MAUSAM, **54**, 4 (October 2003), 867-880

551.509.326 : 551.558.1

# Objective forecast of thundery/nonthundery days using conventional indices over three northeast Indian stations

P. MUKHOPADHYAY, J. SANJAY and S. S. SINGH

*Indian Institute of Tropical Meteorology, Pune – 411 008, India*

(*Received on 9 January 2001, Modified 24 March 2003*)

**सार** – उत्तरी पूर्वी भारत के तीन स्थानों नामतः गुवाहाटी, डिबरूगढ़ और अगरतला के रेडियोसौंदे डाटा (आर.एस./आर.डब्ल्यू.) का उपयोग करते हुए वर्ष 1980 से 1984 के चार महीनों (मार्च, अप्रैल, मई और जून) के संवहन से पहले के वायुमंडल का अध्ययन किया गया है। इस अध्ययन का उद्देश्य इन तीन स्थानों के लिए मेघ गर्जन/बिना मेघ गर्जन वाले दिनों का पूर्वानुमान करने के लिए पूर्वसूचकों के रूप में प्रयुक्त किए जा सकने वाले निर्धारित थ्रेशहोल्ड मानों के साथ उपयुक्त सूचकांक की जाँच करना है। इस अध्ययन में कुल ग्यारह अक्षाकों (इनडाइसिस) पर विचार किया गया है। तीन स्थानों को एक साथ लेते हुए 0000 और 1200 यू.टी.सी. के आर. एस./आर. डब्ल्यू. आकड़ों से आवश्यक तापगतिकीय और शुद्ध गतिक प्राचल प्राप्त किए गए है। मेघ गर्जन और मेघ गर्जन रहित दिनों में अंतर बताने के लिए अक्षांकों (इनडाइसिस) की क्षमता की गुणात्मक तुलना करने के लिए संभाव्य वितरण वक्र आरेखित किए गए हैं। माध्य और मानक विचलनों के आकलन किए गए है और इन्हें ज़ेड – साँख्यिकी में प्रयुक्त किया गया है। जो अक्षांक (इनडाइसिस) 90 प्रतिशत अथवा उससे अधिक का महत्वपूर्ण ज़ेड मान दिखाते है, उनका और विश्लेषण करने के लिए उन्हे रख लिया जाता है और शेष छोड़ दिये जाते हैं। चुने हुए अक्षांको (इनडाइसिस) के थ्रेशहोल्ड मान इनइरेटिव प्रक्रिया द्वारा निर्धारित किए गए होते है। जहाँ सूचकांक के मान का माध्य पहले अनुमान के रूप में प्रयुक्त होते हैं और कुशल स्कोर (स्किल स्कोर) आकलित किए जाते हैं। फिर पहला अनुमान परिवर्तित हो जाता है और स्क्लिस् दोबारा आकलित किए जाते है। प्रत्येक चुने हुए सूचकांक के सर्वोत्तम स्कोर के प्राप्त हाने तक यह प्रक्रिया जारी रहती है। इन अक्षांकों (इनडाइसिस) के थ्रेशहोल्ड मानों का उपयोग जाँच वाले वर्ष 1985 में, मेघगर्जन और मेघगर्जन रहित दिनों का पूर्वानुमान देने के लिए किया गया है। गुवाहटी, डिबरूगढ़ और अगरतला के लिए 0000 और 1200 यू.टी.सी. पर मेघगर्जन रहित दिनों के पूर्वानुमान में एच.आई के सर्वोत्तम स्क्लि के होने का पता चला है।

**ABSTRACT.** The preconvective atmosphere of the four months (March, April, May and June) for the year 1980-84 have been studied using the Radiosonde data (RS/RW) of the three stations of northeast India namely Guwahati, Dibrugarh and Agartala. The objective is to identify a suitable index for these stations with a prescribed threshold value that can be used as the predictor for forecasting thundery/nonthundery days. Total eleven indices are considered in this study. The thermodynamic and kinematic parameters required for calculation of the indices are derived from the RS/RW data of 0000 and 1200 UTC and taking three stations together. Probability distribution curves are plotted to make a qualitative comparison on the ability of the indices to differentiate the thundery and nonthundery days. Mean and standard deviations are calculated and these are used to apply Z-statistics. The indices that have shown Z values at 90% or more significant level are considered for further analysis and rest are rejected. Threshold values of the selected indices are assigned by an iterative process where the mean of value of the index is used as the first guess and skill scores are calculated. Next the first guess value is changed and the skills are recalculated. The process is continued till the best score is attained for each selected index. The threshold values of these indices are used to predict the thundery and nonthundery days of the verification year 1985. It is found that HI has the best skill in forecasting thundery/nonthundery days at 0000 and 1200 UTC for Guwahati, Dibrugarh and Agartala stations.

**Key words –** Northeast India, Thunderstorm prediction, Conventional indices.

## 1. Introduction

Thunderstorms are a major cause of natural disasters in many parts of India. Among these, the northeastern region experiences thunderstorm at a higher frequency (Rao and Raman 1961) particularly in the premonsoon months (March, April, May and early June). In this region thunderstorm appear with severe intensity (Hoddinot 1986) causing heavy loss to life and property. Hence there is an urgent need to look into the present state of understanding and forecasting these severe weather systems. In general the atmospheric condition that triggers severe weather over tropics can be categorized as (*i*) Conditional instability, (*ii*) Low level convergence, (*iii*) Advection of moisture at the lower level (850 hPa), (*iv*) Source of vertical lift of the parcel to trigger the convection and (*v*) Upper air divergence. These conditions are prerequisite for the development of the thunderstorms. According to Doswell (1987), the large scale processes help in developing a suitable thermodynamic structure required for the formation of the convective systems while mesoscale processes act mainly to initiate convection leading to thunderstorm. Thus thunderstorms are an outcome of interaction between the synoptic scale flow and localized mesoscale forcings. Predictions of thunderstorms using stability indices and assessment of success by the measure of skill scores have been extensively attempted by many researchers. Stone (1985) discussed the performance of stability indices over eastern United States and their relation to thunderstorm activity. Schultz (1989) compared several stability indices to study convective weather events over northeast Colorado using data for the summer of 1985. Fuelberg and Biggar (1994) made a comprehensive study on the preconvective environment of summer thunderstorm over Florida Panhandle. Scheafer (1990) discussed in detail the advantages and limitations of Critical Success Index (a commonly used skill score) in assessing forecast skills of thunderstorm. In another study, Doswell *et al*. (1990) discussed the efficiency of different skill scores in rare event (tornadoes, flash floods) forecasting based on contingency tables. Over the Indian region, especially over northeast India, several studies on thunderstorm forecasting have been done in the past. The Frequency of thunderstorm in different months over India has been extensively discussed by Rao and Raman (1961). Koteswaram and Srinivasan (1958) discussed the synoptic conditions favourable for the development of thunderstorm and infer that the simultaneous presence of the low level convergence and upper air divergence is the key factor for thunderstorm development. Synoptic features associated with premonsoon thunderstorms over Assam have been studied by Sen and Basu (1961). A study by Choudhury (1961) emphasizes the contributions of low level convergence and orographic lifting as the principal causes of the thunderstorm development in the northeastern region of India. Mukherjee (1964) showed that the frequency of thunderstorm over Guwahati was highest in night time during premonsoon months. He inferred that hills in the region had a profound role in the development of thunderstorm.

