A Comparative Study of the Atmospheric Layers below First Lifting Condensation Level for Instantaneous Pre–Monsoon Thunderstorm Occurrence at Agartala (23°30′N, 91°15′E) and Ranchi (23°14′N, 85°14′E) of India

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ABSTRACT

An attempt has been made to investigate the role of vertical wind shear, convective instability and the thermodynamic parameter $(\theta_{es}-\theta_e)$ below the first lifting condensation level (FLCL) in the occurrence of instantaneous premonsoon thunderstorm over Agartala (AGT) and Ranchi (RNC) at 12 GMT. Radiosonde data of 1988 have been utilized here. The study has however been confined to 1000 hPa–500 hPa range at most.

Here the convectively unstable layers with positive vertical wind shear upto 500 hPa have been termed as 'Favourable Layers' (FL) and the level at which an initially stable layer turns out to be convectively unstable for the first time has been termed as 'Transition Level' (TL). It is observed that the changes in vertical wind shear are positive at TL at the time of occurrence of thunderstorm (TS) and the corresponding change is negative on fair–weather situation.

Moreover, the 90% confidence interval for $(\theta_{es}-\theta_e)$ *reveals that for AGT the upper layer thermodynamic* characteristic is important at the time of occurrence of TS whereas for RNC, the value of $(\theta_{es}-\theta_e)$ at the surface is much more effective.

Key words: Convective instability, Vertical wind shear, Saturated equivalent potential temperature, Equivalent potential temperature, Confidence interval

I. INTRODUCTION

It is a well–known fact that thunderstorm, specially severe in nature is strongly favoured by convective instability, abundant moisture at low levels, strong wind shear and a dynamical lifting mechanism that can release the instability.

From simple layer concept, it is known whether a layer which may at present be stable has the potentiality to become unstable with the appropriate amount of lifting is determined by convective instability, (i. e. $\frac{\partial\theta_e}{\partial z}<0$) (Bryes, 1974).

It has been observed that for a storm cell travelling at the speed of the wind in the middle troposphere, the low level air has a strong component of relative motion toward the approaching storm. In absence of suitable shear, the magnitude of the inflow cannot be properly matched to the magnitude of the buoyant updraft and as a result, any vigorous updraft resulting from large thermal instability cannot be sustained. Moncrieff and Green (1972) showed theoretically that a low value of Ri (Richardson number) owing to strong low–level shear accompanying strong thermal instability favours maintenance of a vigorous and nearly steady–state convective circulation (Kessler, 1982).

In fact, a number of authors, viz, Showlter (1953), Galway (1956), Darkow (1968), Fujita (1970) had attempted to introduce indices for the prediction of TS development. The importance of 500 hPa level had been stressed by them. Another author, Omotosho (1987) showed a strong relationship between TS– occurrence at Kano, Nigeria and static control exerted by the environment through the vertical wind shear over the station.

According to Betts (1974), the difference $(\theta_{es}-\theta_e)$ is a measure of the unsaturation or humidity of the atmosphere, i. e $(\theta_{es}-\theta_e)$ gives a measure of moisture departure from the saturated state. Obviously, convective instability, positive vertical wind shear and low value of $(\theta_{es}-\theta_e)$ are very helpful for the convective development. This is more important for the layers below the level of cloud development which may be taken around 500 hPa. So, here these three parameters have been studied at layers below first lifting condensation level (FLCL) only, which usually lies below 500 hPa level.

In an earlier work, Sen and Basu (1961) informed the time of TS occurrence at Agartala. According to them an appreciable number of thunderstorms occur there in afternoon hours.

According to Krishna Rao (1961) 'The period during which most thunderstorms occur, considering India as whole, is from March to September, but the occurrence, is more abundant during March to May'. He mentioned that the thunderstorms in different parts of India have different characteristics. He concludes, 'It is very essential that the characteristics of thunderstorms in different parts of the country (India) should be studied'.

So, in the present work, an attempt has been made to analyze the behaviour of the above mentioned parameters for the thunderstorms occurring at 12 GMT during the pre–monsoon season, i. e. from March to May. To compare with the fair–weather situation, a number of cases have also been taken up, which did not show any development at 12 GMT.

Though the two locations, viz, AGT (23°30′N, 91°15′E) and RNC (23°14′N, 85°14′E) are geographically quite separated, yet they have been selected for comparison because both are at hilly terrain. However, RNC lies over a plateau and its station height is 655 mts. and AGT is surrounded by hills and its station height is 16 mts.

