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Lapse rate change due to advection at lower levels and occurrence of pre-monsoon thunderstorms

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ABSTRACT. Using the method of vertical wind shear vector difference, the change in lapse rate brought about by advection alone (upto a height of 5000—7000 ft) was estimated for Calcutta from the upper wind data of 0200 GMT ascent for every day, spread over a period of one month of the usual peak activity of nor'westers (violent thunderstorms). This change applied to the morning tephigram is found to provide a moderately successful tool for prediction of local afternoon thunderstorms. The percentage of success for the period studied is nearly 80 per cent.

1. Introduction

Although the estimation of instability for purposes of forecasting local weather of the convective type has to be based on the available radiosonde data, such estimations from these radiosonde ascents alone have been observed to be of limited use for forecasting thunderstorms, particularly in pre-monsoon season, affecting Calcutta. In fact, Roy (1950) who has made a study of the tephigrams during pre-monsoon season of March—May 1949, has also remarked of the limited utility of 0300 GMT radiosonde ascents in the prognosis of thunderstorm developments of this season. He has remarked that the modifications in the atmospheric structure are more of a local character and the occurrence or non-occurrence of nor'westers may not, therefore, be indicated always by soundings made 6 to 12 hours earlier (0300 GMT ascent). To study this aspect of local factors modifying the structure of the atmosphere, at least for the lower levels, an attempt has been made in this note to study the lapse rate changes that would be taking place in the lower layers due to air-flow pattern alone and to see if any relation exists between this change in lapse rate conditions at lower levels with the subsequent development of thunderstorms.

In this study attention has been confined to the conditions at lower most levels, *viz.*, 1000 to 5000 ft a.s.l. primarily because of the lack of wind data at upper levels at 0200 GMT and secondly due to the fact that during the pre-monsoon months, there is usually an inversion in the transition layer between the moist air below and drier air aloft—approximately between 3000-ft and 5000-ft level, inhibiting vertical development of clouds. Intensity of this inversion which may further increase or decrease due to changes in lapse rate arising out of particular flow pattern may contribute substantially in inhibiting or producing potentialities of development of thunderstorms.

2. Estimation of local change of lapse rate

A quantitative estimation of the local change of lapse rate can be made by a method described by Martin (1944) who following Fletcher (1942) has derived the following expression for the gradient of lapse rate —

$$-\nabla\lambda = \frac{fT}{gh^2}(\delta V_2 - \delta V_1) \times k \qquad (1)$$

(Vector notations have been used) where, $\delta V_2 - \delta V_1$ is the "shear difference vector". Here vector δV_1 is the vectorial difference between V_1 and V_0 where V_1 is the velocity vector at the level 1 (higher level) and V_0 the velocity vector at the level 0 (initial level). Similarly δV_2 represents vector difference between V_2 and V_1 where V_2 represents the velocity vector at the level 2 (or level higher than 1). The cross product $(\delta V_2 - \delta V_1) \times k$ then always represents a vector directed at right angles across $\delta V_2 - \delta V_1$ from the left to the right of the shear difference vector. h represents the interval of height through which successive increments

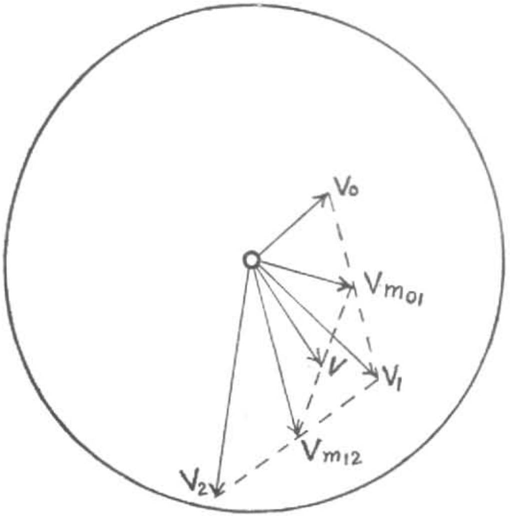

Fig. 1

δV_1 and δV_2 are measured from the initial point. λ represents the lapse rate$=-\partial T/\partial z$. Other symbols have their usual meaning, *viz.*, f=Coriolis parameter, T= temperature and k=unit vector.

