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Radar study of thunderstorms around Delhi during monsoon season

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सार -- 1965 से 1972 तक 8 वर्ष की अवधि के मानसून ऋतु के दौरान किए गए दिल्ली के आस-पास 100 कि. मी. के अंदर संवहनी मेघों के रेडार प्रेक्षणों का प्रयोग करते हुए मानसून ऋतु के दौरान दिल्ली क्षेत्र में तड़ित्-झंझाओं के विकास की आवृत्ति और कुछ उनके सामान्य लक्षणों का अध्ययन किया गया है। इस उद्देश्य के लिए उन संवहनी मेघों, जिनकी रेडार प्रतिध्वनि 8 कि. मी. के परे पहुंचती या बढ़ी हुई हो, को गर्जन-मेघ माना गया है। अध्ययन से पता चलता है कि दिल्ली में और इसके आस-पास बनने वाले संवहनी मेघों का लगभग 34 प्रतिशत तड़ित्-झंझाओं के रूप में विकसित होता है। तूफान कोषाणुओं की ऊंचाई वितरण और तूफान प्रतिध्वनियों के स्थानिक वितरण पर भी विचार विमर्श किया गया है।

ABSTRACT. Frequency of thunderstorm development in Delhi region during the monsoon season and some of their general characteristics have been studied using the radar observations of convective clouds within 100 km around Delhi made during the monsoon season of the 8-year period from 1965 to 1972. For this purpose convective clouds whose radar echo tops reached or extended beyond 8 km have been considered as thunder clouds. The study revealed that about 34 per cent of the convective clouds, forming in and around Delhi, develop into thunderstorms. Height distribution of the storm cells and spatial distribution of storm echoes are also discussed.

1. Introduction

The thunderstorms are manifestation of great instability in the atmosphere. The progress made so far on the study and understanding of thunderstorms is mainly due to the valuable observations obtained by means of radiosonde network, instrumented aircraft, radars and satellites. Some of the studies of the last one decade are presented by Battan (1980), Chatterjee and Prem Prakash (1986), Cynthia and Carbone (1987), Mukherjee and Das (1983). Wakimoto (1982) etc.

The present study was conducted to provide further information about the thunderstorm activity in Delhi region, during the monsoon season (June-September), namely, statistics of their frequency of occurrence, their spatial and height distributions, role of thunderstorms on seasonal rainfall, thermodynamical conditions associated with thunderstorm days and forecasting probability of their occurrence. The study is based on radar and radiosonde observations. Results of the study are presented and discussed.

2. Equipment and data used

The study is based on hourly radar observations of precipitation echoes from convective clouds within 100 km around Delhi, made during the monsoon season of the 8-year period from 1965 to 1972. The observations were taken mainly between 1000 IST and 1700 IST. A 3.2 cm Japanese radar of type NMD-451A has been used for this purpose. Details of the radar set are given in Table 1.

During the above period height measurements of as many as 1971 convective clouds were randomly made. Out of these, those clouds whose radar echo tops reached or extended beyond 8 km have been presumed to be of thunder type and considered in our present study. This threshold value of the height of the each top for thunderstorm identification was taken due to the fact that clouds whose heights are less than 8 km may not have sufficient charge separation to be classified as thunder clouds. There were 660 such cases in all which constitute about 34 per cent of the total number of convective clouds sampled during the period under survey.

3. Results and discussion

3.1. *Frequency of occurrence*

Table 2 gives the break-up of the number of convective clouds sampled during the monsoon season of different years and percentage of them which showed thunderstorm development.

The last column of the table shows the seasonal rainfall at Delhi in different years as recorded at Safdarjung. The figures within brackets in the same column gives the rainfall departure from normal (normal rainfall : 598.7 mm).

It may be seen from the table that percentage of convective clouds showing thunderstorm development was maximum in 1969 (53.9 per cent) when the seasonal rainfall was in excess by 12 per cent and minimum

TABLE 1

Radar characteristics

Wavelength	3.2 cm
Peak power transmitted	250 KW
Pulse length	1 μ sec
Minimum detectable signal	−90 dBm
Pulse repetition frequency	300 Hz
Horizontal and vertical beamwidth	1.2°

TABLE 2

Percentage of convective clouds showing thunderstorm development during the monsoon season in different years and seasonal rainfall

Year	No. of convective clouds (A)	No. of thunder-storms (B)	(B)/(A) (%)	Seasonal rainfall (mm)
1965	278	106	38.1	522.1 (−13%)
1966	343	71	20.7	531.7 (−11%)
1967	162	72	44.4	913·2 (+53%)
1968	91	37	40.7	572.7 (−4%)
1969	128	69	53.9	669.6 (+12%)
1970	273	111	40.7	517.0 (−14%)
1971	383	102	26.6	829.0 (+38%)
1972	259	92	35.6	836·0 (+40%)
Total	1917	660	34.4	

