

## Pre-convective environment of pre-monsoon thunderstorms around Chennai – A thermodynamical study

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*(Received 23 January 2004, Modified 3 August 2004)*

**सार** – इस शोध पत्र में 0000 यू.टी.सी. उपरितन वायु (रेडियो सॉंदे/रेडियो पवन) और 0600 एवं 0900 यू. टी. सी धरातलीय मौसम वैज्ञानिक आँकड़ों का उपयोग करते हुए मार्च- मई 2003 के दौरान चेन्नै के आसपास के संवहन से पूर्व के पर्यावरण का अध्ययन किया गया है। इस अध्ययन से निम्नलिखित परिणामों का पता चला है: (i) 850 है. पा. पर सकारात्मक (नकारात्मक) ओसांक विसंगति की प्रबलता संवहनी अस्थिरता  $-6^{\circ}$  केलविन/कि.मी. 1000 और 700 है. पा. के बीच बढ़ती हुई (संवहनी स्थिरता जैसे ह्रास दर  $-3^{\circ}$  केलविन/कि. मी. से कम) और 0000 यू. टी. सी. पर 850 है. पा. की सतह में सकारात्मक (नकारात्मक) सापेक्षिक आर्द्रता विसंगति प्रबल संवहन (एन. ओ.) के साथ संबद्ध हैं। (ii) 850 और 700 है. पा. पर एस. एस. ई. से एन. एन. डब्ल्यू तीव्र संवहन के अनुकूल होती है जबकि ई. एन. ई. से एस. एस. ई. पवनें संवहन से संबद्ध नहीं होती है। (iii) जार्ज के सूचकांक, गहन संवहनी सूचकांक और शोआल्टर की स्थिरता सूचकांक अवस्थिति की पद्धति के साथ अच्छी पूर्वानुमान क्षमता दर्शाते हैं। (iv) गालवेज का लिफिटड सूचकांक, एस. डब्ल्यू. ई. ए. टी. सूचकांक, आर्द्रता सूचकांक और बॉयडेन सूचकांक में निरंतर पूर्वानुमान देने की क्षमता नहीं होने के कारण चेन्नै में मानसून से पूर्व की ऋतु (मार्च-मई) के दौरान गर्ज भरे तूफान का पूर्वानुमान देने के लिए ये अनुपयुक्त समझे गए हैं। और (v) 0000 यू. टी. सी. उपलब्ध संवहनी विभव ऊर्जा (सी. ए. पी. ई) और संवहनी अवरोध ऊर्जा (सी. आई. एन. ई.) के आधार पर किया गया पूर्वानुमान हमारी पूर्वानुमान क्षमता के सुधार पर कोई प्रकाश नहीं डालता है।

**ABSTRACT.** Pre-convective environment around Chennai during March – May 2003 has been studied using 0000 UTC upper air (RS/RW) and 0600 and 0900 UTC surface meteorological data. The study revealed the following results : (i) prevalence of positive (negative) dew point anomaly at 850 hPa, convective instability exceeding  $-6^{\circ}$  K/km (convective stability, *i.e.*, lapse rate less than  $-3^{\circ}$  K/km) between 1000 and 700 hPa and positive (negative) relative humidity anomaly in the layer 850-500 hPa at 0000 UTC are associated with strong (no) convection (ii) SSE<sup>ly</sup> to NNW<sup>ly</sup> at 850 hPa is favourable for strong convection whereas ENE<sup>ly</sup> to SSE<sup>ly</sup> winds at 850 hPa are associated with no convection (iii) George's K index, Deep Convective Index and Showalter's stability index show better forecasting skill over the method of persistency (iv) Galway's lifted index, SWEAT index, humidity index and Boyden index do not have forecasting skill over persistency and hence they are considered unsuitable for forecasting thunderstorm during pre-monsoon season (March – May) over Chennai and (v) forecast based on 0000 UTC convective available potential energy (CAPE) and convective inhibition energy (CINE) does not throw any light in improving our forecasting skill.

**Key words** – Tropical convection, CAPE, CINE, Stability indices, Equivalent potential temperature, Forecast skills and scores.

### 1. Introduction

Climatologically, Chennai (formerly known as Madras) has thunderstorm frequency varying between one and three days during pre-monsoon (March – May) season [India Meteorological Department (IMD), 1999]. Since the average frequency of thunderstorms is based on the observations made by the two observatories located at Nungambakkam (about 4 km from the coast) and Meenambakkam (about 18 km from the coast), the average frequency need not be the representative of convective activity over a larger radius circle, say 200 km, from Chennai. Radar climatological study made by Lakshmanaswamy and Rao (1974) indicates that the frequency of convective activity is much more than the

climatological thunderstorm frequencies. However, in view of lack observatories over these areas these convective events can not be classified as thunderstorms since all convective clouds need not be thunderstorms.

It has been well recognised that the interaction between the synoptic scale flow and mesoscale processes initiate strong convection leading to the formation of local thunderstorms and severe local storms (Doswell, 1987). The local conditions that are favourable for thunderstorm development could be identified as low level convergence and moisture incursion, conditional instability, trigger mechanism for vertical lifting etc. Empirical/objective methods of forecasting thunderstorms have tremendous operational importance especially in

**TABLE 1**  
**Month-wise convective activity within 220 km radius from Chennai**

Type	Dates during March 2003	Dates during April 2003	Dates during May 2003	Number of occurrences
No Convection (NC)	1-12; 21-27; 30 Freq : 21	1; 7-10; 14-18; 21-27 Freq : 17	2; 7; 9; 18 Freq : 4	42
Weak Convection (WC)	13; 14; 28 Freq : 3	2; 11; 13 Freq : 3	3; 11; 19; 31 Freq : 4	10
Strong Convection (SC)	15 -18; 20 Freq : 5	3 -5; 12; 19 - 20; 28 - 29 Freq : 8	4 -6; 8; 10; 12; 20 -29 Freq : 16	29

SC : Day on which the areal coverage of a single storm is atleast 500 km<sup>2</sup>.

WC : Day on which 1 to 5 cells (the largest cell having an area of less than 500 km<sup>2</sup>) was observed.

