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Thunderstorms over Gangetic West Bengal in the pre-monsoon season and the synoptic factors favourable for their formation

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ABSTRACT. The occurrence of thunderstorms in the pre-monsoon season over Gangetic West Bengal in relation to low level synoptic conditions as well as high level perturbations has been examined. It is shown that neither of these factors by itself can produce convective activity, the important condition being the super-position of upper divergence associated with a high level perturbation over a low level convergent area. The upper divergence occurs due to a variety of perturbations—a straight jet stream, a jet stream trough, a trough or even an anticyclonic vortex—and the lower convergence is provided by a low or trough at the surface. The importance of shearing advection in producing divergence in jet stream zone is pointed out and the relative efficacy of the various perturbations in producing squalls associated with thunderstorms is analysed.

1. Introduction

The occurrence of severe thunderstorms over northeast India during March to May often accompanied by destructive squalls, locally known as "Nor'westers", is well known. Various authors have attempted to explain the synoptic aspects of the phenomenon from a study of surface conditions and upper air flow mainly in the lower troposphere.

During recent years Ramaswamy and Bose (1953) pointed out the importance of upper tropospheric conditions in the causation of these severe storms. They considered the movement of a 'cold pool' of air in the mid and upper troposphere (700 mb ~ 500 mb and 500 mb ~ 300 mb), associated with troughs in the westerlies as responsible for the thunderstorms, instability being generated by the over-running cold air. This mechanism, however, was found insufficient to explain the occurrence of thunderstorms well ahead of the cold pool as pointed out by Desai and Rao (1954) and Mull, Gangopadhyaya and George (1955). Ramaswamy (1956) in a more detailed analysis altered the emphasis from the cold pool to the vorticity advection associated with advancing troughs in upper westerlies. The occurrence of thunderstorms ahead of the trough in a jet stream could be explained by this model as due to the upper divergence ahead of the trough and the corresponding low level convergence. He considered also that this upper divergence was responsible for all spring-time convective phenomena (thunderstorms, duststorms etc) not only over India but also over many other parts of the world (U.S.A., South Africa etc). The effects of surface heating and of other lower tropospheric agencies like convergence associated with troughs and valley flow, are in his view, of minor importance in comparison with the role of the upper divergence.

Desai (1957), however, has questioned this and would still consider low level conditions like insolation, valley convergence etc, as the primary triggering off processes. Bose (1957) has made a study of low level convergence and found that thunderstorms do not always occur though there may be well marked low level convergence on the morning weather maps.

In this paper, an attempt has been made to examine the relative importance of high as well as low level conditions in the generation of thunderstorms over Gangetic West Bengal during the pre-monsoon season.

2. Divergence associated with high level perturbations over north India

The role of divergence in upper levels in the development of various atmospheric phenomena ranging from cumulus growth to tropical hurricanes has become increasingly apparent in recent years. Ramaswamy's (1956) emphasis on the effect of the jet stream trough on the generation of thunderstorms is, therefore, pertinent.

Since westerly troughs with or without an embedded jet stream are not the only upper perturbations over north India in the pre-monsoon season, it is necessary to examine whether other factors also produce upper divergence during these months. Koteswaram and Parthasarathy (1954) pointed out the existence of a westerly jet stream with a mean location over 27°N at an altitude of approximately 12 km over northern India during this season. They also noticed upward vertical currents in the right entrance and left exit of such jet streams. The existence of straight jet streams or jet maxima which move from west to east over northern India is quite a common observation in this season. As such, the vertical circulation observed by Koteswaram and Parthasarathy (1954) naturally suggests convective activity associated with straight jet streams or jet maxima. We shall now examine the distribution of divergence in various types of upper perturbations.

Pronounced upper divergence may be associated with (*i*) a trough or ridge, (*ii*) a straight jet stream, (*iii*) a trough (or ridge) with an embedded jet and (*iv*) an anticyclonic vortex.

Divergence can be computed by kinematic, adiabatic or vorticity methods. In the absence of adequate wind data, the vorticity method is helpful. Neglecting certain minor terms involving the horizontal gradient of vertical velocity, the vorticity theorem may be written as —

$$\frac{dQ}{dt} = -DQ \qquad (1)$$

where $Q = q + f$; Q being the vertical component of absolute vorticity and q of relative vorticity. f is the Coriolis parameter and D the horizontal divergence.

