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The relationship between Initial Electric Field Activity and Precipitation Process in Thunderstorm Cell growth in the Tropics*

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ABSTRACT. The results of initial electric field activity and precipitation process in nine thunderstorms at Poona are presented and compared with the findings of previous workers. The storms are classified as Type 'A' and Type 'B' storms. In Type 'A' storms the surface field first increases when the size of the precipitation particles reach a definite size showing that the charge separation process in clouds is related directly to the precipitation process. The first appearance of precipitation beneath the cloud appears, usually about twenty minutes after the first increase of electric field occurs. The positive electric field then decreases, becomes zero, and reversed to the negative direction as soon as the precipitation starts. In Type 'B' storms, the field reversal suddenly takes place before the onset of rain at the ground. There is a distinct time lag between the field reversal and onset of rainfall at the ground during thunderstorms. This enables us to get an approximate idea of the distance of fall of raindrops, assuming the terminal velocity for the average size of raindrops for a particular rate of rainfall at onset. The approximate temperature of the origin of raindrops can then be calculated with some limitations. Evidence is given in certain isolated thunderstorm cell growth that the development of electric field is associated with the initial radar (10 cm) precipitation echo. The limitations of using radar alone to study the initial stage of precipitation development and the nature of possible physical processes have been emphasised. The nature of electric charge carried by rain together with the calculated temperature of the origin of rain drops helps to decide whether the rain is due to the "Bergeron' process or the 'Coalescence" process.

1. Introduction

A knowledge of the precipitation elements present in a thunderstorm at the time of appearance of the initial electric field change from the positive fine weather field will be very useful in evaluating charge generation mechanisms. Workman and Reynolds (1950) assert that separation of electric charge within the cloud is closely associated with precipitation mechanisms and does not take place until precipitation processes are well under way. It takes place according to them, at temperatures between 0°C and —15°C most probably between —5°C and —10°C. The first internal flash occurs about 12 minutes after the initial 3-cm radar echo. Reynolds (1953) assumed after careful calculations that the precipitation particles are of the order of 200 micron radius at the time of 3-cm radar echo. He also inferred (1955) that the charges in the thunderstorm cell begin to separate at about two minutes after the particles reach the size of 200 micron radius. At that time the surface field was found to increase, thereby showing clearly that the charge separation process was intimately connected with the precipitation process.

During the summer of 1954, Reynolds and Brook (1956) studied four isolated thunderstorm cells in New Mexico in which the appearance of initial (3 cm) radar precipitation echo could be correlated with the appearance of initial thunderstorm electric field. They concluded that (1) the existence of radar detectable precipitation is necessary, but not sufficient condition for thunderstorm electrification and (2) for the appearance of significant cloud electrification, the radar echo must show rapid vertical development. If this condition was satisfied, they observed that the appearance of initial radar echo almost coincided with the appearance of the initial electric field.

During the summer of 1956, Brook (1957) repeated his 1954 study of the initial electric

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TABLE 1

Summary of thunderstorm data for the period 1955

S. No.	Date	Time interval between initial field increase and max. field* (min)	Time interval between field reversal and onset of precipitation at ground (min)	Intensity of rainfall at onset at the ground (mm/hr)	Terminal velocity of average rain drop at onset (m/sec)	Height of fall of precipitation (m) a.g.l. (m)	Temp. of ht. (col. 7) (°C)	Freezing level a.s.l. (m)	Updraft calculated from rise of radar echo or from terminal velocity (m/sec)	Approx. temp. of initial radar echo using Wexler's hail growth calculation (°C)	Type of storm
1	2	3	4	5	6	7	8	9	10	11	12
1	17-9-55	20	25	15	4·8	7200	—12·2	4900	4—5	—14 to —17	A
2	18-9-55	20	27	15	4·8	7776	—14·0	5360	4—5	—14 to —17	A
3	26-9-55	..	35	15	4·8	10080	—31·0	5160	4—5	—14 to —17	B
4	27-9-55	..	35	15	4·8	10080	—31·0	4990	4—5	—14 to —17	B
5	27-9-55	25	20	15	4·8	5760	— 3·5	4990	4—5	—14 to —17	A
6	28-9-55	18	30	15	4·8	8640		4000	4—5	—14 to —17	A
7	30-9-55	..	12	10	4·6	3312	+ 8·0	5150	4—5	—14 to —17	B
8	19-10-55	..	14	5	4·2	3528	+ 8·2	5300	4—5	—14 to —17	B
9	20-10-55	..	15	15	4·8	4320	+ 3·2	5000	4—5	—14 to —17	B

*Time needed for precipitation to develop

field changes in isolated thunderstorms and arrived at the following conclusions—

1. The initial radar echo is found to precede the initial electric field by an average time of about ten minutes.
2. The top of the echo when it first evidences electrification is always found above approximately 21,000 ft, *i.e.*, colder than —10°C. Echoes which do not grow above this level do not produce detectable electric field. The tops of initial echoes were found to occur at temperatures from +2°C to —10°C with an average value of —4°C.
3. Comparison of his study with the study of Ludlam and Mason (1956) suggest that the height of the top of the initial echo is determined by the height of the zero degree isotherm. Brook, therefore, concluded that a melting process, rather than a coalescence process may be responsible for producing many of the initial radar echoes in thunderstorms.

Recently Moore and Vonnegut (1958) have questioned the assumption that falling of charged precipitation is responsible for thunderstorm electrification. Their measurements show that vertical components of the electric field as great as 10 or 20 V/cm are developed *in the cloud prior* to the initial appearance of precipitation detected as a radar echo. They have also observed reversal of potential gradient *within the cloud* which sometimes reached values in excess of —10 V/cm before any radar echo can be detected. According to them, therefore, electrification might exist within the cloud for some time before it could be detected at the ground. Also the electric field produced at the ground by electric charges in the cloud would be greatly attenuated because of distance. In India Koteswaram and De (1959) studied the vertical development of precipitation echoes from cumulus clouds near Calcutta during the post-monsoon season of 1956, using a Decca Type-41, 3-cm radar. They showed that the origin of the first precipitation echoes was below the freezing level in most cases. The rate of growth of the precipitation echoes was found to be comparable with that found in U.S.A. A condensation coalescence mechanism was suggested for the formation of rain from these clouds. Battan (1953) (U. S. A.), Feteris and Mason (1956) (England) also arrived at similar conclusions from their studies. Mani and Venkiteshwaran (1961) have made detailed study of thunderstorms at Poona using a 10-cm radar (SCR-717C). In 25 of the 39 cases studied, the base of the initial echo was below the 0°C isotherm and in the other remaining 14 occasions at or above it. They concluded by saying that radar observations are not conclusive unless simultaneous visual and aircraft observations are also taken regarding the processes involved in the initial release of precipitation in thunder clouds.

As the interpretation of the initial radar echo from the inferred-in-cloud temperature alone to distinguish between ice and water is a questionable procedure, the author has presented in this paper the relationship between the initial electric field change from the fine weather positive field at the ground and the precipitation process together with simultaneous 10-cm radar observations wherever possible at Poona during a number of thunderstorms. In every case studied the reversal of the field (positive-zero-negative) takes place earlier than the precipitation at the ground. There is a distinct time lag between the field reversal and onset of precipitation at the ground enabling us to calculate approximately the distance of fall of the rain drop assuming an average terminal velocity of the rain drop arriving at the ground for a particular rate of rainfall. This enables us to know whether the origin of the rain drop is above or below the freezing level and by how much. There are limitations in using this method which are discussed below. From the observations at Poona during a number of thunderstorms at Poona, it is seen that both the Bergeron-Findeisen process and coalescence process are involved in the formation of rain in active tropical thunderstorms. The most effective process of charge generation and separation in Cumulonimbus as far as observations from Poona are concerned, seems to be associated with the co-existence of supercooled water and ice. The results of the investigations are given below.

