551·508·85 : 551·576

Heights of Cumulonimbus cloud tops over North India: A Radar study

S. M. KULSHRESTHA

Meteorological Office, New Delhi

(*Received 27 March 1961*)

ABSTRACT. In India, the only information on heights of cumulonimbus cloud tops, available so far, is based on very limited number of observations either from debriefing reports of aircrafts or from meteorological reconnaissance flights. To gain more exhaustive and complete knowledge of cumulonimbus cloud tops over North India, a radar study based on the records of the 469 storms observed during a period of 31 months, was conducted at New Delhi using the CPS-9 radar. The result of the analysis are detailed out and discussed in the light of the existing information on the subject.

1. Introduction

1.1. The cumulonimbus cloud represents a spectacular and very violent form of atmospheric convection. In its method of development, it appears to be a cumulus cloud 'gone wild.' These constitute a serious hazard to aviation. A precise knowledge of the structure, and particularly the vertical extent of cumulonimbus clouds, is therefore most essential from the point of view of safety in aviation.

1·2. As far as India is concerned, very little information is available in respect of heights of cumulonimbus cloud tops. Although the importance of such a study has been realised for quite a long time but no precise information could be collected because of lack of sufficient observational data. During the last few years, however, some studies have been made available but these are either based on debriefing reports from 'Comet' jet airliners or on observations from a limited number of meteorological reconnaissance flights. These methods suffered from serious handicaps. The debriefing reports from airliners referred to fixed routes at scheduled times. The meteorological reconnaissance flights were mostly conducted in the mornings. As such, a complete picture could not be expected from these studies. A developing cumulonimbus cloud could not be watched through its entire life history. Only a limited number of cumulonimbus clouds, falling near the route, could be observed.

1·3. With all these limitations in view, Deshpande (1961) felt that it was necessary to obtain additional data on heights of cumulonimbus cloud tops over India either through aircraft or radar. Such a study was undertaken based on the observations recorded by the high power radar CPS-9* at New Delhi and the results are presented in this paper.

2. Earlier work

2·1. In India, the first report on heights of cumulonimbus tops was prepared by Ramamurthi (1955) who based his analysis on 63 cases of thunderstorms from the debriefing reports of Comets operating over New Delhi—Calcutta route during May 1952 to December 1953, *i.e.*, for about a period of 20 months. His main conclusions for this sector were—

(*i*) Tops of cumulonimbus clouds in this sector were generally from 28,000 to 40,000 feet.

*Specifications of the radar CPS-9 : Wavelength 3·2 cm, Peak Power 250 KW, Beam-width 1 degree conical, Pulse-widths 0·5 and 5·0 microseconds

(*ii*) Very few instances were available of cumulonimbus tops being below 25,000 feet.

(*iii*) On several occasions, tops extended well above 40,000 feet and sometimes touched even 50,000 feet.

(*iv*) The seasonal distribution of maximum heights of cumulonimbus cloud tops was as follows:

Winter	
December to February	35,000 ft
Pre-monsoon	
March to May	48,000 ft
Monsoon	
June to September	50,000 ft
Post-monsoon	
October to November	30,000 ft

2·2. Venkateswara Rao (1955) started with a larger number of Comet debriefing reports. He analysed 187 cases of thunderstorm reports during 1952-53, *i.e.*, for almost the same period as Ramamurthi. While Ramamurthi confined himself to particular routes, Venkateswara Rao has taken all the reports for various flights 'across the Indian subcontinent'. It is therefore natural to expect that Venkateswara Rao's conclusions will be more general in nature. His main conclusions were:

(*i*) There was not a single case of a thundercloud maturing and dissipating below 30,000 ft.

(*ii*) About 80 per cent of cumulonimbus clouds had their tops between 35,000 to 50,000 ft.

(*iii*) About 8 per cent of cumulonimbus clouds extended beyond 50,000 ft.

(*iv*) Cumulonimbus tops are invariably below 50,000 ft in winter but go higher in other seasons.

(*v*) The highest top of 55,000 ft was observed in the monsoon season. Venkateswara Rao has not mentioned the part of the country where this was observed.