NC : Either no convection or cloud development confined to a height far less than 6km.

aviation services. Based on the available morning (0000 UTC) upper air (RS/RW) data, the forecaster has to foresee the atmospheric condition that would be conducive for the development of thunder clouds in the afternoon or evening. Some of the conventional forecasting tools available with the forecaster are Showalter's stability index (Showalter, 1953); Galway's lifted index (Galway, 1956); George's K index (George, 1960); Boyden index (Boyden, 1963); humidity index (Litynska *et al.*, 1976); convective available potential energy (Moncrieff and Miller, 1976); total-total index (TTI) of Miller (1972) and modified TTI of Sadowski and Rieck (1977), severe weather threat (SWEAT) index [World Meteorological Organisation (WMO), 1992] and deep convective index (Barlow, 1993). Detailed description of these indices are beyond the scope of this paper and may be seen in WMO (1992), Fuelberg and Biggar (1994) and Mukhopadhyay *et al.* (2003) besides the original references mentioned above. Most of these indices had been used by many researchers for forecasting thunderstorm over Indian stations but the degree of success varied in each case (Jeevananda Reddy and Rao 1977; Suresh *et al.*, 1996; Mukhopadhyay *et al.*, 2003). An analytical study of thunderstorms from April to December over Chennai was made by Sivaramakrishnan and Ramakrishnan (1995) and an attempt to forecast thunderstorm based on thermodynamical parameters during pre-monsoon and southwest monsoon season (June to August) was made by Suresh *et al.* (2001).

The prime objective of this paper is to ascertain the applicability of the above mentioned conventional indices as tools for forecasting thunderstorms around Chennai and working out the critical threshold values for the best possible indices. In addition, the pre-convective

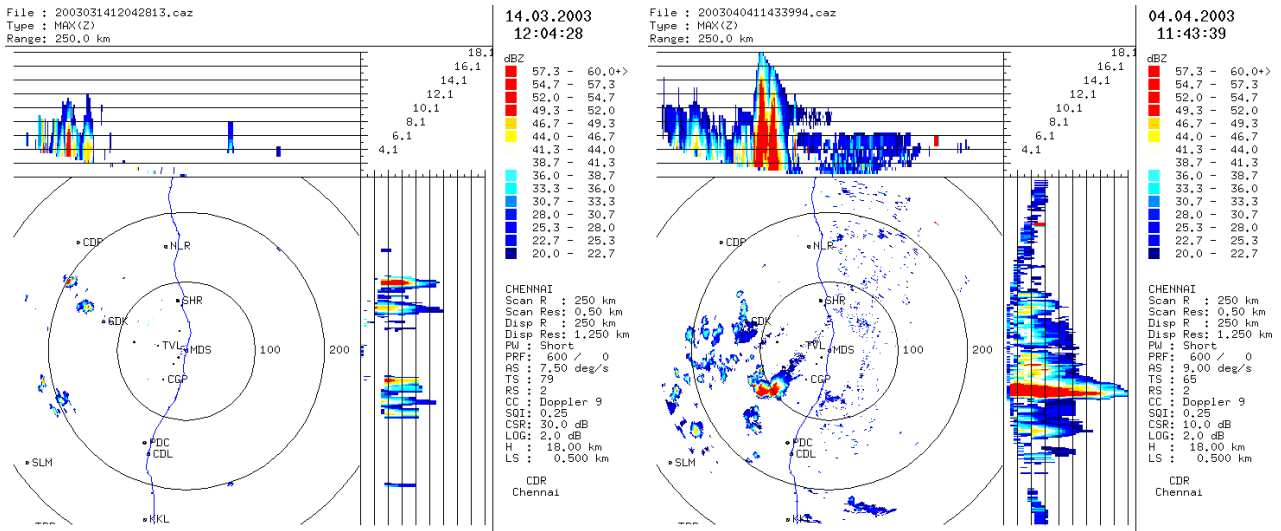
environment around Chennai have also been analysed thermodynamically with a view to understand the area of convective activities, preferred time of activity, if any, and the atmospheric condition that could produce convective activity over a radius of 220 km.

## 2. Data and method

During pre-monsoon season of the year 2003, a number of severe thunderstorm/severe local storm activities had been observed through a S-band Doppler Weather Radar (DWR) functioning at Cyclone Detection Radar (CDR) station, Chennai between 0600 and 1800 UTC on a number of days over a range of 220 km from CDR. The activity was observed at times on consecutive days also. The frequency of convective activity is very much higher than that has been recorded by the surface meteorological observatories located at Nungambakkam and Meenambakkam and the climatological records. We classified the storms with radar reflectivity factor exceeding 45 dBZ and cloud top exceeding 6 km as convective storms, as this sort of criteria is normally followed by the radar and aviation meteorologists. Further, the convective activities have been classified as deep/strong convection (SC), weak convection (WC) and no convection (NC), similar to the classification adopted by Fuelberg and Biggar (1994), as described below :

SC : The areal coverage of a single storm is atleast 500 km<sup>2</sup>. There could be more than one storm in the study area of 220 km radius.

WC : One to five storm cells in the study area with a restriction that the area of the largest cell is less than 500 km<sup>2</sup>.



**Fig. 1.** Plot of maximum reflectivity over each pixel of scan resolution 0.5 km. The height of reflectivity as viewed from north to south is shown in the top and as viewed from east to west is shown at the right hand side. The left hand side figure is a typical example of weak convection (area of a single cell is less than 500 km<sup>2</sup>) and the right hand side figure is an example of strong convection (area of a single cell is more than 500 km<sup>2</sup>)

**TABLE 2**

**Spatio - temporal variability of weak and strong convective activities around Chennai**

Month	Frequency	Time of first occurrence (UTC)					Direction of appearance from CDR, Chennai							
		0006 - 0800	0800 - 1000	1000 - 1200	1200 - 1400	S	SW	W	NW	N	NE	E	SE	
March	8	3	1	1	3	-	2	3	3	-	-	-	-	
April	11	4	5	1	1	2	2	3	4	-	-	-	-	
May	20	5	6	6	3	3	10	2	2	-	-	2	1	

NC : Either no convection or a few isolated cell whose radar reflectivity factor may be well below the threshold limit of 45 dBZ (usually < 20 dBZ) and vertical extent of the cloud far below 6 km height - which is the threshold criteria for towering Cu clouds.