The spacing L of the isolines of λ corresponding to certain value of $\delta\lambda$ (*i.e.*, change in lapse rate in a horizontal plane) can be, as has been shown by Martin (1944), determined from the equation

$$L = \frac{g}{fT} \times \frac{\delta \lambda\, h^2}{|\delta V_2 - \delta V_1|} \qquad (2)$$

where $|\delta V_2 - \delta V_1|$ represents the numerical value of shear difference vector.

If this equation is used for finding out values of L for a certain fixed change of λ in the horizontal plane, say at intervals of $\delta\lambda = 0{\cdot}5°$ F per 1000 ft, equation (2) can be written as

$$L = K.\ \frac{h^2}{|\delta V_2 - \delta V_1|} \qquad (2a)$$

where K is a constant as the area considered is too small to cause any significant variation of f, the Coriolis factor. Using equation (2a) and expressing h in thousands of feet Martin has tabulated values of K against those of L expressed in miles which can be straight away used to determine values of L. From the spacing of the isolines the gradient of the lapse rate can be easily determined.

Now, the local change of lapse rate can be found from the following equation (Martin 1944)

$$\frac{\partial \lambda}{\partial t} = -V \nabla \lambda \qquad (3)$$

where V is the mean wind vector which can be calculated from polar diagram following the same method as Martin (1944) by plotting the winds of the levels 0, 1 and 2 and taking the mean of V_0 and V_1 ($=V_{m01}$) and V_1 and V_2 ($=V_{m12}$) and finally the mean of V_{m01} and V_{m12} as shown in Fig. 1.

It may be worthwhile to point out that since cooling by evaporation from falling rain etc is absent at the initial stage, the change in the lapse rate, apart from other non-adiabatic processes is brought about mainly by the vertical variation of temperature due to advection. Thus, there can be creation or augmentation of instability at lower levels due to advection alone under any of the following circumstances—

(*a*) Temperature at both the levels are rising—rise being more at lower level

(*b*) Temperature increase at lower level without any change in temperature at upper level

(*c*) Temperature fall at both the levels—fall being more at upper level

(*d*) Fall in temperature at higher level, no temperature change at lower level

(*e*) Temperature rise at lower level and temperature fall at upper level

It may, however, be mentioned that so far as lower level instability is concerned all the above types of changes are not equally effective for production of thunderstorm. It is obvious that change of the type (*e*) constitutes the most potent conditions for thunderstorm and changes of type (*a*) signifies lesser degree of instability, as it is likely to increase the negative area and hence is unlikely to favour formation of thunderstorms unless the moisture supply and the degree of difference in warming between the lower and upper levels are very marked. Similarly, changes of type (*c*) may constitute very favourable conditions for thunderstorm even with smaller cooling owing to non-adiabatic heating of the air close to ground over compensating the cooling caused by advection at the lower slab.

In addition to assessing the change in lapse rate at lower levels by equations (2) and (3) above, it is desirable to study further the change in instability (or stability) at the lower layers by estimating whether there is warming or cooling at the upper slab of these lower layers. The temperature gradient is given by

$$\frac{2f}{g} \,.\, k \times \frac{\delta V}{\delta z} = - \frac{\nabla T}{T} \qquad (4)$$

where, k = unit vectorial vector

f = Coriolis parameter

v = wind velocity

z = height

$-\nabla T$ = temperature gradient

T = temperature

Temperature change due to advection is given by

$$\frac{\partial T}{\partial t} = - v.\, \nabla T \qquad (5)$$

From (4) we can re-write the equation (5) as

$$\frac{\partial T}{\partial t} = v.\, \frac{2Tf}{g} \,.\, k \times \frac{\delta V}{\delta z} = \frac{2Tf}{g} \times k\, \frac{\delta V}{\delta z} \times v = \frac{2Tf}{g}\, v \left| \frac{\delta V}{\delta z} \right| \sin\theta \qquad (6)$$

where θ is the angle between the direction of the wind shear and wind velocity measured in a counter clockwise direction.