90% confidence intervals for all the three parameters have been constructed for both the thunderstorm and the fairweather situation to estimate them statistically.

II. DATA

Daily radiosonde records at 12 GMT for Agartala (AGT) and Ranchi (RNC) for the year 1988 constitute the data for this study. The numbers of instantaneous premonsoon thunderstorms considered for Agartala and Ranchi are 8 and 5 respectively, which include both dry TS and TS with rain. For Agartala, 15 fair–weather situations at 12 GMT and for Ranchi, 13 fair–weather situations at 12 GMT have been investigated to bring out the difference. But only some representative TS and NTS (fair–weather) days and the significant layers have been included in the Tables 1A, 1B, 2A & 2B.

III. METHODOLOGY

In the present work, the average characteristics of the atmospheric layers below first lifting condensation level (FLCL) as well as the characteristic of the favourable layers below FLCL have been studied separately for both TS and NTS (fair–weather) situation.

The layers for which $\frac{\partial \theta_e}{\partial z}<0$, where 'z' denotes the vertical height in meter, are convectively unstable layers.

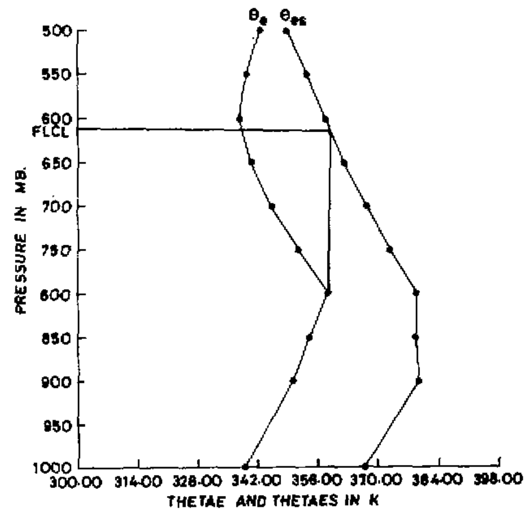

Fig. 1. Determination of first lifting condensation level (FLCL) below 500 hPa from θ_{es} & θ_e profile.

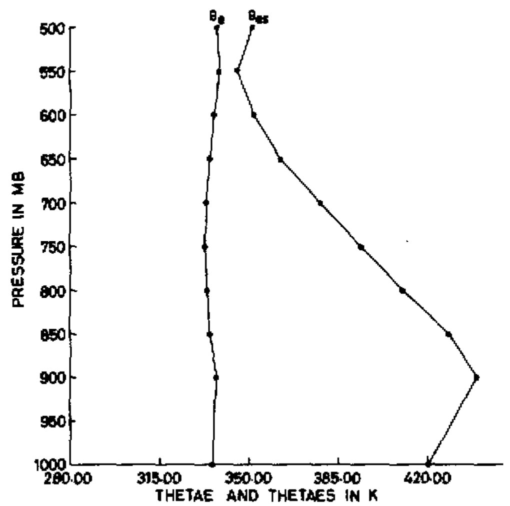

Fig. 2. Non-existence of first lifting condensation level below 500 hPa.

Here FLCL has been determined from the θ_{es} & θ_e profile (Figs. 1 and 2). The convectively unstable layers with positive vertical shear upto 500 hPa are termed as 'Favourable Layers'. The convectively unstable layers with negative vertical wind shear or the convectively stable layers have been assumed to be inimical to the development or maintenance of thunderstorms.

Equivalent potential temperature (θ_e) and saturated equivalent potential temperature (θ_{es}) for different layers have been calculated by the standard formulae (Bolton, 1980).

The difference, ($\theta_{es} - \theta_e$) gives a measure of the unsaturation of the atmosphere, i. e. it can be considered as a measure of the moisture departure from the saturation state. (Betts, 1974).

Next, 90% confidence intervals have been constructed for the above mentioned parameters to estimate those parameters statistically, where 90% confidence interval' is an interval within which one can be 90 percent confident that the true parameter value lies (Fischer, 1972).

IV. OBSERVATIONS AND DISCUSSIONS

1. *Convective Instability*

(1) *Agartala*

The surface layers and the layers adjacent to the surface may be either stable or unstable on both the situations (i. e. TS and fair–weather situation).

(2) *Ranchi*

The surface or the layers adjacent to the surface are observed to be stable in fair–weather situation.

But for instantaneous thunderstorm occurrence, the corresponding layers may be either stable or unstable.