Expressing in terms of the partial differentials,

$$\frac{\partial Q}{\partial t} + \mathbf{V}.\nabla Q + w\frac{\partial Q}{\partial Z} = -DQ \qquad (2)$$

where $\mathbf{V}.\nabla Q$ denotes horizontal advection of vorticity. Assuming that the local vorticity tendency is small compared to other factors, divergence D is indicated by the vorticity advection term —

$$-\mathbf{V}.\nabla Q - w\frac{\partial Q}{\partial Z}$$

Expressing in polar co-ordinates

$$Q = VK_s - \frac{\partial V}{\partial n} + f \qquad (3)$$

where V is the velocity, K_s is the curvature of the streamline, s is taken along the streamline and n normal to it. If K_n is the orthogonal curvature, the horizontal advection of vorticity may be expressed by —

$$-\mathbf{V}.\nabla Q = -V\frac{\partial Q}{\partial s}$$

$$= -V^2\left(\frac{\partial K_s}{\partial s}+K_s\ K_n\right)+ V\cdot\frac{\partial}{\partial s}\cdot\frac{\partial V}{\partial n} \qquad (4)$$

neglecting the variation of f along the streamline.

The vertical advection of vorticity would be given by—

$$-w\frac{\partial Q}{\partial Z} = -w\left(K_s\ \frac{\partial V}{\partial Z}+V\frac{\partial K_s}{\partial Z} - \frac{\partial}{\partial Z}\cdot\frac{\partial V}{\partial n}\right) \qquad (5)$$

Hence equation (2) may be written as —

$$DQ = -V^2\left(\frac{\partial K_s}{\partial s}+K_s\ K_n\right)+V\frac{\partial}{\partial s}\times\frac{\partial V}{\partial n}-w\left(K_s\ \frac{\partial V}{\partial Z}+V\frac{\partial K_s}{\partial Z}-\frac{\partial}{\partial Z}\cdot\frac{\partial V}{\partial n}\right) \quad (6)$$

It is customary to assume w, the vertical velocity, to be negligible when compared to the horizontal velocity and also that the variation of horizontal wind shear along the streamline to be normally small. With these assumptions, only the first term on the right hand side of equation (6) remains and the horizontal vorticity advection is given by

$$DQ = -V^2\left(\frac{\partial K_s}{\partial s}+K_s\ K_n\right) \qquad (7)$$

Petterssen, Dunn and Means (1955) pointed out how in jet streams with large velocities, the associated vorticity advection is also large. Ramaswamy (1956) has drawn attention to this equation and assumed that it solved the difficulty involved in neglecting the shear term, so far as jet stream zones are concerned. Though the equation would indicate considerable vorticity advection in curved flow where K_s has a finite value, it gives zero vorticity advection in the case of straight jet streams where K_s is zero. It is, however, well-known that considerable vorticity advection does exist in the entrance and exit sectors of the straight jet streams. Here the shearing advection terms in equation (6) become important. In such a case, *i.e.*, straight flow, equation (6) reduces to

$$DQ = V\frac{\partial}{\partial s}\cdot\frac{\partial V}{\partial n}+w\frac{\partial}{\partial Z}\cdot\frac{\partial V}{\partial n} \qquad (8)$$

Koteswaram and George (1958) drew attention to the importance of the first term in equation (8), *viz.*, horizontal shearing advection at upper levels in the development of tropical depressions in association with upper easterly jet streams. Reckoned over a fairly large area, the contribution of the second term would be negligible in spite of the vertical gradient of the horizontal shear in jet streams.

We may get an idea of the order of magnitude of the first term by a rough calculation. The maximum anticyclonic wind shear at, say, 20°N would be numerically equal to the Coriolis parameter (5×10^{-5} sec^{-1}). Assuming this value to be reached in about 10° longitude (1000 km) along a jet stream of mean velocity 100 knots, the first term would be equal to $2\cdot5\times10^{-9}$ sec^{-2}, which is of the same order of magnitude as the advection of vorticity in a trough, due to the curvature term alone. It is evident, therefore, that the shearing advection cannot be neglected in jet stream zones. The first term in equation (6) which is the curvature term is important in troughs and ridges but the second term becomes significant in jet streams.

Riehl (1954) has given schematic models for divergence associated with a trough or ridge with a jet maxima at the trough or ridge line. Fig. 1 illustrates the distribution of divergence in a trough (or ridge) with a jet maximum located to the east (or west) of it. At A and A′ the curvature and the shear terms are additive, resulting in maximum divergence, while at B and B′ they are opposite, indicating minimum divergence or

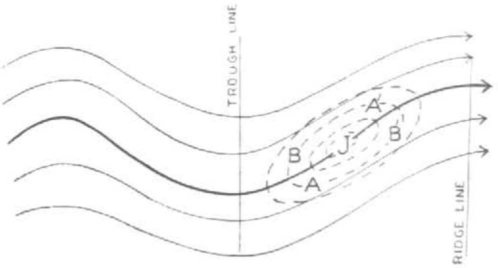

Fig. 1. Schematic model for divergence in a trough (or ridge) with a jet maximum located to the east (or west) of it

Solid lines—stream lines; Broken lines—isotachs; Continuous thick line—axis of the jet stream

even convergence. Hence, in any jet stream situation, the locations of the entrance and the exit zones of the jet are important in determining areas of upper divergence.

