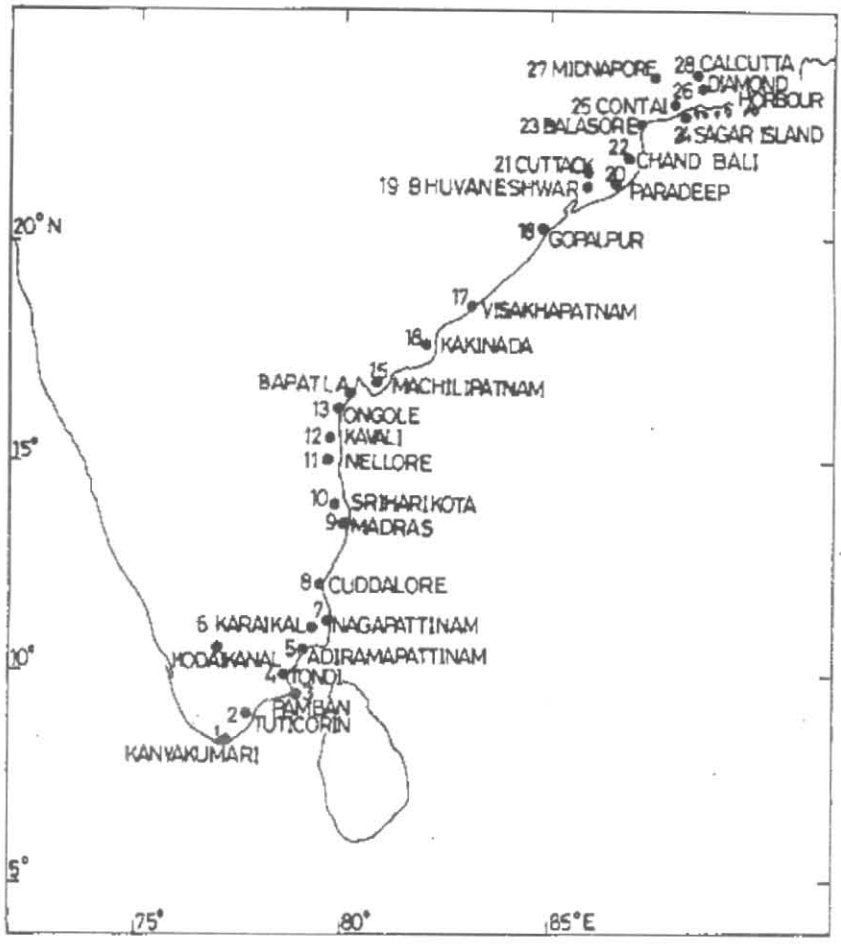
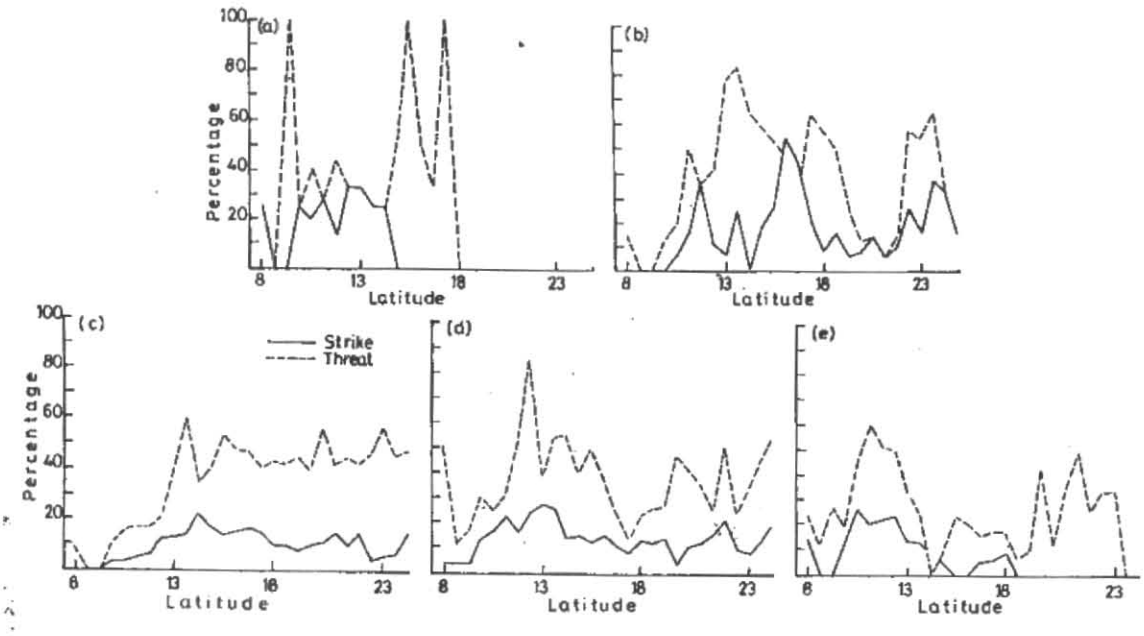



