

## Role of total-totals stability index in forecasting of thunderstorm/non-thunderstorm days over Kolkata during pre-monsoon season

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**सार** – इस षोघ-पत्र में कोलकाता (डमडम) के रेडियोसॉंदे ऑकड़ों का उपयोग करके मानसून पूर्व के महीनों (मार्च, अप्रैल और मई) के दौरान गर्ज के साथ तूफान आने की गतिविधि का अध्ययन किया गया है। इस अध्ययन का उद्देश्य कोलकाता में गर्ज के साथ तूफान आने/नहीं आने की घटना के पूर्वानुमान में टोटल-टोटल्स इंडेक्स (टी. टी. आई.) की उपयोगिता की जाँच की गई है। इस जाँच से पता चला है कि गर्ज के साथ तूफान आने के दिनों और गर्ज के साथ तूफान नहीं आने के दिनों को पहचानने के लिए टोटल-टोटल्स इंडेक्स का प्रारंभिक तौर पर पूर्व सूचक के रूप में उपयोग किया जा सकता है। जब टोटल-टोटल्स इंडेक्स (टी. टी. आई.) मान अधिक होता है तब गर्ज के साथ तूफान आने की संभावना अधिक होती है। यद्यपि, केवल टी. टी. आई. का उपयोग करके, प्रत्येक मामले में गर्ज के साथ तूफान आने का सटीक पूर्वानुमान करना वास्तव में संभव नहीं है क्योंकि केवल टी. टी. आई. से सकल वायुमंडलीय परिस्थितियाँ स्पष्ट नहीं हो पाती हैं। तथापि, टोटल-टोटल्स इंडेक्स के प्रारंभिक मान का उपयोग करके सटीक पूर्वानुमान किया जा सकता है।

**ABSTRACT.** The thunderstorm activity over Kolkata during pre-monsoon months (March, April and May) has been studied using the radiosonde data of Kolkata (Dumdum). The objective of the study is to examine the utility of Total-Totals Index (TTI) in forecasting occurrence/non-occurrence of thunderstorm over Kolkata. The investigation reveals that Total-Totals Index can be preliminarily used as a predictor to differentiate thunderstorm and non-thunderstorm days. The probability of occurrence of thunderstorm is higher when Total-Totals Index value is higher. While the exact prediction of thunderstorm in all the cases, using the TTI alone, is obviously not possible as TTI alone does not describe the total atmospheric conditions. However, a significant forecast can be furnished by using a threshold value of Total-Totals Index.

**Key words** – Thunderstorm, Pre-monsoon, Kolkata, Totals Totals Index (TTI).

### 1. Introduction

Thunderstorms are one of the most impressive and dreadful weather phenomena in the atmosphere, which are manifested by lightning and sharp and/or rumbling sounds, usually associated with torrential rain, squall or gusty winds, and sometimes accompanied with damaging hail. While it has a number of beneficial effects such as maintaining electrical field of the earth's surface and atmosphere, good rainfall and providing relief from scorching heat due to down drafts, still it is a major cause of natural disasters and a major hazard to aviation in many parts of India. Among these, northeastern region comprising of Assam and adjacent states, sub-Himalayan West Bengal and Sikkim and Gangetic West Bengal (GWB) experiences thunderstorms at higher frequency particularly in the pre-monsoon season (March, April and May). In these regions, thunderstorms appear with severe intensity (Hoddinot, 1986) causing extensive damages to property and sometimes injury or loss of life. Due to the

high destructive nature and occurrence in the month of 'Baishakh', thunderstorms over Gangetic West Bengal are called 'Norwesters', locally known as 'Kalbaishakhi'. Hence, there has been always a great need for a simple method, which can predict the possibility of occurrence of a thunderstorm. There are three essential requirements for the occurrence of thunderstorms, *viz.*,

- (i) Conditional and/or convective instability in the atmosphere
- (ii) Moisture incursion in the lower tropospheric levels and
- (iii) Lifting mechanism to realize the instability, leading to convection in the atmosphere.