Relatively fewer attempts have been made in forecasting thundery/nonthundery days using conventional indices with an emphasis to their efficiency in thunderstorm prediction. In the present study, an attempt has been made to utilize the simpler diagnostic technique of using stability indices in forecasting thundery and nonthundery days. We have chosen eleven indices. These indices are K index (George 1960), Total-Total (TT) index (Miller 1970), Surface Lifted Index (SLI) (Means 1952), Deep Convective Index (DCI) (Barlow 1993), Humidity Index (HI) (Litynska *et al*. 1976), Boyden Index (BI) (Boyden 1963), Convective Available Potential Energy (CAPE) (Moncrieff and Miller 1976), Normalised CAPE (NCAPE) (Blanchard 1998), Severe Weather Threat (SWEAT) (Bidner 1970), Bulk Richardson Number (RINO) (Weissman and Klemp 1982) and Vertical wind shear (SHEAR). These indices have their inherent advantages and limitations. The purpose of this paper is to identify the suitable index with a prescribed threshold in forecasting thundery/nonthundery days for the stations namely Guwahati, Dibrugarh and Agartala of northeast India. The performance of different indices to predict thundery days are compared with the help of skill scores following Huntrieser *et al*. (1997). The paper is arranged in the following manner. Prevailing synoptic feature and data used in the study are given in section 2. Methodology is described in section 3. Results for three northeast stations are discussed in section 4. Summary and discussion of the work is given in section 5.

## 2. Synoptic condition and data used

Sen and Basu (1961) have given a complete picture of synoptic features that prevail in premonsoon months over northeast India. The chief synoptic features are the existence of a high pressure area south of 20° N extending vertically up to middle troposphere and a low pressure area north of 25° N in the lower troposphere. The wind at lower level up to 850 hPa normally remains southerly or southwesterly. The large scale flow in the upper atmosphere beyond 300 hPa remains westerly. Often western disturbances in the form of a low pressure area and/or trough embedded in the westerlies pass over the region in an eastward direction. The troughs in these westerlies often get extended up to Gangetic West Bengal, causing the incursion of moist southwesterlies/southerlies from Bay of Bengal. Localised convection many time is induced by a low level cyclonic circulation extending vertically up to 2.1 km. The strong solar insolation and orographic lifting helps to form local convergence (IMD, 1944) in this area. This frequently triggers deep convection that leads to severe weather.

The RS/RW data of 0000 and 1200 UTC for the premonsoon months (March, April, May and June) of the five years (1980-84) for Guwahati (26.18° N, 91.75° E), Dibrugarh (27.48° N, 94.92° E) and Agartala (23.88° N, 91.25° E) are used for the study. The data for the year

**TABLE 1**

**Description of Indices**

| Indexes | Code | Reference(s) | Expression | Explanation | Comments |
|---|---|---|---|---|---|
| K | K | George (1960) | $(T + T_d)_{850} - T_{500} - (T_{700} - T_{d700})$ | $T$ and $T_d$ are the dry bulb and dew point temp. Subscripts indicate the pressure levels in hPa | Combination of 850-500 hPa lapse rate, 850 hPa moisture, levels of saturation at 700 hPa |
| Total Total | TT | Miller (1967) | $2(T_{850} - T_{500}) - (T_{850} - T_{d850})$ | Notations similar to K index | Lapse rate between 850 and 500 hPa and measure of saturation at 850 hPa |
| Surface Lifted Index | SLI | Means (1952) | $T_{500} - T'_{sfc\delta 500}$ | $T$ is the environmental temperature ($^{o}$C) at 500 hPa. $T$ is the temperature of the parcel at 500 hPa after it is lifted dry adiabatically from surface (sfc) to its condensation level and moist adiabatically thereafter | Thermal stability of the atmosphere at 500 hPa in terms of environmental temperature and parcel temperature. |
| Deep Convective Index | DCI | Barlow (1993) | $(T + T_d)_{850}$ - SLI | Notation as above | Measure of lower level temperature and 500 hPa thermal instability |
| Humidity Index | HI | Litynska *et al.* (1976) | $(T - T_d)_{850} + (T - T_d)_{700} + (T - T_d)_{500}$ | Notation as above | Combination of measure of saturation at 850, 700 and 500 hPa |
| Boyden Index | BI | Boyden (1963) | $H_{700} - H_{1000} - T_{700} - 200$ | $H$ is the height of the indicated pressure level in decameter | |
| Severe Weather Threat | SWEAT | Bidner (1970) | $12T_{d850} + 20(TT - 49) + 4\,V_{850} + 2V_{500} + 125\ \text{SHEAR}_{850\delta 500}$ | $V$ is the wind speed at the pressure level SHEAR is the wind shear from 850 to 500 hPa | Combination of thermal and thermo-mechanical stability |
| Convective Available Potential Energy | CAPE | Moncrieff and Miller (1976) | $g\int_{Z_{\text{LFC}}}^{Z_{\text{LNB}}} \frac{T_{ve} - T_{vp}}{T_{ve}}\,dz$ | $T_{ve}$ is the virtual temperature of the environment and $T_{vp}$ is the virtual temperature of the parcel. $Z_{\text{LNB}}$ and $Z_{\text{LFC}}$ are the height at level of neutral buoyancy and level of free convection | |
| Normalised CAPE | NCAPE | Blanchard (1998) | $\frac{\text{CAPE}}{Z_{\text{LNB}} - Z_{\text{LFC}}}$ | Notation as above | |
| Vertical Wind Shear | SHEAR | Weissman and Klemp (1982) | $\frac{\int_0^6 \rho(z)\lvert v(z)\rvert dz}{\int_0^6 \rho(z)dz} - [1/2\{v(0)+v(.5)\}]$ | $\rho(z)$ is the density of air at a height z. $v(0)$ and $v(.5)$ wind speed at at 0 km and 0.5 km | Density weighted vertical wind shear from 0 to 6 km |
| Bulk Richardson No | RINO | Weissman and Klemp (1982) | CAPE/0.5 [SHEAR]$^2$ | | |

1985 is used to verify the forecast skill of the indices for these three stations. The RS/RW data are scrutinized carefully and data from such ascent are used where the meteorological parameters *viz.* wind, dry bulb temperature, dew point temperature at standard pressure levels are available. In some cases the RS/RW ascent is incomplete or there are cases when the ascent has reached up to the lower troposphere (700 hPa or so) only. These ascents are not considered. As per the World Meteorological Organisation (WMO) weather code if there is a report of thunderstorm in the present weather (ww) or report of thunderstorm during past six hour from the time of observation (W), the day is considered to be a thundery day. This criterion is used to define thundery days.