2. Description of equipment used in the investigation

1. A rain electrograph for measuring the electricity carried by rain,

2. A tilting type raingauge for measuring the quantity of rain carrying the measured quantity of electricity and at the same time the rate of rainfall,

3. An intensity raingauge using a Bibby type impulse recorder for recording at a distance the duration and intensity of rainfall,

4. A point discharge galvanometer for measuring the current of electricity discharged into the atmosphere through a freely exposed insulated platinum point and indirectly providing a measure of potential gradients greater than 600 Volts/metre,

5. A quick run photographic electrograph constructed by the Cambridge Instruments Co. Ltd. using a radio active collector,

6. A 10-cm radar, type (SCR-717 C) with peak power of transmitter approximately 40 k.w. and pulse duration $1 \cdot 125$ μ sec (microsecond) operating over five ranges, *viz.*, 4, 10, 20, 50 and 100 nautical miles.

A full description of the above instruments has been given earlier by the author (1957, 1959, 1961, 1962), Gupta *et al.* (1955) and Gupta and Venkiteshwaran (1958).

3. Analysis of observational data

A detailed analysis of the data for 9 thunderstorms is given in Table 1.

The storms are classified as type 'A' and type 'B' storms. In type 'A' storms, the

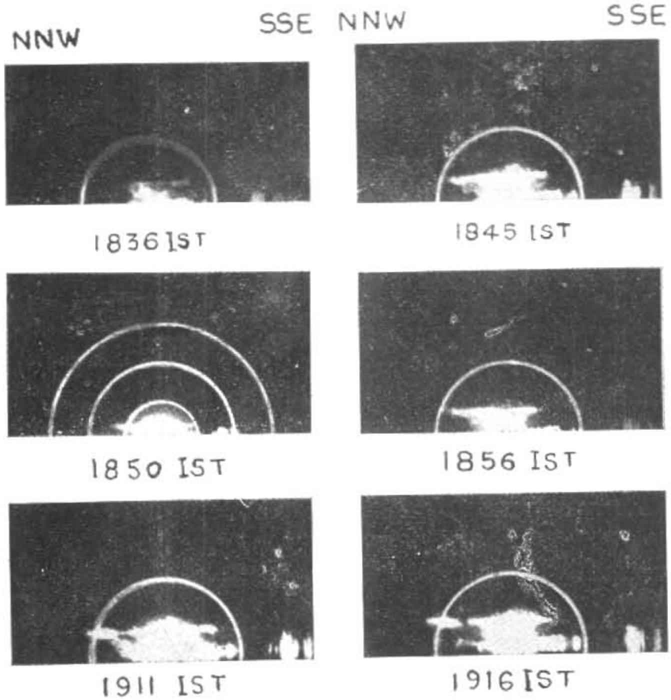


Fig. 1. 10-cm radar echoes showing melting band phenomena during the dissipating stage of a thunderstorm at Poona on 22 March 1955. The band is found to extend towards the north from 1836 hr to 1916 hr. Band height 12,500 ft a.s.l. (approx.)

(Range markers at 5 miles interval)

initial positive field first increases with the development of thunderstorm cell growth as noticed by Reynolds (1955), then decreases and finally becomes zero and negative. In type 'B' storms, the field reversal suddenly takes place before the onset of rain at the ground.

Table 1 shows that storms 1, 2, 5, 6 (type A) give an average time interval of twenty minutes between the initial field change from the positive normal fine weather field and the maximum field increase, the time needed for precipitation to develop as envisaged by Reynolds (1955). The time lag between the reversal of field and onset of rain at the ground varies from 15 to 20 minutes.

Storms 3, 4, 7, 8, 9 (type B) do not show sudden increase of field but sudden reversal of field before onset of rain at the ground. The time lag between the reversal of field and onset of rain at the ground varies from 20 to 30 minutes showing clearly that in both types of thunderstorms, the field reversal takes place ahead of the precipitation at the ground.

The calculations in Table 1 clearly show that the origin of the rain drops, for the thunderstorms taken for study is far above the freezing level suggesting Bergeron-Findeisen mechanism for the thunderstorm rainfall. Figs. (11, 10), (13, 12) and (9, 8) show the intensity of rainfall at minute intervals during severe thunderstorms on 18, 25-26 September and 19 October 1955. On the top of each histogram +, —, 0 markings are given to indicate the nature of electric charge of the rain drops during that minute interval. They show that in some thunderstorms, all the rain drops during the entire period of rainfall are not charged. It is possible that the origin of the drops having electric charge and drops having no

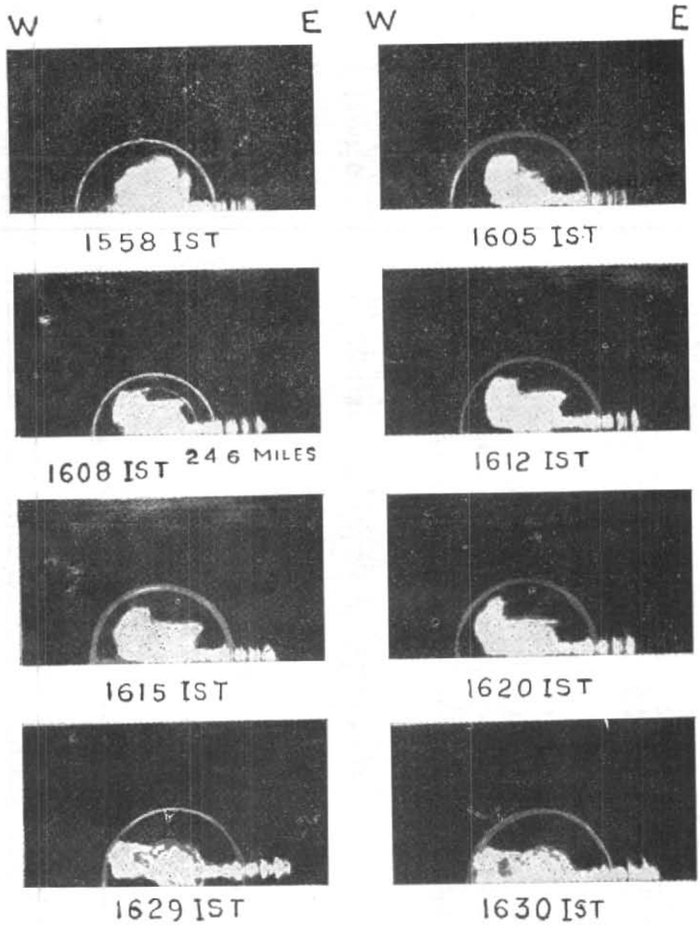
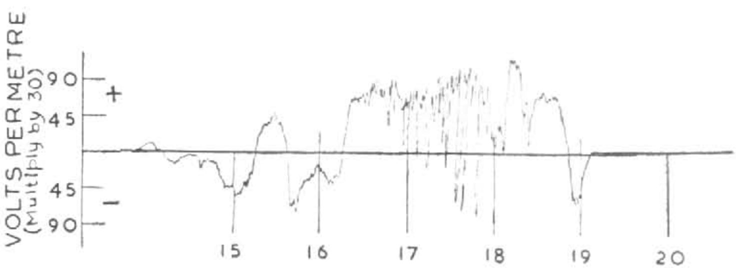


Fig. 2. Radar echoes from a growing thunderstorm at Poona on 20 Sep 1956 using a 10-cm radar
(1558—*Cb* shower over station. 1608—M. band formation. Ht. 1300 ft a.s.l.)
The simultaneous presence of melting band and adjacent growing radar echoes suggests that ice phase is involved in Tropical Thunderstorms

electric charge may be at different levels, one above the freezing level and the other below the freezing level depending upon the intensity of rainfall and consequent change in the drop size and terminal velocity. The author argued earlier (1961) that for rain to have appreciable charge the rain must have started as ice or at least in the form of ice for some part of its history. Non-freezing rain is found to have less or no appreciable electric charge with the limitations of the apparatus used. This affords a method of identifying occasions of rain from non-freezing clouds.