2. *Nature of Vertical Wind Shear at Transition Level (TL)*

(1) *Agartala*

When the layers are unstable for the first time with stable layers below, the change in the vertical wind shear at the transition level (TL) is positive. This condition may be regarded as one of the important conditions for devolopment of TS. Presence of such TL has been observed in 75% of the thunderstorm days and 46.6% of the fair–weather days being considered. It has also been noted that the corresponding change is negative for a fair–day. This proposition is valid for 80% of TS–cases with TL and 85.7% of NTS–cases with TL studied. (Tables 1A & 1B).

(2) *Ranchi*

The same result holds for Ranchi. Presence of TL was observed in 40% of the TS–days and 57.5% of the NTS–days considered. The above proportion is valid for 100% of TS–cases with TL and 87.5% of NTS–cases with TL studied (Tables 2A & 2B).

3. *Strength of Average Vertical Wind Shear below FLCL*

(1) *Agartala*

The strength of average vertical wind shear (positive) below FLCL is comparatively higher at the time of occurrence of thunderstorm than that at fair–weather situation (Table 3).

(2) *Ranchi*

The same result holds for Ranchi (Table 3).

4. *Magnitude of* $(\theta_{es} - \theta_e)$

(1) *Agartala*

The magnitude of the parameter $(\theta_{es} - \theta_e)$ for the favourable layer is strictly smaller at the time of occurrence of thunderstorm than that at fair–weather situation. The same result holds for average $(\theta_{es} - \theta_e)$ below FLCL (Table 3). But the surface value of $(\theta_{es} - \theta_e)$ carries no information.

(2) *Ranchi*

The magnitude of the parameter $(\theta_{es} - \theta_e)$ at the favourable layer is not at all significant here. To the contrary, the magnitude of $(\theta_{es} - \theta_e)$ at the surface is strictly smaller at the time of occurrence of thunderstorm than that on fair–weather situation. The average $(\theta_{es} - \theta_e)$ gives no indication of TS (Table 3).

V. CONCLUSION

It is known that the two basic conditions necessary for an element to become unstable with respect to its surroundings are ···

(1) A sufficient amount of moisture in the air.

(2) A mechanically produced lifting of sufficient strength to overcome the stablizing forces at the lower levels (Byers, 1974).

So, here the condition ··· 'Increase in the vertical wind shear at TL' may be regarded as *one of the basic mechanisms that helps the layer to overcome the stabilizing forces at lower* levels at both Agartala and Ranchi.

The study also reveals that at both Agartala & Ranchi, the average value of $\frac{\partial\theta_e}{\partial z}$ below FLCL gives no definite indication about the occurrence of thunderstorm.

But the major difference is noticed in the nature of the parameter $(\theta_{es} - \theta_e)$. At Ranchi, the presence of convectively stable layers at the surface or adjacent to the surface, when the change in vertical wind shear is negative at TL and the parameter $(\theta_{es} - \theta_e)$ is large enough at the surface, clearly indicates the non–occurrence of premonsoon thunderstorm there, whereas at Agartala, the surface features are not the determining factors, rather, the upper layer characteristics are much more significant there.

In fact, Agartala and Ranchi—both are at a hilly terrain. But Ranchi lies over a plateau in Chottanagpur Hills of Bibar region and here the station height is 655 mts, while Agartala is surrounded by hills, but here the station height is only 16 mts. So, it is apparent at Ranchi, the topography is much more effective in premonsoon (instantaneous) thunderstorm occurrence there.

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Table 1A. Values of the Parameters at Thunderstorm Si tuation at Agartala

Date / Nature / Sh. Ch at TL	FLCL / TL (hPa)	Significant layers below FLCL (hPa)	Conv. Inst. (km^{-1})		Vert. Shear (S^{-1})		$(\theta_{es} - \theta_{e})$ (k)		
			at Significant layers	Average below FLCL	at sign. layers	Average below FLCL	at significant layers	Average below FLCL	at surface
14.04.88 TS(17) positive	710 950	1000 950 950—900	0.16 −0.06	−0.02	$+4 \times 10^{-3}$ $+8 \times 10^{-3}$	$+3.7 \times 10^{-3}$	20.905 12.403	17.628	28.829
21.04.88 TS(17) –	850 –	1000—950 950—900 900—850	−0.01 −0.07 −0.06	0.05	$+4 \times 10^{-3}$ N N	$+2.7 \times 10^{-3}$	16.922 12.672 8.723	12.722	18.873
25.04.88 TS(95) negative	885 950	1000—950 950—900	0.4 0.2	0	N -4×10^{-3}	-3.3×10^{-4}	18.425 10.696	11.385	22.403
23.04.88 TS(17) positive	750 900	1000—950 950—900 900—850	0.01 0.01 −0.004	−0.04	-4×10^{-3} 4×10^{-3} N	-2.2×10^{-3}	30.799 19.867 10.023	15.125	36.582
09.05.88 TS(17) positive	950 950	1000–950 950–900	0.24 −0.03	0.24	$+7 \times 10^{-3}$ $+8 \times 10^{-3}$	$+7 \times 10^{-3}$	4.058 0.001	4.058	8.114
13.05.88 TS(17) positive	910 950	1000 950 950–900	0.03 −0.01	0.01	$+5 \times 10^{-3}$ $+8 \times 10^{-3}$	$+6.5 \times 10^{-3}$	10.533 5.051	7.792	14.674
28.05.88 TS(95) positive	880 950	1000–950 950–900	0.11 −0.37	−0.13	$+4 \times 10^{-3}$ $+3 \times 10^{-3}$	$+2 \times 10^{-2}$	8.637 11.914	10.276	12.600