3. Case study

Two typical examples are given below as illustrations of the method described above.

Case 1 : 26 April 1953 (Tephigram favourable for thunderstorm)

The 0500 GMT tephigram of this day showed instability at all levels upto 615 mb. There was no lower level inversion and lapse rate was close to dry adiabatic lapse rate upto 615 mb. Difference between shear vectors between 3000 and 5000-ft levels (*i.e.*, δV_2) and between 1000 and 3000-ft levels (*i.e.*, δV_1) were computed and found to be 010°/27 kts. Isolines of λ were, therefore, on this day oriented in a direction north to south (010°/190°) with relatively stabler or much less unstable air to the west. Spacing of the isolines of λ was calculated from equation (2) and was found to be equal to 9·6 miles (approximately). V (mean wind) was found to be 215°/24 kts =215°/26 mph (approximately). From above values, advective lapse rate change computed from equation (3) above is found to be equal to —0·6° F/1000 ft/hr.

Temperature advection at upper level (1000—5000 ft slab)

Shear vector between 3000 and 5000 ft= 010°/17kts =010°/19 mph (approximately). Mean wind and temperature between 3000 and 5000 ft = 215°/22 kts =215°/24 mph (approximately) and 290° A respectively. From these the temperature change due to advection is found from equation (6) to be equal to 4·1° F in six hours, thus leading to decrease in instability and inhibition of convection at lower levels. It is interesting to note that on this day there was no thunderstorm activity over Calcutta and neighbourhood.

Case 2 : 29 April 1953 (Tephigram unfavourable for thunderstorm)

The tephigram on this day (Fig. 2) shows an inversion from 2800 to 4100 ft. It is apparent, from the tephigram, that the temperatures

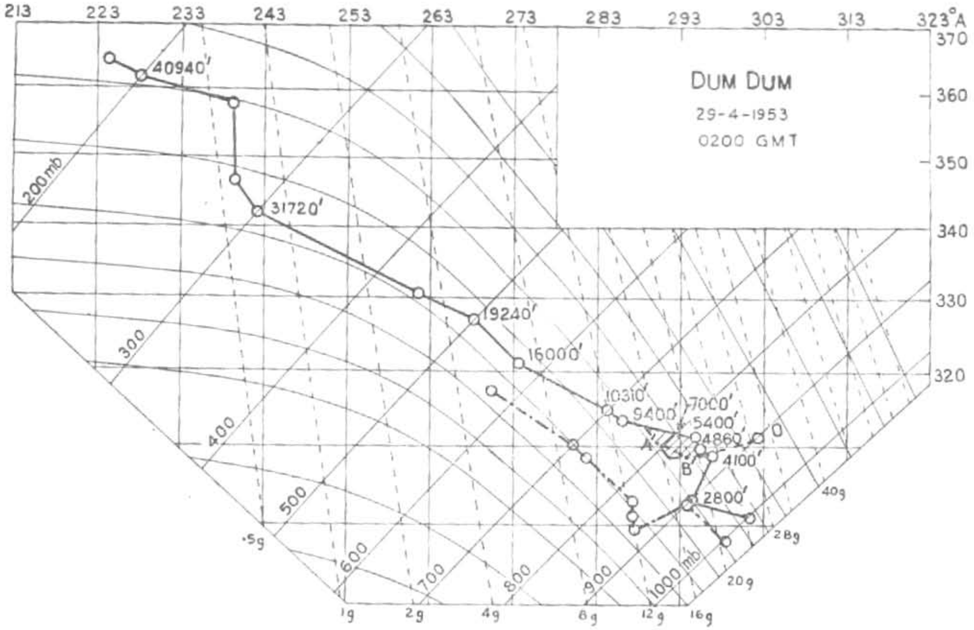

Fig. 2

Hatched area shows the amount of energy required to be spent in order to realise latent instability in the case of unmodified tephigram