**Fig. 1.** Locations of different coastal stations

TABLE 1

**The probable location of formation in terms of mean latitude / longitude and standard deviation of storms affecting various states in different months**

| Name of State of landfall | April | May | October | November | December |
|---|---|---|---|---|---|
| Tamilnadu<br>S.D. | 7.8°N/83.6°E<br>1.2°/3.2° | 9.2°N/83.3°E<br>2.1°/1.1° | 9.5°N/86.0°E<br>1.0°/2.5° | 9.0°N/85.8°E<br>1.62°/3.81° | 7.9°N/84.8°E<br>1.2°/3.75° |
| Andhra Pradesh<br>S.D. | 8.5°N/90.1°E<br>1.0°/0.8° | 11.4°N/87.1°E<br>2.1°/4.12° | 11.7°N/87.6°E<br>2.9°/3.8° | 10.7°N/89.0°E<br>3.0°/5.7° | — |
| Orissa<br>S.D. | — | 15.8°N/89.8°E<br>3.2°/2.0° | 15.7°N/89.3°E<br>3.0°/2.4° | 11.5°N/91.5°E<br>2.5°/4.2° | — |
| West Bengal<br>S.D. | — | 14.8°N/86.6°E<br>3.7°/3.3° | 17.0°N/88.8°E<br>3.3°/3.7° | 12.0°N/91.8°E<br>5.7°/4.1° | — |




**Figs. 2(a-e).** Strike and threat probability for (a) April, (b) May, (c) October, (d) November and (e) December

Arabian Sea'' for the period 1891 – 1970 and for the period 1971 – 97 from the report of the ' Annual Cyclone Review' meeting and reports on 'Cyclonic Disturbances over North Indian Ocean' prepared by India Meteorological Department . Initially 28 stations have been identified along the east coast of India and their positions are given in Fig. 1. From the 0300 UTC positions of the storms the distances from these stations have been computed. From these distances the number of days the storm is located in various class intervals namely 0-100, 100-200, 200-300 kms etc have been computed for each of the stations. Then the probability that a storm located at the range of 400 to 500 kms to come within 100 kms is defined as striking probability and the probability of such storm to come within 100 to 200 kms is defined as threatening probability and the results are discussed.

For each of the coastal state the storms that affected it were identified and their origins were noted in terms of latitude and longitude at the stage where the systems concentrated into depression. With this information the mean position of formation and their standard deviation in respect of each states have been computed and result are analyzed for their variability in space and time using *t* and *F* test. The direction of movement of a storm has also been estimated based on the mean direction of a storm formed earlier in the season by regression analysis and results are discussed.