2·3. Deshpande (1961) came forth with an analysis based on a total number of 70 reports of cumulonimbus cloud tops actually observed in meteorological reconnaissance flights by the Indian Air Force. He did not observe any cumulonimbus cloud top extending beyond 50,000 ft. The season-wise distribution of maximum heights of cumulonimbus cloud tops observed during these flights was as follows:

Winter	41,000 ft (Only one report)
Pre-monsoon	38,000 ft
Monsoon	50,000 ft
Post-monsoon	44,000 ft

As he himself has remarked, his data suffered from the serious drawback that most of these observations were recorded in the mornings. Most of the cumulonimbus clouds which were observed during these flights were very likely to be still in the growing stage and must not have reached the mature stage. Deshpande's estimates of heights are therefore very likely to be underestimates. It is shown subsequently in this paper that it was really so.

3. Data used for the present study

3·1. The high power radar CPS-9 has a maximum range of 400 statute miles radius. Due to the limitations imposed by the curvature of earth and by the large attenuation and dissipation of radar energy in tropics, it is considered a fair estimate that all thunderstorms, occurring within a radius of 250 miles round the station, must definitely be recorded by the radar. Thus the radar coverage is expected to be very satisfactory over an area of atleast about 200,000 square miles round New Delhi, if not more. Hence an analysis of heights of cumulonimbus cloud tops, based on the radar observations in this area, can safely be taken to be representative of conditions prevalent in north India.

3·2. The present study covers a total period of 31 months from December 1957 to June 1960. During this period, 469 storms

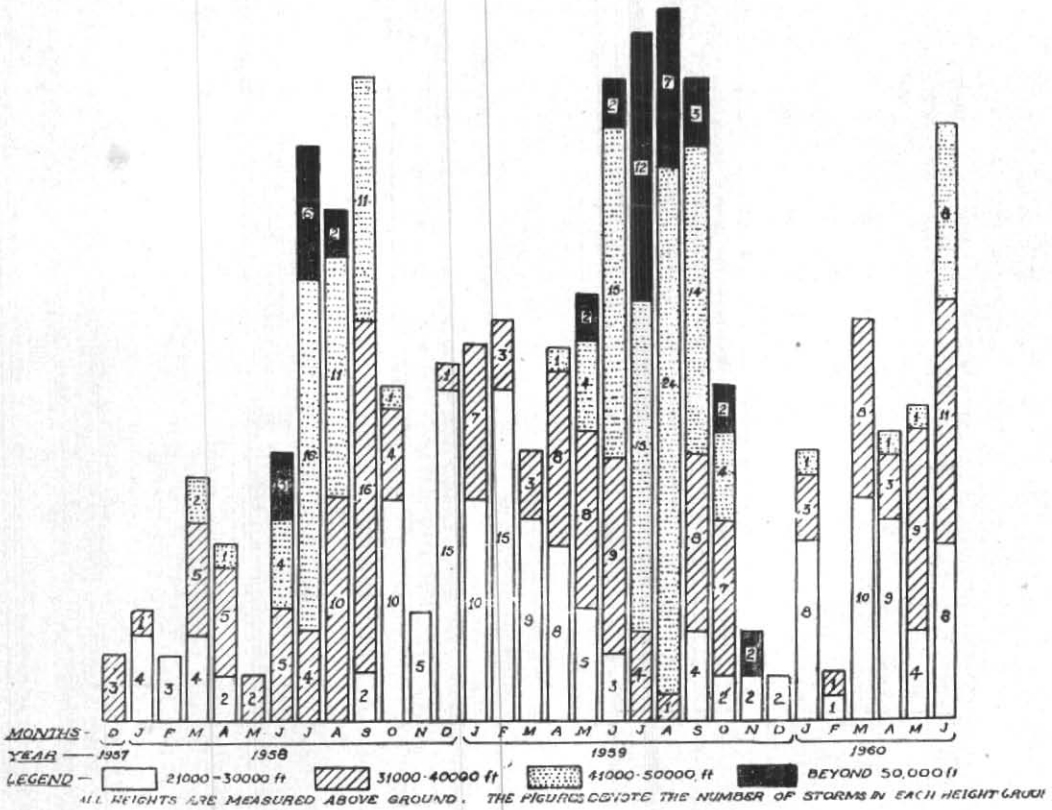

Fig. 1. Frequency distribution of heights of tops of Cumulonimbus around New Delhi (December 1957—June 1960)

were observed on the radar. The heights have been corrected for errors due to the curvature of the earth but not for the errors due to the finite width of the radar beam. That is why, comparatively larger height intervals (10,000 ft) have been chosen in this analysis.