A′B′=Modified dry bulb curve assuming uniform cooling of 1°·3 C in the layer 5000/7000 ft

OA′B′=Modified dry bulb curve assuming an increase in lapse rate between 3000 and 7000 ft by another 7°·2 C

above 4000 ft are extremely important in estimating the energy to be spent for the realisation of the latent instability. Hence the slab of 3000—7000 ft was chosen for estimating the effects of advection. Winds at 3000, 5000 and 7000 ft a.s.l. at Calcutta for 0200 GMT ascents on this day were 200°/16 kts, 220°/20 kts and 210°/14 kts respectively.

The shear vector between 3000 and 5000 ft a.s.l. (δV_1), 5000 and 7000 ft a.s.l. (δV_2) are shown by AB and BC in the diagram (Fig. 3). The difference in shear vector is shown by BD. The direction and magnitude of these shear vectors δV_1, δV_2 and $\delta V_2 - \delta V_1$ are 270°/7kts, 060°/7 kts and 075°/15 kts respectively. Mean wind direction between 3000 and 5000 ft a.s.l., 5000 and 7000 ft a.s.l. and between 3000 and 7000 ft a.s.l. are shown by OM_1, OM_2 and OM respectively. Their direction and magnitude are 210°/17 kts, 215°/17 kts and 215°/17 kts respectively. From above, taking the value of K of eqn. (2a) as equivalent to 72 the spacing between the isolines of λ (0·5°F/1000 ft/hr) may be found out. This is equal to $72 \times 4/17 = 17$ miles (approximately). From this $V - \nabla\lambda$ can easily be found out and is found to be equal to +1°.4F/4000 ft/hr or 0°.8C/4000 ft/hr, *i.e.*, advective lapse rate change during the 9-hour period may be considered to be equal to 7°.2 C/4000 ft. Temperature advection between the level 5000 and 7000 ft a.s.l. was found out from the equation

$$\frac{\partial T}{\partial t} = \frac{2T\omega \sin\phi}{g} \; v \left| \frac{\partial v}{\partial z} \right| \sin\beta$$

Putting the corresponding values of ϕ ($23\frac{1}{2}$ deg.), g and mean temperature as 290°A, the above equation reduces to