Studies of development in association with upper divergence should, therefore, take into account not only the effect of the curvature term in equation (6) as was done by Ramaswamy (1956) but also the effects of the shear terms mentioned above.

3. Analysis of convective activity during the pre-monsoon seasons of 1953—1956

The pre-monsoon periods of 1953—56 were selected for the analysis of thunderstorm activity due to the availability of rawin data in northeast India. Isobaric charts at sea level for 0300 GMT and streamline charts at upper levels at 0300 GMT and 0900 GMT were examined and vertical time sections of winds were prepared for Calcutta and Gauhati.

3.1. *Detection of upper level perturbations*

On many days it was not possible to locate exactly the jet maximum or the trough line in the upper troposphere on the streamline charts nor was it possible to trace their day-to-day movement due to paucity of data. The situation became complicated in double or split jet streams which were found over northern India on quite a number of occasions. The relationship between convective zones and jet streams or troughs on streamline charts could not also be uniquely determined. It was, therefore, considered preferable to rely upon vertical time sections for indicating the passage of upper troughs of jets over a station. Attention was fixed to Calcutta time-sections since thunderstorm occurrence at the station is not complicated by orography.

While the passage of troughs over Calcutta could be fairly accurately fixed by the wind shift, the reporting of a wind maximum at the station need not necessarily mean the location of a jet maximum. It can, however, be assumed that the jet maximum is situated to the north or south of the station, although not over it, on these occasions, when Calcutta had a wind maximum at a particular level relative to the few previous and subsequent ascents.

With the passage of each jet maximum or trough line over Calcutta, the outbreak or otherwise of thunderstorms over Calcutta and neighbourhood (Gangetic West Bengal) was looked for, and statistics indicating such association prepared for each month under study. Since the upper divergence associated with a jet maximum is distributed in the forward as well as the rear sectors as explained in Section 2, the occurrence or non-occurrence of thunderstorms 24 hours before or after the passage of a jet maximum was taken into account. The upper perturbation is described as a jet if a wind maximum 50 knots or more passes over Calcutta within 24 hours before or after the reported occurrence or non-occurrence of thunderstorms. As regards the troughs, similar occurrence or non-occurrence within 24 hours ahead of the trough line was classified since the rear of the trough is normally a convergence zone and vorticity advection is concentrated mainly in the vicinity of the trough line.

3.2. *Classification of surface synoptic situations*

The surface synoptic conditions were classified according to the presence or absence of winds with southerly components at least upto 3000 ft a.s.l. over Calcutta. These winds may be associated either with a low level 'low' to the west of Calcutta or with the intensification or extension of the seasonal

TABLE 1

Number of thunderstorm days in Gangetic West Bengal

Low level conditions		Upper tropospheric perturbation				
		Jet	Jet-cum-trough	Trough	No jet or trough	No data
		(1)	(2)	(3)	(4)	(5)
Southerlies upto 3000 ft a.s.l. or more	With surface low	22	15	9	5	5
	Without surface low	9	2	3	3	3
No southerlies upto 3000 ft a.s.l.		0	0	0	1	0

TABLE 2

Number of non-thunderstorm days in Gangetic West Bengal

Low level conditions		Upper tropospheric perturbation				
		Jet	Jet-cum-trough	Trough	No jet or trough	No data
		(1)	(2)	(3)	(4)	(5)
Southerlies upto 3000 ft a.s.l. or more	With surface low	36(2)	8(1)	4	30	3
	Without surface low	21(8)	8(0)	5	20	1
No southerlies upto 3000 ft a.s.l.		22(10)	6(2)	0	10	2

trough into Gangetic West Bengal or neighbourhood. The southerly winds were looked for since they supply the moisture from the Bay of Bengal and the 'low' helps in producing convergence at low levels.

Thunderstorms reported over Calcutta or anywhere in Gangetic West Bengal, were also indicated in the time-sections mentioned in 3·1. It was thus possible to visualise both the surface and the upper air flow patterns which existed over Calcutta and Gangetic West Bengal, before the outbreak of thunderstorm. A thunderstorm day was considered to mean a day when thunderstorm was reported from any station in Gangetic West Bengal.

