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TROPICAL CYCLONES – STATISTICAL PERSPECTIVES

1. One of the areas of concern in meteorology includes Severe Tropical Cyclones (STC) and the associated catastrophic ravages to life, property and environment. Severe Tropical Cyclones are among the most destructive natural hazards around the globe. Strong winds, heavy and torrential rain, cumulative effects of storm surges and the astronomical tides associated with STC have made it extremely devastating. The accurate prediction of the trend of genesis of cyclonic disturbances, its intensification to severe tropical cyclones, the track of their movement, landfall and the possibility of surge formation are very difficult and thus is challenging for the atmospheric scientists. In order to achieve comprehensive understanding of the properties and behaviour of tropical cyclones, it is imperative to approach the problem from two different points of view, which should ultimately converge. One of these is the analysis of the observed data to identify the process/processes responsible for the genesis of tropical cyclones, prelude to model development (Bansal and Dutta, 1974; Chan and Gray, 1982; Das, 1987; Raghavan and Sensarma, 2000). The other approach refers to the simulation of numerical models for a particular tropical cyclone and to look for a positive and linear correlation between the model output and the observational facts (Ghosh, 1977; Krishnamurti and Oosterhop, 1989; Krishnamurti *et al*. 1990; Prasad *et al*., 1992 and many others). Numerous forecast techniques have been developed using the aforesaid two approaches.

The present study belongs to the first category of the two approaches. Statistical method is presented here to forecast the occurrence of severe tropical cyclones. The method of forecasting adopted here comprises hypothesis testing. The advantages of the method are, firstly it is quite simple and secondly it can provide an accurate forecast with a confidence limit up to 95% to 99 % for a long period of time.

2. *Testing of hypothesis* - Pearsonian chi-square technique and / or Kruskal-Wallis H-test (Wilks, 1995) have been used to see the efficiency of these methods in drawing inference on the occurrence of severe tropical cyclones.

Pearsonian chi-square technique is defined as;

$$\chi^2 = \sum_i \left(O_i - E_i\right)^2 / E_i \qquad (1)$$

where

$O_i \rightarrow$ observed frequencies of the i^{th} class and

$E_i \rightarrow$ expected frequencies of the i^{th} class.

This method can be applied to examine the relationship between two attributes or between a predictor and predictand (Wilks, 1995). A table containing the frequencies in the subclasses or the frequencies of the predictor and predictand scattered over different subclasses of an attribute is called the contingency table.

TABLE 1

Modification of Table for Kruskal-Wallis H-test

Months	Frequencies of STCs with different ranges of central pressure (hPa)						Rank (R_i)
Jan	Observed	0	0	1	1	0	
	Rank	11.5	11.5	29	29	11.5	92.5
Feb	Observed	0	0	0	0	0	
	Rank	11.5	11.5	11.5	11.5	11.5	57.5
Mar	Observed	0	0	1	1	1	
	Rank	11.5	11.5	29	29	29	110
Apr	Observed	0	0	0	2	4	
	Rank	11.5	11.5	11.5	38.5	46	119
May	Observed	6	3	9	8	4	
	Rank	51	43	55.5	53.5	46	249
Jun	Observed	0	2	1	2	2	
	Rank	11.5	38.5	29	38.5	38.5	156
Jul	Observed	0	0	1	1	1	
	Rank	11.5	11.5	29	29	29	110
Aug	Observed	0	0	2	1	0	
	Rank	11.5	11.5	38.5	29	11.5	102
Sep	Observed	2	0	1	3	3	
	Rank	38.5	11.5	29	43	43	165
Oct	Observed	1	5	5	8	14	
	Rank	29	48.5	48.5	53.5	59	238.5
Nov	Observed	9	6	4	10	18	
	Rank	55.5	51	46	57.5	60	270
Dec	Observed	0	0	1	10	6	
	Rank	11.5	11.5	29	57.5	51	160.5

A statement, H_0 that assumes the independence of the two attributes or two variables is called the null hypothesis. This null hypothesis is to be tested against an alternative hypothesis that assumes the opposite. Based on the null hypothesis, expected frequencies are calculated and a chi-square statistic is formed using the observed and expected frequencies. If the value of χ^2 obtained this way exceeds the tabular value of χ^2 with appropriate degree of freedom (Dixon and Massey 1983), then the null hypothesis is rejected upto a level of significance; otherwise the null hypothesis is accepted. This technique can be applied to any physical system only if the following conditions are satisfied;

(*i*) The sample observations should be independent,

(*ii*) No theoretical frequency should be less than 5 and

(*iii*) Total frequency should be reasonably large (≥ 50).