$$\triangle T = \cdot 02 \; v \; |\nabla v| \; \sin\beta \qquad (7)$$

where $\triangle T$ is the temperature change over a

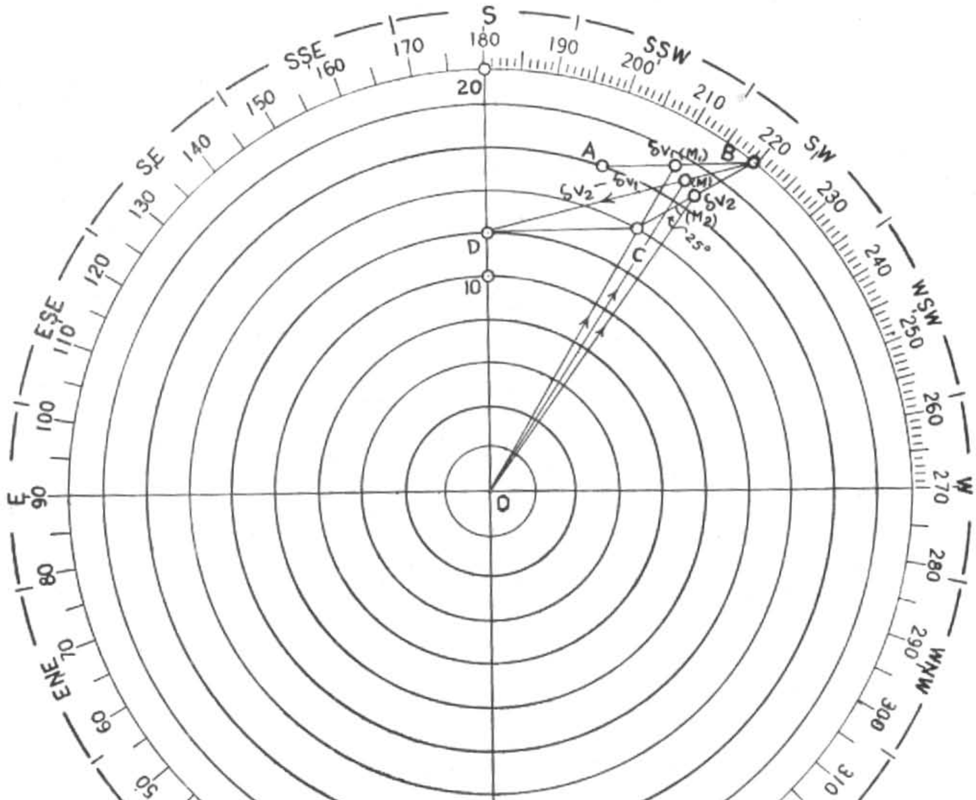

Fig. 3

layer 2000-ft thick in 9 hours, v the mean wind between the layer and ∇v the wind shear.

Now mean wind between the layer 5000 and 7000 ft a.s.l. OM_2 was found to be 215°/17 kts and ∇v, *i.e.*, the wind shear between 5000 and 7000 ft a.s.l. (δV_2) was 060°/7 kts. Substituting the above values in equation (7), change in temperature in 9 hours

$$= -\cdot 02 \times 19 \times 8 \times \sin 25^\circ$$
$$= -1^\circ\cdot 3\ \mathrm{C}$$

Now assuming a uniform cooling of 1°·3 C we may reconstruct the dry bulb curve and the tephigram between 5000 and 7000 ft. The reconstructed tephigram on the above basis is shown by A′ B′ (Fig. 2). It is evident from the modified curve that the negative area would have almost been wiped off, had this factor alone been operative, and thus would be conducive to the realisation of latent instability on this day.

Assuming the above modification, A′B′, on the upper part of the curve and assuming lapse rate change due to advective effects to be 7°·2 C between the layer 3000 and 7000 ft we may modify the lower part of the tephigram also. This modified curve is shown by OA′B′. It is clear that the inversion at the lower level would have been wiped off and the lapse rate conditions between 3000 and 5000 ft would be superadiabatic due to this factor and, therefore, would have been very much helpful for *Cb* development.

Out of the 22 cases examined (Tables 1 and 2), advection caused increasing instability and decreasing instability on 10 occasions each and very little change was observed on 2 occasions. Out of these 10 occasions when advection caused decreasing instability, thunderstorm occurred on one occasion only and it is interesting to note that on this single occasion cooling was noticed at upper level, *i.e.*, 3000—5000 ft slab. Out of the 10 cases of advection causing increasing instability, on 6 occasions there was tendency of cooling at upper level and thunderstorm occurred on 5 occasions, *i.e.*, 80 per cent occasions if only this aspect is taken into consideration. It is most interesting to note that there was no thunderstorm even on a single occasion with warming in the upper portion of the usual inversion (3000-5000 ft), which would obviously tend to increase the negative area and shows clearly the importance of local modifying factors. This alone would eliminate possibility of thunderstorm activity on 13 days out of 22 days. Out of rest of the days (9 days), there was thunderstorm activity on 7 days. This alone, in the cases studied, would have given a 78 per cent success in the forecasting probability of thunderstorm activity in the afternoon.

4. Conclusion

Considerable changes in lapse rates do occur in pre-monsoon season due to advective processes alone. From the above it is found that inspite of some inherent flaws in assuming constancy of wind at lower levels for a considerable length of time, geostrophic assumptions and ignoring changes in temperature due to vertical shrinking or stretching of the air column, radiation, evaporation cooling, non-adiabatic heating etc, this simple way of estimating changes in lapse rate due to advection alone read along with the latest available tephigram and synoptic situation may provide a useful tool for forecasting local thunderstorms.