3.3. *Results of the analysis*

The results of the above analysis with regard to thunderstorm and non-thunderstorm days in Gangetic West Bengal, are given in Tables 1 and 2 respectively. The analysis extends over the period in each year where there was a westerly flow in the upper troposphere as indicated in the time-section for Calcutta. The actual periods covered by the tables are— 1 April to 28 May 1953, 1 April to 19 May 1954, 1 March to 24 May 1955 and 1 March to 30 April 1956.

3.4. *Favourable surface and upper air conditions*

It is clear from Table 1 that the majority of thunderstorms over Gangetic West Bengal were associated with upper perturbations like a jet or a trough accompanied by a low level 'low' which was responsible for southerly flow at least upto 3000 ft a.s.l. The number of occasions when no surface 'low' was present over Gangetic West Bengal, but still the thunderstorms occurrred in association with upper perturbations was small, indicating that the superposition of the upper perturbation over the low level 'low' is a powerful factor setting off thunderstorms. It is also noteworthy that the maximum number of cases 31, occurred with straight jets without a trough. The jet stream trough accounted for 17 cases and trough without a jet for 12 cases.

An examination of Table 2, with respect to non-thunderstorm days, shows that there was quite a number of days when a jet maximum or a jet-cum-trough passed over or near Calcutta with favourable conditions at the surface also, but no thunderstorms occurred over Gangetic West Bengal. As explained in Section 2, the passage of a jet maximum over or near Calcutta need not necessarily indicate upper divergence over Gangetic West Bengal, the divergence being confined to the right entrance and the left exit portions of the jet. In such a case, thunderstorms may occur to the southwest or northeast of Calcutta (or Gangetic West Bengal), *viz.*, in Orissa or in Sub-Himalayan West Bengal and Assam. It was found that on many occasions they did occur in these areas though none were reported in Gangetic West Bengal, during the passage of upper jet maxima over Calcutta. Such cases, when thunderstorms were reported either from Orissa or Assam and Sub-Himalayan West Bengal, were eliminated and the figures obtained by elimination are given within brackets in Table 2. The small number of non-thunderstorm days so obtained after elimination indicates that thunderstorms failed to occur over northeast India only very rarely given favourable surface and upper air conditions mentioned in this paragraph.

3.5. *Relative importance of surface and upper air conditions*

If we consider the conditions given in rows 1 and 2 of Tables 1 and 2 as favourable surface conditions and those in cols. 1, 2 and 3 as favourable upper air conditions for thunderstorm activity, it is possible to examine the effects of various upper perturbations with favourable and unfavourable surface conditions as well as different surface flow patterns under favourable and unfavourable upper air conditions. Statistics for the above combinations are given in Tables 3 and 4. The numbers given in these tables for non-thunderstorm days are eliminated figures (in bracket) in Table 2 as explained at the end of the previous paragraph.

TABLE 3

Surface conditions		Upper tropospheric perturbation			
		Jet	Jet-cum-trough	Trough	No jet or trough
Favourable	T	31	17	12	8
	N	10	1	9	50
Unfavourable	T	0	0	0	1
	N	10	2	0	10

T—Thunderstorm days N—Non-thunderstorm days

TABLE 4

Upper tropospheric perturbation		Surface conditions		
		Southerly winds upto 3000 ft a.s.l. or more		No southerly winds upto 3000 ft a.s.l.
		With surface low	Without surface low	
Favourable	T	46	14	0
	N	7	13	12
Unfavourable	T	5	3	1
	N	30	20	10

T—Thunderstorm days N—Non-thunderstorm days

It is seen from Table 3 that with favourable surface conditions, a straight jet stream accounted for 31 thunderstorm days compared to 17 and 12 for jet-cum-trough and trough respectively; with unfavourable conditions at surface no thunderstorms occurred. A straight jet is seen to be responsible for the largest number of thunderstorm days given favourable surface conditions.

Table 4 indicates that the existence of a low level 'low' over Gangetic West Bengal or to the west of it accounts for 46 thunderstorm days given favourable upper air conditions, while the number of thunderstorm days with southerlies at low levels but without a surface low was 14 and without southerlies nil. The existence of a surface low over or near Gangetic West Bengal appears to be the most potent surface factor for thunderstorm activity over Gangetic West Bengal given favourable upper air conditions.

3·6. *Importance of superposition of upper divergence over lower convergence*

It is clear from the above analysis that the existence of either upper or lower perturbation alone is insufficient for formation of thunderstorms over Gangetic West Bengal. It is the *superposition* of upper divergence associated with a perturbation like a jet, jet-cum-trough or trough on the convergence associated with a low level 'low' or even straight southerly flow (velocity convergence) at least upto 3000 ft a.s.l. that seems to be of major importance in the outbreak of thunderstorms over Gangetic West Bengal. It is also well known that most of the thunderstorms in Gangetic West Bengal start in the afternoon in Chota Nagpur and travel east or southeastwards, though cases of thunderstorms occurring at other times are not infrequent. This would imply that surface insolation and orography in Chota Nagpur are additional factors helping to trigger off the thunderstorms over the area.