Since the convective activity normally pertains to the period 0600 – 1200 UTC, we used the 0000 UTC RS/RW data of Chennai for the period March – May 2003 to forecast the convective activity. We also used the synoptic surface observation data of 0000, 0600 and 0900 UTC of airport Meteorological office, Meenambakkam for the same period. Mean has been computed based on March – May 2003 data for both surface and upper air meteorological parameters of interest and anomaly has been worked out for each of the convective classification defined earlier. Fine tuning of the thresholds of various

indices have been attempted iteratively using the parameters computed through measures of central tendency (mean, standard deviation, median, minimum and maximum value of indices in each of the convective situations). The prediction efficiency has been validated by computing different parameters such as probability of detection (POD), probability of false detection (POFD), skill score (SS), false alarm ratio (FAR), true skill score (TSS), critical success index (CSI) etc. Details of these scores may be seen in Schaefer (1990), Doswell *et al.* (1990) and Wilks (1995).

**3. Results**

Based on the convective classification defined in section 2, we identified 29 SC, 10 WC and 42 NC days during March – May 2003. The month-wise break up has been tabulated in Table 1. It has been observed that

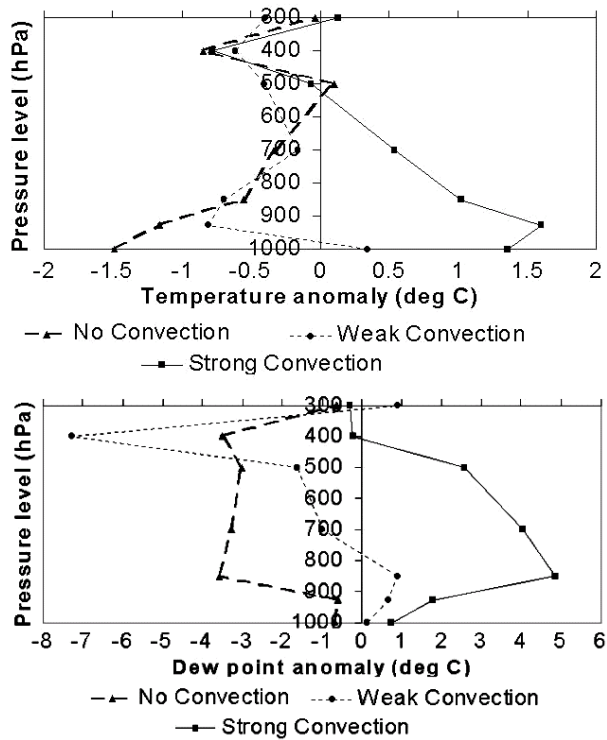
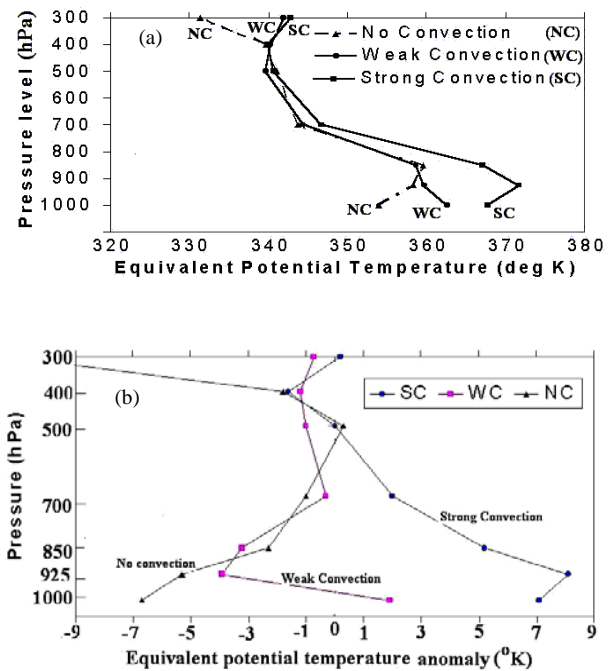


Fig. 2. Temperature, Dew point anomaly at 0000 UTC, March – May 2003

frequency is more than 60% of the days in May and between 25 and 40% during the other pre-monsoon months. The SC activities were observed at times on consecutive days as well. A typical case of SC and WC activities has been shown in Fig. 1. The time of occurrence of weak and strong convection and the area of their occurrence have been tabulated in Table 2. The convection begins between 0600 and 1400 UTC during all the pre-monsoon months and the modal frequency of WC and SC lies during 0800 – 1200 UTC. The convection, mostly, has its origin from NW to SW of Chennai wherein topography (Nagari hills located about 80km and continuation of high lands from the Seshachalam hills NW of CDR; Javadi Hills, Melagiri range and Sheveroy/Yercaud hills in the West to SW) plays a vital role in triggering convection. These facts are in agreement with the earlier studies made by Lakshmanaswamy and Rao (1974) and Sivaramakrishnan and Ramakrishnan (1995).

### 3.1. Temperature and dew point

A critical analysis of the 0000 UTC upper air temperature and dew point revealed that +ve temperature anomaly from surface up to about 550 hPa was associated



Figs. 3(a&b). (a) Vertical profile of equivalent potential temperature ( $\theta_e$ ) and (b) Equivalent potential temperature anomaly

with SC while -ve anomaly with NC. The +ve temperature anomaly of more than  $1^\circ\text{C}$  from surface to 850 hPa makes the lower troposphere warm and favours convective instability whereas the cooling over these layers enhances the convective stability and thereby inhibits the vertical growth of clouds. Moreover, +ve dew point anomaly was seen from surface to 400 hPa during SC and -ve anomaly during NC. The +ve dew point anomaly at 850 hPa (mean value  $+4.8^\circ\text{C}$ ) during SC and -ve anomaly (mean value  $-3.5^\circ\text{C}$ ) during NC could be used to discriminate a SC day from NC. Fig. 2 depicts the temperature and dew point anomaly at 0000 UTC during March – May 2003. In the case of WC, both the temperature and dew point anomalies are intermediary between SC and NC. Though the temperature anomalies are well within the natural variability and observational errors, if any, the dew point anomaly (especially the anomaly at 850 hPa) can be used as one of the tools to forecast the possibility of thunderstorm around Chennai. This supports the applicability of most of the thunderstorm forecasting indices using 850 hPa dew point temperature as one of their components. Lapse rate of temperature and dew point have been computed from surface to various possible levels within the lower and mid troposphere but no plausible clue could be deciphered with this parameter.