The Stability index is a factor indicating the instability conditions in the atmosphere (Srinivasan, 1962). During the last six decades, various types of

TABLE 1

## Description of different skill scores used for categorical forecasts

Skill scores	Code	Formula	Limits	Remark
Critical Success Index	CSI	$N_1/(N_1+N_2+N_3)$	$0 \leq \text{CSI} \leq 1$	Higher value signifies good forecast
Efficiency	EI	$(N_1+N_4)/N_1+N_2+N_3+N_4$	$0 \leq \text{EI} \leq 1$	Higher value signifies good forecast
Probability of Detection	POD	$N_1/(N_1+N_3)$	$0 \leq \text{POD} \leq 1$	Higher value signifies good forecast
No Hit Rate	NHR	$N_3/(N_1+N_3)$	$0 \leq \text{NHR} \leq 1$	Lower value signifies good forecast
False Alarm Rate	FAR	$N_2/(N_1+N_2)$	$0 \leq \text{FAR} \leq 1$	Lower value signifies good forecast

Where  $N_1, N_2, N_3$  and  $N_4$  are defined by the following contingency table:

	Event observed	Event not observed
Forecast Event	$N_1$	$N_2$
Forecast No Event	$N_3$	$N_4$

stability indices have been proposed and extensively used for thunderstorm forecasting. Some of them are:

- (i) Showalter index (SI) (Showalter, 1953)
- (ii) Lifted Index (LI) (Galway, 1956)
- (iii) K- Index (KI) (George, 1960)
- (iv) Total-Totals Index (Miller, 1972), (Asnani, 1993), etc.

Over Indian region, some studies on thunderstorm forecasting based on stability index have been carried out in the past. Basu (1962) discussed the performance of Showalter Index in thunderstorm forecasting at Delhi. A comparative study was conducted by Seshadri and Jain (1990) about the utility of Showalter Index and Galway Index. Their investigation revealed that Galway Index is a better predictor as compared to the Showalter Index for an objective assessment of development of summer thunderstorms in and around New Delhi. Lal (1990) has examined the role of Showalter Index for forecasting of thunderstorm activity over Lucknow. Lal (1989) studied the usefulness of Total-Totals Index to forecast thunderstorm activity around Delhi and Jodhpur during March and June and this study reveals that higher values of Total-Totals Index correspond to more favourable conditions of thunderstorm activity. Koteswaram and Srinivasan (1958) have studied the synoptic factors favourable for development of thunderstorm over GWB during pre-monsoon months and have inferred that, thunderstorms fail to occur over GWB unless there are southerly winds (responsible for advection of moisture

TABLE 2

## Three hourly frequency distribution of thunderstorm occurrence over Kolkata and neighbourhood in pre-monsoon season during the period 1991-95

Time of commencement of thunderstorm	No. of occurrence
0000 hrs (IST) – 0300 hrs (IST)	19
0300 hrs (IST) – 0600 hrs (IST)	9
0600 hrs (IST) – 0900 hrs (IST)	<b>5</b>
0900 hrs (IST) – 1200 hrs (IST)	8
1200 hrs (IST) – 1500 hrs (IST)	19
1500 hrs (IST) – 1800 hrs (IST)	<b>41</b>
1800 hrs (IST) – 2100 hrs (IST)	34
2100 hrs (IST) – 2400 hrs (IST)	7

(Maximum and minimum frequency are in bold type)

into the area) at least up to 1.0 km above sea level, in spite of other conditions being favourable. The afternoon solar insolation and moist air mass flow up to about 1-2 km towards West Bengal, especially over south Bengal, during Norwesters' season in West Bengal triggers deep convection which leads thunderstorm activity over the region (IMD, 1944). Kar and Bandyopadhyay (1998) have analysed the occurrences of thunderstorms over a few stations in West Bengal during the pre-monsoon season. The Totals Totals Index (TTI) takes into account both, the static stability conditions (lapse rate) and the moisture content in the lower levels of the atmosphere. With this backdrop, in the present study, an attempt has been made to examine the significance of Total-Totals Index in

TABLE 3(a)

Various statistical parameters of TTI, based on 0000 UTC data

Category	Mean	Median	Standard Deviation	Skewness
Thunderstorm day	49.5	49.4	5.7	0.04
Non thunderstorm day	44.4	45.0	8.1	-0.67

TABLE 3(b)

Various statistical parameters of TTI, based on 1200 UTC data

Category	Mean	Median	Standard Deviation	Skewness
Thunderstorm day	51.5	52.3	6.1	0.07
Non thunderstorm day	45.1	45.4	7.1	-0.33

forecasting thunderstorm and non-thunderstorm days over Kolkata during pre-monsoon season (March, April and May).