3·7. *Squalls in association with thunderstorms*

The thunderstorm days given in Table 1 include all occasions of thunderstorm activity in Gangetic West Bengal, irrespective of their association with squalls or not. Table 5 shows the classification of thunderstorms in Calcutta area (Dum Dum and Alipore) during the years 1953 - 56, with and without squalls, under different upper air conditions.

Table 5 indicates that there were about one half the number of days without squalls as those with squalls under a 'jet' situation. On the other hand, with a trough or jet-cum-trough passing over Calcutta, the percentage of squalls is very high. It should, however, be noted that the largest number of squalls occurs with a jet stream, obviously due to the fact that the number of thunderstorms are also maximum with it.

TABLE 5

Number of thunderstorm days at Calcutta

Upper tropospheric perturbation (1)	Jet (2)	Jet-cum-trough (3)	Trough (4)	No jet or trough (5)
No. of thunderstorm days with surface squalls	17	14	8	3
No. of thunderstorm days without surface squalls	9	3	1	0

NOTE—Thunderstorm days when there was no upper air data have been omitted

As explained in Section 2, maximum vorticity advection generally occurs in the vicinity and ahead of a trough line with or without a jet. As such the percentage of squalls ahead of upper trough lines (cols. 3 and 4 —Table 5) is understandable. Exceptions occur when a well marked jet maximum is located to the rear of the trough line and the maximum vorticity advection is shifted away to the vicinity of the jet maximum (Fig. 2). It is seen that such exceptions are not many. Table 5, however, provides a useful prognostic indication for squalls caused by different upper level perturbations.

A comparison of the speed of the squalls experienced at Calcutta with the speed of the maximum wind reported on the day, did not reveal any significant correlation. A plot of the squall speed and the maximum wind in the upper air indicated a very random distribution. An examination of the monthly frequencies of thunderstorms with the mean monthly resultant upper winds at or near the jet level over Calcutta during the pre-monsoon seasons of 1953-56 did not also indicate any relationship between the strength of the upper wind and the frequency of the thunderstorms. As mentioned in Section 2, the upper vorticity advection in jet streams is related to the wind shear as well as the speed and not to speed alone.

3·8. *Thunderstorms with weak upper winds*

As explained in paragraph 3·3 the analysis has until now been confined to the period

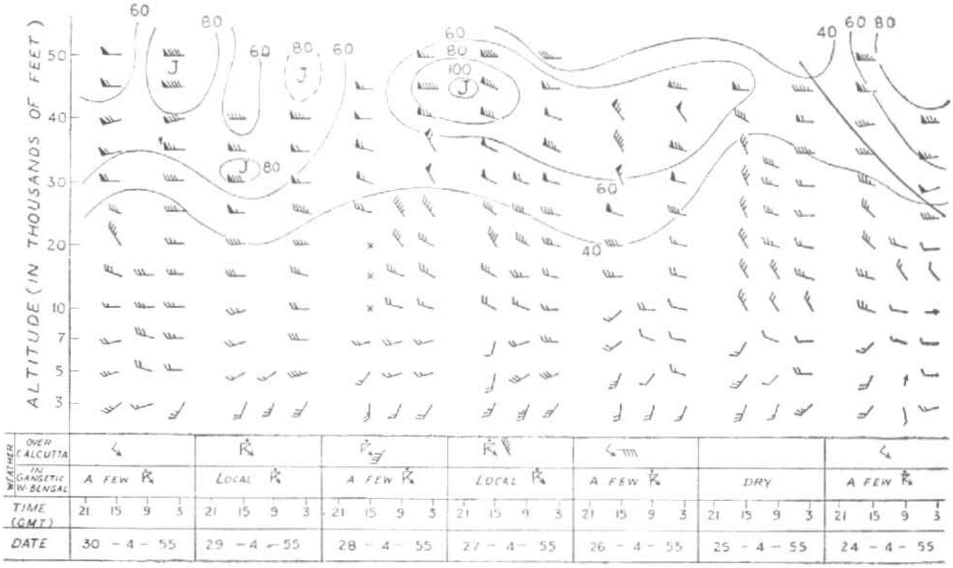

Fig. 2. Vertical time-section of winds over Calcutta, 24 to 30 April 1955
Solid lines—isotachs, wind speed in knots. Thick line—trough line.
Calcutta squall direction and speed marked along with weather

of westerly flow in the upper troposphere, the perturbations being of the types (*i*), (*ii*) and (*iii*) of Section 2. There is, however, a period between the cessation of westerly flow in the upper troposphere and its replacement by easterlies before the advance of the southwest monsoon, when the high level winds over northeast India are chaotic and the flow seems to break up into a series of cyclonic and anticyclonic vortices of the type noticed by Riehl (1948) over the Pacific in the summer season. Such anticyclonic vortices would be associated with upper divergence (type *iv* of Section 2) and cyclonic vortices with convergence. When an upper anticyclonic vortex becomes superposed over a lower convergent area, thunderstorm activity should be expected.