'N' stands for neutral Shear. 'Sh.Ch' stands for 'shear change'. 17 & 95 are weather codes.

Table 1B. Values of the Parameters at Fair weather *Situation* at Agartala

Date / Sh. Ch. at TL	FLCL / TL (hPa)	Significant layers below FLCL (hPa)	Conv. Inst. (km^{-1})		Vert. Shear (s^{-1})		$(\theta_{es} - \theta_e)$ (k)		
			at Significant layers	Average below FLCL	at sign. layers	Average below FLCL	at significant layers	Average below FLCL	at surface
18.03.88	825	1000 950	−0.08	−0.11	$+5 \times 10^{-3}$	$+6.6 \times 10^{-4}$	29.555	25.058	32.901
–		950 900	−0.13		$+3 \times 10^{-3}$		24.433		
		900 850	−0.12		-6×10^{-3}		21.186		
19.03.88	800	1000–950	0.21	−0.05	-1×10^{-3}	3.5×10^{-3}	9.506	10.602	12.540
negative	950	950–900	0.31		-6×10^{-3}		11.697		
22.04.88	690	1000 950	0.04	−0.07	$+3 \times 10^{-3}$	$+1.5 \times 10^{-3}$	25.783	22.944	27.035
negative	900	950–900	0.01		$+6 \times 10^{-3}$		22.767		
		900–850	−0.01		3×10^{-3}		18.869		
24.04.88	740	1000–950	0.02	−0.09	$+3 \times 10^{-3}$	$+1.2 \times 10^{-3}$	36.278	24.871	43.318
negative	950	950 900	−0.03		-2×10^{-3}		24.586		
28.04.88	750	1000–950	0.08	0.08	1×10^{-3}	$+1.6 \times 10^{-3}$	31.781	23.359	34.786
negative	950	950–900	0.04		-2×10^{-3}		26.097		
29.04.88	815	1000–950	0.10	−0.05	$+1 \times 10^{-3}$	$+1.5 \times 10^{-3}$	17.160	15.784	22.296
negative	950	950–900	−0.14		N		13.819		
08.05.88	No.FLCL	x	x	x	x	x	x	x	12.320
30.05.88	730	1000–950	0.06	0.02	$+1 \times 10^{-3}$	-4×10^{-4}	7.66	8.644	7.708
positive	850	950 900	0.05		-3×10^{-3}		7.58		
		900 850	0.05		-2×10^{-3}		7.526		
		850–800	−0.03		N		8.711		

Table 2A. Values of the Parameters at Thunderstorm Situation at Ranchi

Date / Nature Sh. Ch. at TL	FLCL / TL (hPa)	Significant layers below FLCL (hPa)	Conv. Inst (km^{-1})		Verti. Shear (s^{-1})		$(\theta_{es} - \theta_e)$ (k)		
			at Significant layers	average below FLCL	at significant layers	Average below FLCL	at significant layers	Average below FLCL	at surface
16.04.88 TS (95)	810 -	Surf–900 900–850	−0.22 −0.134	−0.17	-1×10^{-3} $+8 \times 10^{-3}$	$+3 \times 10^{-3}$	41.30 51.41	42.75	21.601
25.04.88 TS (95) positive	720 850	Surf–900 900–850 850–800	0.116 0.087 −0.043	0.025	$+5 \times 10^{-3}$ -1×10^{-3} $+2 \times 10^{-3}$	$+3.5 \times 10^{-3}$	35.82 27.68 18.51	23.44	38.53
31.05.88 TS (95) positive	740 850	Surf–900 900–850 850–800	0.254 0.001 −0.494	−0.095	$+4 \times 10^{-3}$ -9×10^{-3} $+1 \times 10^{-2}$	$+2 \times 10^{-3}$	12.64 11.42 22.83	19.81	16.85