## 3. Methodology

### 3.1. *Stability indices*

The thermodynamic parameters [*e.g.* dry bulb temperature ($T$) and dew point temperature ($T_d$)] and kinematic parameters [*e.g.* horizontal wind components ($u$, $v$)] available at standard pressure levels are interpolated in the vertical at intervals of 20 hPa. Specific humidity is derived from dew point temperature at a particular pressure. The stability indices namely K, TT, SLI, DCI, HI, BI and SWEAT are computed using the parameters at standard pressure levels. The equidistant pressure level data are used to compute CAPE, NCAPE, SHEAR and RINO. The indices with their physical meaning are explained in Table 1. K index considers the saturation at 700 hPa where as TT considers the saturation at 850 hPa. In addition both these indices include the dry bulb temperature difference between 850 and 500 hPa that in fact gives the measure of lower tropospheric insolation. SLI deals with the stability of the parcel at 500 hPa and it checks whether the parcel is warmer/cooler than its environment at 500 hPa level. DCI is a combination of lower tropospheric (850 hPa) temperature and SLI. HI uses the level of saturation at 850, 700 and 500 hPa. BI is a combination of geopotential height at 1000 and 700 hPa and temperature at 700 hPa. SWEAT is computed using wind speed at 850 and 500 hPa and TT index. CAPE is calculated as per Moncrieff and Miller (1976) as a function of virtual temperature of parcel and environment. NCAPE is expressed as CAPE normalized by the height difference between level of neutral buoyancy (LNB) and level of free convection (LFC). SHEAR is considered as density weighted wind shear of the lowest 6 km of the atmosphere. RINO is calculated as CAPE normalized by density weighted vertical wind shear (Weissman and Klemp 1982). The mean, standard deviation and the probability distribution (Grosh and Morgan 1975) of each index are computed. Further statistical methods are used to quantify the usefulness of the selected indices.

**TABLE 2**

**Contingency table**

| | | Prediction | |
|---|---|---|---|
| | | Event predicted | Event not predicted |
| Observation | Event observed | A (Hits) | B (Misses) |
| | Event not observed | C (False Alarms) | D (Nonevent Hits) |

### 3.2. *Statistical significance*

To determine statistically which index best differentiates thundery (X) and nonthundery (Y) atmosphere, test statistics ($Z_{XY}$) as introduced by McClave and Dietrich (1988), are computed as follows

$$Z_{xy} = (M_X - M_Y)[s^2{}_x/n_x + s^2{}_Y/n_y] \qquad (1)$$

Where $M_X$ and $M_Y$ are mean stability values of any index for category X and Y, $n_x$ and $n_y$ represent the number of events in each category. $s_x$ and $s_y$ are corresponding standard deviation. Larger absolute values of $Z_{xy}$ represent the usefulness of the index in differentiating between thundery and nonthundery days. However this method does not quantify the accuracy of forecasts. Therefore several skill scores are computed to assess the forecast ability of each index.

### 3.3. *Skill scores*

For each index (Table 1) the number of correctly forecasted events (A), events not correctly forecasted (B), events forecasted but not observed (C) and events not forecasted and also not observed (D) are computed with respect to the contingency Table 2. Based on these, five skill scores (Table 3) *viz*. Probability of Detection (POD), False Alarm Ratio (FAR), Critical Success Index (CSI), True Skill Statistics (TSS) and Hiedke Skill Score (HSS) are computed. POD is the ratio of events that are correctly forecast to the total number of events (A+B). FAR is the ratio of false alarm (C) to the total number of predicted events (A+C). CSI is the ratio of number of correctly forecasted events to the sum of the total number of events and false alarm (A+B+C). Therefore CSI varies directly with the number of correct event forecast and varies inversely with both the number of incorrect event forecast (false alarm) and number of missed events. However CSI does not take into account the number of correct nonevent

**TABLE 3**

**Description of different skill scores**

| Skill score | Code | References | Equation | Limits |
|---|---|---|---|---|
| Probability of detection | POD | Donaldson *et al.* (1975) | POD = A/(A+B) | 0≤ POD ≤ 1 |
| False alarm ratio | FAR | Donaldson *et al.* (1975) | FAR = C/(A+C) | 0≤ FAR ≤ 1 |
| Critical success index | CSI | Donaldson *et al*. (1975) | CSI = A/(A+B+C) | 0≤ CSI≤ 1 |
| True skill statistics | TSS | Hansen and Kuipers(1965) | TSS = (A/A+B)-(C/C+D)<br>= (AD-BC)/(A+B)(C+D) | -1≤ TSS≤ 1 |
| Hiedke skill score | HSS | Brier and Allen (1952) | HSS = (CF - E)/(N-E)<br>=2(AD- BC)/ (A+B)<br>(B+D) + (A+C)(C+D) | -1≤ HSS ≤ 1 |

CF = Total number of correct forecast = A + D
N = Total number of events = A+B+C+D
A+C = Total number of forecast for the event
A+B = Total number of observed event
C+D = Total number of observed nonevent
B+D = Total number of forecast for the nonevent
E = Expected number of correct forecast by chance = (A+C)(A+B) + (C+D)(B+D)/N

**TABLE 4**

**Mean and Standard Deviation of indices based on 0000 UTC data of Guwahati, Dibrugarh and Agartala stations**

| Index | Thundery day | | Nonthundery days | |
|---|---|---|---|---|
| | Mean | Standard deviation | Mean | Standard deviation |
| K | 32.6 | 9.2 | 31.2 | 8.6 |
| TT | 45.5 | 6.6 | 46.5 | 6.3 |
| SLI | -2.2 | 2.6 | -2.8 | 35.7 |
| DCI | 29.6 | 12.2 | 26.1 | 14.4 |
| HI | 14.4 | 9.7 | 21.7 | 10.9 |
| BI | 101.8 | 3.0 | 103.0 | 4.0 |
| SWEAT | 418.4 | 284.1 | 410.1 | 292.6 |
| CAPE | 296.7 | 606.8 | 311.1 | 694.5 |
| NCAPE | 0.9 | 0.94 | 1.1 | 1.2 |
| SHEAR | 1.8 | 2.6 | 1.7 | 2.4 |
| RINO | 182.1 | 487.4 | 171.2 | 475.7 |

(nonthundery days) forecasts (D). Hence Scheafer (1990) stated that CSI is a biased score that is dependent upon the frequency of the forecasted event. TSS is expressed as the difference between the probability of detection of an event and the probability of detection of a false event. The highest and lowest possible TSS score is 1 and –1. HSS is the ratio of categorically correct forecast (A+D) above the expected number of correct forecast due purely by chance to the total number of events also above the expected number of correct forecast by chance. HSS is defined such that a perfect set of forecast (all categorical hits) will show a score 1, a set of random forecasts will be 0 and that having lesser hits compared to the forecast by chance will have negative score. Although CSI does not consider the number of correct nonevent forecast, TSS and HSS do consider that. But the limitation of TSS and HSS is that, if the number of correct forecasts (A) and number of correct nonevent forecasts (D) are interchanged and number of misses (B) and number of false alarms (C) are interchanged between each other, scores remain unchanged whereas CSI score will change. Due to this inherent advantage and disadvantage, Doswell *et al.* (1990) concluded that "no single measure of forecasting success can give a complete picture and it is desirable to include in addition to HSS, the CSI, POD and FAR in any summary of forecasting verification".