A number of thunderstorms at Poona show the melting band phenomena during the dissipating stage (Figs. 1 and 3) and adjacent growing radar echoes of super-cooled water above the melting band (Fig. 2) showing clearly that ice and supercooled water in juxtaposition are present in thunderstorms which are essential to the main process of charge separation or towards the final stages in a thundercloud.

Wexler (1953) compiled the theoretical growth of hail and the behaviour of the first radar echo in cumuliform clouds. He derived



A – Portion of Electrograph Record during severe lightning flashes
MAY 5, 1955

B – Typical record of variations in point discharge current
corresponding to A Scale : 1 Microampere =

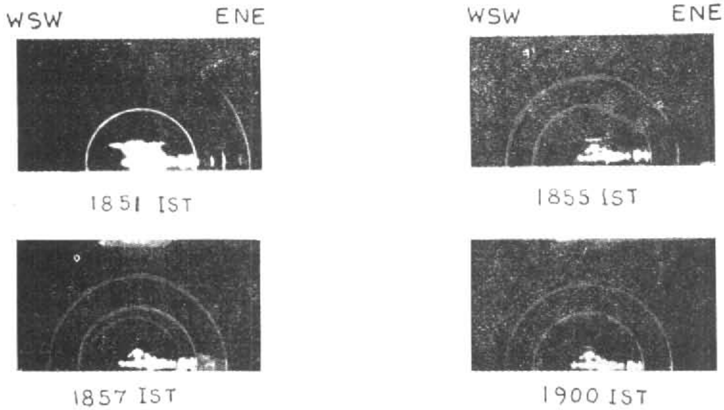


Fig. 3. 10-cm radar echoes showing the melting band phenomena towards the dissipating stage of thunderstorm with severe lightning flashes on 5 May 1955

(Range markers at 5 miles interval)

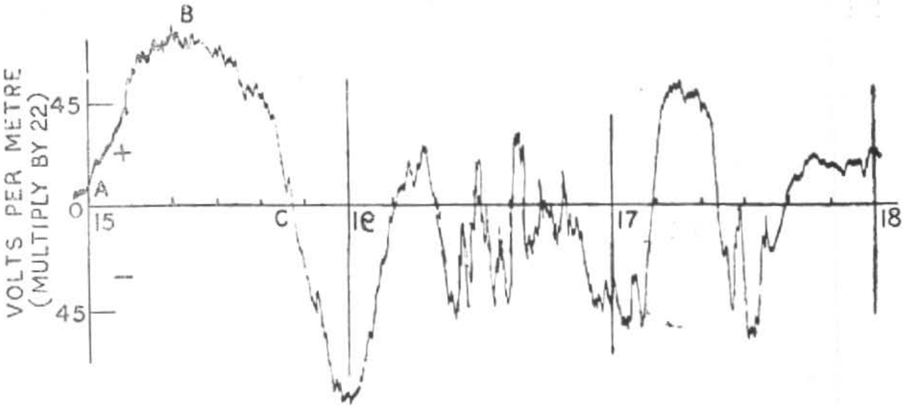
M. band was first observed at 1735 hr but very little rain reached the ground

an approximate relationship between updraft velocity and the approximate location of the first radar echo (Table 2). He concluded that ice phase must be involved in thunderstorms.

Fig. 3 shows the simultaneous records of electric field, point discharge current, and radar melting band phenomena during a thunderstorm on 5 May 1955 with severe lightning flashes, suggesting that lightning takes place in cumulonimbus clouds where the ice phase is involved.

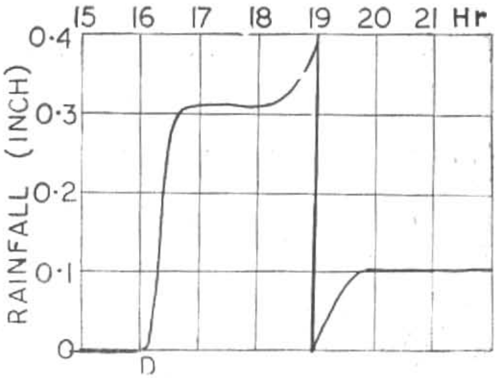
4. Storm analysis

A few typical storms have been described below to show the relationship between the initial electric field and precipitation process as revealed by 10-cm radar echoes. The time of onset of cloud electrification is defined like Reynolds and Brook (1956) as



(a) Portion of electrograph record during a thunderstorm at Poona on 17 Sep 1955

Time lag between field reversal at C and onset of rainfall at D=25 minutes (17 Sep 1955)



(b) Natural syphon raingauge record on 17 Sep 1955

Fig. 4

the time at which the electrograph records indicated a significant departure from the fair weather positive potential gradient.

TABLE 2

Approximate relationship between updraft velocity and location of first radar echo

Updraft velocity (m/sec)	First radar (3·2 cm) echo (°C)
2	0 to — 7
5	—14 to —17
8	—21 to — 24

(Data taken from Wexler's Paper, *J. Met.*, **10**, p. 289, 1953)

Thunderstorm of 17 September 1955(Fig. 4)—Cloud electrification in the storm was first observed at 1500 IST. The field increased and reached a maximum at about 1520 hrs and then decreased becoming zero at about 1548 hrs and reversed in sign to a negative value. As it was only 1/8 clouded with *Cb* over the station at about 1606 hrs the 10-cm radar was switched on at 1606 hrs with the antenna scanning in a vertical NE-SW direction. The radar set was equipped for automatic vertical scanning (RHI) and for continuous photograhic recording of the plan position indicator (PPI). The radar picture taken at 1610 hrs (Fig. 5) clearly showed a big patch in the northeasterly direction about 5-10 miles away from the

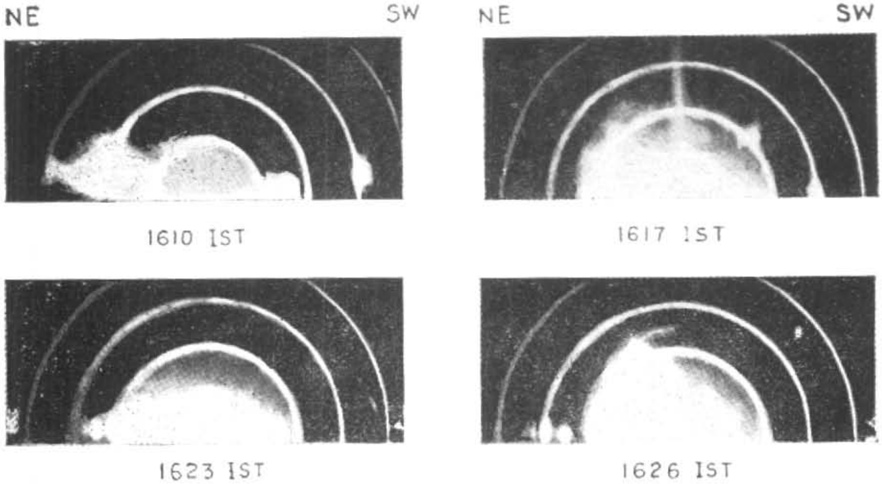


Fig. 5. 10-cm radar echoes associated with the thunderstorm on 17 Sep 1955 at Poona showing considerable vertical development at 1626 IST
(Range markers are for 5 nautical miles)

station. The *Cb* cell then gradually spread over the station and rain started at about 1613 hrs. At 1626 hrs the echo showed considerable vertical development. There was lightning and considerable point discharge current. The rain drops were found to be charged. The intensity of rain weakened at about 1700 hrs and again increased at about 1800 hrs. Rain stopped at about 1945 hrs. The time interval between field reversal and onset of precipitation at the ground was found to be 25 minutes and the intensity of rainfall at onset being 15 mm/hr, the distance of fall of raindrops is $25 \times 60 \times 4 \cdot 8$ $=7200$ metres. The approximate temperature as inferred from Poona radiosonde ascent for this height is about —12·2°C, which fairly agrees with the theoretical calculation by Wexler for the approximate temperature of initial radar echo (—14°C to —17°C), for an updraft of 4–5 metres per sec.