Weak upper winds are generally associated with quiescent weather; this is generally true when the flow pattern in the upper troposphere is westerly. However, when the flow breaks down into vortices as mentioned above it is observed that thunderstorms and squalls are quite common. During 50 days of weak upper flow in the month of May in 1953–56 there were 17 thunderstorm days (34 per cent), while the corresponding figure for westerly flow is 30 per cent. It is clear that these thunderstorms initiated by upper anticyclonic vortices over low level convergent zones are just as frequent as in the other processes described before.

4. Illustrative situations

A few typical illustrations of the various factors discussed in the previous section are given in subsequent paragraphs.

4.1. *Upper trough or ridge and jet stream trough*

Ramaswamy (1956) has given a number of illustrations of the effect of these perturbations in initiating thunderstorms. No further examples of this type are, therefore, necessary. We have, however, pointed out that in the case of jet stream trough, the maximum vorticity advection need not always be near the trough line but it may be displaced with respect to the location of the exit and entrance sectors of the jet. Fig. 2 is the example of a case when the upper vorticity advection

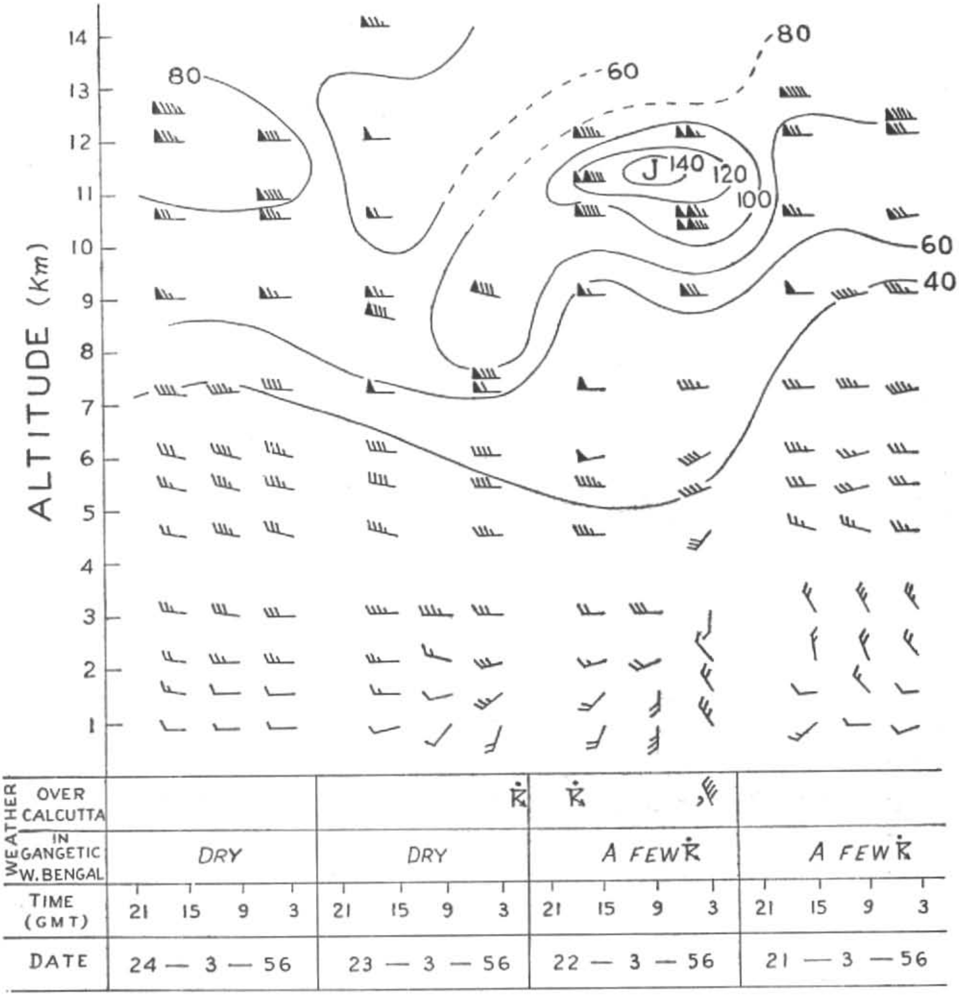

Fig. 3. Vertical time-section of winds over Calcutta, 21 to 24 March 1956

Solid lines—isotachs; winds speed in knots. Calcutta squall direction and speed marked along with weather

