551.576.1: 621.396.9

Radar observations on the formation of Cumulus clouds near Calcutta during the monsoon season*

A. C. DE and D. K. RAKSHIT

Meteorological Office, Dum Dum Airport, Calcutta

(*Received 3 January 1959*)

ABSTRACT. Radar observations on the formation of cumulus clouds near Calcutta during the monsoon season of 1958 have been presented. RHI data on 83 individual cloud cells have been analysed and their rates of growth and decay calculated. It has been suggested that the condensation-coalescence process is responsible for the initiation of precipitation in convective clouds during monsoon season near Calcutta.

1. Introduction

In recent years there have been detailed radar observations on the precipitation echoes from convective clouds. These observations have thrown much light on the various stages of growth and decay of convective clouds in different regions. Our knowledge about the characteristics of the initial formation and growth of convective clouds in the Indian latitudes is still very limited due to absence of adequate observations. In this paper, it is proposed to present an analysis of some radar observations taken with a powerful radar at Dum Dum Airport, Calcutta during the monsoon of 1958. The available data have been analysed on the lines of an earlier study by Battan (1953). The vertical development of precipitation echoes from cumulus clouds near Calcutta during the post-monsoon season has been reported in an earlier communication (Koteswaram and De 1959). The observations were taken with a Decca Type-41 Radar in which there was no provision for Range Height Indication (RHI) presentation. The number of observations reported was also not as large as desired. The above limitations were eliminated in the observational data used for the analysis reported in this communication.

2. Type of radar used and method of observations

The observing radar was a Japanese Type NMD-451A Radar installed recently at Dum Dum Airport. The radar operates on 3-cm wave band and has peak power of 250 KW. The beam width is sufficiently narrow (1·2° beween half power points) and the maximum range is 300 km. Apart from the Plan Position Indication (PPI) presentation, there is also provision of RHI presentation, the maximum range of which is 100 km. The PPI and RHI presentations are obtained on 12 inch scopes.

The method of observations was as follows—

The PPI pictures were obtained for 0° elevation of the aerial beam and the positions of the echoes were noted. The observations were repeated for different elevation angles upto +10°. The echoes which appeared on the scope only at higher elevation angles (larger than +2° or so) were selected for the study. The aerial was then pointed to the selected direction of the azimuth and the RHI pictures obtained. The heights of the tops and bottoms of the echoes were carefully measured. The radar was operated continuously and the observations recorded every two minutes.

3. Data

The data were collected from the radar observations made during the period of May to August 1958. Radar observations made on 83 occasions of individual cloud cells for which growth and decay had to be fully studied were utilised for the present study.

*Paper was also presented at the Symposium on "Physics of Cloud and Rain in the Tropics" held during 29 October to 1 November 1960 at the Meteorological Office, Poona.

Quite a number of observations on other occasions had to be abandoned for various reasons noted below and data for such occasions were not taken into account.

(*i*) Some portion of cloud extended horizontally due to wind drift to such an extent that the entire cloud could not be illuminated by the radar beam, (*ii*) Some cloud echoes disappeared within a minute or so of their first formation, (*iii*) Some clouds when first observed were already in the developed stage, and (*iv*) Some secondary cells appeared quite close to the primary cell which ultimately merged into one larger cell.

It is worthwhile to mention that sufficient care was taken throughout all these observations to scan the cell at the azimuth where the echo intensity was strongest; otherwise general drift of the echo cell might cause uncertainties in the observations. One other point also deserves to be mentioned. The cells selected for study were isolated ones—well away from the general rainfall field in the vicinity.

4. Visual observations

An attempt was made to find out the difference between the height of top of the radar echo and that of the visual cloud. The following method was employed for visual observation. An optical theodolite was placed very close to the radar antenna, *i.e.*, on the steel staging where the antenna is located. An isolated cloud cell was then selected. The same cloud cell was simultaneously 'seen' through the optical theodolite and the radar. The angle of elevation of the optical theodolite corresponding to the top of the visual cloud and the horizontal distance and height of the top of the radar cloud were simultaneously recorded. While the height of the top of the radar cloud was obtained directly on the RHI scope, the same of the visual cloud was calculated from the angle of elevation and the horizontal distance readings.