Figures within brackets indicate percentage departure from normal.

in 1966 (20.7 per cent) when the season's total rainfall was deficient by 11 per cent. However, high percentage of convective clouds also showed storm development in some other years, like 1970, when the monsoon rainfall was deficient, whereas low percentage of storm development was seen in some good monsoon years, like 1971. It shows that the excess or deficient rainfall in a particular season does not only depends on the number of thunderstorm activity occurring in that season, rather it depends on many other factors, like number of rain events, their duration, areal coverage, etc. In order to look into this aspect, a comparison of some of the precipitation events as observed by radar was made for the three pairs of contrasting monsoon seasons, namely, 1966 (deficient) and 1967 (excess); 1968 (deficient) and 1969 (excess); and 1970 (deficient) and 1971 (excess). The result is given in Table 3.

It may be seen from the table that out of the three pairs, the total number of days when precipitation events were observed within 100 km around Delhi, total number of precipitation echoes and their average areal coverage were more on rainfall excess years in two pairs compared to rainfall deficient years. However, total areal echo coverage was more in rainfall excess years in all the three pairs.

TABLE 3

Relationship between seasonal rainfall and radar observations of precipitation events

Year	No. of days when precipitation echoes observed within 100 km	Total No. of precipitation echoes	Total areal echo coverage (km²)	Average areal echo coverage (km²)	Percentage departure of rainfall from normal (598.7 mm)
1966	42	2133	126743	59.4	−11
1967	37	2752	241531	87.8	+53
1968	36	1716	159841	93.1	−4
1969	52	2567	177874	69.3	+12
1970	49	3864	290924	75.3	−14
1971	58	3368	299410	88.9	+38

TABLE 4

Percentage of convective clouds showing thunderstorm development in different months of the monsoon season

Month	No. of convective clouds (A)	No. of thunder-storms (B)	(B)/(A) (%)
Jun	309	148	47.9
Jul	751	253	33.7
Aug	599	183	30.6
Sep	258	76	29.5
Total	1917	660	34.4

Table 4 shows the percentage of convective clouds depicting thunderstorm development in different months. It may be seen from the table that maximum number of convective clouds showed thunderstorm development in the month of June. Percentage of such storm development was comparatively lower in other months. This feature is in conformity with what is expected on the consideration that the atmospheric instability is more in June as compared to other months.

3.2. *Height distribution*

The percentage frequency distribution of the heights of the echo tops of 660 storms among different height intervals are given monthwise in Table 5. Heights of about 62 per cent of the storm echoes were found to be limited to 10.0 km. Frequency of occurrence of such storm was maximum in September (69.7 per cent) and minimum in July (55.3 per cent). Also out of the total number of storm cells studied only 3.2 per cent of them grew beyond 16 km (average tropopause level of this region). Occurrence of such deep convection was found to be maximum in July (4.0 per cent) and minimum in August

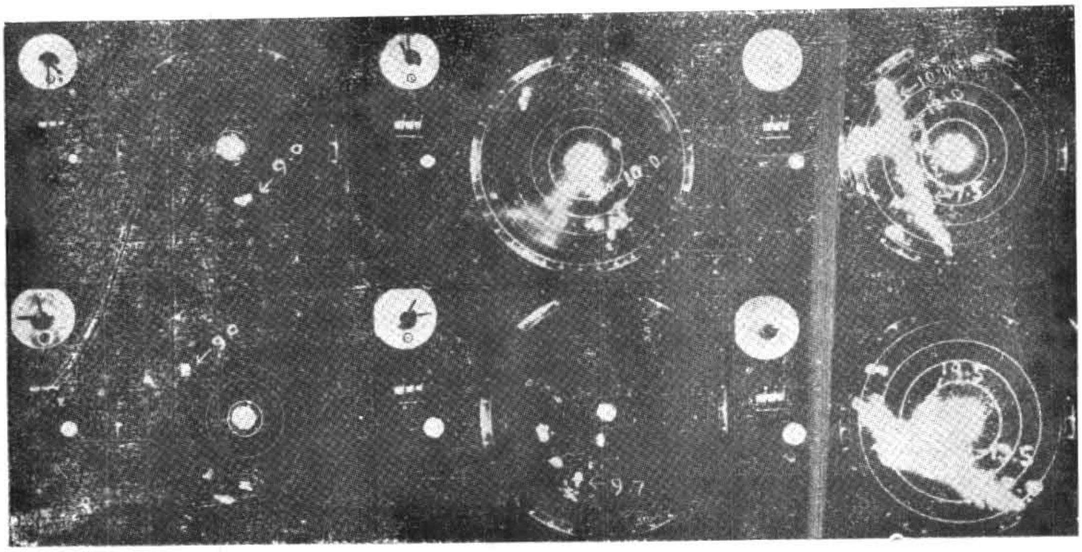

Fig. 1. PPI pictures showing three categories of thunderstorm echoes (Range : 50 km figures marked by arrows indicated the height of the storm cells)