If any cell frequency is less than 5, then that cell should be amalgamated with the adjacent cell. In a (2 × 2) contingency table, since amalgamation is not possible, Yate's correction (Rao, 1973) is applied for such cases.

Huge amalgamation of a cell leads to some error, which may cause inaccuracy, to some extent, in the inference. Pearsonian chi-square technique, thus, has got some limitations though it is quite simple to handle with. In course of this study, Pearsonian chi-square technique is

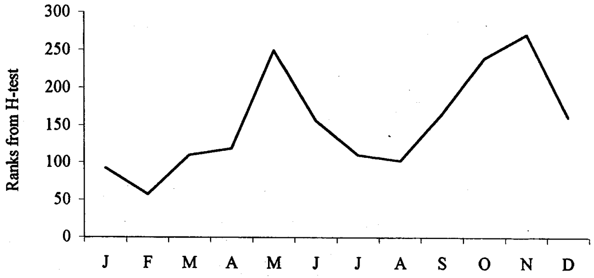

Fig. 1. Dependence of the frequency of severe tropical cyclones upon particular months of a year

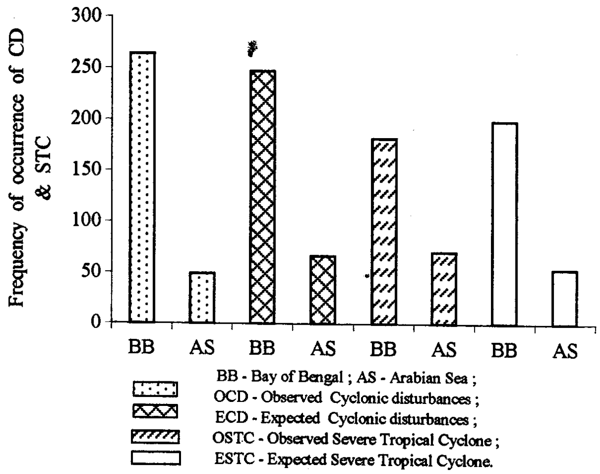

Fig. 2. Variation of frequency of occurrence of CD & STC over Bay of Bengal and Arabian Sea

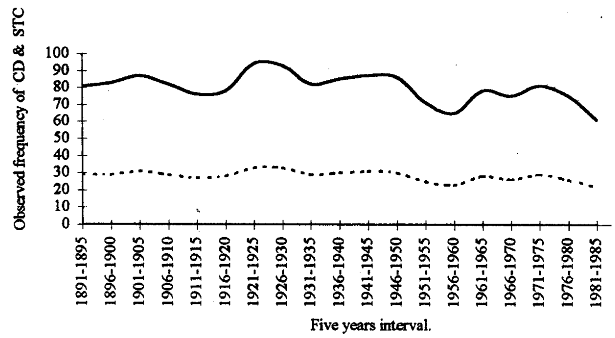

Fig. 3. Graphical representation of the occurrence of CD (———) and STC (-----) in five years interval of time

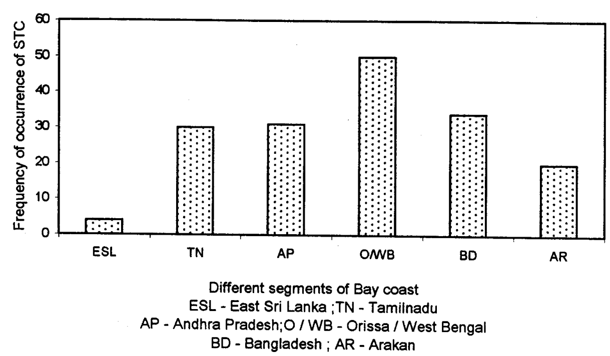

Fig. 4. Dependence of the frequency of occurrence of severe tropical cyclone (STC) upon particular coasts

used for those cases that satisfy all the above conditions and needs no huge amalgamation. But, whenever huge amalgamation is required for any cell, Kruskal – Wallis H-test is used before applying chi-square technique to have accurate inference.