On a large number of occasions the observations had to be abandoned due to the abundance of cloud cells in the vicinity of the observing cloud. On some occasions, while the observations were being taken, stratocumulus or small cumulus clouds were drifted in the field of vision. However, on the days when the observations were successful, it was found that the visual cloud top was about 3000 ft above the radar echo top. It may be argued that the discrepancy may be partly due to the fact that the distance of the front edge of the cloud cell whose top was seen through the theodolite might be less than that of the echo seen on the radarscope. The above argument is not tenable because of the fact that both visual and radar observations, reported in this section, were taken for the maximum height of the isolated cloud cell and the distance utilised for calculating the height of the top of the visual cloud also corresponded to that portion of the cloud cell.

5. Analysis of data

Initial echoes—The type of the data utilised is illustrated in Figs. 1 and 2 and Tables 1 and 2. Fig. 1 shows the growth and decay of one echo on 24 June 1958. The top and bottom of the echo were first noticed at 5·0 and 2·4 km respectively. The cell grew for 26 minutes and decayed gradually thereafter in 28 minutes, the total cycle from the start of observation to its decay being 54 minutes (from 1133 to 1227 IST). Fig. 2 shows an interesting example of a convective cumulus cloud on 27 June 1958 which ultimately developed into a cumulonimbus cloud. The top and bottom of the cell were first noticed at 4·5 and 3·5 km respectively (at 1527 IST). The cell grew for 56 minutes reaching a maximum height of 14·2 km. The decay could be studied for 24 minutes when the observation had to be abandoned due to the appearance of secondary echoes very close to the main cell. Wind shear effect and scanning at different azimuth were, however, not attempted in this particular case. Temperature at various levels obtained from 1200 GMT radiosonde ascent over Dum Dum on the same dates have been shown in Figs. 1 and 2.

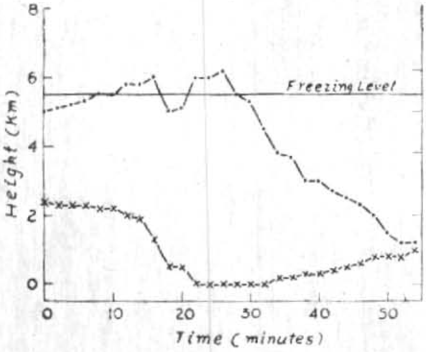

Fig. 1. Growth and decay of radar cloud as seen on the radarscope at Dum Dum Airport on 24-6-1958

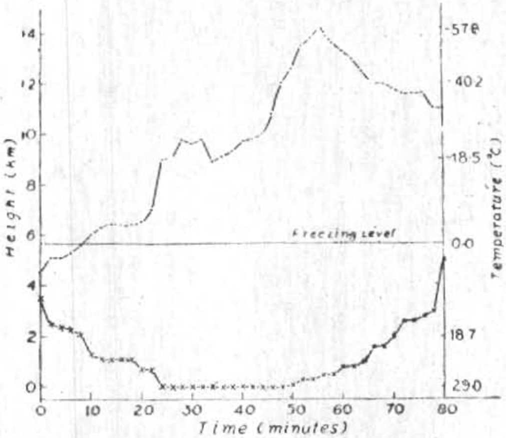

Fig. 2. Growth and decay of radar cloud as seen on the radarscope at Dum Dum Airport on 27-6-1958

Summaries of the temperatures at the top and bottom of the first echoes, the maximum height reached, the time taken in attaining the maximum height, mean rate of rise and the time interval between the first formation of radar echoes and precipitation reaching ground are shown in Table 3. It can be seen that in more than 90 per cent of the cases, the tops of the first echoes were at temperatures above the freezing. It is also seen that the distribution differed considerably from one day to another and also on the same day for different instances.

The data can be compared with those of Workman and Reynolds (1949), Reynolds and Braham (1952) and Battan (1953). Workman and Reynolds found that the average temperature at the top of the first radar echo (from 12 clouds) over New Mexico was —10°C. They concluded that the rain which form the first echo in cumulus clouds over New Mexico is chiefly due to the Bergeron process while the mechanism of rain formation over Ohio is different. Battan analysed 112 clouds and found that in 60 per cent of the cases, the first echo was at temperatures above freezing.