## 3. Results and discussions

The probability of a storm formed in the Bay of Bengal to cross over Tamil Nadu coast in the month of April is 0.1, over Andhra Pradesh it is 0.07 and in other states it is nil. In the month of May the probability is 0.07 over Tamil Nadu, 0.13 over Andhra Pradesh, 0.03 over Orissa and 0.06 over West Bengal. For the month of October the probability is 0.05 over Tamil Nadu , 0.28 over Andhra Pradesh and 0.12 over Orissa and 0.25 over West Bengal. For the month of November the probability is 0.25 over Tamil Nadu, 0.21 over Andhra Pradesh, 0.04 over Orissa and 0.03 over West Bengal. In December the probability is 0.09 for Tamil Nadu, 0.01 for Andhra Pradesh and for other states it is nil.

Table 1 gives the mean latitude and longitude at the time the systems concentrated into depression before crossing a particular state. It is seen that the storms affecting Tamil Nadu have their origin around 9.3° N/85.0° E in the month of October and November and 7.9° N/84.0°E during April and December. For the month of May the mean position is 9.2° N/83.3°E. Therefore the storm which affect Tamil Nadu generally have less distance to travel before crossing the coast as the consequence of this most of the systems are of less intense type.

The storms affecting Andhra Pradesh have their origin around 11.5°N/87.0°E in the month of May and October, 10.7° N/89.0°E in November and 8.5°N/90.0°E in April. Incomparision with storms affecting Tamil Nadu it is seen that storms affecting Andhra Pradesh have to travel longer distance.

The storms affecting Orissa coast have their origin 16.0°N/89.0°E during May and October, 11.5°N/91.5°E in

December and the storms affecting West Bengal is 14.8°N/86.6°E in May 17.0°N /88.8°E in October and 12.2° N/92.0° E in November.

From the $t$ - test it is seen that the storms affecting Tamil Nadu have their origin different from the origin of the storms affecting other states. In the month of May the origin of formation of storms affecting Andhra Pradesh and Orissa are different. From $F$ test it is seen that longitudinal variations of formation is higher than the latitudinal variability of the storm affecting Tamil Nadu and Andhra Pradesh in the month of October and November. In respect of other months the variations are not significant. $F$ - test further reveals that the origin of storms affecting Tamil Nadu coast clustered around the mean value for all the months than remaining states. In the same way storms affecting Andhra Pradesh have their origin clustered around mean value for the month of May and October. Therefore, the forecasting of storms affecting Tamil Nadu is easier then the storms affecting other states because the formation position of storms are generally closer to the coast and also by the fact that their standard deviations of formation positions are comparatively small. In the month of April and December Tamil Nadu and Andhra Pradesh are only affected. Therefore higher order forecasting skill is required in the month of May, October and November because the probability of a storm to cross in these maritime states are non zero and also due to their higher variability in their formation position.

Figs. 2(a-e) gives the striking probability and threatening probability of a storm located at the range of 500 km distance from the respective stations in the east coast of India in different months.

*April*

It has been found that in month of April striking probability is clustered near 8.5° N, and in this month the striking probability over entire coast is 9% and the threatening probability is 15%. In this month striking probability of a storm located at about 500km mean distance from Tamil Nadu is highest. For Orissa and West Bengal both striking and threatening probability are zero.

*May*

For this month the storms, which strike the coast, are between 16.5° N to 18.0°N.The striking probability over the entire coast is 17% and to threaten the coast is 41%. The probability to strike Tamil Nadu is 9% and to threaten the coast is 32%. Over Andhra Pradesh and West Bengal the probability to strike the coast is 24%for both and to threaten the coast is 52% and 62% respectively. Over Orissa the probability to strike a coast is 9%and to threaten the coast is 16%.

*October*

In this month the probability to strike east coast is 11% and threaten the coast 40%. Over Tamil Nadu probability to strike the coast is 7% and to threaten the coast is 22%. Over Andhra Pradesh, Orissa and West Bengal the probability to strike the coast is around 12% and to threaten the coast is around 45%.

*November*

In this month the probability to strike east coast of India is 14% and to threaten the coast is 36%. The highest striking probability of 15% is observed over Tamil Nadu and comparable values are seen in other states, which vary, between 12 to 14%. The threatening probability is the highest over West Bengal and in other states it is around 36%.

