

Measure of CINE – A relevant parameter for forecasting pre-monsoon thunderstorms over GWB

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सार - इस शोध-पत्र में पश्चिमी बंगाल के गांगेय क्षेत्र में मानसून ऋतु से पूर्व के दिनों में गर्जते तूफानों की घटनाओं का पूर्वानुमान करने के लिए उपलब्ध संवहनी स्थितिज ऊर्जा (सी.ए.पी.ई.) और संवहनी संदमन ऊर्जा (सी.आई.एन.ई.) के योगदान का विवेचन करने के लिए ज़ेड-सांख्यिकी के महत्व को जाँचने की पद्धति की जानकारी दी गई है।

इनसे प्राप्त परिणामों से यह पता चलता है कि सी.ए.पी.ई. और सी.आई.एन.ई. के बीच सहसंबंध नकारात्मक होता है। परिणामों से यह भी पता चलता है कि जहाँ पर इस प्रकार के तूफान सबसे अधिक आते हैं वहाँ पर संवहनी स्थितिज ऊर्जा के निम्नतर मान निर्धारित किए जा सकते हैं किन्तु उपलब्ध संवहनी स्थितिज ऊर्जा के संबंध में न तो निम्नतर और न ही उच्चतर मानों के लिए यह संभव है। अतः इस शोध-पत्र का समापन इस अदभुत निष्कर्ष के साथ होता है कि केवल संवहनी संदमन ऊर्जा के माप ही सुसंगत प्राचल हैं, जबकि पश्चिमी बंगाल के गांगेय क्षेत्रों में मानसून ऋतु से पूर्व के गर्जते तूफानों के पूर्वानुमान करने के लिए उपलब्ध संवहनी स्थितिज ऊर्जा का कोई उल्लेखनीय योगदान नहीं है। लेकिन यह स्थिति अमरीका के बड़े मैदानी भागों के भीषण तूफानों से संबंधित अवधारणा से एकदम विपरीत है।

ABSTRACT. A method of testing the significance of Z-Statistic is introduced in this paper to discern the role of Convective Available Potential Energy (CAPE) and Convective Inhibition Energy (CINE) in forecasting the occurrence of pre-monsoon thunderstorms over Gangetic West Bengal (GWB).

The result reveals that a negative correlation exists between CAPE and CINE. It further indicates that a range for the lower values of CINE can be fixed where the frequency of occurrence of such storms will be maximum, but such range, either for lower or for higher values of CAPE, is not possible. The paper, thus, ends with a very interesting finding that a measure of CINE is the only relevant parameter whereas CAPE has no significant role in forecasting the occurrence of pre-monsoon thunderstorms over GWB, which is in contrast to the concept of severe thunderstorms of Great Plains of America.

Key words – CAPE, CINE, GWB, Pre-monsoon thunderstorms, Z-Statistic.

1. Introduction

Thunderstorms, in general, connotes a perennial feature of India, but the storms of pre-monsoon season (March - May) are most violent, particularly, over GWB. Whatever might be the origin of development, the effects are appallingly disastrous when accompanied by hail, tornado and high wind speed. This has, doubtless, occupied the attention of the professional meteorologists over the last eight decades or so. The prediction of the

genesis of such phenomena continues to be an area of dominant concern for the atmospheric scientists of India. The studies on the phenomena were initially based on the analysis of the conventional surface and upper air parameters before and immediately after the occurrence of the thunderstorms (Normand, 1938; Sen, 1931; Sohoni *et al.*, 1928; Chatterjee and Sur, 1938, Raisarkar, 1953, Desai and Rao, 1954, Ramaswamy, 1956, Koteswaran and Srinivasan, 1958, Weston, 1972, Mukherjee and Chaudhury, 1979, Kanjilal *et al.*, 1989, Dhar and Sinha,

1994, Chaudhuri and Ghosh, 1997, and many others). The analyses of the non-conventional parameters, like Satellite and Radar imageries, were done to mark the zone of instability (De, 1952, Das *et al.*, 1957; De and Sen, 1961, Mull *et al.*, 1963; Chaudhuri and Rakshit, 1970, Kalsi and Bhatia, 1992, and many others). These studies were mainly qualitative in nature. Some of them are case studies as well. Probably due to the complex nature of the phenomena and non-availability of the proper network of observations, no single technique, so far, could prove to be efficient and sufficient for forecasting the occurrence of these storms quantitatively.