TABLE 3

Anomalies of 0000 UTC relative humidity (%) during March – May 2003 over Chennai				
Pressure level (hPa)	March – May over all	Anomaly (%)		
		No Convection	Weak Convection	Strong Convection
1000	84.9	3.6	- 0.6	- 2.9
925	74.6	0.0	3.6	- 1.3
850	46.5	<b>- 9.1</b>	3.2	<b>12.4</b>
700	46.3	<b>- 8.5</b>	- 4.3	<b>10.8</b>
500	31.2	<b>- 9.4</b>	- 7.8	<b>9.0</b>
400	32.3	- 5.4	- 14.3	6.1
300	43.3	- 1.8	- 2.8	- 2.7

### 3.2. Convective instability and equivalent potential temperature

Equivalent potential temperature ( $\theta_e$ ), which is a measure of the total energy as well as the entropy of the moist air, has been computed for all the levels upto 300 hPa with a view to identify the layers that are convectively unstable. Decrease of  $\theta_e$  with height ( $d\theta_e / dz < 0$ ) indicates convectively unstable layer (Pielke, 1984). Fig 3(a) shows the vertical profile of  $\theta_e$  at 0000 UTC during different atmospheric conditions. Convective stability ( $d\theta_e / dz > 0$ ) prevailed in the lowest atmosphere (1000 – 925 hPa) during NC and SC days making it difficult to forecast the possible occurrence of thunderstorm based on this boundary layer information. However, in the layer 925 – 850 hPa, strong convective instability (-6.22 °K/km) was seen during SC days while somewhat less convective instability (-2.3 °K/km) was observed during WC days. But the prevalence of convective stability in this layer on NC days (+1.76 °K/km) makes the distinction between SC / WC and NC days. Moreover, the strength of convective instability during SC days (-6.82 °K/km) is about twice as observed during NC days (-3.36 °K/km) in the layer 1000 – 700 hPa. It may be seen that the  $\theta_e$  decreases continuously in the case of NC from 850 to 300 hPa. But in the case of SC and WC days, the  $\theta_e$  reaches a minimum around 500 hPa and slowly rises thereafter. The prevalence of middle level dryness (corresponding to the minimum  $\theta_e$ ) and convective instability below this layer has been well correlated with the wet and dry microburst activity in the celebrated papers of Fujita and Caracena (1977); Caracena and Maier (1987); and Atkins and Wakimoto (1991). The minimum  $\theta_e$  confined between 500 and 400 hPa and rising thereafter is a favourable indication of possible convective activity during WC and SC days.

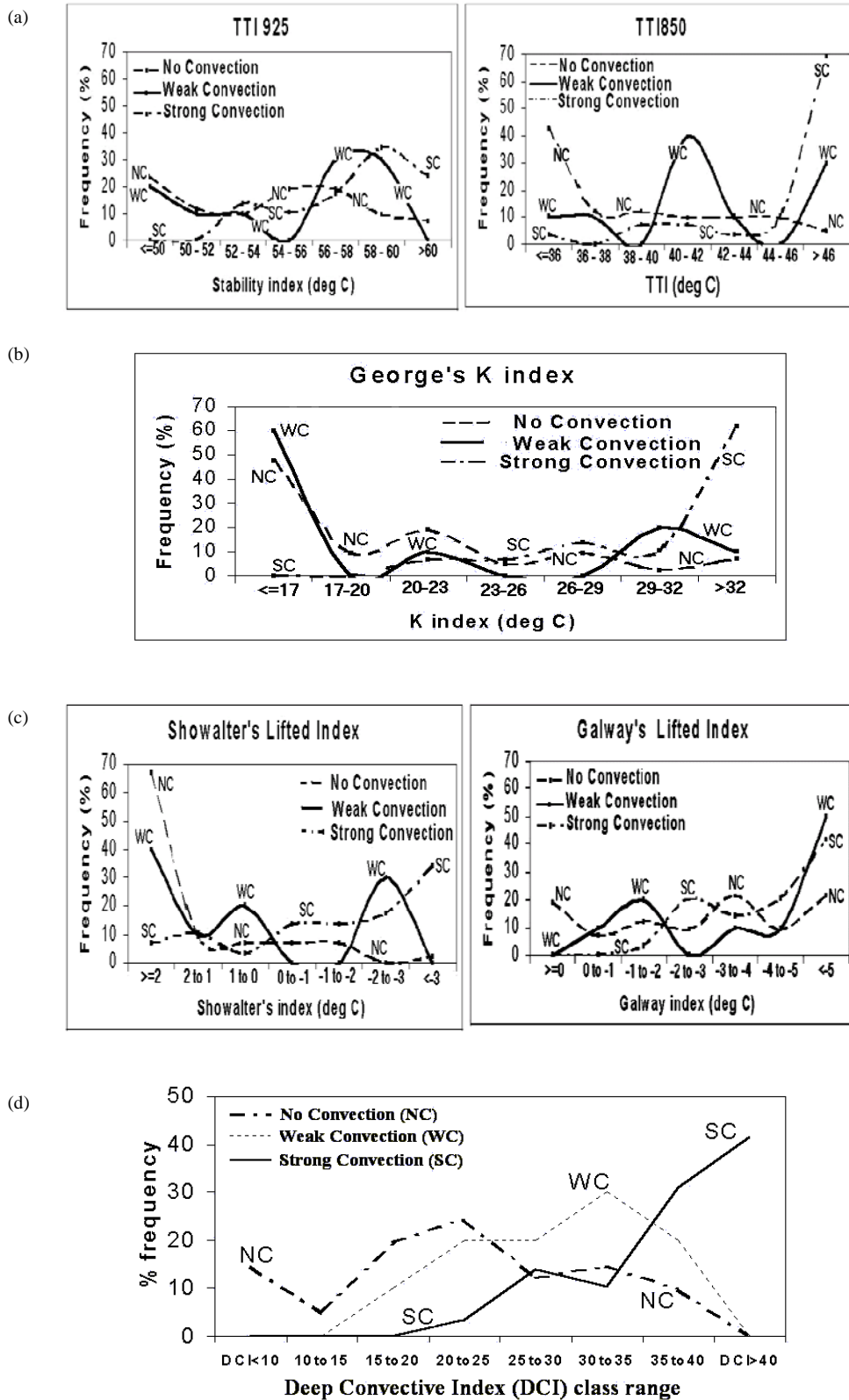
The large value of  $\theta_e$  in the lowest few km of the warm and moist atmosphere and the lowest value at middle and upper cold atmosphere can be conceived as similar to that of the positive area of temperature – entropy gram ( $T - \Phi$  gram) which is the condition of high convective instability. Anomalies of  $\theta_e$  have been worked out for SC, WC and NC days and shown in Fig. 3(b). Positive  $\theta_e$  anomaly from 1000 to 500 hPa in the case of SC days and -ve anomaly during NC days have been observed. This indicates that during SC days, the lower atmosphere at 0000 UTC is much warmer than the NC days.