## 2. Data and methodology

### 2.1. Data

The daily surface weather data of four stations of Kolkata and neighbourhood *viz.*, Dum Dum (Lat. 22° 39' N, Long. 88° 27' E), Alipore (Lat. 22° 32' N, Long. 88° 20' E), Hooghly (Lat. 22° 59' N, Long. 88° 22' E), and Canning (Lat. 22° 15' N, Long. 88° 40' E), and the daily RS/RW data of 0000 UTC and 1200 UTC for pre-monsoon season (March, April and May) of the six years (1991-1996), as a sample of cases, for Kolkata, are used for the study. These data are obtained from National Data Center, India Meteorological Department, Pune. Using the daily surface weather data, the days of thunderstorm-occurrence (*i.e.*, thunderstorm-days) are differentiated from the non-thunderstorm days. The surface data has been examined in three hourly intervals for each day of all three stations. If thunderstorm occurrence is reported by any station in any time interval in a day, that day is accounted as a thunderstorm day.

### 2.2. Methodology

The Total-Totals Index (TTI) has been computed by following relation,

$$\text{Total-Totals Index (TTI)} = T_{850} + T_{850} - 2 \times T_{500},$$

Where  $T_{850}$ ,  $T_{850}$  and  $T_{500}$  represent 850 hPa level air temperature, 850 hPa level dew point temperature and

500 hPa level air temperature, respectively (all temperatures are in °C).

The Total-Totals Index for each day for both 0000 UTC and 1200 UTC radiosonde ascents of Kolkata (Dum Dum) is calculated for the period 1991-1996. Then, for each occurrence of thunderstorm preceding or concurrent both time RS/RW observation hours *i.e.*, 0000 UTC and 1200 UTC, TTI values are considered separately and those values are considered as index values for 0000 UTC and 1200 UTC respectively of thunderstorm days. The other values for both times (0000 UTC and 1200 UTC) are considered as TTI values of non-thunderstorm days.

The mean, median, standard deviation, coefficient of skewness and frequency distribution of TTI values for 0000 UTC and 1200 UTC of thunderstorm days as well as for non-thunderstorm days are computed for the period 1991-1995.

A threshold value of Total-Totals Index has been estimated on the basis of five years data (1991-1995) to predict thunderstorm and non-thunderstorm days through an iteration process by utilizing the skill scores used for categorical forecast. The different skill scores and their meaning are explained in Table 1. The mean value of TTI for thunderstorm days is taken as the initial guess in the iterative process. The process is continued till the best possible forecast-skill scores are achieved.

In order to verify that the forecast for thunderstorm and non-thunderstorm days based on the estimated threshold value is statistically significant or not, Chi-square test is utilized. For this, the forecast contingency table for an independent year 1996 has been prepared on