The purpose of the present study is to introduce a method, which is new for such systems, to view the role of CAPE and CINE in forecasting the genesis of pre-monsoon thunderstorms over GWB.

2. Role of CAPE and CINE

Conditional instability is known to be the mechanism by which thunderstorms are formed (Williams, 1995). The energy that drives conditional instability is convective available potential energy (CAPE) and is defined as;

$$\text{CAPE} (z) = \int_{\text{LFC}}^{\text{LNB}} \{(T_p - T_e) / T_e\} g \, dz \quad \text{J / kg} \quad (1)$$

Where

LNB → level of neutral buoyancy, where upward buoyancy vanishes,

LFC → level of free convection, the altitude at which the parcel first becomes upwardly buoyant,

T_p → temperature of the parcel of air,

T_e → environmental temperature,

g → acceleration due to gravity.

CAPE represents the maximum limit of energy a parcel can extract from the environment, once it becomes buoyant. In order to release CAPE, a small negative area identified as convective inhibition energy (CINE) must be supplied. CINE offers the measure of the energy barrier that must be surmounted and is defined as;

$$\text{CINE} (z) = \int_{\text{Srf}}^{\text{LFC}} \{(T_e - T_p) / T_e\} g \, dz \quad \text{J / kg} \quad (2)$$

Where

Srf → surface level.

In mid-latitude, meteorologists put thrust on CAPE to estimate the energy release because the synoptic systems are available there in plenty to minimize CINE. Observations disclose that, for a given temperature and moisture content at the surface, the quantitative value of CAPE is enhanced by advection of cold air above the LFC. The CAPE pushes the air parcels upwards, while the upper level features like, field of divergence ahead of a trough and rear of a ridge, or hydrodynamic pressure induced by wind shear pulls the parcel up. The occurrence of severe thunderstorms of Great Plains of America is unique in a sense that such events occur there due to the enhancement of CAPE (Ray, 1986).

In tropics, on the other hand, Indian subcontinent is normally barotropic during the period of pre-monsoon season as the horizontal temperature gradient is less. Besides the presence of feeble induced low-pressure areas on the surface level, there exists no significant synoptic system, which can be observed from climatological charts. It is mentioned here that by strong or significant synoptic system, it is meant that the synoptic conditions could be expressed objectively. Attention is, therefore, drawn here towards small – scale and lower level features that tend to minimize CINE. Thus, for forecasting the genesis of pre-monsoon thunderstorms over GWB, it is surmised that the magnitude of CINE is more relevant than that of CAPE. The concept has been made authentic by applying the proposed method.

3. Methodology

The method adopted for the present study is based on the testing of the significance of test – statistic.

There are various aspects of hypothesis testing that are quite relevant in the field of atmospheric sciences (Wilks, 1995). There are two types of testing procedure for a hypothesis;

(i) Parametric test,

(ii) Non-parametric or distribution – free test.

In the physical systems for practical purposes, distribution – free test is more acceptable because this test

TABLE 1

Frequency (percentage) of pre-monsoon thunderstorms associated with different CAPE and CINE

CAPE (J / kg)	CINE (J / kg)				Total
	0-150	151-300	301-450	451-600	
0000 – 1000	16 (12.9%)	16 (12.9%)	07 (5.7%)	00 (0%)	39 (31.5%)
1000 – 2000	25 (20.2%)	07 (5.6%)	02 (1.6%)	00 (0%)	34 (27.4%)
2000 – 3000	22 (17.7%)	04 (3.2%)	00 (0%)	01 (1%)	27 (21.9%)
> 3000	24 (19.4%)	00 (0%)	00 (0%)	00 (0%)	24 (19.4%)
Total	87 (70.2%)	27 (21.7%)	09 (7.3%)	01 (1%)	124 (100%)

can be performed without any restriction on the theoretical distribution of the observational data so that the data from any distribution can be treated in the same manner.