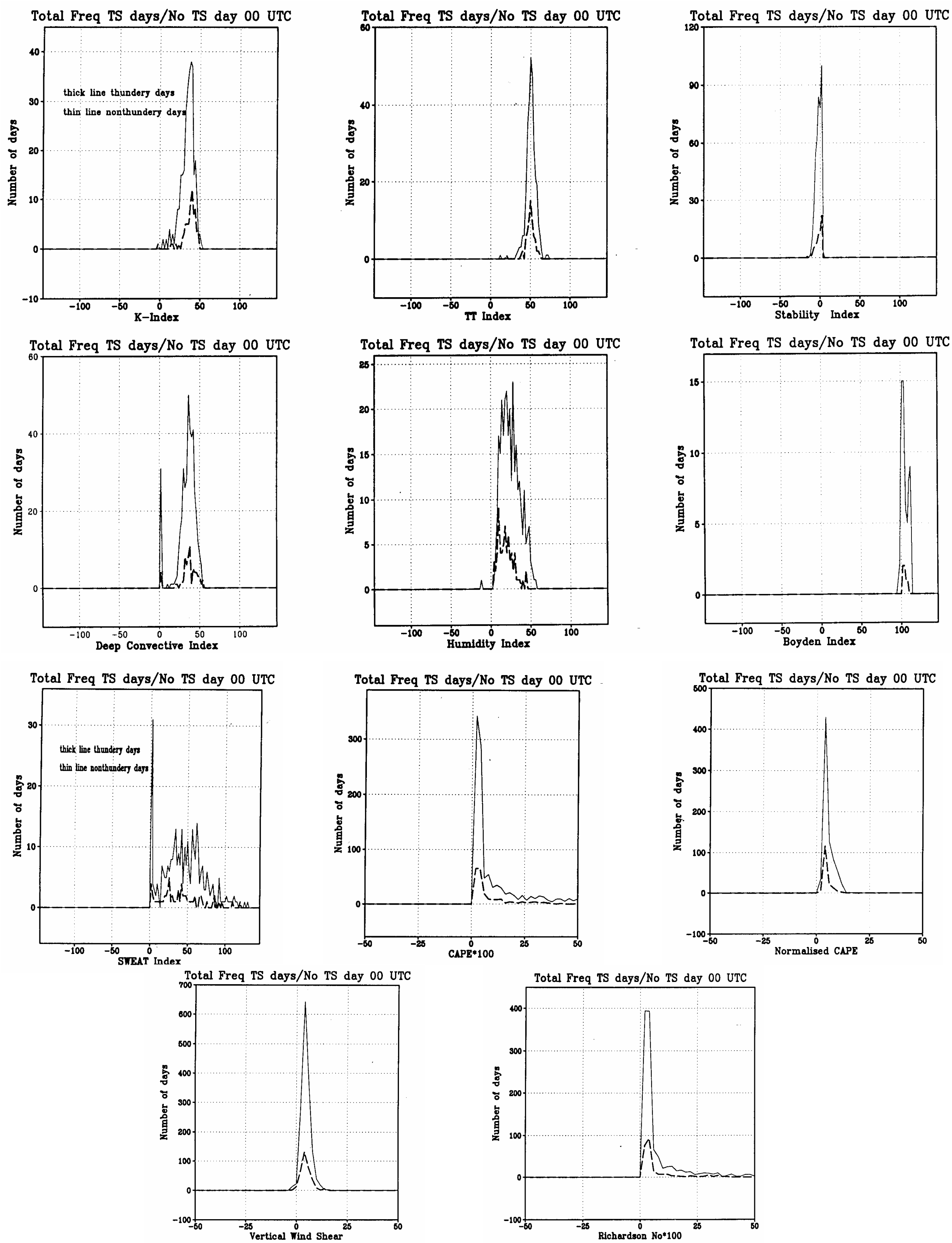


**Fig. 1.** Frequency of thundery (TS) and nonthundery (No TS) days of 0000 UTC for Guwahati, Dibrugarh and Agartala stations

**TABLE 5**

**Values of Test statistics ($Z_{XY}$) for eleven indices at 0000 UTC of Guwahati, Dibrugarh and Agartala stations. Values with 90% significant level is denoted with single star (*). Values with 95% significant level is denoted with (**) double star and that with 99% significant level is denoted with triple star (***)**

| Index | Values of $Z_{XY}$ |
|---|---|
| K | 0.88 |
| TT | -0.85 |
| SLI | -1.61* |
| DCI | 1.32* |
| HI | -2.69*** |
| BI | -0.76 |
| SWEAT | -0.16 |
| CAPE | -0.27 |
| NCAPE | -1.19 |
| SHEAR | 0.78 |
| RINO | 0.27 |

The skill score computations in this paper are made after determining for each index the threshold value (differentiating thundery and nonthundery days) that produced best possible forecast skill score in all five categories through an iterative process. The iteration is started by assuming the mean value of an index for thundery days as the initial threshold and calculating the scores. This threshold is then changed and the skill scores are recalculated. The process is continued till the best skill scores are attained.

The validity of the forecast through this process is for 12 hours. The forecast by indices based on 0000 UTC sounding will be valid during the next 12 hour ending at 1200 UTC and similarly the forecast based on 1200 UTC sounding will be valid for the next 12 hour ending at 0000 UTC.

## 4. Results

The results for 0000 UTC and 1200 UTC are discussed and presented separately.

### 4.1. *Results of 0000 UTC*

The mean and standard deviation of all the indices for five years (1980-84) for the three stations are shown in Table 4. The probability distributions of these indices are plotted in Fig. 1. The probability distribution of TT, BI, SWEAT, CAPE, NCAPE, SHEAR and RINO are such that they do not reveal distinct difference between thundery (thick line) and nonthundery days (thin line). Thus to speak in subjective manner, these indices are less likely to become a useful indicator for thunderstorm occurrences and nonoccurrences. Among the rest of the indices K, SLI, DCI and HI show skewed distribution of thundery days frequency with respect to nonthundery day frequency curve. The frequency curve of K index for thundery days is skewed to the right with respect to that of nonthundery days. Similarly the frequency curve for thundery days for SLI is skewed to the right with respect to nonthundery days curve. Thus these two indices show some ability to differentiate the atmosphere between thundery and nonthundery days. The frequency curve for nonthundery days of DCI is bimodal. One of its peak is very close to 0. As a result the frequency curve of thundery days is well separated from this peak however the other maxima of nonthundery days is overlapping. This proves that DCI has some ability to differentiate the thundery and nonthundery atmosphere. In case of HI the two curves are skewed to each other most distinctly. These curves are implying that the frequency curve of thundery days of an index is reaching its maxima at a particular value when the frequency curve of nonthundery days is showing a decreasing trend. Thus it suggests that these indices have better potential to differentiate the atmosphere.