### 3.3. Relative humidity

Contrasting difference in relative humidity (RH) could be seen between SC and NC days in the low and mid troposphere (Table 3). While +ve RH anomaly of about 10% is seen during SC days between 850 and 500 hPa, negative anomaly of similar magnitude has been observed during NC days. The RH during NC days in the layer 850 – 500 hPa is about 20% lower than that of SC days. This is in perfect agreement with the earlier studies of forecasting thunderstorms elsewhere, as mid tropospheric humidity is essential for the development of convective storms (Burpee, 1979; Lopez *et al.*, 1984; Watson *et al.*, 1991 and Fuelberg and Biggar, 1994).

### 3.4. Applicability of stability indices and thresholds applicable for Chennai

Various indices mentioned above have been computed based on 0000 UTC upper air and 0600 and 0900 UTC surface meteorological data and a plot has been



**Figs. 4(a-d).** Percentage frequency of occurrence of convective events *vis-a-vis* (a) TTI 925 and TTI 850, (b) George's K index, (c) Showalter's stability index and Galway's lifted index and (d) Deep convective index

**TABLE 4**  
Contingency tables for stability indices.

Forecast	TTI 925			TTI 850			Index				
	TTI $\geq 55$	Observed		TTI $\geq 42$	Observed		Criteria	Observed			
		Yes	No		Total	Yes		No	Total	Yes	No
Yes	29	19	48	Yes	28	11	39	Yes	a	b	a+b
No	10	23	33	No	11	31	42	No	c	d	c+d
Total	39	42	81	Total	39	42	81	Total	a+c	b+d	a+b+c+d
POD = a / (a+c); FAR = b / (a+b) POFD = b / (b+d) TSS = (ad-bc) / [(a+c)(b+d)] CSI = a / (a+b+c)											
Forecast	GKI			SHI			GLI 100				
	GKI $\geq 27$	Observed		SHI $\leq 1$	Observed		GLI $\leq -2$	Observed			
		Yes	No		Total	Yes		No	Total	Yes	No
Yes	27	5	32	Yes	29	11	40	Yes	36	26	62
No	12	37	49	No	10	31	41	No	3	16	19
Total	39	42	81	Total	39	42	81	Total	39	42	81
Forecast	SWEAT			DCI			PERSISTENCY				
	SWEAT $\geq 300$	Observed		DCI $\geq 29$	Observed		One day	Observed			
		Yes	No		Total	Yes		No	Total	Yes	No
Yes	7	2	9	Yes	30	12	42	Yes	28	13	41
No	32	40	72	No	9	30	39	No	11	29	40
Total	39	42	81	Total	39	42	81	Total	39	42	81

Abbreviations have been defined in the text

made for some of the indices which have some 'forecasting skill' over a range of values. Figs. 4(a-d) shows the plot of predictability of convective events using TTI 850, TTI 925, GKI, SHI, GLI and DCI. It can be seen that TTI 850 predicts more than 70% of the SC incidences when its score exceeds 46 and NC cases when its value is less than 36. Compared to TTI 925, TTI 850 has better predictability value. GKI of more than 30 predicts the SC cases well and values less than 17 predict NC cases similar to the predictability of NC cases by TTI 925. Showalter's index predicted extremely well the NC cases when its value is large +ve ( $> 2$ ) and its utility in predicting SC and WC cases has some potential albeit lesser magnitude than the TTI 850 and GKI. Galway's lifted index has mixed rate of success in predicting NC. Since convection commences sometime during 0600-1200 UTC, it has been considered preferable to use the latest available surface information at 0600 and 0900 UTC to work out the GLI. These indices are called GLI 06 and GLI 09 respectively. However appreciable improvement could not be seen even with these two indices utilising latest surface meteorological information in predicting

convective events over Chennai. The DCI discriminates well the SC weather condition from WC and NC when its value increases far beyond 35. DCI of less than 15 is indicative of total absence of SC cases and more than 40 is indicative of total absence of NC cases. However, both NC and SC frequencies are seen in the intermediary range between these two. The contingency table with threshold values for different indices has been tabulated in Table 4. For this purpose, both SC and WC categories have been merged as a single convection type since we want to predict the convective storm in a day-to-day operational forecasting set up and discriminate convection from no convection.