3·3. In this analysis, each storm was followed through its entire life history and the maximum height reached by the tops was recorded.

3·4. The year has been broadly divided into the following seasons for the purpose of computing the seasonal frequencies:

December to February	Winter
March to May	Pre-monsoon
June to September	Monsoon
October to November	Post-monsoon

4. Analysis

4·1. It was seen during the course of this analysis that almost all storms in north India reach 25,000 ft atleast.

4·2. Fig. 1 illustrates the frequency distribution of heights of tops of cumulonimbus clouds around New Delhi and gives the numbers of storms falling in each height-group or height-interval in various months during the 31-month period of this study. This histogram in Fig. 1 also depicts the month by month variation in the maximum heights attained by storms. It is significant that the maximum number of storms occur over north India during the monsoon season when the heights of tops of the cumulonimbus clouds are also largest. The post-monsoon season has the least number of storms but

TABLE 1

Frequency distribution of cumulonimbus cloud tops among different height-groups for the total period of 31 months (December 1957—June 1960)

Height-group (1000's of ft)	Number of storms	Percentage of the total
21—30	145	31
30—40	149	32
41—50	134	28
51 and above	41	9
Total	469	100

TABLE 2

Frequency distribution of cumulonimbus cloud tops among different height-groups during Winter season

Height group (1000's of ft)	Number of storms	Percentage of the total
21—30	58	75
31—40	19	24
41—50	1	1
51 and above	..	..
Total	78	100

TABLE 3

Frequency distribution of cumulonimbus cloud tops among different height groups during Pre-Monsoon season

Height-group (1000's of ft)	Number of storms	Percentage of the total
21—30	51	45
31—40	51	45
41—50	10	9
51 and above	2	1
Total	114	100

TABLE 4

Frequency distribution of cumulonimbus cloud tops among different height-groups during Monsoon season

Height-group (1000's of ft)	Number of storms	Percentage of the total
21—30	17	7
31—40	68	28
41—50	118	50
51 and above	35	15
Total	238	100

TABLE 5

Frequency distribution of cumulonimbus cloud tops among different height-groups during Post-Monsoon season

Height-group (1000's of ft)	Number of storms	Percentage of the total
21—30	19	49
31—40	11	28
41—50	5	13
51 and above	4	10
Total	39	100

TABLE 6

Seasonal percentage frequency distribution of cumulonimbus cloud tops among different height-groups

Season	Percentage Frequencies — Height-Groups (1000's of ft)				Total Number of storms
	21 to 30	31 to 40	41 to 50	>50	
Winter	75	24	1	..	78
Pre-monsoon	45	45	9	1	114
Monsoon	7	28	50	15	238
Post-monsoon	49	28	13	10	39

the heights of tops are the smallest in winter season.

4·3. The total percentage frequency distribution of the storms among different height groups is shown in Table 1. Tables 2 to 5 show the seasonal percentage frequency distribution among different height-groups. Table 6 gives a consolidated picture of the seasonal percentage frequency distribution of cumulonimbus tops among different height-groups.

4·4. The processes which give rise to the maximum development of cumulonimbus clouds at different hours of the day and in different seasons are not similar. An effort has been made to find out the preferred periods of attainment of maximum heights by cumulonimbus clouds in the different seasons. For this purpose, a day has been divided into six significant periods—each of four hours duration—as follows:

Early morning	00 — 04 IST
Morning	04 — 08 IST
Noon	08 — 12 IST
Afternoon	12 — 16 IST
Evening	16 — 20 IST
Night	20 — 24 IST

The percentage frequency distribution of the storms attaining maximum heights during these periods of the day in the four seasons was worked out and is presented in Table 7.

TABLE 7

Percentage frequency distribution of cumulonimbus clouds attaining maximum heights during different periods of the day in the four seasons

Period of the day (Time in IST)	Percentge Frequencies			
	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Early morning (00—04)	3	4	4	..
Morning (04—08)	10	9	9	8
Noon (08—12)	18	5	5	18
Afternoon (12—16)	29	38	42	41
Evening (16—20)	14	34	29	20
Night (20—24)	26	10	11	13

5. Conclusions

5·1. It will be seen from this analysis that:

(1) About 63 per cent of cumulonimbus clouds mature and dissipate below 40,000 ft; about half of these dissipating below 30,000 ft itself.