**TABLE 6**

**Skill scores and prescribed threshold values of selected indices for 0000 UTC of Guwahati, Dibrugarh and Agartala stations**

| Indices | POD | FAR | CSI | TSS | HSS |
|---|---|---|---|---|---|
| SLI < -0.2 | .785 | .828 | .164 | .064 | .026 |
| DCI > 28.0 | .778 | .807 | .182 | .136 | .074 |
| HI < 21.0 | .625 | .765 | .195 | .165 | .122 |

To get a qualitative idea about the efficiency of the indices to discriminate the atmosphere in terms of thunder and no thunder, the mean value of the indices are considered. The mean values of TT, BI and SHEAR (Table 4) for thundery and nonthundery days are very much similar which suggests the inefficiency of these indices to distinctly differentiate the two types of (thundery and nonthundery) atmosphere. In a study by Fuelbarg and Biggar (1994) some of the indices are rejected on the basis of this criterion. It may be noted here that the probability distribution curves of these indices do not show any ability to distinguish the two types of atmosphere. The remaining eight stability indices (K, SLI, DCI, HI, SWEAT, CAPE, NCAPE and SHEAR ) are found to have better and larger difference in mean values between the two categories (thunder and nonthunder).

**TABLE 7**

**Contingency table and skill scores based on 0000 UTC data and verified with following 1200 UTC observations of Guwahati, Dibrugarh and Agartala stations for the year 1985 (Highlighted values are best scores among the indices)**

Total thundery days (TD) observed –19%
Total nonthundery days (NTD) observed –81%

| Index | Observation | Prediction TD (%) | Prediction NTD (%) |
|---|---|---|---|
| SLI< -0.2 | TD (%) | 12 | 7 |
| (POD = .631, FAR = .833, CSI = .151 TSS = -.109, HSS=.052) | NTD (%) | 60 | 21 |
| DCI > 28.0 | TD (%) | 6 | 13 |
| (POD = .316, FAR = .869, CSI = .101 TSS = -.178, HSS = -.115) | NTD (%) | 40 | 41 |
| HI<21.0 | TD (%) | 10 | 9 |
| (POD = .526, FAR = .697, CSI = .238 TSS = .242, HSS = .189) | NTD (%) | 23 | 58 |

To select those indices that will pass the significance test, Z statistics ($Z_{XY}$) is computed for all the eleven indices as shown in Table 5. So far as statistical significance (Table 5) is concerned, HI, SLI and DCI are found to have highest $Z_{XY}$ value and thus signifies that these three are having best potential to differentiate the thundery and nonthundery days. Rest of the eight indices are not found to have desired level of significance to be considered as predictors of thundery and nonthundery days and hence rejected. In order to quantify the accuracy of forecasts different skill scores are computed for the three indices namely SLI, DCI and HI which have shown at least 90% significant level or more.

Table 6 gives the prescribed threshold and corresponding skill scores for these selected indices. The best skill are obtained from DCI and HI with the threshold values 28.0° C and 21.0° C respectively. This means that thundery (nonthundery) days will be forecast when DCI is greater (less) than 28.0° C and for HI the forecast will be thundery (nonthundery) when its value will be less (greater) than 21.0° C. From the skill score point of view, POD score of 0.785 for SLI is highest closely followed by 0.778 for DCI. The best CSI, TSS and HSS scores are found for HI and the values are 0.195, 0.165 and 0.122 respectively. As discussed earlier in section 3, TSS and HSS score will be given maximum emphasis as these two are supposed to reflect the true skill of categorically correct forecast. These values of skill scores are found to be consistent with the results reported earlier on different geographical location (Huntrieser *et al.* 1997; Fuelbarg and Biggar 1994; Jacovides and Yonetani 1990).

**TABLE 8**

**Mean and standard Deviation of different indices based on 1200 UTC data of Guwahati, Dibrugarh and Agartala stations**

| Index | Thundery days Mean | Thundery days Standard deviation | Nonthundery days Mean | Nonthundery days Standard deviation |
|---|---|---|---|---|
| K | 30.5 | 6.8 | 32.0 | 7.7 |
| TT | 47.4 | 7.5 | 47.5 | 6.0 |
| SLI | -3.4 | 2.9 | -3.2 | 2.8 |
| DCI | 32.0 | 6.4 | 31.1 | 7.8 |
| HI | 19.5 | 10.9 | 20.4 | 10.5 |
| BI | 103.7 | 3.7 | 102.1 | 2.9 |
| SWEAT | 455.1 | 228.4 | 461.1 | 271.4 |
| CAPE | 1055.8 | 1305.5 | 790.7 | 1158.7 |
| NCAPE | 2.1 | 1.7 | 2.0 | 1.8 |
| SHEAR | 2.1 | 2.4 | 1.5 | 2.3 |
| RINO | 609.9 | 1091.8 | 501.2 | 953.2 |

4.1.1. *Verification of prediction at 0000 UTC*

In order to verify the performance of the selected indices for an independent data set, the forecasts are verified with the thunder/no thunder observations of 1985. The contingency table and different skill scores for SLI, DCI and HI are shown in Table 7. SLI has predicted highest percentage of correct thundery days (12%) out of 19% realized and this is reflected in POD score (0.631).