Thunderstorms of 27 September 1955(Figs. 6 and 7)—There were two thunderstorms on this day, one commencing at about 1625 hrs and another at about 2230 hrs. The first belonged to type 'B' and the second one to type 'A'. The 10-cm radar showed an initial echo at about 1632 hrs and the rain at the ground was noticed at 1635 hrs (B in Fig. 7). The antenna was scanning in W-E vertical direction. At 1640 hrs, the radar echoes were moving west from east and a sharp shower was noticed at the ground. The rain stopped at about 1704 hrs. The rain patch in the radar screen also disappeared at that time. This echo also showed considerable vertical development giving an updraft of nearly 6-7 metres per sec. Rain drops were electrically charged. The field reversal was noticed at 1600 hrs giving the time lag between field reversal and onset of precipitation as 35 minutes.

In the second storm, type 'A', initial electrification started at 2215 hrs (A). The field increased to a maximum at about 2235 hrs (B) and then decreased, becoming zero at about 2240 hrs(C)and became negative. Rain commenced at 2300 hrs (D in Fig. 7) and continued till 0230 hrs on 28 September. The rain showed considerable electric charge with both positive and negative values depending upon the sign of the field showing the mirror image effect of Simson (1949). No radar pictures are available for this storm. There was considerable point discharge current

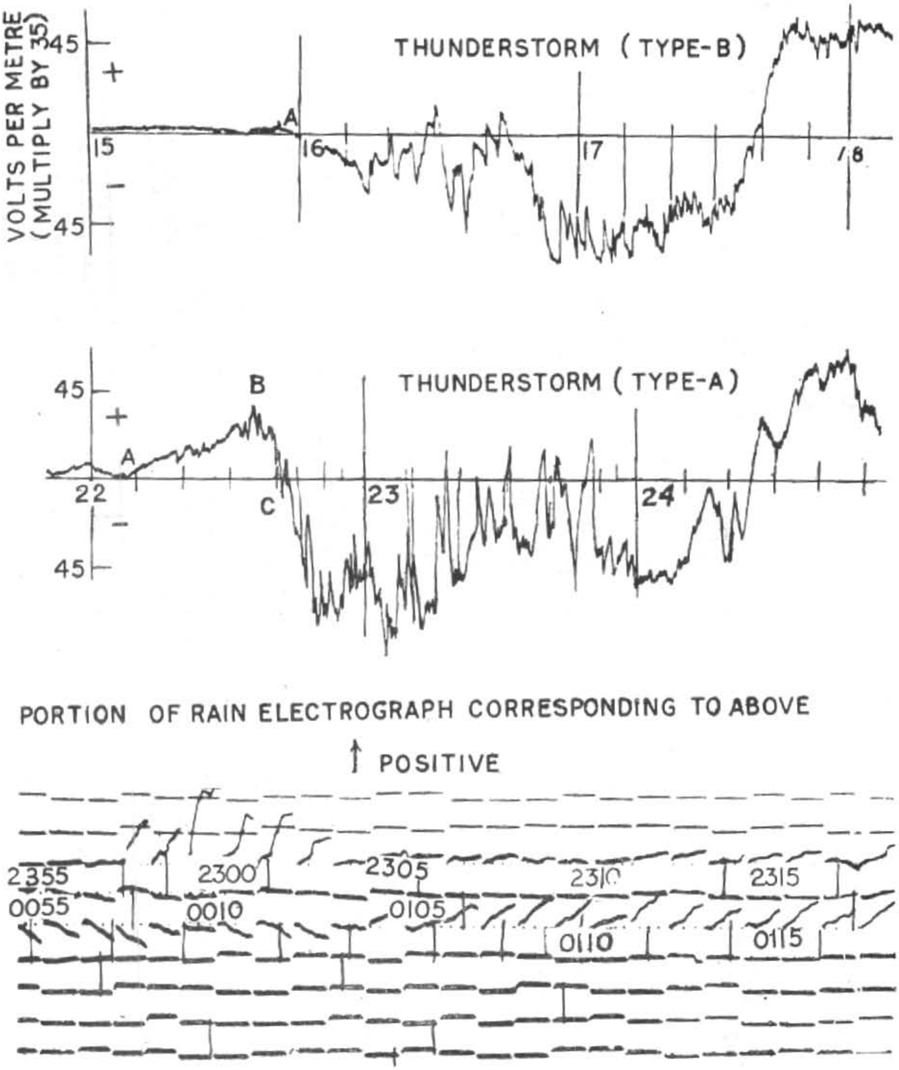
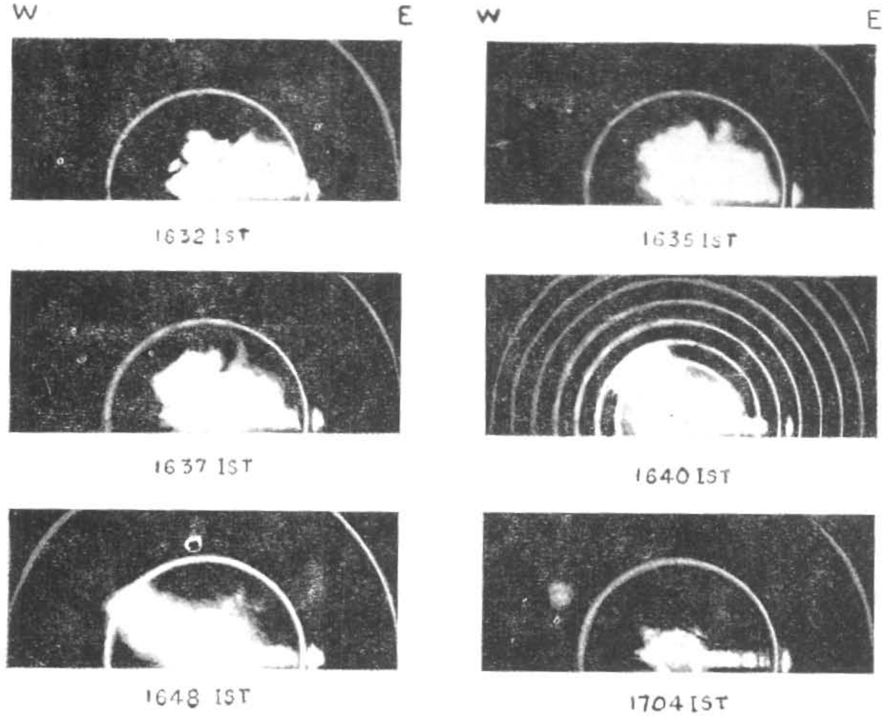


Fig. 6

for this storm. The time lag between field reversal and onset of precipitation is 20 minutes.