Growth of convective precipitation—For studying the amount of growth of cumulus clouds, which may be taken as a measure of the convection within the cloud, the observations were divided into three groups, similar to those of Battan: Group A, those echoes which grew less than 5000 ft after first appearance; Group B, those echoes which grew more than 5000 ft but less than 10,000 ft after first appearance; Group C, those echoes which grew more than 10,000 ft after first appearance. Summaries of the temperatures of first formation of echoes in Groups A, B, and C are given in Tables 4 and 5. It may be seen from these tables that the average temperature at the top of the first echo decreases gradually from Group A to Group C, *i.e.*, echoes which grew the most after detection were those having the coldest first echo—this is opposite to the findings of Battan. It may be that in the tropics initial rain echo at lower temperatures is susceptible to more growth. It is also seen that the percentage of occasions when the temperature at the top of the first echo was above freezing is 100 per cent in Group A, 94 per cent in Group B and 89 per cent in Group C...

The radar echoes of Group A are of short duration, the average being 12·3 min. In 83 per cent of the cases (out of a total of 58 cases), the precipitation reached the ground. The rate of growth of the top of echo was

900 ft/min at the initial stage which reduced to 150 ft/min near about the maximum growth. The rate of height change of the bottom of the echo was almost of the same order, *viz.*, 500—100 ft/min.

The average duration of the radar echoes of Group B was 21·3 min. In 93 per cent of the cases (out of a total of 16 cases), the precipitation reached the ground. The rate of growth of the top of echo was 900 ft/min at the initial stage which reduced to 150 ft/min near about the maximum growth. The rate of height change of the bottom of the echo was 600 ft/min at the beginning which increased to 700 ft/min and finally reduced to 100 ft/min.

The average duration of the radar echoes of Group C was 36·2 min. In 100 per cent of the cases (out of a total of 9 cases), the precipitation reached the ground. The rate of growth of the top of echo was 1000 ft/min at the beginning which was reduced to 600 ft/min at the maximum height. The rate of height change of the bottom of the echo was 550 ft/min at the beginning reducing to 50 ft/min.

From the above, it is seen that the average growth rates of convective precipitation in Groups A, B and C are 350, 525 and 800 ft/min respectively. It is also observed that, the tops of radar clouds in Group A did not at all reach the freezing level, those in Group B just crossed the freezing level and those in Group C crossed the freezing level and grew upto 25,000 ft. From the visual observations the base of the clouds were estimated to be about 2000 ft, while the base of the radar echoes lay between 3500 to 4500 ft. Previous workers (Pishkin 1948)have found that larger droplets occur in the upper regions of the cumulus clouds. It may, therefore, be said that the larger droplets were carried upward by strong vertical air currents which in some cases (Groups B and C) are more than the terminal velocity of 1 mm diameter drops (Gunn and Kinzer 1949), *viz.*, 800 ft/min.

Precipitation reaching ground—In order to find out the conditions under which precipitation reaches ground, the data under three different groups (A, B and C) have been analysed. The result is shown in Table 6. From the table the following salient features may be noticed—

(*i*) Duration of precipitation increases from Group A to Group C, (*ii*) Height of top of echoes when precipitation reaches ground increases from Group A to Group C, (*iii*) The time interval between the first formation of radar echo and the precipitation reaching ground is almost the same in Groups A and B, but much more in C, and (*iv*) The time interval between the first formation of the radar echoes and the maximum height increases from Group A to Group C.

From the above, some interesting correlation between the extent of growth of radar clouds and the duration of precipitation can be found out. It is seen that the above correlation is positive, that is, the larger the radar cloud grows, the larger is the duration of precipitation.

Effect of updraft on the formation of precipitation—The effect of initial rate of growth of the echo on eventual development of rainfall may now be examined. Wherever the initial rate of growth was observed to be higher, say of the order of 800-1000 ft/min, precipitation echo did show appreciable development.

The vertical velocities in these clouds must have been sufficiently strong to carry the larger water droplets of appreciable size and ultimately produced heavier precipitation. This is in agreement with the findings of Bowen (1951) who found that the maximum heights attained by the drops and the maximum drop diameters emerging from the cloud base increase as the vertical air velocity increases.