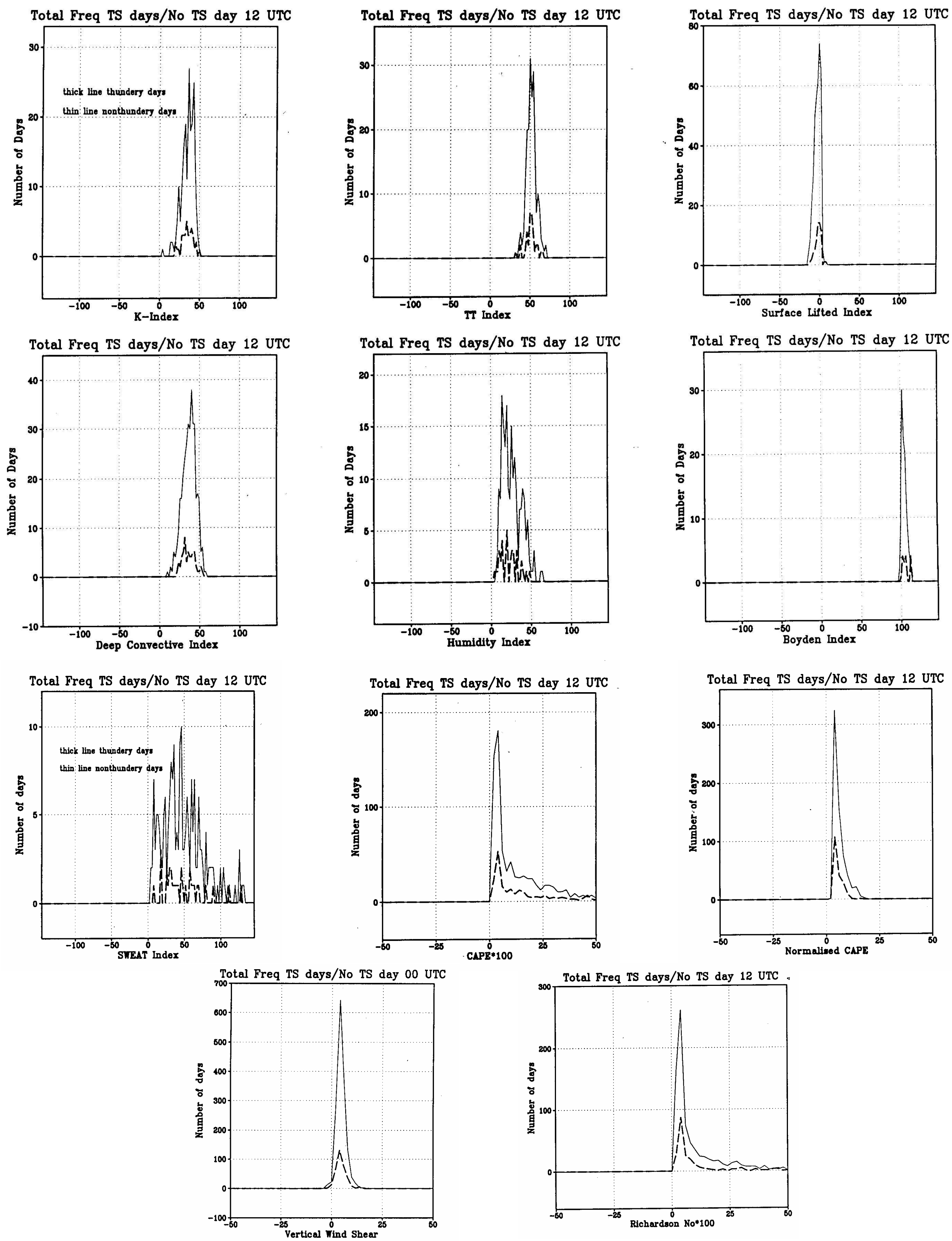


**Fig. 2.** Frequency of thundery (TS) and nonthundery (No TS) days of 1200 UTC for Guwahati, Dibrugarh and Agartala stations

**TABLE 9**

**Values of Test statistics ($Z_{XY}$) for eleven indices at 1200 UTC for Guwahati, Dibrugarh and Agartala stations. Values with 90% significant level is denoted with single star (*). Values with 95% significant level is denoted with (**) double star and that with 99% significant level is denoted with triple star (***)**

| Index | Values of $Z_{XY}$ |
|---|---|
| K | -1.00 |
| TT | -0.08 |
| SLI | -0.39 |
| DCI | 0.70 |
| HI | -2.38*** |
| BI | 1.38* |
| SWEAT | -0.11 |
| CAPE | 2.44*** |
| NCAPE | 0.49 |
| SHEAR | 4.24*** |
| RINO | 1.23 |

The fact that percentage of false alarm (60%) in the thundery days forecast is highest in case of SLI makes the FAR score to be 0.833. It produces only 21% correct nonthundery days forecast. Thus other skill scores for SLI are also very low. Although the POD score 0.631 is high compared to other indices, TSS and HSS are low mainly due to large false alarm**.** DCI has predicted 6% thundery days correctly, 40% is the false alarm and 41% is the correct nonthundery days forecast and the skill scores of DCI in five categories are 0.316 (POD), 0.869 (FAR), 0.101 (CSI), -0.178 (TSS) and -0.115 (HSS). The skill scores for this index are not good mainly due to low percentage of correct thundery days forecast and large false alarms. HI has predicted substantially high percentage of thundery days (10%), least false alarm (23%) and 58% correct nonthundery days forecast. Thus HI with its prescribed threshold of 21.0 yields best score in all the categories except POD. The POD score of HI is 0.526 and it is the second highest score among the three indices. The POD score of HI is slightly lesser than that of SLI due to 10% correct forecast produced by HI as against 12% by SLI. The reason behind HI showing best skill score in all the other four categories (except POD) is higher percentage of correct thundery and nonthundery days forecast, lower percentage of false alarm and misses. Thus from all the aspects of forecast HI seems to perform better than other indices at 0000 UTC over the selected stations.

**TABLE 10**

**Skill Scores and prescribed threshold values of selected indices for 1200 UTC of Guwahati, Dibrugarh and Agartala stations**

| Indices | POD | FAR | CSI | TSS | HSS |
|---|---|---|---|---|---|
| HI < 19.0 | .536 | .694 | .184 | .154 | .087 |
| BI > 102.5 | .615 | .789 | .176 | .132 | .063 |
| CAPE >896.8 | .410 | .794 | .212 | .102 | .072 |
| SHEAR < 2.33 | .600 | .792 | .181 | -.105 | -.063 |

## 4.2. *Results of 1200 UTC*

The mean and standard deviation of all the indices for five years (1980-84) data set are calculated and shown in Table 8. The probability distributions of all the eleven indices for 1200 UTC are plotted in Fig. 2. K, TT, SLI, DCI, SWEAT, CAPE, NCAPE, SHEAR and RINO are found to show probability distribution that fails to reveal distinct difference between thundery (thick line) and nonthundery (thin line) days. Thus these indices at a glance seem to have less possibility of producing good forecast for thundery/nonthundery days. HI like 0000 UTC has shown a skewed distribution. The probability distribution curve for thundery days is skewed to the left with respect to that of nonthundery days. The most prominent intersection of two curves (thundery and nonthundery days) is seen in case of BI. Thus qualitatively HI and BI seem to have better ability to differentiate the two categories of the atmosphere at 1200 UTC. It can be seen from Table 8 that indices namely K, TT, SLI and NCAPE have their respective mean values for thundery and nonthundery days very much close to each other which further suggests that they are not able to differentiate the two types of (thundery and nonthundery) atmosphere with good efficiency. The remaining seven indices are found to have larger difference in mean values between the two categories.