Thundershower on 19 October 1955 (Figs. 8 and 9) — In this storm, sky was overcast with large *Cu* from about 1900 to 2050 hrs. During this period the field at the ground is not sufficiently different from the fair weather positive gradient. As soon as the clouds reached the rain bearing stage, the field changed from positive to zero at 2050 hrs, and became negative till 2215 hrs. The rain drops were found to have no charge till 2114 hrs and then found to have positive charge till 2138 hrs. There was again no charge in the rain drops for the next 17 minutes and then there was positive charge till 2207 hrs. This shows that all the rain drops are not charged during the entire period of rain



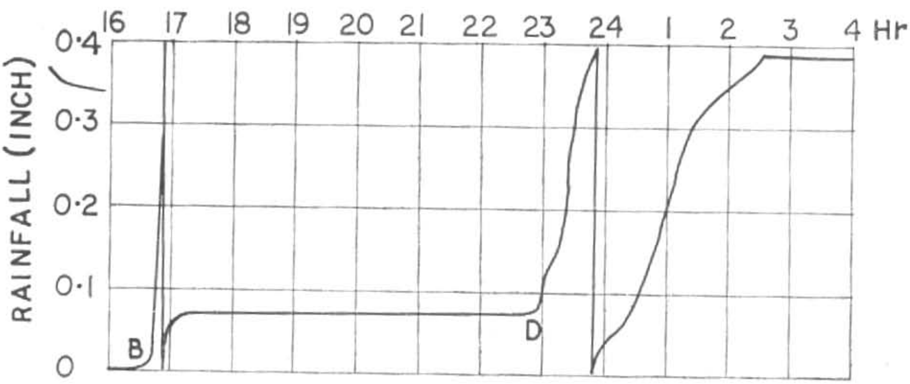
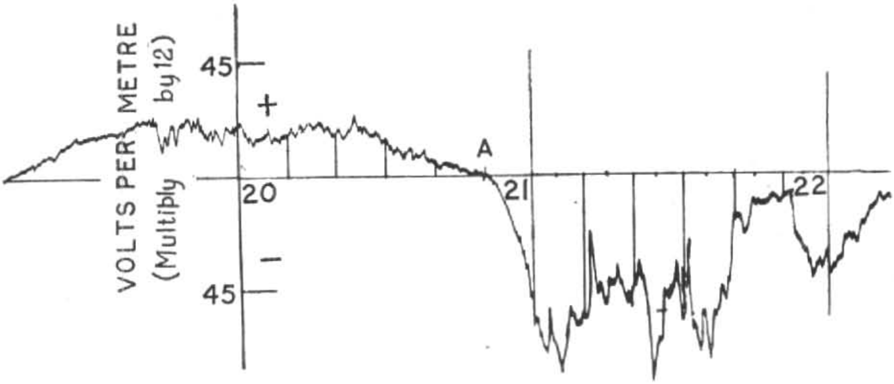
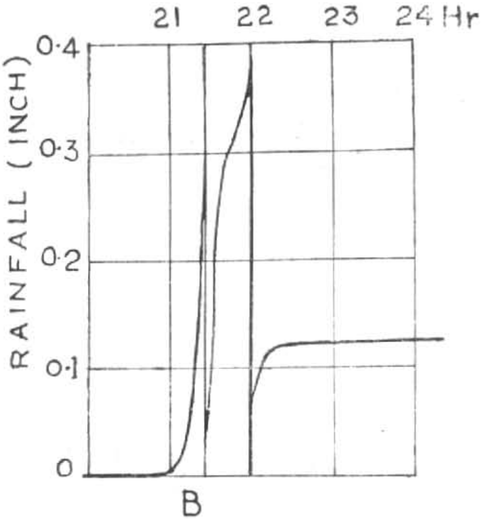


Fig. 7. 10-cm radar echoes associated with the thunderstorm at about 1625 IST on 27 Sep 1955 at Poona. The initial echo was seen at 1632 IST but the field reversal took place earlier at 1600 IST



(a) Portion of electrograph record during an instability shower at Poona on 19 October 1955
Time lag between field reversal at A and onset of rainfall at B=14 minutes (19 Oct 1955)



(b) Natural syphon raingauge record on 19 Oct 1955

Fig. 8

It is seen from Table 1 (S. No. 8), the initial height of fall of rain drop is 3528 metres and corresponding temperature is $+8\cdot2$°C. These drops may be due to coalescence process taking place below the freezing level and, therefore, the initial raindrops are not charged. The charged rain drops may be due to the ice crystal process or Dinger-Gunn effect (1946), as the point discharge current during the period of rainfall was very small.

Thunderstorm of 18 September 1955 (Figs. 10 and 11)—On 18 September, the skies were covered with 3 to 4/8 medium clouds till the middle of the day. In the afternoon development of large *Cu* into *Cb* was noticed.

Cloud electrification started at about 1720 hrs as shown by the rise in the electric field measured at the ground (type A). The field reached a maximum at about 1740 hrs and then decreased, becoming zero at about 1748 hrs and reversed in sign to negative. Thunder was heard at 1800 hrs and rain commenced at about 1815 hrs giving a time lag of approximately 27 minutes. There was

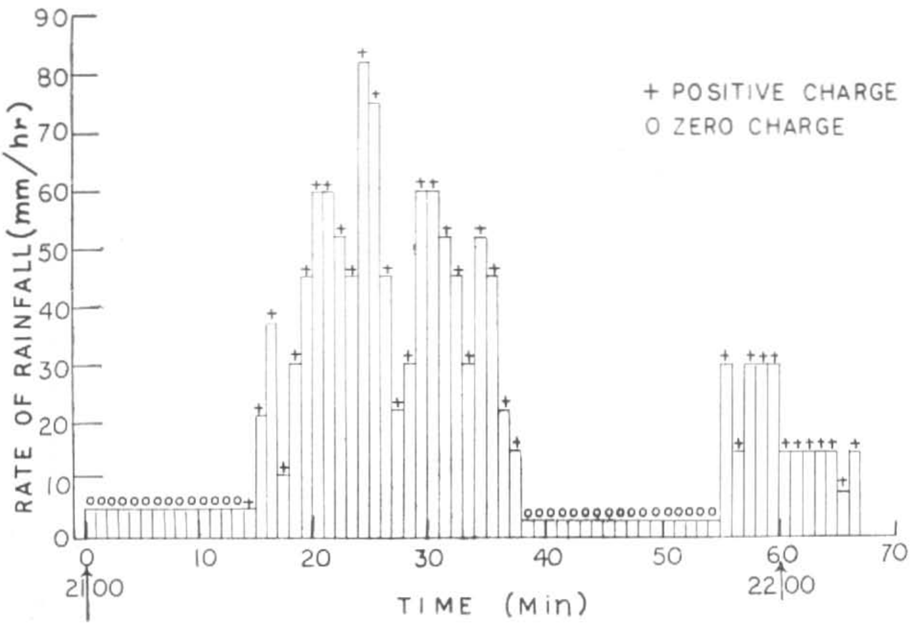


Fig. 9. Thunderstorm at Poona, 19 Oct 1955

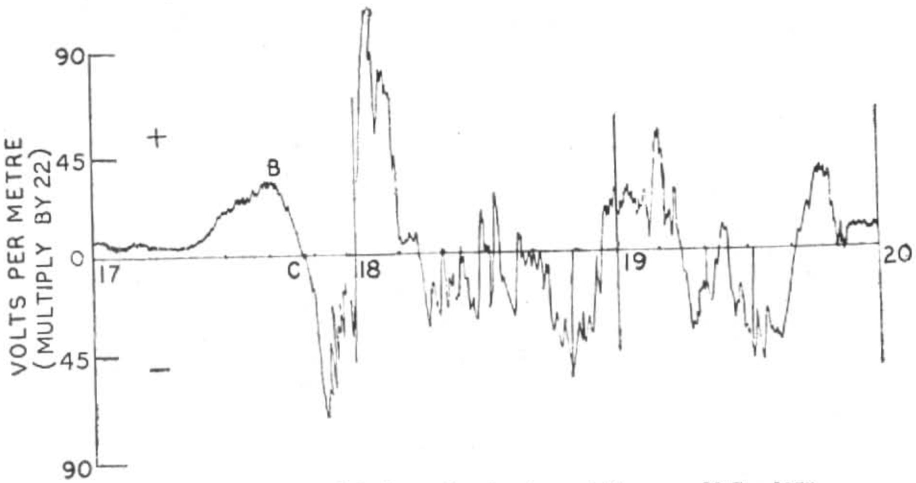
a big squall with maximum wind speed of 52 miles per hour. The intensity of rainfall reached a peak value of 90 mm per hour at 1836 hrs. The raindrops were all positively charged. There was another thunderstorm the same night (type B) commencing at about 2200 hrs. Rain actually commenced at 2230 hrs and ended at about 2302 hrs. The raindrops were found to be mostly negatively charged showing clearly the difference in the electrical structure of the two thunderstorms.