*December*

The probability to strike the east coast is 9%, for Tamil Nadu it is 14% and for Andhra Pradesh it is 7%. For remaining states the probability is nil. The probability to threaten the east coast of India is 26%, it is 35% over Tamil Nadu , 22% over Andhra Pradesh, 21% over Orissa and 3% over West Bengal.

An analysis has been made to study the movement of cyclonic storms over Bay of Bengal. For this purpose the positions of storms at 0300 UTC on each day of the storms and the direction of motion at that instant is noted. From this direction of motion the mean direction of each storm is estimated for the period 1971 to 1997 and the storms that reached the intensity of cyclonic storm stage or above (wind speed >33 kts) alone is taken into consideration. The period is restricted for the purpose of reliability of the track. The percentage of the storms that crossed south the place of crossing of a storm formed earlier to the given storm has been computed under the condition that the formation of given storm is south of the earlier one. For this purpose storms formed in the first instant in post monsoon season of the year have been noted. Then the latitudinal positions of formation of the storm and latitude at which the storm crossed is noted. From these information the percentage of storms crossed south of these storms when formation position is in south of earlier one and the percentage of storms that interacted with earlier one is also noted. It is seen that about 65% of the storms formed south of the earlier one crossed south of the crossing place of earlier one and 15% interacted with

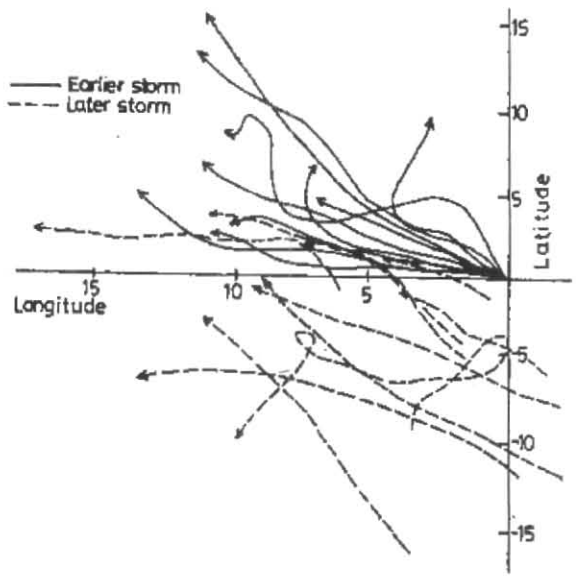



**Fig. 3.** Tracks of later storm (formed south of earlier storm) with reference to earlier storm (1977-97)

the earlier storms. Only 20% are left undetermined.

The correlation coefficient between the difference in latitude of formation of earlier storm and later storm and that of crossing of earlier storm and later storm has been computed and found to be 0.56 which is significant at 5%level. The undetermined 20% can be explained by the following manner. During the period under study it has been seen that storms formed during post monsoon season have a tendency to travel in a specified path in any given year. That is to say there is a annual behavior of storm which may have a global teleconnection. For example Gupta and Muthuchami (1990) found that a year earlier to El-nino storms over Bay of Bengal have a tendency to move northward and during El-nino years they move west to northwestward. It has been found that 56% of the occasions the storms during the season moved west or west northwest direction, on 19% of the occasions They moved northward, on 13% occasions they interacted with other systems, and remaining 13% are not affected by annual behavior (The tracks of the storms before crossing only taken into consideration). Fig. 3 gives the tracks of the storms formed earlier and tracks of the storm formed later but originated in southerly latitude than earlier one in the post monsoon season for the period 1977-97 excluding El-Nino (-1) years as an illustration. It can be seen from the Fig.4 that in the year 1981 all the storms formed in the season moved northward as in the case many other years. The tracks of the year (Fig.5) 1977 illustrates that how the storm formed later moved westwards as in the case of earlier one. The storm formed on 14th November