#### 3.4.1. Analysis of 0600 and 0900 UTC surface temperature and dew point temperature

The surface temperature and dew point at 0600 and 0900 UTC have been examined with a view to identify the probable linkage of latest humidity value with convection. Though positive temperature and dew point anomalies are associated with SC and WC and negative anomalies are

TABLE 5

Performance of different stability indices in forecasting convective activities around Chennai during March – May 2003

Parameters	TTI 925	TTI 850	GKI	SHI	GLI 00	GLI 06	GLI 09	SWEAT	DCI	Persistency
Skill Score	0.29	0.46	0.58	0.48	<u>0.67</u>	0.61	0.66	0.14	0.65	0.41
POD	0.74	0.72	0.69	0.74	0.62	0.67	0.72	0.18	<u>0.77</u>	0.72
POFD	0.45	0.26	0.12	0.26	0.31	0.43	0.38	<u>0.05</u>	0.29	0.31
FAR	0.40	0.28	<u>0.16</u>	0.28	0.35	0.41	0.36	0.22	0.29	0.32
TSS	0.29	0.46	<u>0.57</u>	0.49	0.31	0.24	0.34	0.13	0.49	0.41
CSI	0.50	0.56	<u>0.61</u>	0.58	0.46	0.46	0.51	0.17	0.59	0.54
(TSS - TSS <sub>pers</sub> )	(-0.12)	<b>0.05</b>	<b>0.16</b>	<b>0.08</b>	(-0.1)	(-0.17)	(-0.07)	(-0.28)	<b>0.08</b>	----

Note : 1. Bold figures in (TSS - TSS<sub>pers</sub>) are indicative of forecasting skill over persistency and those furnished in brackets (-ve values) indicate that there is no skill over persistency.  
2. The best score amongst various indices has been underlined.

with NC categories as expected, except the dew point anomaly at 0900 UTC (*viz.*, 1.5° C) the magnitudes of other anomalies are not appreciable and they are well within the instrumental error/accuracy or natural variability of these variables. This perhaps could be the reason for the poor efficiency of GLI 06 and GLI 09 as stated earlier. However, 0900 UTC dew point anomaly may be considered for forecasting thunderstorm and its efficacy is to be watched for some period before making it for operational use.

### 3.4.2. Suitability or otherwise of a few indices

The optimum threshold values of those indices that have successfully predicted the occurrence of thunderstorm with the best POD, TSS, CSI and low FAR have been retained and those indices that did not show any improvement in two or three trial values based on the measures of central tendency have been rejected for further analysis. The mean and standard deviation of Boyden index have practically no variability between the three cases and hence this index does not appear to have any predictability value. The humidity index which depends on dew point depression at 850, 700 and 500 hPa does not explain any additional variance than that is explained by TTI 850, TTI 925 or GKI. The standard deviation of humidity index and SWEAT index are very high and the skill score, POD are comparatively low. Hence these three indices have not been considered useful for forecasting convection over Chennai. Various scores of the indices have been tabulated in Table 5. All the test scores based on one day persistency have been computed for comparison purposes. The TSS obtained from persistency (TSS<sub>pers</sub>) is subtracted from TSS of a particular index so that one can easily identify the merit of the index under consideration. If the value (TSS - TSS<sub>pers</sub>) of an

index is positive then one can confirm that it predicts atleast a few convective situations more than that could be predicted from the method of persistency alone. This method used by Fuelberg and Biggar (1994) for forecasting thunderstorm over Florida Panhandle has been adopted in this paper.

Efficiency of all GLI scores (GLI 00, GLI 06 and GLI 09) are lower than that of persistency in forecasting convection around Chennai in contrary to their efficacies in predicting thunderstorms over Florida Panhandle as claimed by Fuelberg and Biggar (1994). Hence BI, HI, GLI 00, GLI 06, GLI 09, and SWEAT indices are considered unsuitable for forecasting convection over Chennai.

### 3.4.3. Indices having forecasting value

GKI has the second least POFD (the least POFD resulted from the SWEAT index) and the highest CSI and predictability over persistency (Table 5). The empirical values of this index has been varied in all possible combinations as well as based on the optimal values used elsewhere and found that the best threshold for forecasting convection over Chennai during pre-monsoon season is  $GKI \geq 27$ . Though the higher threshold values of GKI reduced the POFD (POFD = 0.071 when  $GKI > 32$  as against POFD = 0.12 when  $GKI \geq 27$ ), the POD and CSI were very low in these cases. This is because the number of 'misses' (event occurred without prediction) were very high in these thresholds. Hence, based on our analysis, it is concluded that the  $GKI \geq 27$  may be used as a tool to forecast convection around Chennai. In the next hierarchy of efficiency, both SHI (less than 1) and DCI (more than 29) have the maximum POD, CSI and efficiency over persistency with minimum POFD. Then comes TTI 850 in



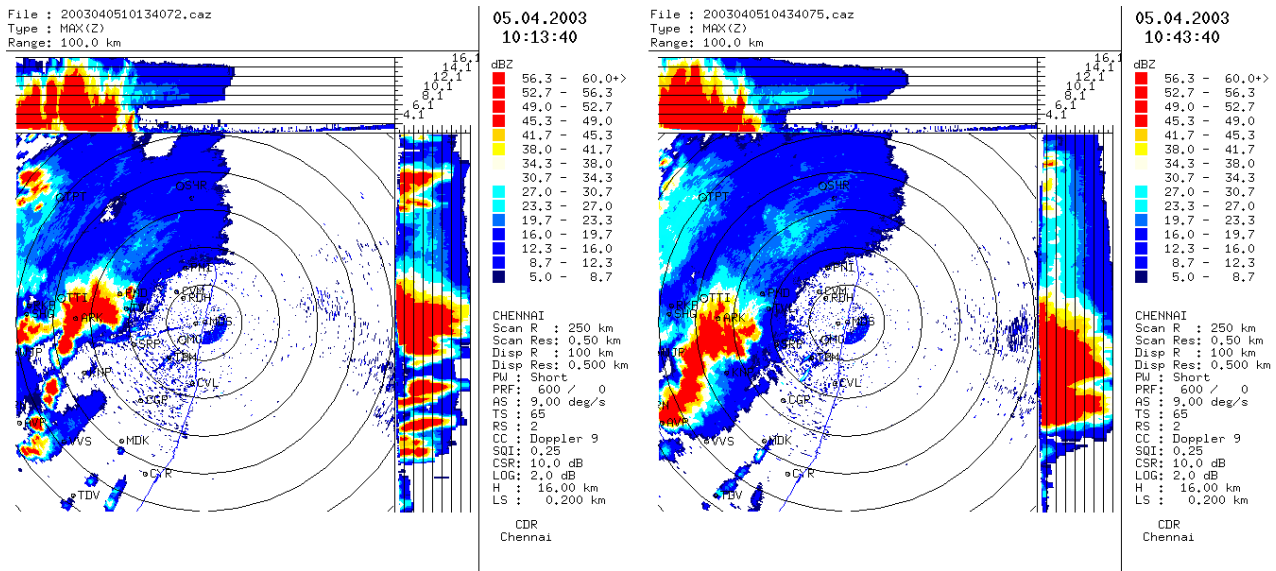


Fig. 5. Maximum radar reflectivity display on a severe convection day (at 1013 and 1043 UTC on 5 April, 2003). The plan view is the maximum radar reflectivity over each pixel from bottom to top of the cloud system. The height scale on the right (top) indicates the maximum radar reflectivity of the volume of the cloud seen from west to east (south to north)

forecasting convection around Chennai during pre-monsoon.