To make a quantitative assessment of the suitability of the indices the Z statistics is applied to all the eleven indices and shown in Table 9. The indices that show Z values at 99% significant level are CAPE, SHEAR and HI. BI shows Z value at 90% significant level. K, TT, SLI, DCI, SWEAT, NCAPE and RINO could not show any level of significance thereby suggesting poor ability to differentiate the two categories of the atmosphere. In order to assess the quantitative accuracy of forecast by statistically significant indices, different skill scores are computed for HI, BI, CAPE and SHEAR. Table 10 shows the prescribed threshold and corresponding skill scores for

**TABLE 11**

**Contingency table and skill scores based on 1200 UTC data and verified with following 0000 UTC observations of Guwahati, Dibrugarh and Agartala stations for the year 1985 (Highlighted values are best scores among the indices)**

Total thundery days (TD) observed –23%
Total nonthundery days (NTD) observed –77%

| Index | Observation | Prediction TD (%) | Prediction NTD (%) |
|---|---|---|---|
| HI < 19.0 | TD(%) | 15 | 8 |
| (POD = .652, FAR = .400, CSI = .454 TSS = .522, HSS = .506) | NTD(%) | 10 | 67 |
| BI > 102.5 | TD(%) | 10 | 13 |
| (POD = .434, FAR = .803, CSI = 0.156 TSS = -0.097, HSS = -0.078) | NTD(%) | 41 | 36 |
| SHEAR < 2.33 | TD(%) | 8 | 15 |
| POD =.347, FAR = .857, CSI = .112 TSS = -.275, HSS = -0.183) | NTD(%) | 48 | 29 |
| CAPE > 896.8 | TD(%) | 6 | 17 |
| (POD = .261, FAR = .854, CSI = .103 TSS = -.193, HSS = -.152) | NTD(%) | 35 | 42 |

the indices. The POD score (0.615) for BI with threshold 102.5 and TSS and HSS scores for HI with threshold 19.0 are found to be the highest. So far as FAR score is concerned, the index that will show lesser FAR will be adjudged best and again HI has shown best FAR (0.694). In other category namely CSI, TSS and HSS, HI has shown highest skill with the prescribed threshold. The threshold values for CAPE and SHEAR are 896.8 and 2.33 respectively. In CSI category CAPE has shown highest score 0.212 followed by 0.184 by HI. The values of the skill scores are found to be of the similar order with the results of Huntrieser *et al*. (1997), Jacovides and Yonetani (1990).

4.2.1. *Verification of prediction at 1200 UTC*

The indices (HI, BI, CAPE and SHEAR) with their prescribed threshold are used to predict the thundery/nonthundery days for the four months (March, April, May and June) for the year 1985 and verified by the observation reported with the RS/RW data. The contingency table showing the details of forecast by the indices and corresponding skill score are shown in Table 11. HI has predicted 15% correct thundery days out of 23% observed. The next better forecast for thundery days are by BI which has predicted 10% thundery days but false alarm is very less in case of HI (10%) and it is substantially higher for BI (41%). The percentage of correct forecast of nonthundery days is also highest (67%) for HI. As mentioned in section 3 the TSS and HSS are the most complete in the sense it reflects true ability of an index in producing categorically correct forecast. Table 11 shows that BI, SHEAR and RINO all have negative TSS and HSS values. HI alone shows positive TSS and HSS value and amongst all the category of skill score values for HI are once again is found to be the highest. Thus it should be emphasized that HI has the best ability to predict the thundery/nonthundery days for 1200 UTC for the three stations of northeast India namely Guwahati, Dibrugarh and Agartala.

## 5. Summary and discussion

In this study we have investigated the preconvective environment of premonsoon months over three northeast Indian stations namely Guwahati, Dibrugarh and Agartala. Eleven indices namely K, TT, SLI, DCI, HI, BI, SWEAT, CAPE, NCAPE, SHEAR and RINO are calculated for March, April, May and June for five (1980-84) years. The probability distribution of all the indices are plotted to make a qualitative estimate of the potential of each index to differentiate the thundery and nonthundery days. The mean and standard deviation are computed for each index for 0000 and 1200 UTC and are used to calculate the test statistics ($Z_{XY}$) to examine whether the difference of mean values of the indices for thundery and nonthundery days are significant. The index that is found significant with at least 90% level, is accepted. The selected indices for 0000 UTC for Guwahati, Dibrugarh, Agartala stations are SLI, DCI, and HI and that for 1200 UTC are HI, BI, CAPE and SHEAR. The threshold values of the statistically significant indices are calculated through an iterative process. After fixation of threshold, the indices are used to predict thundery and nonthundery days of the verification year 1985. The accuracy of the forecast is compared by five different skill scores. The most commonly used index for operational thunderstorm forecasting over Indian region is TT. Our study clearly shows TT as an inefficient predictor for 0000 and 1200 UTC for the three northeastern stations. As mentioned earlier (section 3.1) TT takes into account temperature (dry bulb) difference between 850 and 500 hPa and level of saturation at 850 hPa. It does not take into account the measure of saturation at any other level (700 hPa, 500 hPa), which is crucial for thunderstorm development. As such this could be one of the reason behind the failure of TT for 0000 and 1200 UTC thundery days forecasting. The possible reason behind the poor forecasting skill of SLI could be that SLI takes into account the thermal stability of the parcel and environment at 500 hPa, which is necessary but not sufficient for thunderstorm development. DCI is found to be a significant predictor for 0000 UTC but not for 1200 UTC for the three northeastern stations. DCI (Table 1) is expressed as a function of temperature at 850 hPa (dry bulb and dew point) and SLI. Similar to SLI, DCI does not show any better skill for 0000 UTC forecasting over Guwahati, Dibrugarh and Agartala. Percentage of false alarm are equally high for SLI and DCI at 0000 UTC over Guwahati, Dibrugarh and Agartala. BI also has not been found to be a good predictor for 0000 UTC. It could be due to the fact that lower tropospheric (1000 hPa – 700 hPa) thermal and geopotential field does not represent the deep convection based on 0000 UTC sounding. The SWEAT index is found effective for prediction of extra tropical thunderstorms where baroclinicity and shear associated with frontal systems, play a dominant role in the formation of thunderstorm. SWEAT is expressed as a function of TT index that has shown poor skill to predict thundery days. All these factors are responsible behind poor performance of SWEAT as predictor. It is well known that a deep layer of the atmosphere over northeast India remains convectively unstable during all the days of the premonsoon months. This feature is also reflected by the mean values of CAPE and RINO indices for all the four stations for both the time. As a consequence these two indices are not able to show good skill in thundery/nonthundery days forecast in any of the three stations at 0000 and 1200 UTC. It may be asked why some of the indices in spite of having significant difference (more than 90% level) between the mean values for thundery and nonthundery days are not able to show good forecast skills. The reason could be that Z statistic is statistical measure by which the indices are tested but in reality the physiographical complexity of the region and the three dimensional dynamical structure play the major role in the formation of thunderstorm (no thunderstorm) and this can not be represented properly by any statistical measure. Small vertical wind shear in the lowest 6 km of the troposphere is necessary for the growth of deep convection but no substantial variation of low level shear is seen that can be used as a good predictor over northeast Indian stations.