3.1. Z - Statistic

If $x_1, x_2, x_3, x_4, \dots, x_n$ represents a random sample from normal $N(\mu, \sigma^2)$ population then sample mean \bar{x} becomes $N(\mu, \sigma^2/n)$, whatever might be the size of 'n'.

Hence the test-statistic,

$$Z = \{(\bar{x} - \mu) \sqrt{n}\} / \sigma \text{ is } N(0,1) \tag{3}$$

where standard deviation,

$$\sigma = \sqrt{(1/n) [\sum_i (x_i - \mu)^2]} \tag{4}$$

and mean

$$\mu = (1/n) \sum_i x_i \tag{5}$$

However, if the sample size is sufficiently large, then irrespective of the distribution of the population, relation (3) holds.

Comparing the computed value of the test-statistic under null hypothesis;

$$H_0 ; \mu = \mu_0$$

against alternative hypothesis;

$$H_1 ; \mu \neq \mu_0$$

at the level of significance, α , an appropriate decision is made. Here the question of a one-tailed or two-tailed test arises (Figs. 2 & 3). Whether a test is one-tailed or two-tailed depends upon the nature of the hypothesis being tested. Depending on the nature of the problem, an alternative hypothesis H_1 is framed so as to make the test a one or two tailed. This is decided on the basis of a prior reason to expect that violation of null hypothesis would lead to the values of test-statistic on a particular side of the null distribution.

If $|Z| \leq Z_{\alpha/2}$ (or Z_α), the null hypothesis will be accepted, otherwise the null hypothesis will be rejected.

Some difference between the observed sample mean and hypothetical population mean is inevitable because of the fluctuation of random sampling. If the difference $|\bar{x} - \mu_0|$ is too large, it cannot be explained by sampling fluctuation alone and the authenticity of the null hypothesis would be in doubt. It may be noted that

$$P[|Z| > A] = P[|(\bar{x} - \mu_0) \sqrt{n} / \sigma| > A] = \alpha \tag{6}$$

implies that $[|(\bar{x} - \mu_0) \sqrt{n} / \sigma|]$ will be greater than a constant 'A' in only 100 α % cases in the long run of repeated random sampling of size 'n' (Wilks,1995).

4. Results and discussions

The present study is made with the conventional surface and upper air meteorological data of pre-monsoon seasons (April), collected from the available observatories over GWB. CAPE and CINE have been computed using relations (1) and (2) respectively. The frequencies of occurrence of thunderstorms with percentage of occurrence within different ranges of CAPE and CINE have been displayed in Table 1. The table shows that the frequency of occurrence of pre-monsoon thunderstorms over GWB is maximum (70.2%) within the range (0 – 150) of CINE in J/kg., which is the lowest range of CINE. The division of different ranges of CAPE is also quite reasonable because each subclass has significant number of thunderstorm frequency (Table 1).

The following aspects have been taken up in the present study to view the role of CAPE and CINE in forecasting the occurrence of pre-monsoon thunderstorms;

- (i) whether a relationship can be established between CAPE and CINE during the occurrence of pre-monsoon thunderstorms.

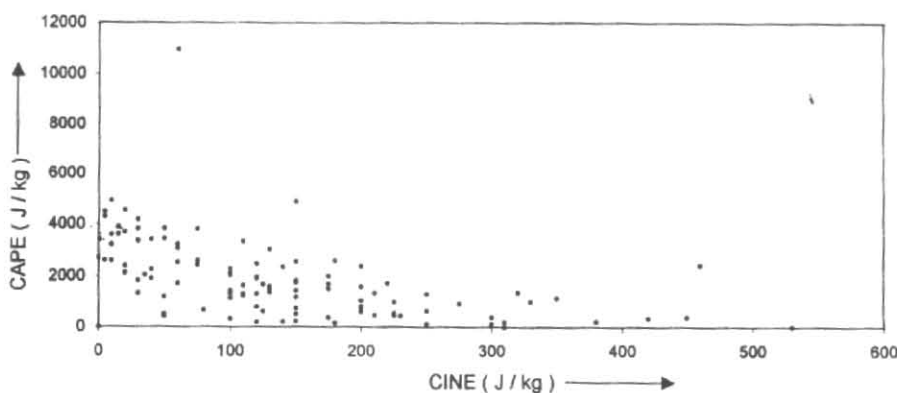


Fig. 1. Relation between CAPE & CINE over GWB during pre-monsoon season

- (ii) whether a range of CINE can be fixed so that the frequency of pre-monsoon thunderstorm is maximum within that range.
- (iii) whether a range of CAPE can be fixed so that the frequency of pre-monsoon thunderstorm is maximum within that range.