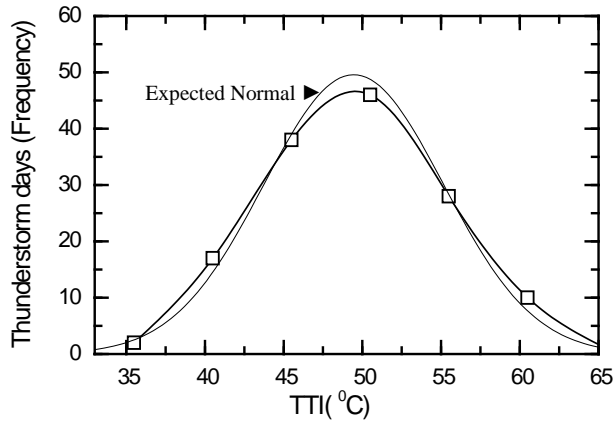


Fig. 1. Frequency distribution of thunderstorm days for 0000 UTC TTI value

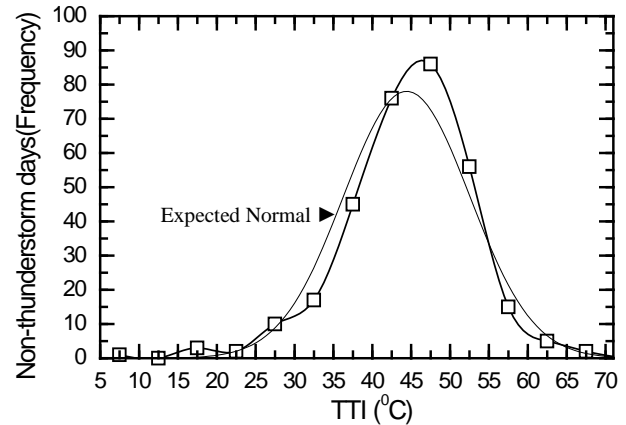


Fig. 3. Frequency distribution of non-thunderstorm days for 0000 UTC TTI value

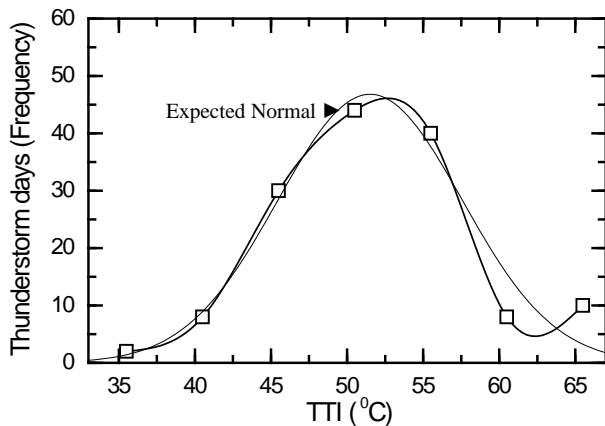


Fig. 2. Frequency distribution of thunderstorm days for 1200 UTC TTI value

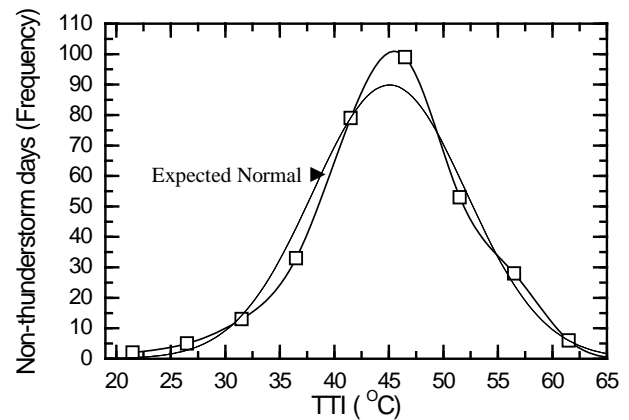


Fig. 4. Frequency distribution of non-thunderstorm days for 1200 UTC TTI value

the basis of observations and prediction using the threshold value of TTI. Again, to analyze the performance of forecast for thunderstorm and non-thunderstorm days of 1996 based on threshold values of Total-Totals Index, the skill scores are computed.

### 3. Results and discussion

On scrutinizing the surface weather data of all four stations of Kolkata and its neighbourhood for the pre-monsoon seasons of the years 1991 to 1995, it has been found that the total thunderstorm days are 142 and non-thunderstorm days are 318, during the said period. Three hourly frequency distribution of thunderstorm occurrence has been depicted in Table 2. It is observed from Table 2 that the maximum number of cases of commencement of

thunderstorm occurred during 1500 hrs (IST) to 1800 hrs (IST) followed by time interval 1800–2100 hrs (IST). This result is also supported by the climatological study of frequency of pre-monsoon thunderstorm over three stations of GWB including Alipore (Kolkata) by Kar and Bandhyapadhyay (1998). Also, it is seen from the Table 2, that the lowest frequency of commencement of thunderstorm occurred in the time interval 0600-0900 hrs (IST). Thus, it is inferred that afternoon or evening is the most favourable time of occurrence of thunderstorm than late night and morning hours over Kolkata and its neighbourhood, as day heating (insolation) plays a significant role.

The mean, median, standard deviation and coefficient of skewness of TTI values for 0000 UTC and

TABLE 4

**Test for forecast verification of 1996**  
**(i) Contingency Table for 0000 UTC**

Forecast	Observation		Total
	Thunderstorm day	Non-thunderstorm day	
Thunderstorm day	19 (8)	16 (27)	35
Non-thunderstorm day	3 (14)	54 (43)	57
Total	22	70	92

(Values in brackets are expected frequency).

$$\chi^2_{\text{(computed)}} = 31.06 \quad \chi^2_{\text{(tabulated at 95\%)}} = 3.84$$

**(ii) Contingency Table for 1200 UTC**

Forecast	Observation		Total
	Thunderstorm day	Non- thunderstorm day	
Thunderstorm day	13 (9)	24 (28)	37
Non- thunderstorm day	9 (13)	46 (42)	55
Total	22	70	92

(Values in brackets are expected frequency)

$$\chi^2_{\text{(computed)}} = 3.97 \quad \chi^2_{\text{(tabulated at 95\%)}} = 3.84$$

1200 UTC of both thunderstorm days as well as non-thunderstorm days are shown in the Table 3(a) and Table 3(b) respectively. Also, the frequency distribution curves of both thunderstorm and non-thunderstorm days for both times (0000 UTC and 1200 UTC) are plotted in the Figs. 1, 2, 3 and 4. From Figs. 1 and 2, it is evident that the frequency distribution curves for thunderstorm days are nearly normal and positively skewed. Similarly, it is apparent from the Figs. 3 and 4 that the frequency distribution curves for non-thunderstorm days are also nearly normal but negatively skewed. The values of coefficient of skewness for both 0000 UTC and 1200 UTC TTI values of thunderstorm days are positive, as stated in Table 3(a) and Table 3(b). The listed values in Table 3(a) and Table 3(b) showed that the values of coefficient of skewness are negative in each hour (0000 UTC and 1200 UTC) corresponding to non-thunderstorm days. Consequently, it suggests that the Total-Totals Index has some ability to distinguish the atmospheric conditions between thunderstorm and non-thunderstorm days.