Fig. 5 shows a typical SC that had occurred between 40 and 120 km NW to SW of Chennai on 5 April, 2003 (date selected at random). The convection was purely *in situ* as no synoptic scale disturbance was seen on 4<sup>th</sup> and 5<sup>th</sup> April in surface and upper air charts. The convective activity commenced around 0700 UTC towards WNW of Chennai between 60 and 100 km. Peak activity was observed between 1013 and 1043 UTC with radar reflectivity exceeding 55 dBZ upto a height of 11 km and exceeding 45 dBZ for beyond 16 km - a condition conducive for hail stones of 10-20 mm size with a probability of more than 0.80 (Waldvogel *et al.*, 1979). Based on the 0000 UTC upper air RS/RW data, TTI850 was 46.9, GKI was 33.4, DCI 33.7 and SHI was -1.8. All these indices have predicted the possible occurrence of SC on that day.

3.4.4. Test of significance using Z statistics

The significance of these indices in discriminating SC from NC, NC from WC, WC from SC has been tested using Z statistics (Makridakis and Wheelwright, 1978; McClave and Dietrich, 1988). The Z statistic can be computed using the relationship  $Z_{12} = (M_1 - M_2) * \{[(s_1^2 / n_1) + (s_2^2 / n_2)]^{0.5}\}$  where  $(M_1, s_1, n_1)$  are the mean, standard deviation and number of items of series  $\{X_1\}$  and the subscript 2 are for the second series respectively. Larger absolute Z value indicates that the categories/samples are significantly different. For computing this statistics, each of the sample data should

TABLE 6

Z statistics discriminating the strong (SC), weak (WC) and no convection (NC) categories around Chennai during March – May, 2003

Z	TTI925	TTI850	GKI	SHI	GLI00	DCI
Z <sub>WC, SC</sub>	-1.75*	-2.19**	-2.82***	+2.00**	0.65	-2.67***
Z <sub>NC, SC</sub>	-3.49***	-3.68***	-3.83***	+3.56***	2.89***	-4.04***
Z <sub>NC, WC</sub>	-1.83*	-1.78*	-1.59	+1.67*	1.99**	-1.48

Note : \* / \*\* / \*\*\* are significant at 90%, 95%, 99% level of significance.

be totally independent. In other words, persistency should be excluded. Since the rainfall from thunderstorms have persistency, we ensured that there is atleast a gap of 3 days between two convective events based on the dimensionality analysis of daily rainfall over Chennai done by Suresh (1996) since auto correlation coefficients (ACC) were significant upto 3<sup>rd</sup> lag. The Z statistics of different indices have been tabulated in Table 6. All the indices discriminate the NC from SC category at 99% level of significance. Since both GLI 00 and TTI 925 have the efficiency lower than that of persistency, these indices are not recommended for operational use. Of the remaining indices, GKI, DCI, SHI and TTI 850 may be considered as tools for forecasting convective activity around Chennai.

3.4.5. Surface and upper wind analysis

The surface and upper winds at 0000 UTC have been analysed for the different categories of convection. Mean winds at various levels have been computed. From a plot

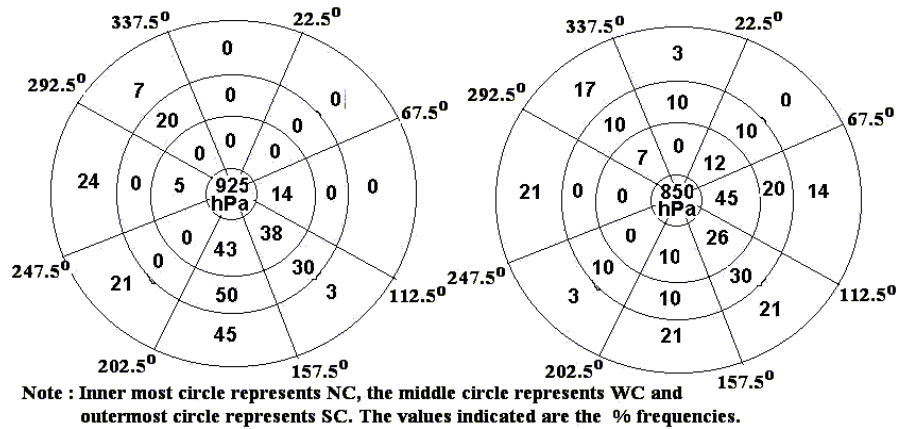


Fig. 6. Wind rose of mean wind direction at 925 and 850 hPa during different convection categories around Chennai, March – May 2003

of mean winds (figure not shown), it has been observed that the wind veers with height during SC days and it backs with height in NC days between 1000 and 850 hPa. Wind speed during SC days is stronger than the NC days at 1000 and 925 hPa. Further analysis of winds revealed that the winds at 925 and 850 hPa appear to have some correlation with the convective activity. Wind rose of 925 and 850 hPa wind direction for NC, WC and SC days has been shown in Fig. 6. While ENE<sup>ly</sup> to SSW<sup>ly</sup> at 925 and 850 hPa are associated with NC days, SSE<sup>ly</sup> to WNW<sup>ly</sup> are associated with SC days. When the winds are southerly at 925 hPa, frequencies of both convection and no convection are almost the same and no clear cut signal could be drawn from the winds at this level. However, if we consider 850 hPa winds alone, then we can conclude that ENE<sup>ly</sup> to SSE<sup>ly</sup> winds are associated with NC (with more than 71.5% frequency) and SSE<sup>ly</sup> to NNW<sup>ly</sup> winds with SC (62.1% frequency).