4.1. A relation between CAPE and CINE

A scattered diagram (Fig 1) is drawn with CINE as variable 'x' and CAPE as variable 'y'. The sample means of CINE and CAPE being \bar{x} and \bar{y} respectively. The figure shows that the orientation of the sample points represents a linear pattern with negative slope of the form; $y = (-m)x$. This indicates that CAPE and CINE should be negatively correlated. Thus, minimum CINE is expected to be associated with maximum CAPE.

4.2. Range for CINE

A sample of 124 thunderstorms has been collected for this study. This gives a mean CINE, $\bar{x} = 131$. A standard deviation of these CINE, $s = 102.78$.

Initially, based on observation (Table 1), the mean CINE is assumed to be 150 J/kg because 70.2% of the thunderstorms occurred for CINE within the range 0 J/kg to 150 J/kg.

Thus, the null hypothesis can be defined as;

$$H_0 : \mu = 150$$

Without contradicting the observation, an alternative hypothesis becomes;

$$H_1 : \mu < 150$$

A one-tailed test (Fig. 2) is to be performed in this case.

As the variance for CINE associated with the occurrence of thunderstorms is not known, the standard deviation, σ is estimated, using the formula;

$$\sigma^2 = S^2 = [n / (n - 1)] s^2 \quad (7)$$

as

$$\sigma = S = 103.19$$

where

$$n = 124.$$

The test-statistic,

$$Z = (-) 2.053 \quad [\text{from equation (3)}]$$

and

$$Z_{0.05} = 1.645 \quad [\text{from standard table}]$$

This shows that the absolute value of the test-static, Z computed for the samples exceeds the tabular value at 5% level of significance. Thus, null hypothesis is rejected and the alternative hypothesis is accepted. This indicates that, in 95% cases, mean CINE, during the occurrence of pre-monsoon thunderstorms, will be less than 150 J/kg.

To fix the range for CINE, a two-tailed test has to be performed (Fig. 3).

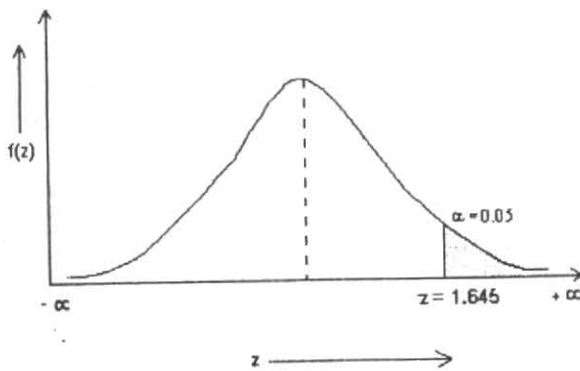


Fig. 2. Probability density for standard normal distribution

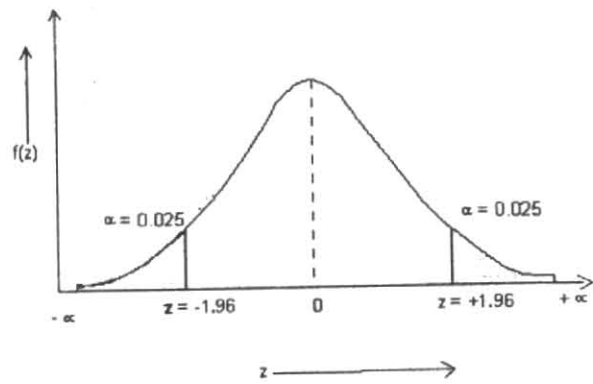


Fig. 3. Probability density for standard normal distribution

The test-statistic for this case is;