To examine more precisely the efficiency of the TTI in differentiating thunderstorm and non-thunderstorm days, the mean values of TTI for four different types (such as 0000 UTC and 1200 UTC TTI values of thunderstorm days and also for non-thunderstorm days) are considered, from Table 3(a) and Table 3(b). From this and also, from Figures 1 to 4, it is noted that the frequency distribution curve for thunderstorm days and non-thunderstorm days

based on both categories of TTI value are nearly normal. Hence, for a meaningful analysis it can be assumed that the populations of all categories are normally distributed. The distribution curves of thunderstorm days are positively skewed whereas the same for the non-thunderstorm days are negatively skewed. As a whole, it suggests that higher the TTI value, more is the possibility of occurrence of thunderstorm.

In order to obtain a threshold value of TTI to predict the occurrence of thunderstorm, different skill scores for categorical forecast mentioned in the methodology, are computed for different values of TTI. Performing the estimation process to determine the threshold value of TTI, it has been observed that the best threshold values for 0000 UTC and 1200 UTC are 47.0 and 48.4, respectively.

On the basis of estimated threshold values, the forecast contingency table has been prepared for the verification year 1996 (Table 4). The computed values of chi-square statistic for both categories 0000 UTC and 1200 UTC are higher than tabulated value of chi-square with one degree of freedom at 95% significant level. Hence, the forecasts based on the prescribed threshold values are significantly skilled.

To examine the quality of forecasts in verification year 1996 based on threshold TTI values, the different skill scores have been computed for both categories

TABLE 5

## Skill scores for verification year 1996

Skill Score	0000 UTC	1200 UTC
Critical Success Index (CSI)	0.50	0.28
Efficiency Index (EI)	0.79	0.64
Probability Of Detection (POD)	0.86	0.59
No Hit Rate (NHR)	0.14	0.41
False Alarm Rate (FAR)	0.46	0.65

0000 UTC and 1200 UTC as shown in Table 5. The values of skill scores for both categories indicate that the forecast is quite good on the basis of prescribed threshold values of TTI. So the prescribed threshold values may be used as an important predictor to differentiate between occurrence and non-occurrence of thunderstorm activity over Kolkata and its neighbourhood. However the values of some skill scores indicate that TTI values are fairly high in a few cases of non-thunderstorm days and also in some occurrence of thunderstorm the TTI values are less than the prescribed threshold TTI values. It may be due to the fact that occurrence of thunderstorm depends on prevailing synoptic situation and the lifting mechanism leading to high instability condition of the atmosphere in addition to the atmospheric condition accounted by TTI values. Another possible cause may be that, in some cases thunderstorm activity observed over Kolkata drifted from distant location like Jharkhand and eastern parts of Bihar. Hence, in future an integrated study needs to be carried out to develop a new index for forecasting thunderstorm activity more accurately over Kolkata and neighbourhood considering all synoptic as well as thermodynamic conditions of the atmosphere.

#### 4. Conclusions

(i) During pre-monsoon season afternoon or evening time is more prone to occurrence of thunderstorms over Kolkata and its neighbourhood than midnight and morning time.

(ii) The Total-Totals Index (TTI) can be used as an important predictor to differentiate thunderstorm and non-thunderstorm days. The higher values of TTI indicate the favourable condition for thunderstorm activity, which in turn suggest that high instability and lower level moisture content of the atmosphere play a crucial role in occurrence of thunderstorm over Kolkata and its neighbourhood.

(iii) A threshold value of TTI (47.0 for 0000 UTC and 48.4 for 1200 UTC) may be used as an indicator in forecasting of thunderstorm-occurrence over this region.

(iv) The TTI values are fairly high in few cases of non-thunderstorm days as a result in all cases exact forecast can not be possible by using only TTI value. Further studies are required considering a great detail of stability indices, synoptic situation and thermodynamic conditions of the atmosphere for forecasting thunderstorm occurrence over this region.

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