5. Discussion

1. *Time of fall and time lag* — One may argue about the dangers and difficulties in calculating the level of origin of raindrops from the time interval between the zero field change and the arrival of precipitation at the ground. In thunderstorms, there are usually strong updrafts and downdrafts of several metres per second, so that the fall speed of the drops from the freezing level or above, may be markedly different from their terminal velocities in still air. Also the first drops to reach the ground may not have been involved in charge separation. The charge separation process may occur above the 0°C level but at the same time raindrops may grow by coalescence in the lower part of the cloud and reach the ground before the raindrops resulting from melting hail, which originates at higher levels in the clouds.

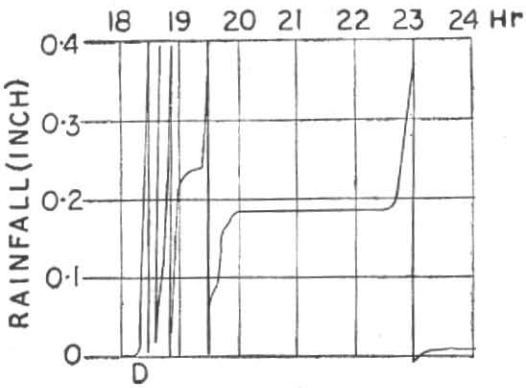
But it has been observed that the rate of growth of radar echo tops during the initial electrification in the present study indicates an average upward and downward velocities varying from 400 ft to 1500 ft per minute (*i.e.*, 2 m/sec to 7·6 m/sec). The terminal velocity for a 15 mm per hour rate of rainfall generally observed on the ground at onset of rainfall during thunderstorm at Poona corresponding to 1-2 mm (median size) raindrop diameter is of the same order as the velocity of the updraft or downdraft. Therefore it is not unreasonable that such drops must be falling at the time of reversal of the positive field to negative.

2. Application of mean drop size in the calculation used to a given rate of rainfall is a questionable procedure in individual cases



(a) Portion of electrograph record during a thunderstorm at Poona on 18 Sep 1955

Time lag between field reversal at C and onset of rainfall at D=27 minutes (18 Sep 1955)



(b) Natural syphon raingauge record on 18 Sep 1955

Fig. 10

of rainfall. In answer to this it may be mentioned that the author (1961) has made a detailed study of raindrops size characteristics in different types of tropical rain as a function of rain intensity at Poona and so is justified in using the median value of the drop size for a particular rate of rainfall as the rate of rainfall is accurately measured at minute intervals from the continuous photographic records.

3. One has to be sure whether there is only one thunderstorm cell concerned, and there is no need to consider the *approach* of the storm as well as the *development*. Then only we can be sure of the calculations of the distance of raindrops from the time lag. The storms taken for study are concerned with the development of one cell only over the station beginning from practically clear skies.

4. There is one point, which is inherent in Vonnegut's arguments, as to which comes first; initiation of precipitation or initiation of electrification process. Reynolds and Brook (1956) have assumed that it is precipitation which causes electrification and therefore drops or ice particles start to fall, and to give radar echoes, before electrical effects occur. On the other hand, Moore and Vonnegut (1958) have ascribed the electrical effects observed in clouds to some other process

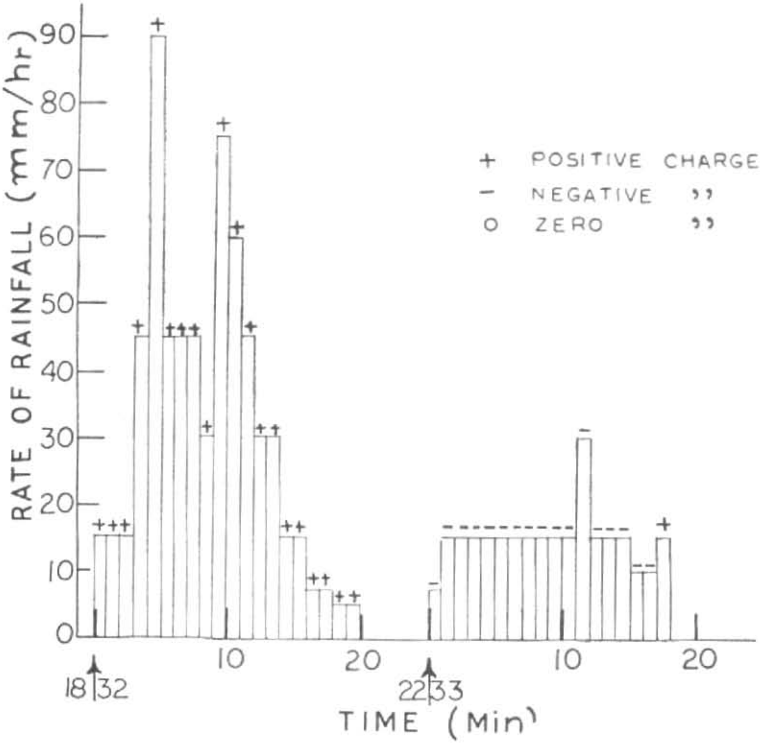
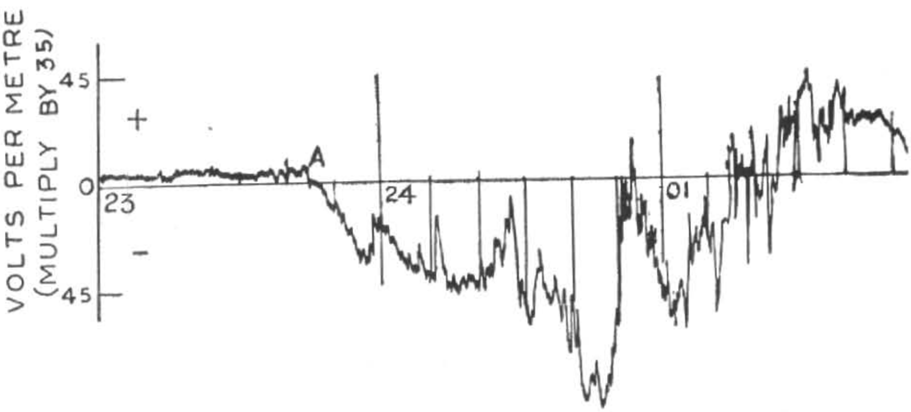


Fig. 11. Thunderstorm at Poona, 18 Sep 1955

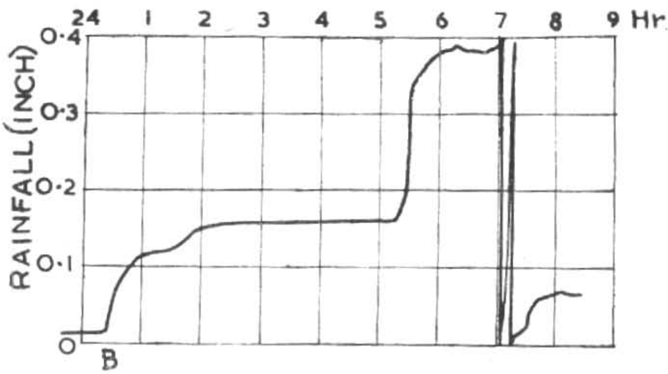
and think that the formation of precipitation occurs later assisted by electrification. The present study more or less agrees with the findings of Reynolds and Brook, from the correlation of initial electric field activity in clouds and precipitation processes as revealed by growing radar echoes.