Descent of the base of the echo—It has been stated earlier that the base of the radar clouds descends at an initial average velocity of about 500 ft/min. As already explained by Battan, the observed descent of the base of the radar echoes may be due either to the descent of the detectable water droplets as a result of downward current or to the growth of water droplets of detectable size at the appropriate lower levels. And at appreciably lower levels, the lowering of the echo may be entirely due to fall of raindrops. With the available observations under study, it is not possible to suggest any conclusive explanation in this regard.

Mechanism of the growth of precipitation—In view of the above discussions, it is suggested that the precipitation in convective clouds during monsoon season near Calcutta is initiated by condensation—coalescence mechanism as suggested by Battan (1953), Feteris and Mason (1956) and Ludlam and Mason (1957).

It has been seen that in all the cases studied, during the period, May-August 1958, the first radar echo was noticed at temperatures much above freezing. Therefore, the Bergeron process does not seem to have played any significant role in the precipitation mechanism leading to detection on the radarscope. It may, however, be argued that there is a possibility of origination of the cells from ice particles falling from above the freezing level which remain undetected till they reach freezing level. The argument does not seem to be valid for the following reasons. Firstly in that case the first echo would have been noticed very near the freezing level. Secondly, with the powerful radar (250 KW) as used in these observations, the ice phase would also have been detected (in a number of instances, the cirrus tops have been detected with this radar).

A more plausible mechanism would be the condensation-coalescence process responsible for the initiation of precipitation. Moist air ascends to higher altitudes and condenses to water droplets, depending upon the availability of the condensation nuclei. Due to the presence of updraft, the water drops are carried higher and some of them grow larger than the others. When the drops exceed some critical size, growth by coalescence perhaps takes place at an accelerated rate as suggested by Langmuir (1948) and rain is formed.

6. Acknowledgement

The authors are greatly indebted to Dr. S. N. Sen, Director, Regional Meteorological Centre, Calcutta for suggesting the problem and for his valuable discussions during the preparation of the manuscript. Thanks are also due to Sarvashri N. B. Ghosh, B. C. Sen, P. C. Mukherjee and A. K. Bandopadhyaya of Radar Unit, Main Meteorological Office, Dum Dum, for their co-operation.

REFERENCES

Battan, L. J.	1953	*J. Met.*, **10**, 5, pp. 312-324.
Bowen, E. G.	1951	*J. atmos. terr. Phys.*, **1**, pp. 125-150.
Feteris, P. J. and Mason, B. J.	1956	*Quart. J. R. met. Soc.*, **82**, 354, pp. 446-451.
Gunn, R. and Kinzer, G. D	1949	*J. Met.*, **6**, p. 246.
Koteswaram, P. and De, A. C.	1959	*Indian J. Met. Geophys.*, **10**, 2, pp. 173-178.
Langmuir, I.	1948	*J. Met.*, **5**, pp. 175-192.
Ludlam, F. H. and Mason, B. J.	1957	Imp. Coll. Sci., Tech. London, Tech. Rep., Contract No. AF-61 (514)-923.
Pishkin, N. S.	1948	U. S. S. R. Acad. Sci. Inf. 12, 3, p. 11.
Reynolds, S. E. and Braham, R.	1952	*Bull. Amer. met. Soc.*, **33**, p. 123.
Workman, E. J. and Reynolds, S. E.	1949	*Ibid.*, **30**, pp. 142-144.

TABLE 1

Details of radar observation showing growth and decay of radar cloud as seen on the radarscope at Dum Dum Airport on 24 June 1958

Time (IST)	Azimuth (°N)	Range (km)	Height (km)	
			Top	Base
1133	050	40-41	5·0	2·4
1135			5·1	2·3
1137			5·2	,,
1139			5·3	,,
1141			5·5	2·2
1143			,,	,,
1145	052	41-42	5·8	2·0
1147			,,	1·9
1149			6·0	1·3
1151			5·0	0·5
1153			5·1	,,
1155			6·0	0·0
1157			,,	,,
1159	053	41-43	6·2	,,
1201			5·5	,,
1203			5·3	,,
1205			4·5	,,
1207			3·8	0·2
1209	054	42-43	3·7	,,
1211			3·0	0·3
1213			,,	,,
1215			2·7	0·4
1217			2·5	0·5
1219			2·3	0·6
1221		42	2·0	0·8
1223			1·5	,,
1225			1·2	,,
1227			,,	1·0
1229	Disappeared			