TABLE 5

Percentage frequency distribution of the heights of echo-tops of thunderstorm among different height intervals in different months of the monsoon season

Month	Height (km)					Total No. of thunder-storms	Percentage of the season	Maximum height (km)
	8.0–10.0	10.1–12.0	12.1–14.0	14.1–16.0	>16.0			
Jun	62.8	16.2	8.1	9.5	3.4	148	22.4	19.0
Jul	55.3	17.8	11.0	11.9	4.0	253	38.3	20.0
Aug	67.8	15.8	7.7	7.1	1.6	183	27.7	20.0
Sep	69.7	13.1	4.1	9.2	3.9	76	11.5	18.0
Total	62.1	16.4	8.6	9.7	3.2	660	100	20.0

(1.6 per cent). Maximum height of the echo tops observed was 20 km. Also out of the 660 storms about 38 per cent of them occurred in July.

3.3. *Spatial distribution*

To assess whether there is any preferential region of storm development within 100 km around Delhi, the region was divided into eight sectors. The frequency distribution of storm echoes in different sectors is given below :

Sector	0°-45°	45-90°	90-135°	135-180°	180-225°	225-270°	270-315°	315-360°
Frequency	76	66	75	88	80	95	97	85

Although maximum thunderstorm development appears to occur in westnorthwest (270° to 315°) sector, and minimum in eastnortheast (45° to 90°) sector, but the application of statistical test (Chi-square test) showed that they are not statistically significant (at 5 per cent level) and the echo distribution was found to be uniform.

3.4. *Storm heights vis-a-vis their echo configuration*

An investigation was made regarding heights of the storm tops in relation to their echo configuration. For this purpose storm echoes have been classified into different height groups at 2-km interval. Thunderstorm echoes in each height group were then further classified into three types, namely, (*i*) isolated type, (*ii*) cluster type and (*iii*) line type. The storm echoes of the first type were those echoes when no other radar echoes were present within 30 km of them. Echoes of the second type were associated with one or more neighbouring radar echoes within a distance of 30 km. Echoes of the third type were part of a line of echoes. The three types of the echoes are shown in Fig. 1 and their percentage frequency distributions in different height groups are given in Table 6.

It may be seen from the table that out of the 660 storms only 7 per cent of them were of isolated type. In rest of the 93 per cent cases, they were either of cluster or line type. Also, the percentage of line type echoes increased progressively with the height of the storm echo tops and as much as 53 per cent of those thunderstorm echoes whose heights were more than

TABLE 6

Percentage frequency distribution of thunderstorms of different echo top heights among different echo categories

Ht. of echo top (km)	Category			No. of cases
	Isolated	Cluster	Line type	
8.0-10.0	6	82	12	410
10.1-12.0	7	68	25	108
12.1-14.0	5	69	26	57
14.1-16.0	8	59	33	64
>16.0	14	33	53	21
Total	7	74	19	660

16 km were found to be of line type. This feature suggests that very tall thunderstorms tend to organise themselves in a line.

3.5. *Atmospheric thermodynamical conditions*

To see whether there existed some distinctive features in the atmospheric thermodynamical conditions on days on which thunderstorms occurred, a comparative study of the temperature and moisture distribution with height has been made for two classes of days, namely, days on which atleast one of the convective clouds developed into thunderstorm, *i.e.*, it reached a height of 8 km more, and days on which heights of the convective clouds were comparatively less, *i.e.*, less than 6 km. For this purpose, radar data and upper air data of Delhi (0530 IST) of only the 5-year period from 1966 to 1970 have been considered. There were 74 days on which heights of the echo tops reached or extended beyond 8 km and 37 days on which heights of the echo tops were less than 6 km.

Fig. 2 shows the mean vertical profiles of temperature and mixing ratios prepared for the two classes of days. The figure shows that there is no marked difference in temperature between the two classes of days. However, mixing ratio from surface to about 6 km is higher on days when thunderstorm occurred.