Results show that atmospheric instability is influenced by the availability of moisture at lower and middle troposphere leading to the development of thunderstorm over these stations. Among the eleven indices, HI is found to be the best indices in predicting thunderstorm at 0000 and 1200 UTC for the three selected stations. In the studies of Michalpoulou and Jacovides (1987) and Jacovides and Yonetani (1990), HI is found as a good predictor for nonfrontal thunderstorm.

In contingency Table 7 and Table 11, some thundery days are missed in the forecast of the indices. For some of these missed thundery days, the value of the selected index is found close to the threshold. For these days, synoptic charts of the region are referred to examine the approaching low pressure or trough causing severe weather. Such days with observed severe weather and values of index closer to threshold are included as correctly forecasted thundery days and then skill scores are recalculated. This attempt however has not produced any significant improvement. The small temporal and spatial dimension of the perturbation which has no signature in the large scale flow could be the possible reason. Thunderstorm over northeast India can occur over a meteorological station and surrounding (localized) or it may affect large areas (wide spread). In the present study we have not classified thundery days from this angle. Similarly nonthundery days can be classified as days with weak convection or days with no convection. Future studies will incorporate these classifications. A new index suitable for the Indian region will also be developed for more accurate and location specific predictions of thunderstorms.

*Acknowledgements*

The authors are thankful to Dr. G. B. Pant, Director, Indian Institute of Tropical Meteorology for his keen interest in the study. The suggestions of Dr. Heidi Huntrieser about the physical significance of some indices are gratefully acknowledged. They are also thankful to Dr. M. K. Rama Varma Raja for his help in computation of a few indices. The RS/RW data used in the study are provided by India Meteorological Department and is gratefully acknowledged.

**References**

Barlow, W. R., 1993, "A new index for the prediction of deep convection," Preprints, 17th Conf. On Severe Local storms, St. Louis, MO, *Amer. Meteor. Soc*., 129-312.

Bidner, A., 1970, "The Air Force Global Weather Central Severe Weather Threat (SWEAT) index - A preliminary report", *Air Weather Service Aerospace Sciences Review*, AWS RP 105-2, No 70-3, 2-5.

Blanchard, D. O., 1998, "Assessing the vertical distribution of Convective Available Potential Energy", *Wea. Forecasting*, **13**, 870-877.

Boyden, C. J., 1963, "A simple instability index for use as a synoptic parameter", *Meteor. Mag*., **92**, 198-210.

Brier, G. W. and Allen, R. A., 1952, "Verification of weather forecasts", Compendium of Meteorology, *Amer. Meteor. Soc*., 841-848.

Choudhury, A. K., 1961, "Premonsoon thunderstorms in Assam, Tripura and Manipur", *Indian J. Met. & Geophys*., **3**, 319-321.

Donaldson, R., Dyer, R. and Kraus, M., 1975, "An objective evaluator of techniques for prediction of severe weather events", Preprints, ninth Conf. On Severe Local Storms, Norman, OK, *Amer. Meteor. Soc*., 321-326.

Doswell, C. A. III, 1987, "The distinction between large-scale and mesoscale contribution to severe convection: A case study example", *Wea. Forecasting*, **2,** 3-16.

Doswell, C. A. III, Davies-Jones, R. and Keller, D. L., 1990, "On summary measures of skill in rare event forecasting based on contingency tables", *Wea. Forecasting*, **5**, 576-585.

Fuelberg, H. E. and Biggar, D. G., 1994, "The preconvective environment of summer thunderstorms over the Florida Panhandle", *Wea. Forecasting*, **9**, 316-326.

George, J. J., 1960, "Weather forecasting for Aeronautics", Academic Press.

Grosh, R. C. and Morgan Jr., G. M. 1975, "Radar-thermodynamic hail day determination", Ninth Conf. On Severe Local Storms, Norman, OK, *Amer. Meteor. Soc*., 454-459.

Hanssen, A. W. and Kuippers, W. J. A., 1965, "On the relationship between the frequency of rain and various meteorological parameters", Verhand. K. Nederlands. Meteor. Inst., **81**, 2-15.

Hoddinot, M. H. O., 1986, "Thunderstorm observations in West Bengal 1945-46", *Weather*, **41**, 2-5.

Huntrieser, H., Schiesser, H. H., Schmid, W. and Waldvogel, A., 1997, "Comparison of traditional and newly developed thunderstorm indices for Switzerland", *Wea. Forecasting*., **12**, 108-123.

Jacovides, C. P., and Yonetani, T., 1990, "An evaluation of Stability indices for Thunderstorm Prediction in Greater Cyprus", *Wea. Forecasting*., **5**, 559-569.

Koteswaram, P., and Srinivasan, V., 1958, "Thunderstorms over Gangetic West Bengal in the premonsoon season and the synoptic factors favourable for their formation". *Indian J. Met. & Geophys*., **4**, 301-312.

Litynska, Z., Parfiniewicz, J. and Pinkowski, H., 1976, "The prediction of airmass thunderstorms and hails", *W. M. O. Bull*., **450**, 128-130.

McClave, J. T. and Dietrich II, F. H., 1988, "Statistics", Dellen Publishing Company, 1014.

Means, L. L., 1952, "Stability index computation graph for surface data", 2pp [Unpublished manuscript available from F. Sanders, 9 Flint St., Marblehead, MA 01945].

Michalopoulou, H. and Jacovides, C. P., 1987, "Instability indexes for the Cyprus area", *Meteor. Atmos. Phys*., **37**, 153-157.

Miller, R. C., 1967, "Notes on analysis and severe storm forecasting procedures of the Military Weather Warning Centre", AWS Tech. Rep 200, USAF, p170.

Moncrieff, M. W. and Miller, M. J., 1976, " The dynamics and simulation of tropical cumulonimbus and squallines", *Quart. J. Roy. Meteor. Soc*., **102**, 373-394.

Mukherjee, A. K., 1964, "Study of thunderstorms around Guwahati Air Port", *Indian. J. Met. & Geophys.*, **3**, 425-430.

N'orwesters of Bengal 1944, Published by India Meteorological Department, Technical Note No. 10.

Rao, K. N. and Raman, P. K., 1961, "Frequency of days of thunder in India", *Indian J. Met. & Geophys*., **1**, 103-108.

Scheafer, J. T., 1990, "The Critical Success Index as an indicator of warning skill", *Wea. Forecasting*., **5**, 570-575.

Schultz, P., 1989, "Relationships of several stability indices to convective weather events in northeast Colorado", *Wea. Forecasting*, **4**, 73-80.

Sen, S. N. and Basu, S. C., 1961, "Premonsoon thunderstorm in Assam and synoptic conditions favourable for their occurrence", *Mausam*, **12**, 15-20.

Stone, H. M., 1985, "A comparison among various thermodynamic parameters for the prediction of convective activity", NOAA Tech. Memo., NWS ER-68, NWS Eastern Region, Garden City, NY, p14.

Weissman, M. L. and Klemp, J. B., 1982, "The dependence of numerically simulated convective storms on vertical wind shear and buoyancy", *Mon. Wea. Rev*., **110**, 504-520.