REFERENCES

Fletcher, Robert D.	1942	*Bull. Amer. met. Soc.*, **23.**
Martin, F. L.	1944	*Ibid.*, **25**, 3, pp. 79-87.
Roy, A. K.	1950	*Indian J. Met. Geophys.*, **1**, 1, pp. 77-78.

TABLE 1

Date	Layers considered (ft)	Type of change in lapse rate due to advection	Magnitude of advective lapse rate change (per 1000 ft/9 hrs) (°F)	Temperature change at upper slab of layer considered	Subsequent weather at Calcutta and neighbourhood
16-4-53	1000-5000	Little change	—	Warming	Nil
17-4-53	1000-5000	Decreasing instability	— 0·9	,,	,,
18-4-53	1000-5000	,,	— 0·4	,,	,,
19-4-53	3000-7000	,,	— 0·1	,,	,,
20-4-53	1000-5000	Increasing instability	+ 1·0	Cooling	Squalls at Barrackpore and Dum Dum
21-4-53	1000-5000	,,	+ 0·5	,,	Thunderstorm at Alipore
22-4-53			Ascent failure		
23-4-53	1000-5000	Increasing instability	+ 1·2	Little change	Nil
24-4-53	1000-5000	,,	+ 0·3	Warming	Distant lightning at Dum Dum
25-4-53	1000-5000	Decreasing instability	— 1·0	,,	Nil
26-4-53	1000-5000	,,	— 0·6*	,,	,,
27-4-53			Ascent failure		
28-4-53	1000-5000	Increasing instability	+ 7·1*	Cooling	Thunderstorm at Dum Dum
29-4-53	3000-7000	,,	+ 2·7	,,	Squalls at Barrackpore, Dum Dum and Alipore
30-4-53	1000-5000	Little change	—	Warming	Very light rain† at Dum Dum
1-5-53	1000-5000	Decreasing instability	— 0·2	,,	Nil
2-5-53	1000-5000	Increasing instability	+ 0·1	Cooling	Squalls at Barrackpore, Dum Dum and Alipore
3-5-53	1000-5000	,,	+ 0·5	Warming	Nil
4-5-53 to 6-5-53			Ascent failure		
7-5-53	1000-5000	Increasing instability	+ 1·5	Cooling	Nil (Little moisture)

*Change in 6 hours

†Synoptic situation very favourable for occurrence of Nor'wester

TABLE 1 *(contd)*

Date	Layers considered (ft)	Type of change in lapse rate due to advection	Magnitude of advective lapse rate change (per 1000 ft/9 hrs) (°F)	Temperature change at upper slab of layer considered	Subsequent weather at Calcutta and neighbourhood
8-5-53	1000-5000	Decreasing instability	— 2·7	Warming	Nil
9-5-53	1000-5000	,,	— 0·3	Cooling	Squalls at Barrackpore, Dum Dum and Alipore
10-5-53	1000-5000	Decreasing instability	— 0·9	Warming	Nil
11-5-53 to 13-5-53			Ascent failure		
14-5-53	1000-5000	Increasing instability	+ 1·2	Little change	Squalls at Barrackpore, Dum Dum and Alipore
15-5-53	1000-5000	Decreasing instability	— 1·8	Warming	Nil

TABLE 2

	Instability increasing due to advection (Total No. of occasions = 10)			Instability decreasing due to advection (Total No. of occasions = 10)			Little change due to advection (Total No. of occasions = 2)
	Cooling at upper level	Warming at upper level	Very little change at upper level	Cooling at upper level	Warming at upper level	Very little change at upper level	Warming at upper level
No. of days	6(5)	2(0)	2(1)	1(1)	9(0)	0(0)	2(0)

Figures in brackets indicate occasions of associated thunderstorm