5. It is possible that evaporation of raindrops during their fall may affect the present method of calculation. As the humidity is practically above 85 per cent just before rainfall in the present study the effect of evaporation is not very serious.

6. Some of the calculations given in Table 1 gives the distance of fall of raindrops as 10,000 metres and above, very much above the freezing level. It may be argued whether rain as raindrops can exist above the freezing level. The 10-cm radar echoes noticed in the thunderstorms taken for study shows clearly sometimes echo height as 30,000 or 40,000 ft indicating clearly the presence of supercooled water (Fig. 14). Investigations of this type of echoes have also been made in England by Jones (1954) in meteorological research flights using a single seater aircraft. Observations of the weather by the pilot revealed that the echo at heights above the freezing level was associated with noticeable *precipitation* or with ice formation on the aircraft on 97 per cent of all traverses. On more than half of the flights above the freezing level the precipitation was reported as rain even with environment temperature below —20°C. The amount of water vapour available for the droplets or ice crystal growth at these very low temperatures may be very small, unless there is a high degree of super-saturation. It seems, therefore, that the radar reflecting particles are carried upward in the clouds by the vertical current of the Cumulonimbus. Consideration such as these have led to the suggestion that rain is produced in the Cumulonimbus cloud by droplet growth in the rising air current by condensation and coalescence



(a) Portion of electrograph record during a thunderstorm at Poona on 25-26 Sep 1955



(b) Natural syphon raingauge record on 25-26 Sep 1955

Fig. 12

and that ice crystal is not essential to shower type precipitation. In the laboratory, Mason (1962) has been able to supercool 1 mm radius of quite dirty water to below—20°C. However, he believes that soft hail (or graupel) particles are mainly responsible for charge production at these levels. Recently Mason and Maybank (1960) have found that the freezing of water droplets with a radius 0·03—1·0 mm is often accompanied by the bursting of ice shell and the ejection of small splinters of ice carrying a positive charge, leaving negative charges on the residues of the droplets. This suggests that the formation of pellets of soft hail in a cloud by the impaction and freezing of supercooled drops will lead to the formation of negatively charged hailstones that will fall towards the base of the cloud while the positively charged ice-splinters are carried by the upcurrents towards the top of the cloud, as shown in Fig. 15.

7. Another argument is that the field at the ground is not necessarily controlled by the charges overhead nor is it clear that the time at which the field passes through zero bears any relation to the methed of formation of rain. If h be the height of the lower limit of the region in which the initial process of charge separation within clouds occur, Chalmers (1951) has proved, while discussing the origin of electric charge of rain when point discharge occurs, that the level of zero field is at h and has given a method of calculating the height h. The zero field in the cloud where the rain gets its maximum initial electric charge, is therefore related to the zero field in the ground.

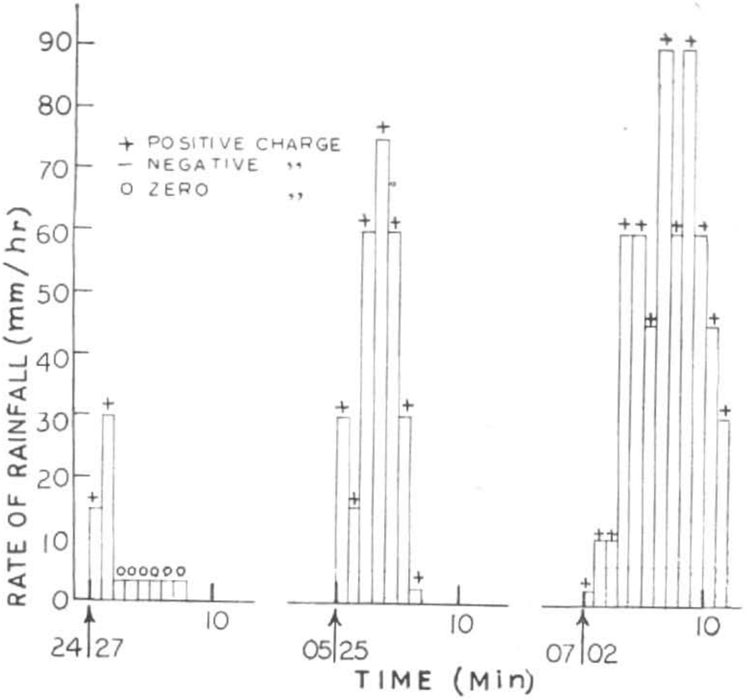


Fig. 13. Thunderstorm at Poona, 26 Sep 1955

Hence the time lag between the zero field at the ground and onset of rainfall gives a measure of the time of the fall of the raindrop from its origin in the cloud to the ground. Further it has been noticed that we may have overcast skies, but the fields at the ground are not significantly different from the fair weather positive gradient. But when the clouds reach the rain bearing stage and begins to rain, the field becomes zero and negative. This is more true of stratiform clouds.

8. It may be argued that because the raindrops are sometimes uncharged during thunderstorm rain, it need not necessarily follow that they were produced by coalescence. Precipitation elements in the cloud may become neutralized or reverse their charge during their fall by melting Dinger-Gunn effect (1946) and by Wilson's capture of ions in the space charge blanket beneath the cloud. It is extremely difficult to deduce what is happening inside the cloud from measurements made on drops reaching the ground because of their complicated electrical and physical (melting, evaporation, motion in vertical air currents etc) processes in which they may be involved during their downward journey.

The author has, however, proved earlier (1961, 1962) that non-freezing rain is practically uncharged and the mechanism for non-freezing rain is mainly due to coalescence process. In another spell of continuous rain at Poona it has been noticed by the author (1961) that even though melting band has been seen throughout by a 10-cm radar, the raindrops during the entire period of rainfall are not charged. As many of the thunderstorms taken for study show the melting band phenomenon during the dissipating stage, it is almost certain that ice phase is involved in tropical thunderstorms and as all the rain drops during the entire period of rainfall are not charged (Figs. 6 and 9) it is presumed that both the coalescence and Bergeron and Findeisen processes are involved in tropical thunderstorm rainfall mechanism.