(2) Only about 9 per cent of all cumulonimbus clouds extend beyond 50,000 ft.

(3) During *Winter* season, 99 per cent of cumulonimbus clouds mature and dissipate below 40,000 ft, there being only one isolated case in the three winter seasons of 1957, 1958 and 1959 when a cumulonimbus cloud extended beyond 40,000 ft. Infact about 75 per cent of cumulonimbus clouds mature and dissipate below 30,000 ft.

(4) During *Pre-monsoon* season, 90 per cent of cumulonimbus cloud tops terminate below 40,000 ft and half of these mature below 30,000 ft. About 9 per cent reach upto 50,000 ft while only 1 per cent extend beyond 50,000 ft.

(5) During *Monsoon* season, only 35 per cent of cumulonimbus clouds mature below 40,000 feet while only 7 per cent mature below 30,000 ft. About 50 per cent of the cumulonimbus clouds reach between 40,000 and 50,000 ft. As many as 15 per cent of the tops extend beyond 50,000 ft. On many occasions, they reach 60,000 ft or even more.

(6) During *Post-monsoon* season, 77 per cent of cumulonimbus tops mature below 40,000 ft; about two-thirds of these maturing below 30,000 ft itself. About 13 per cent of the tops reached between 40,000 and 50,000 ft. As many as 10 per cent of cumulonimbus tops extended beyond 50,000 ft but the heights of tops were, in general, less than those in the monsoon season.

5·2. The maximum height of radar echo of cumulonimbus cloud observed so far over north India was about 61,000 ft (18·6 km) on 3 September 1959.

5·3. Comparing these results with the observations of earlier workers mentioned in Section 2, it will be seen that:

(*i*) Deshpande's figures were under-estimates while those of Ramamurthi were very much under-estimates.

(*ii*) Venkateswara Rao's observations were not very much different but will be seen to be slight under-estimates if we remember that the present study gives the radar-measured heights of the cumulonimbus cloud tops and that the actual heights will definitely be more.

(*iii*) Venkateswara Rao's statement, that there was not a single case of a thundercloud maturing and dissipating below 30,000 ft, is not fully supported by the present study. In this respect, Ramamurthi's conclusion, that very few instances were available of cumulonimbus tops being below 25,000 ft, is fully borne out by the present study.

5·4. According to Venkateswara Rao, the larger heights attained by the tops of thunderclouds in the monsoon season, compared with those in the pre-monsoon months, are attributable to the entrainment of relatively warmer environmental air in the monsoon season.

5·5. It will be seen from Table 7 that over north India, cumulonimbus clouds always attain their maximum heights in the afternoons, *i.e.*, between 12 and 16 hours IST. This is quite understandable in as much as the maximum temperature also occurs during this period. The early morning hours (00–04 IST) are the least preferred. The distribution of the time of maximum development is similar in pre monsoon and monsoon seasons. It is very interesting to note that the percentage frequencies for the different periods of the day work out to be almost the same in these two seasons. The order of preference of the time of maximum development follows the same pattern, *viz.*, afternoon, evening, night, morning, noon and early morning. Another significant point is that in these seasons more cumulonimbus clouds attain maximum heights during morning hours (04-08 IST) than do so during the noon hours (08–12 IST).

During post-monsoon season, the pattern deviates slightly from that in the pre-monsoon and monsoon seasons. Here the order followed is: afternoon, evening, noon, night and morning. During the post-monsoon seasons of 1958 and 1959, no storm was found to attain maximum development during early morning hours (00–04 IST).

During winter, the pattern further deviates. The order followed is: afternoon, night, noon, evening, morning and early morning.

6. Acknowledgement

The author is extremely grateful to Shri P. R. Krishna Rao, Director General of Observatories for suggesting the problem.

REFERENCES

Deshpande, D. V.	1961	*Indian J. Met. Geophys.*, **12**, p. 29.
Ramamurthi, K. M.	1955	*Ibid.*, **6**, p. 243.
Venkateswara Rao, D.	1955	*Ibid.*, **6**, p. 299.