3.4.6. Energetics

Convective available potential energy (CAPE), which is a measure of instability of the atmosphere under moist convection and is the cause for deep convection producing weather systems in local and meso scale (Moncrief and Miller, 1976), has been computed numerically using the formula,

$$CAPE = \int_{LFC}^{LNB} (T_{vp} - T_{ve}) R_d d(\ln p)$$

where LFC and LNB are the levels of free convection and neutral buoyancy and  $T_{vp}$  and  $T_{ve}$  are the parcel and environmental virtual temperatures respectively. The convective inhibition energy (CINE) which inhibits convection and is represented by the negative area of temperature – entropy gram ( $T - \Phi$

TABLE 7

Convective Available Potential Energy (CAPE) and Convective Inhibition Energy (CINE) over Chennai at 0000 UTC, March – May 2003

	CINE			CAPE		
	NC	WC	SC	NC	WC	SC
Mean	332.1	241.0	343.6	638.7	205.2	1259.6
Standard deviation	187.7	307.4	300.2	954.2	343.4	1185.7
Minimum	9.7	2.9	2.0	-18.4	-21.1	0
Maximum	825.7	1156.4	1368.6	3278.7	1025.4	3502.4

gram) has also been computed using the following relationship coined by Williams and Renno (1993).

$$CINE = \int_{Sfc}^{LFC} (T_{vp} - T_{ve}) R_d d(\ln p)$$

where Sfc is the surface. The roles of CAPE and CINE in tropical convection have been studied by many authors (Bhat *et al.*, 1996; Srivastava and Sinha Ray, 1999).

Table 7 summarises the statistical characteristics of CAPE and CINE during different convective categories. Though the higher mean values of CAPE have been associated with SC as one normally expects, the lowest mean value is not associated with NC but with WC. More over, the coefficient of variation (CV) is very high in respect of NC (149%) and WC (167%) than SC (94%). Similar high CVs have been observed over a few stations in northeastern India by Mukhopadhyay *et al.* (2003). The very fact that CAPE has a very high CV for all these cases indicate that forecasting based on 0000 UTC CAPE is questionable. The performance statistics of CAPE exceeding a threshold have been made based on the

TABLE 8

Forecasting convective activity during March – May 2003 over Chennai based on 0000 UTC CAPE

Index	POD	POFD	FAR	CSI	TSS	TSS – TSS <sub>persistence</sub>
CAPE > 896.8*	0.410	N/A	0.794	0.212	0.102	N/A
CAPE > 900	0.410	0.260	0.407	0.320	0.148	(- 0.260)
CAPE > 1200	0.307	0.167	0.368	0.261	0.141	(- 0.267)

Note : \* Source : Mukhopadhyay *et al.* (2003) for forecasting thunderstorm over NE Indian stations.  
N / A : Data not available.

attempt made by Mukhopadhyay *et al.* (2003) and by fine tuning the threshold to the mean value obtained during SC days over Chennai. The results are tabulated in Table 8. Similar results are available for CINE (Table not shown). This re-confirms that forecast based on 0000 UTC CAPE has very little skill not only over NE Indian stations but also over Chennai. Despite very high CAPE, no convection took place on some days and despite very high CINE, strong convection occurred on a few days. This indicates that the tropical convection is not governed by the local influence alone but depends on some large scale processes as well.

#### 4. Discussion

The dynamics of the lower atmosphere (vergence arising out of local as well as large scale processes) may have to be explored using the radial velocity and spectrum width information that are obtained through the Doppler Weather Radars (DWR) installed at Chennai and SHAR Centre, Sriharikota. However, such a study also suffers from the limitations like (i) the velocity information derived from DWR is only radial and not the prevailing wind and some assumptions need to be made to estimate the horizontal wind from radial wind, (ii) radar range – height restrictions based on the scan strategy adopted, curvature effect of the earth, velocity and range aliasing and their dealiasing etc. Despite the above limitations, which of course have been solved in the recent years to a great degree of satisfaction through a number of reliable algorithms, a lot of scope is available for this work and it has been contemplated to make an attempt of such studies on receipt of the data from these DWRs in the ensuing years.

#### 5. Conclusions

The following conclusions are drawn from this study.

(i) Strong Convection (SC) is associated with +ve dew point anomaly and no convection (NC) are associated with

–ve dew point anomaly at 850 hPa at 0000 UTC. The dew point anomaly at 850 hPa may be used as a tool to forecast convective activity over Chennai.

(ii) The strength of convective instability in the layer 1000 – 700 hPa at 0000 UTC may be used as a tool to forecast SC or NC according as the strength of convective instability in the layer exceeds  $-6^{\circ}\text{K/km}$  or  $-3^{\circ}\text{K/km}$  and less.

(iii) SC days have positive humidity anomaly of about 10% while NC days have negative humidity anomaly of 10% in the layer 850 – 500 hPa at 0000 UTC.

(iv) Positive surface dew point anomaly at 0900 UTC is associated with SC while negative anomaly with NC. This information may be useful in amending the forecast based on 0000 UTC. However, this information has to be validated with more data.

(v) George's K index ( $\geq 27$ ), Deep Convection Index ( $\geq 29$ ), Showalter's stability index ( $\leq 1$ ) and TTI 850 ( $\geq 42$ ) have good forecast value and may be used for forecasting convective activity within 220 km around Chennai.

(vi) SWEAT index, Galway's lifted index (based on 0000, 0600, 0900 UTC), humidity index and Boyden index are not suitable for forecasting thunderstorm around Chennai during pre-monsoon season.

(vii) While  $\text{SSE}^{\text{ly}}$  to  $\text{NNW}^{\text{ly}}$  at 850 hPa is favourable for SC,  $\text{ENE}^{\text{ly}}$  to  $\text{SSE}^{\text{ly}}$  winds at 850 hPa are favourable for NC.

(viii) Forecasting of convective activity based on 0000 UTC CAPE of a single station has not been found useful as tropical convection appears to be triggered by large scale processes.

#### Acknowledgements

Facilities extended by the Director General of Meteorology, India Meteorological Department are gratefully acknowledged. Help extended by Prof. G. S. Bhat of Indian Institute of Science, Bangalore to the first author (RS) on matters relating to CAPE is acknowledged with thanks. The authors are thankful to the referee for the comments.

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