TABLE 2

Details of radar observation showing growth and decay of radar cloud as seen on the radarscope at Dum Dum Airport on 27 June 1958

Time (IST)	Azimuth (°N)	Range (km)	Height (km)	
			Top	Base
1527	338	77-78	4·5	3·5
1529			5·1	2·5
1531			5·15	2·4
1533			5·25	2·3
1535			5·6	2·1
1537	339	76-78	6·0	1·25
1539			6·35	1·1
1541			6·4	,,
1543			6·4	,,
1545			6·4	,,
1547			6·5	0·65
1549	340	75-78	7·0	,,
1551			9·0	0·0
1553			..	,,
1555		75-79	9·8	,,
1557			9·6	,,
1559		74-79	9·8	0·3
1601			8·9	0·0
1603			9·1	,,
1605	341	75-80	9·25	,,
1607			9·75	,,
1609			9·8	,,
1611			10·0	,,
1613			10·8	,,
1615			12·0	,,
1617	342	78-80	12·6	0·1
1619			13·5	0·3
1621		80-83	13·8	,,
1623			14·2	0·5
1625			13·6	,,
1627			13·3	0·8
1629	343	81-83	13·0	,,
1631			12·5	1·0
1633			12·0	1·6
1635			12·0	,,
1637			11·8	2·0
1639	344	83-85	11·6	2·6
1641			,,	,,
1643			,,	2·8
1645			11·0	3·0
1647			,,	5·0
1649	Observation discontinued			

TABLE 3

Details of temperature and height of first radar echoes, their rate of growth etc

Date	First radar echo: Top: Temp. (°C)	First radar echo: Top: Height (km)	First radar echo: Base: Temp. (°C)	First radar echo: Base: Height (km)	Max. height attained by echo top (km)	Time taken in attaining the height (min)	Mean rate of rise (ft/min)	Time interval between the first formation of radar echo and precipitation reaching ground (min)
15-5-58	16·8	2·5	29·8	0	4·0	20	250	0
	—4·0	6·0	,,	,,	8·0	12	550	0
8-6-58	—10·5	7·5	29·2	,,	7·5	—	—	0
	—0·8	5·2	,,	,,	5·2	—	—	0
	—49·0	13·0	,,	,,	13·0	—	—	0
	<—50·0	20·0	,,	,,	22·0	5	1300	0
	,,	18·0	,,	,,	18·0	—	—	0
24-6-58	2·5	5·0	15·6	2·4	6·2	24	170	20
25-6-58	9·0	3·7	19·5	1·5	3·9	2	330	10
27-6-58	8·6	3·8	17·5	2·2	3·8	—	—	—
	2·7	5·0	21·3	1·3	5·0	—	—	—
	5·2	4·5	10·1	3·5	14·2	56	600	24
1-7-58	2·0	5·0	17·7	1·8	6·0	4	830	4
2-7-58	—3·7	6·2	13·9	2·5	10·0	14	900	10
	4·2	4·5	17·4	1·8	5·8	4	1070	—
7-7-58	10·2	3·9	29·0	0	5·5	10	510	0
11-7-58	16·8	2·0	24·6	0·5	2·6	6	330	—
	6·6	4·0	13·6	2·7	6·3	8	950	—
	7·8	3·8	21·8	1·0	3·8	—	—	—
14-7-58	10·0	2·3	21·0	1·2	2·4	6	55	—
	16·4	2·2	20·4	1·3	2·5	8	124	—
	10·7	3·4	19·0	1·6	3·8	12	110	6
	15·2	2·5	29·5	0	5·8	10	110	0
	2·9	4·8	14·7	2·6	6·5	4	140	6
15-7-58	9·0	3·9	22·5	1·0	3·9	—	—	—
	3·2	5·0	15·5	2·5	5·6	2	1000	6
19-7-58	17·7	1·7	28·0	0	2·8	6	600	0
	7·3	3·8	7·8	3·7	4·2	4	330	—
	6·4	4·0	11·0	3·0	5·0	4	830	—
	5·0	4·3	28·0	0	4·7	8	410	0
	19·1	1·6	,,	,,	2·5	6	520	0
29-7-58	5·8	4·5	10·0	3·5	4·5	—	—	—
	11·7	3·1	24·8	0·6	3·8	2	1150	4