3.6. *Thunderstorm forecasting*

Two stability indices, namely, George's instability index (K) and Showalter Stability Index (S.S.I.) have been computed to study their usefulness for forecasting probability of thunderstorm development.

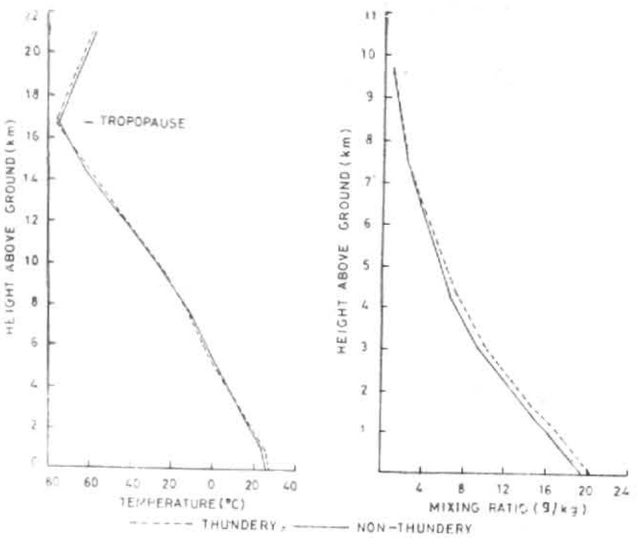

Fig. 2. Profiles of mean temperature and mixing ratio for non-thundery days (solid lines) and thundery days (broken lines)

TABLE 7

Percentage of days when at least one convective cloud showed thunderstorm development on days of different George's instability index (K)

K-values	Total No. of days when convective clouds observed (A)	No. of days when thunderstorms developed (B)	(B)/(A) (%)
<20	2	0	0
20 to 24	3	2	66.6
25 to 29	3	2	66.6
30 to 34	14	7	50.0
35 to 39	38	23	60.5
40 to 44	45	34	75.5
≥45	6	6	100

Table 7 shows the percentage of convective days (last column) when at least one convective cloud showed thunderstorm development on days of different George's instability index (K) values. It may be seen from the table that there was no thunderstorm development on days on which K value was less than 20 but there was thunderstorm activity as much as on 75 per cent of the days on which K value lay between 40 and 44. The table also suggests that there is 100 per cent probability of thunderstorm development on days when K value is equal to or greater than 45.

TABLE 8

Percentage of days when at least one convective cloud showed thunderstorm development on days of different Showalter Stability Index (S.S.I.)

S.S.I. values	Total No. of days when convective clouds observed (A)	No. of days when thunder-storms developed (B)	(B)/(A) (%)
≤−4.0	16	14	87.5
−3.9 to −3.0	13	10	76.9
−2.9 to −2.0	24	18	75.0
−1.9 to −1.0	24	16	66.7
−0.9 to 0.0	14	8	57.1
0.1 to 1.0	10	5	50.0
>1.0	10	3	30.0

A similar analysis based on Showalter stability index is presented in Table 8. The table shows that there is about 88 per cent chance of thunderstorm occurrence on days when S.S.I. value is less than or equal to—4.0. The probability of storm development progressively decreases with the increase in S.S.I. value and there is only 30 per cent chance of storm development when the S.S.I. value exceeds 1.0.

4. Limitations

It is necessary to mention the limitations of the radar observations taken. They are :

(a) On account of operational difficulties, radar observations were normally restricted to 7 hours (1000-1700 IST) on each day. However, earlier studies (Kulshrestha 1962) have shown that during the monsoon season more than 50 per cent storm development takes place in the Delhi region during the above period.

(b) On account of the random sampling procedure adopted, the convective echoes were not followed throughout their life time in majority of the cases. Hence, the heights reported here are not necessarily the maximum heights which the echoes attained during their life cycle.

5. Conclusion

Despite the obvious deficiencies in the radar data coverage, and hence in the analysis, the study indicated that about 35 per cent of the convective clouds forming in this region, grow into thunder clouds. They mature and dissipate below 10 km in about 62 per cent cases and in only 3.2 per cent cases they penetrate tropopause. It was also observed that very tall thunderstorms tend to organise themselves in a line. Examination of the spatial distribution of storm echoes showed that there is no preferential region of storm development within 100 km around Delhi. The study also suggested that George's instability index and Showalter stability index are good indicators for forecasting probability of thunderstorm development in this region. A broad study of the seasonal rainfall in relation to radar observed precipitation events showed that seasonal rainfall does not merely depend on the number of thunderstorms occurring in a particular season, rather it depends on total number of rain spells in that season and their areal coverage.

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