occurred well to the rear of a trough line due to the above effect. The trough line passed over Calcutta on 24-25 April. But another spell of thunderstorms and squalls occurred again from 26 to 29 April with upper north-westerly flow to the rear of the trough due to a jet maximum which passed over or near the station on 27-28 April.

4.2. *Straight Jets*

Fig. 3 illustrates the occurrence of thunderstorms with the passage of a straight westerly jet. A wind maximum of 140 knots passed over Calcutta on 22 March 1956 and thunderstorms and squalls occurred simultaneously with its transit.

The spatial distribution of thunderstorms in association with a straight jet on 22 April 1957 is given in Fig. 4. The occurrence of convective activity in the right entrance and left exit of a jet maximum over north-east India may be seen. The location of

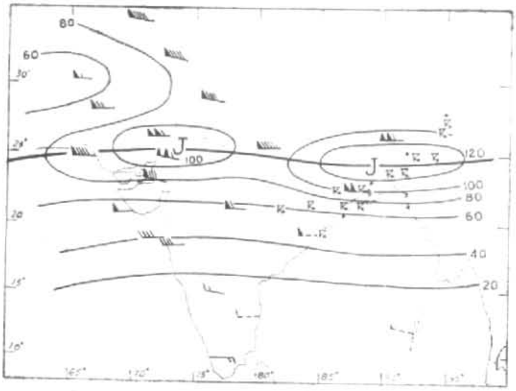

Fig. 4. Upper winds at 10·5 km at 1200 GMT on 22 April 1957

Solid lines—isotachs, wind speed in knots; Jet stream marked thick. Dashed winds—off-time reports. Winds for Pakistan stations refer to 0900 GMT. Weather reported in and around northeast India during 24 hrs ending 0300 GMT next day indicated on the map.

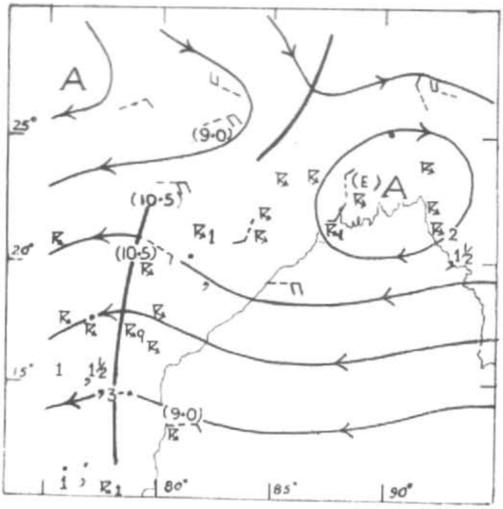

Fig. 6. 12-km stream line flow pattern at 0300 GMT on 23 May 1956

A—Anticyclone. Trough lines marked **thick.** Rainfall in inches and weather symbols refer to 24 hrs succeeding map time. Off-time winds marked by dashed lines, E (1500 GMT), height of lower level winds indicated in brackets.