Table 2B. Values of the Parameters at Fair weather Situation at *Ranchi*

Date Sh. Ch.	FLCL / TL (hPa)	Significant layers below FLCL (hPa)	Conv. Inst. (km^{-1})		Verti. Shear (s^{-1})		$(\theta_{es} - \theta_e)$ (k)		
			at Significant layers	Average below FLCL	at significant layers	Average below FLCL	at significant layers	Average below FLCL	at surface
01.04.88	NOFLCL	x	x	x	x	x	x	x	71.12
12.04.88	530	Surf-900	0.023	0.002	$+2 \times 10^{-3}$	$+7 \times 10^{-4}$	94.06	50.23	88.43
negative	900	900-850	0.003		$+1 \times 10^{-3}$		91.16		
13.04.88	605	Surf-900	0.009	0.0015	$+4 \times 10^{-3}$	$+5 \times 10^{-4}$	79.98	48.11	86.72
negative	800	900-850	0.002		-3×10^{-3}		66.65		
		850-800	0.002		$+5 \times 10^{-3}$		55.05		
		800-750	-0.001		-3×10^{-3}		42.41		
19.04.88	680	Surf-900	0.130	-0.021	$+3 \times 10^{-3}$	$+1.6 \times 10^{-3}$	56.87	34.45	59.47
negative	900	900-850	0.097		$+2 \times 10^{-3}$		45.46		
02.05.88	610	Surf-900	0.012	-0.0007	$+2 \times 10^{-3}$	-5×10^{-3}	28.44	23.80	27.73
negative	800	900-850	0.007		-3×10^{-3}		26.98		
		850-800	0.008		$+1 \times 10^{-3}$		22.71		
		800-750	-0.013		3×10^{-3}		21.83		
11.05.88	540	Surf-900	0.007	-0.0005	$+2 \times 10^{-3}$	$+6 \times 10^{-4}$	106.83	58.08	102.91
negative	900	900-850	-0.002		$+1 \times 10^{-3}$		103.48		
16.05.88	720	Surf-900	0.09	0.02	$+2 \times 10^{-3}$	$+3 \times 10^{-4}$	49.31	29.23	54.13
negative	900	900-850	-0.003		3×10^{-3}		35.68		

Table 3. 90% Confidence Intervals for the Parameters at Agartala and Ranchi

Station Time	Nature of atmosphere	Mean Conv. Inst. (km^{-1})		Mean Vert. Sh. (s^{-1})		Mean $(\theta_{es} - \theta_e)$ (k)		
		Favourable layers below FLCL	Average below FLCL	Favorable layers below FLCL	Average below FLCL	Favorable layers below FLCL	Average below FLCL	Surface
AGT 12 GMT	TS	$-0.16 < \mu < -0.04$	$-0.08 < \mu < 0.06$	$3 \times 10^{-3} < \mu < 1 \times 10^{-2}$	$1 \times 10^{-3} < \mu < 9 \times 10^{-3}$	$7.729 < \mu < 15.111$	$8.91 < \mu < 15.238$	$14.48 < \mu < 26.74$
	NTS (Fair-Weather)	$-0.15 < \mu < -0.09$	$-0.12 < \mu < 0.08$	$4 \times 10^{-3} < \mu < 6 \times 10^{-3}$	$0 \times 10^{-3} < \mu < 2 \times 10^{-3}$	$17.692 < \mu < 23.2$	$16.18 < \mu < 23.74$	$19.52 < \mu < 29.75$
RNC 12 GMT	TS	$-0.2 < \mu < -0.06$	$-0.134 < \mu < 0.06$	$3 \times 10^{-3} < \mu < 7 \times 10^{-3}$	$2 \times 10^{-3} < \mu < 3 \times 10^{-3}$	$20.37 < \mu < 36.22$	$17.98 < \mu < 37.12$	$12.36 < \mu < 38.37$
	NTS (Fair-Weather)	$0.065 < \mu < 0.01$	$-0.011 < \mu < 0.002$	$3 \times 10^{-3} < \mu < 6 \times 10^{-3}$	$4 \times 10^{-4} < \mu < 9 \times 10^{-4}$	$20.92 < \mu < 56.76$	$23.04 < \mu < 46.30$	$58.55 < \mu < 81.71$

'μ' stands for mean value of the parameter.