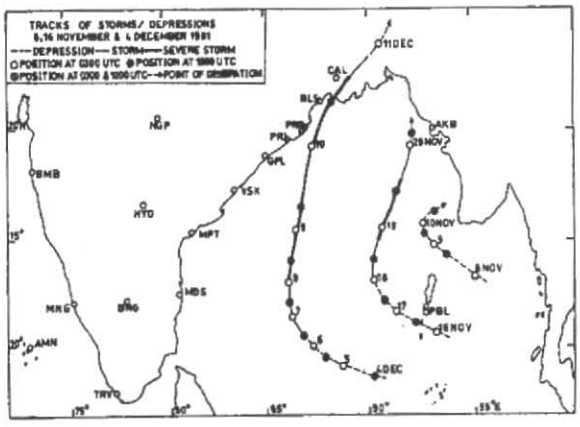



**Fig. 4.** Tracks of cyclonic storms 1981 (Post monsoon season)

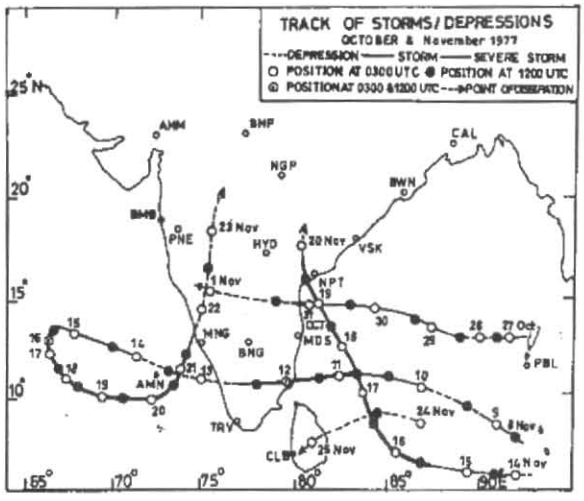



**Fig. 5.** Tracks of cyclonic storms 1997 (Post monsoon season)

Interacted by another one, which was in East Arabian Sea. Due to this interaction this storm changed from its westerly track to northerly course and Arabian Sea system moved in a loop and crossed Karnataka coast, Balasubrananiam and Jayanthi (1982).

A regression line has been fit between the mean direction of the earlier storms and the mean direction of later storm. The equation is given by

$$Y = 0.97X - 2.78$$

Where $X$ is the mean direction (in degrees) of earlier storm and $Y$ is the mean direction of later storm. The standard error to this regression equation is 14°. The correlation co-efficient between $X$ and $Y$ is 0.90, which is

significant at 1% level. Therefore this equation will give a good estimate of a storm to cross a coast given the mean direction of earlier storm.

It is also seen that the least distance between latitude of crossing of earlier one and later one is 3°. Another interesting thing to note is that if a storm happens to move over a place where already a storm has passed over then the storm will weaken in the same place or divert its path towards some other direction. Such examples are observed during 1985,1988,1978 and 1974. During the year 1997 a severe cyclonic storm moved along the east coast of India at the end of September 1997. The cyclonic storm was unable to intensify further when it came to the area of earlier track.

## 4. Conclusions

(*i*) In April, November and December only Tamil Nadu has high striking probability.

(*ii*) In October Andhra Pradesh and West Bengal are having high striking probability and threatening probability

(*iii*) The area of formation of storms affecting Tamil Nadu is significantly different from that of other states and in the month of October the origin of formation of storms affecting Andhra Pradesh is different from other states.

(*iv*) The longitudinal variation of formation is higher than latitudinal variation of storms affecting Tamil Nadu in all the months and Andhra Pradesh in October and November.

(*v*) The mean direction of motion of storms formed later one depends on mean direction of motion of earlier storm.

(*vi*) There is a particular annual behavior of storm in each year unless it is interacted with some other one, *i.e.*, the storms in a year tend to move in a particular direction.

*Acknowledgements*

The author is thankful to Shri A.K.Bhatnagar , DDGM, Regional Meteorological Centre, Chennai for his encouragement in the study and to Shri G.S.Ganesan , Director (retired), for his suggestions. Thanks are also due to S/Shri Bharathiar and N.Selvam for their drawing work.

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