Kruskal – Wallis H – test is defined as ;

$$\mathrm{H} = \left(1/\mathrm{S}^2\right)\left[\sum_i \left(R_i^2/n_i\right) - N\left(N+1\right)^2/4\right] \quad (2)$$

$$\mathrm{S}^2 = \left\{1/\left(N-1\right)\right\}\left[\sum_{i,j} r_{ij}^2 - N\left(N+1\right)^2/4\right] \quad (3)$$

where

$n_1, n_2, n_3, \ldots\ldots\ldots\ldots, n_k \rightarrow$ k-independent samples

$N \rightarrow$ total number of observations,

$r_{i,j} \rightarrow$ rank of j^{th} observation of i^{th} sample and

$R_i \rightarrow$ sum of the ranks of i^{th} sample.

For sufficiently large number of samples, H is distributed approximately as chi-square statistic with (K– 1) degrees of freedom. If the computed value of H exceeds the critical value as obtained from the standard chi-square table, the null hypothesis is rejected; otherwise the null hypothesis is accepted.

In the present paper, we have used the proposed method to look into the following aspects in connection with the occurrence of severe tropical cyclones;

(*i*) whether the frequency of occurrence of severe tropical cyclones depends upon particular months of a year,

(*ii*) whether the severity of a tropical cyclone depends upon the type of the water body,

TABLE 2

Frequency of occurrence of cyclonic disturbances and severe tropical cyclones over Bay of Bengal and Arabian Sea during the period from 1881 to 1989 (Mandal, 1991)

Month	Bay of Bengal		Arabian Sea	
	Cyclonic disturbances	Severe tropical cyclones	Cyclonic disturbances	Severe tropical cyclones
Jan	6	2	2	0
Feb	1	1	0	0
Mar	4	2	0	0
Apr	21	10	6	4
May	50	35	19	15
Jun	37	4	19	12
Jul	41	8	3	0
Aug	30	3	3	0
Sep	39	16	7	3
Oct	78	34	25	12
Nov	97	49	29	22
Dec	41	17	6	2

(*iii*) whether a probable duration could be fixed that an observed cyclonic disturbance (CD) may lead to the formation of severe tropical cyclone (STC),

(*iv*) whether the frequency of occurrence of severe tropical cyclones depends upon particular coasts and

(*v*) whether it is possible to fix a probability distribution to severe tropical cyclones that they would attain a maximum sustained wind speed of 64 knots or more.

3. Result reveals the following :

(*i*) In the long run in 99% cases the frequency of occurrence of severe tropical cyclones significantly depends upon particular months of a year (Table 1 & Fig. 1), which is in accord with the observational facts.

(*ii*) It is observed that the frequency of occurrence of STC is more over Bay of Bengal than over Arabian Sea (Table 2 & Fig. 2), confirming the observations.

(*iii*) The pattern of the curves (Fig. 3) show that the proportion of the observed CD to expected STC would be more or less same in five years interval of time.

(*iv*) The frequency of occurrence of severe tropical cyclones depends upon particular coasts. It is observed that the frequency of occurrence of STC is maximum over the coast of Orissa/ West Bengal and minimum over the coast of east Sri Lanka (Fig. 4).

(*v*) The conversion of an STC to a storm with wind speed at least 64 knots are serially independent Bernoulli variables.

4. Using Kruskal – Wallis H – test, Pearsonian chi–square technique and the concept of Binomial Distribution over more than hundred years data during the period of the occurrence of severe tropical cyclones, we could arrive at the conclusion that with a confidence limit upto 95% to 99% for a long period of time, the frequency of occurrence of severe tropical cyclones strongly depends upon particular months of a year, the type of water bodies over which they generate and particular coasts. It can also be concluded that the proportion of cyclonic disturbances to severe tropical cyclones does not significantly vary within an interval of five years time and the conversion of a STC to a storm with wind speed atleast 64 knots is serially independent.

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