TABLE 3 *(contd)*

Date	First radar echo				Max. height attained by echo top (km)	Time taken in attaining the height (min)	Mean rate of rise (ft/min)	Time interval between the first formation of radar echo and precipitation reaching ground (min)
	Top		Base					
	Temp. (°C)	Height (km)	Temp. (°C)	Height (km)				
29-7-58	1·2	5·5	5·8	4·5	6·0	14	270	—
	13·2	2·8	26·3	0·3	5·4	14	710	2
	4·4	4·8	14·8	2·5	5·0	6	330	4
	10·3	3·4	21·3	1·3	4·6	6	660	2
30-7-58	9·9	3·4	28·7	0	5·9	20	410	0
	5·2	4·3	,,	,,	9·7	22	810	0
	9·9	3·4	24·9	0·6	3·4	—	—	8
	5·2	4·3	28·7	0	4·3	—	—	0
	11·6	3·1	,,	,,	3·1	—	—	0
	7·9	3·8	17·3	2·0	10·0	38	540	6
	12·2	3·0	22·6	1·0	10·8	24	1080	4
31-7-58	14·7	2·5	26·9	0	5·0	14	590	0
	16·7	2·1	,,	,,	2·1	—	—	0
	16·2	2·2	,,	,,	2·5	2	490	0
	19·5	1·6	,,	,,	1·8	2	250	0
	17·9	1·9	,,	,,	2·8	4	740	0
	13·5	2·7	22·4	1·0	,,	2	170	—
	7·6	3·8	19·5	1·6	5·4	4	1320	—
1-8-58	14·4	2·5	28·0	0	2·5	—	—	0
	12·0	3·0	16·8	2·0	3·0	—	—	14
3-8-58	16·5	2·3	27·0	0·2	3·5	4	1030	2
7-8-58	19·2	1·9	23·2	0·9	2·5	4	500	8
	17·9	2·2	24·3	0·6	2·8	10	620	4
9-8-58	7·0	4·4	28·0	0	4·9	6	410	0
	11·2	3·4	24·6	0·6	3·4	—	—	4
	15·1	2·5	25·2	0·5	2·5	—	—	2
	16·4	2·2	28·0	0	2·9	4	580	0
18-8-58	14·9	2·5	19·7	1·3	3·0	6	270	8
	5·4	4·4	11·8	3·1	8·3	8	1600	8
	14·9	2·5	24·5	0·5	2·7	4	330	2
	13·8	2·8	27·7	0	3·4	4	490	0
	1·4	5·3	16·3	2·2	5·3	—	—	—
	16·6	1·9	27·7	0	2·1	1	490	0
	,,	,,	,,	,,	1·9	—	—	0
	13·8	2·8	,,	,,	2·8	—	250	0
	19·7	1·3	,,	,,	1·3	—	—	0

TABLE 3 (*contd*)