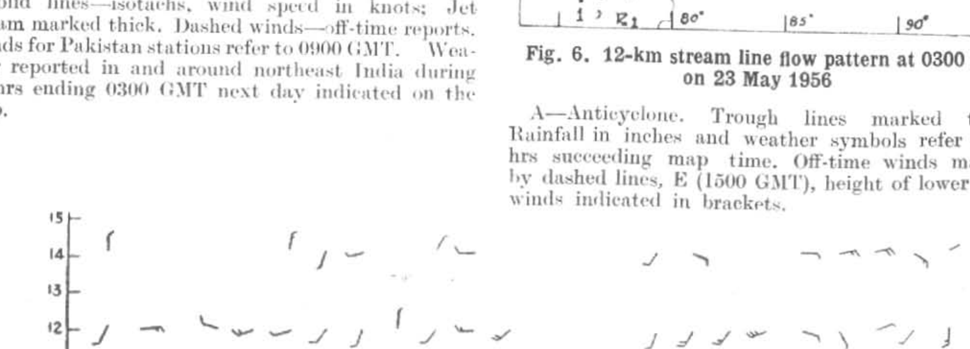

Fig. 5. Vertical time-section of winds over Calcutta, 16 to 27 May 1956

Calcutta squall direction and speed marked along with weather

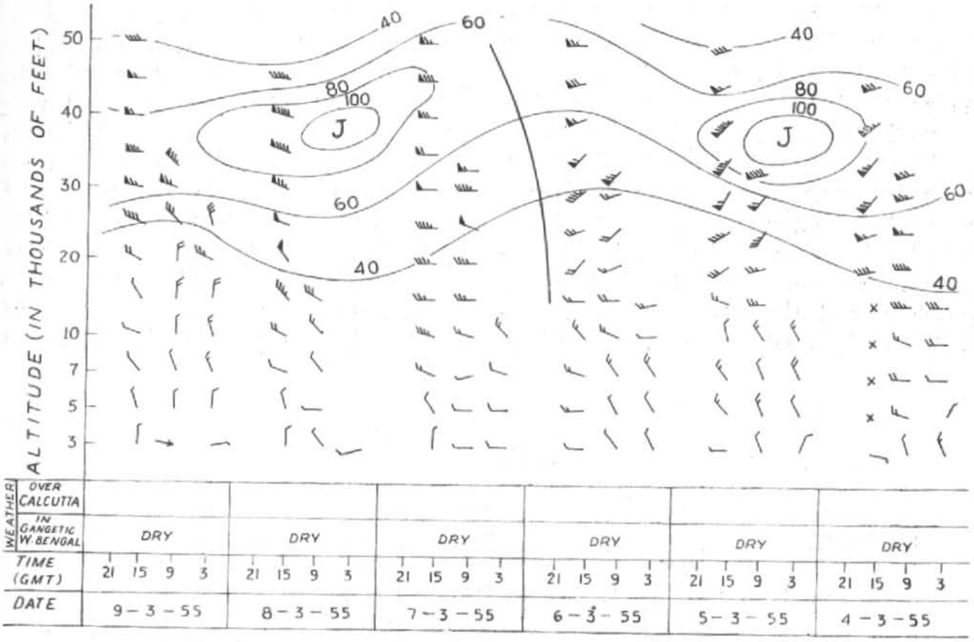

Fig. 7. Vertical time-section of winds over Calcutta, 4 to 9 March 1955
Solid lines—isotachs, wind speed in knots. Thick line—trough line

the jet maximum was confirmed from vertical time-section over Calcutta.

4.3. *Upper anticyclonic vortices*

Fig. 5 illustrates a situation when thunderstorms occurred on a large number of days over Gangetic West Bengal with weak winds in the upper troposphere. Winds above 10·5 km were variable and passage of upper cyclonic and anticyclonic vortices is indicated by the wind shifts from westerly to easterly and *vice versa*. Thunderstorms occurred in association with the divergence induced by the superposition of upper anticyclonic vortices. The flow pattern at 12 km a.s.l. on the morning of 23 May 1956 when an upper anticyclonic vortex persisted ove Gangetic West Bengal and the weather during the next 24 hours is shown in Fig. 6. Koteswaram and George (1957) have shown that soon after the situation illustrated in Fig. 5, the upper divergence associated with an anticyclonic vortex even led to the formation of a severe cyclonic storm over the north Bay of Bengal.

4.4. *Importance of suitable low level conditions*

We have indicated in the preceding paragraphs how the low level conditions are as essential as favourable upper air conditions. All the above illustrated cases of thunderstorm activity with upper perturbations were under favourable low level conditions as evidenced by the existence of southerly winds at least upto 3000 ft in the time sections. A situation when a prominent jet stream trough failed to produce thunderstorm activity due to unfavourable low level conditions is given in Fig. 7. The upper divergence associated with the jet stream trough could not set off the thunderstorms by itself in this case.

5. Conclusion

It is seen from this investigation that for generation of thunderstorm activity over Gangetic West Bengal and by inference, over the rest of northeast India, it is necessary to have suitable conditions for producing low level convergence as well as high level divergence. The occurrence of either of the conditions, by itself, is insufficient for setting off the thunderstorms. The low level convergence alone is not able to trigger off the convective processes, if there is no high level agency for mass depletion. On the other hand, though there is divergence in the upper levels, the corresponding convergence need not necessarily take place near the surface. Dines compensation may be effected between the upper troposphere and the stratosphere (Petterssen 1956). It is only when an area of high level divergence becomes superposed over a low level convergent zone that the level of non-divergence shifts to the middle troposphere and development of weather takes place. If the convergent area (a low in the present case) is situated over the sea, the above superposition may lead to the formation of a depression (Koteswaram and George 1958); but since the low, in the nor'wester season, is over land and without an adequate and continuous supply of moisture it results only in large scale convective activity.

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