$$Z_{0.025} = \pm 1.96 \quad [\text{from standard table}]$$

$$\text{Because } |Z| = Z \quad \text{if } Z > 0$$

$$\text{and } |Z| = (-)Z \quad \text{if } Z < 0 \quad [\text{by definition}]$$

Using equation (6) we obtain;

$$P [|Z| > 1.96] = 0.05$$

$$\Rightarrow P [|(\bar{x} - \mu) | \sqrt{n/S} > 1.96] = 0.05$$

$$\Rightarrow 1 - P [|(x - \mu) | \leq (S/\sqrt{n})1.96] = 0.05$$

$$\Rightarrow P [\{ \bar{x} - (S/\sqrt{n})1.96 \} \leq \mu \leq \{ \bar{x} + (S/\sqrt{n})1.96 \}] = 0.95$$

$$\Rightarrow P [113 \leq \mu \leq 148] = 95\% \quad (8)$$

where $P \rightarrow$ Probability.

It is observed that, if 124 samples of pre-monsoon thunderstorms are repeatedly collected from future thunderstorm days then 95% of the average CINE associated with the occurrence of maximum frequency of pre-monsoon thunderstorms will be within the range 113 J/kg to 148 J/kg. This finding does not involve serious Type - 1 error and is, therefore reasonably accepted. Serious Type - 1 error affects the validity of the findings when the results from the hypothesis test contradict the observational facts. If the null hypothesis would have involved any value corresponding to other ranges of CINE, then the ultimate range of 'μ' would have been the same as in expression (8), otherwise there would appear a

serious Type - 1 error. Thus, it can be stated that the only range for CINE should be 113 J/kg to 148 J/kg within which the frequency of occurrence of pre-monsoon thunderstorms will be maximum.

4.3. Range for CAPE

The null hypothesis is defined in this case as;

$$H_0 : \mu = 3000$$

the alternative hypothesis becomes;

$$H_1 : \mu < 3000$$

The test-statistic, $Z = (-) 6.209$ [from equation (3)] and $Z_{0.05} = 1.645$ [from standard table]

As we see that the absolute value of Z, computed for the samples, exceeds the tabular value of Z, null hypothesis is rejected and the alternative hypothesis is accepted. This indicates that, in 95% cases, the mean CAPE will be less than 3000 J/kg. Proceeding in the similar fashion as section 4.2, it is observed that 95% of the average CAPE will be within the range of 2294 J/kg to 2632 J/kg. This shows that average CAPE associated with the occurrence of pre-monsoon thunderstorms does not correspond to the energy level of highest frequency (Table 1). Thus, the computed range for CAPE involves serious Type - 1 error and, therefore it is not possible to fix a range for CAPE such that the frequency of occurrence of thunderstorms will be maximum within that range (Fig. 4).

5. Conclusions

The findings of the present study lead to the conclusion that a range of lower values of CINE plays the

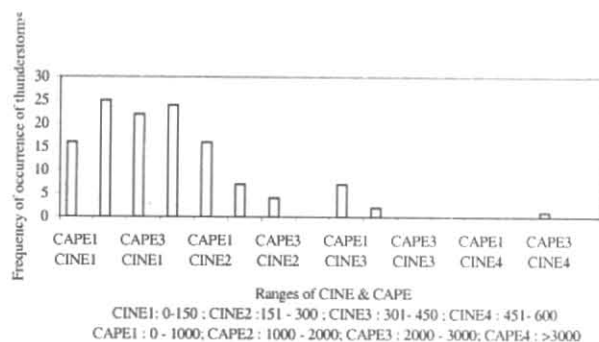


Fig. 4. Frequency of occurrence of thunderstorms associated with different ranges of CAPE & CINE

most dominant role in the genesis of pre-monsoon thunderstorms over GWB. CAPE, regarded to be the most important parameter, so far, for the occurrence of severe thunderstorms over Great Plains of America, is found to play a neutral role in the genesis of pre-monsoon thunderstorms over GWB (20° N to 24° N latitude, 85° E to 93° E longitude).

Thus, it can be stated that, reduction of CINE is important whereas neither reduction nor enhancement of CAPE is relevant for the occurrence of these storms.

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