Date	First radar echo				Max. height attained by echo top (km)	Time taken in attaining the height (min)	Mean rate of rise (ft/min)	Time interval between the first formation of radar echo and precipitation reaching ground (min)
	Top		Base					
	Temp. (°C)	Height (km)	Temp. (°C)	Height (km)				
19-8-58	7·1	3·8	27·7	0	3·8	—	—	0
	13·6	2·8	,,	,,	3·7	6	520	0
	15·6	2·3	,,	,,	2·5	4	250	0
	—4·3	5·6	5·0	4·1	6·1	4	370	—
20-8-58	10·9	3·1	18·5	1·6	3·7	6	330	4
	11·1	3·0	24·2	0·6	3·4	2	660	4
	15·5	2·2	26·0	0·3	3·4	6	660	2
	14·0	2·5	24·8	0·5	3·4	6	490	2
	12·4	2·8	21·9	1·0	3·6	6	440	6
	14·0	2·5	19·0	1·5	5·8	32	580	4
	13·5	2·6	24·8	0·5	3·1	4	410	4
	12·4	2·8	16·5	2·0	3·0	4	170	10
	14·0	2·5	20·5	1·3	3·1	12	330	4
21-8-58	4·4	4·7	23·3	0·9	5·0	4	250	4
	15·7	2·5	27·0	0	5·6	24	470	0
	15·7	2·5	20·3	1·6	3·5	8	410	6
22-8-58	14·4	2·5	28·2	0	2·5	—	—	0
	14·0	2·6	15·9	2·2	3·5	6	490	2
	13·0	2·8	17·4	1·9	5·8	12	820	8
	10·1	3·4	14·4	2·5	4·1	4	580	10
	14·4	2·5	22·1	1·0	3·7	6	660	4
	13·0	2·8	17·4	1·9	5·5	12	738	8
26-8-58	15·9	2·2	27·7	0·2	2·5	4	246	2
	14·2	2·6	29·0	0	3·7	8	453	0
	15·9	2·2	29·0	,,	2·6	4	328	0
	14·6	2·5	29·0	,,	2·7	4	164	0
	14·6	2·5	29·0	,,	4·8	14	538	0
	14·6	2·5	29·0	,,	2·7	2	328	0
	12·6	3·0	15·1	2·4	4·0	2	1640	8
	14·3	2·8	15·9	2·2	2·8	—	—	—
	15·9	2·2	29·0	0	2·5	2	492	0
	10·3	3·5	29·0	,,	5·1	10	525	0
	6·0	4·3	29·0	,,	5·7	8	574	0
	4·4	4·7	14·6	2·5	6·0	12	358	—
28-8-58	14·3	2·8	17·2	2·2	3·2	4	328	6
	14·3	2·8	18·1	2·0	5·0	10	722	4
	14·3	2·8	18·1	2·0	4·8	8	1640	4
	6·0	4·7	29·5	0	15·0	24	1408	0
	13·4	3·0	20·1	1·6	3·9	4	738	6
	14·3	2·8	18·4	1·9	2·8	—	—	4
	9·8	3·8	15·8	2·5	6·2	8	984	8

— under column 9 indicates that precipitation did not reach ground

TABLE 4

Temperature at tops of first radar echoes

Group	Temperature (°C)												Total	Mean
	−2·1 to −4·0	−0·1 to −2·0	0·0 to 1·9	2·0 to 3·9	4·0 to 5·9	6·0 to 7·9	8·0 to 9·9	10·0 to 11·9	12·0 to 13·9	14·0 to 15·9	16·0 to 17·9	18·0 to 19·9		
A			1	3	5	3	1	6	8	17	11	3	58	+12·5
B	1	—	—	1	—	2	4	2	3	3	—	—	16	+ 9·7
C	1	—	—	—	3	2	—	—	1	2	—	—	9	+ 7·6
Total	2	—	1	4	8	7	5	8	12	22	11	3	83	+11·5

TABLE 5

Temperature at bottoms of first radar echoes

Group	Temperature (°C)													Total	Mean
	4·0 to 5·9	6·0 to 7·9	8·0 to 9·9	10·0 to 11·9	12·0 to 13·9	14·0 to 15·9	16·0 to 17·9	18·0 to 19·9	20·0 to 21·9	22·0 to 23·9	24·0 to 25·9	26·0 to 27·9	28·0 to 29·9		
A	2	1	—	1	2	5	4	4	7	4	8	10	10	58	+22·0
B	—	—	—	—	1	2	2	3	—	—	1	4	3	16	+22·1
C	—	—	—	2	1	—	1	—	—	1	—	1	3	9	+21·0
Total	2	1	—	3	4	7	7	7	7	5	9	15	16	83	+21·9

TABLE 6

Precipitation reaching ground

Group	Duration of precipitation (min)	Height of top of echoes when precipitation reaches ground (km)	Time interval between first formation of radar echo and precipitation reaching ground (min)	Maximum height of top of radar echoes (km)	Time interval between first formation of radar echo and maximum height reached (min)
A	8·9	3·0	3·5	3·4	5·0
B	18·1	4·3	3·6	5·7	10·2
C	29·8	5·2	5·6	9·5	24·8