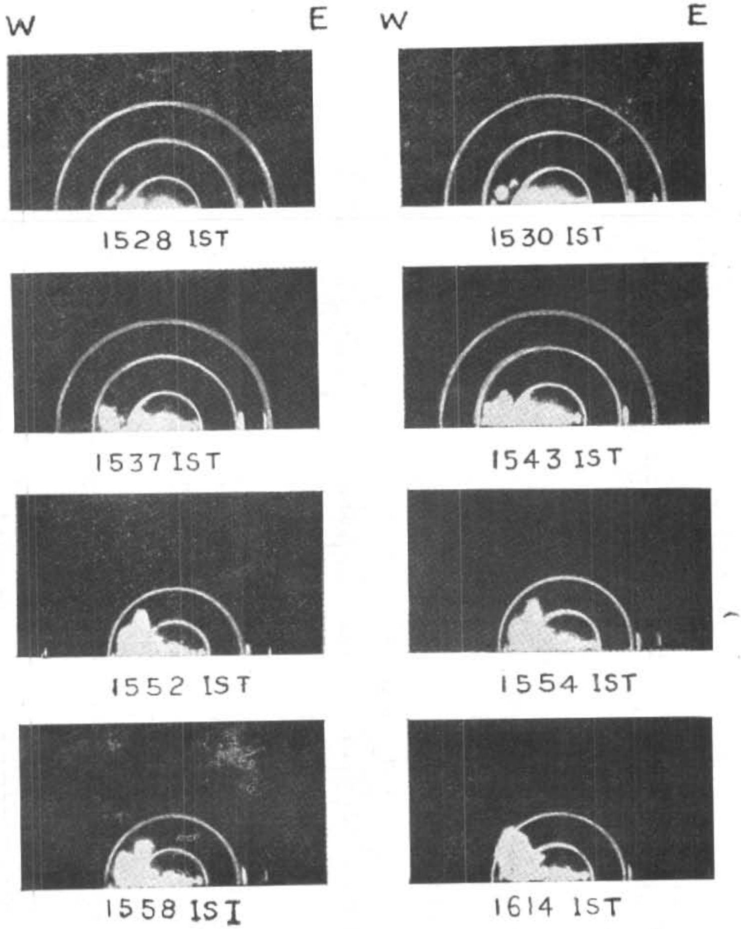
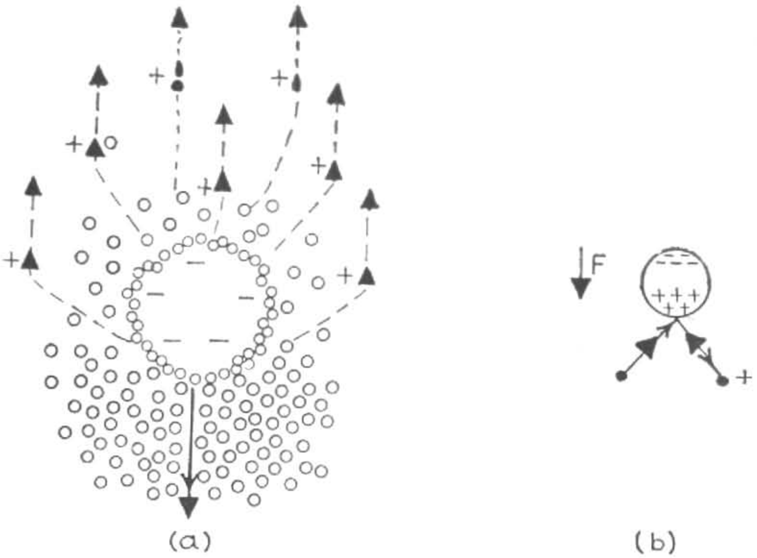


Fig. 14. Radar echoes from a growing thunderstorm at Poona on 23 May 1957

Echo height at 1554 hr is about 8 miles. Range markers at 5 miles intervals

9. An analysis of the minimum temperatures reached by the tops of echoes from Cumulonimbus has been made by a number of workers, Jones (1950), Workman and Reynolds (1949), Battan (1953), Feteris and Mason (1956) and Koteswaram and De (1959). In New Mexico storms studied by Workman and Reynolds the initial echo appeared at about —10°C. In about 60 per cent of a total of 123 cases studied by Battan during the Thunderstorm Project in Ohio the whole of the echo was located at temperatures above 0°C. Feteris and Mason (1956) observed 48 separate echoes to orginate below the —2°C level. Koteswaram and De (1959) studied about 22 cases of convective type of clouds. In about 70 per cent of these cases studied the entire echo was at temperatures below freezing level. These results were interpreted by the various authors that the initially detected precipitation elements were rain drops formed by coalescence without the intervention of ice phase. Irrefutable evidence that showers are formed wholly by the coalescence mechanism was obtained by Styles and Campbell (1953) and by Day (1953) working in Australia, the echoes and the cloud tops being wholly below the 0°C level at the time of maximum development.



(a) Diagram illustrating the growth and negative charging of a hail pellet as it falls through a cloud of supercooled droplets. Droplets that impinge on the hail pellet freeze and eject small positively charged ice splinters which are carried towards the top of a cloud in the up-currents. The heavier hailstones carry a negative charge towards the cloud base (after Mason 1962)

(b) Diagram to illustrate how a raindrop, polarised in an electric field, may become negatively charged if cloud droplets rebound from its lower surface (Elster and Geitel theory 1913)

Fig. 15

The radar information tells us at what height in the cloud the reflecting particles are numerous, and large enough for a detectable signal to be received. It tells us also that this height increases as the vertical velocity increases. It does not, however, tell us whether the particles are water drops, ice crystals, aggregates of ice crystals or ice crystals with a wet skin. One might argue that the appearance of initial echoes below 0°C does not provide conclusive evidence of the rain being formed by the coalescence process but that the drops may have originated at higher levels as ice particles which, because of their lower reflectivity and range attenuation effects, fall undetected until they reached the melting level. Feteris and Mason (1956), Koteswaram and De (1959) have, however, produced strong evidence against such a possibility from their study of convective clouds using 3-cm radar.

However, the 10-cm radar (SCR—717C) used for this investigation can just detect a precipitation rate of 0·02″/hr (·5 mm/hr) at a range of 10,000 ft (Day 1953) if it is assumed that the rain storm completely fills the radar beam and has a size distribution of raindrops as given by Laws and Parsons (1943), *i.e.*,

$$D_0 \text{ (median drop diameter)} = 1\cdot 06\ R'^{\,0.20}$$

$$\text{If } R' = \cdot 02''/\text{hr or } \cdot 508 \text{ mm/hr},$$

$$D_0 = 0\cdot 9 \text{ mm (approx)}.$$

Also drops of 1 mm diameter and density 100 drops/m^3 would be just detected while drops of 0·5 mm diameter would just be visible at the same range of 10,000 ft if their density was 10^4 drops/m^3. So the initial radar echo at a height of 10,000 ft with this 10-cm radar means that the size of the precipitation particles have already increased to raindrop sizes of 0·5 mm or more and so measurement of initial radar echo with this type of radar cannot help us, to understand fully, the initial precipitation mechanisms within the clouds, as smaller size particles are undetected by this type of radar. As the electric field generally reverses in sign from the fine weather positive field to negative before the time of the initial 10-cm radar echo we are justified in assuming that rain drops have already been formed and begun falling and so it is presumed that the time lag between the field reversal and onset of rainfall at the ground gives a measure of the distance of travel of raindrops.

10. The recent writings of C.T.R. Wilson and Vonnegut demand a reconsideration of the possibility of influence mechanisms and the common assumption that a thunderstorm necessarily contains ice in its upper portion has been challenged (Mason 1957). There are also on record 3 or 4 reports of lightning being observed in the Carribean (U.S.A.) from clouds whose tops were warmer than 0°C and could, therefore, have contained no ice (Gunn 1956, Foster 1950). Lightning from such warm clouds appears to be a rare phenomena although rain falls frequently from such warm clouds in the tropics. We, however, see from Fig. 3 that ice phase is involved in thunderstorms which give intense lightnings, as shown by simultaneous presence of radar melting band echoes at the time of lightning. At the present time, it is not possible to suggest a mechanism that would convincingly account for the origin of lightning in clouds consisting only of liquid water.

6. Conclusions

1. There is a distinct time lag between the field reversal (positive-zero-negative) and onset of precipitation at the ground during thunderstorms. This enables to get an approximate idea of the distance of fall of raindrops, assuming the terminal velocity for the average size of raindrop for a particular rate of rainfall at onset. The approximate temperature of the origin of raindrops can then be calculated with some limitations.

2. From the simultaneous records of potential gradient, initial radar echo, intensity of rainfall, electric charge carried by rain, it is seen that separation of electric charge within the cloud is closely associated with precipitation mechanisms in agreement with the results of Reynolds. Moore and Vonnegut have, however, suggested that although precipitation may not have caused the initial electrification, it may be the primary cause of latter electrification.

3. In the storms taken for study although melting band phenomena were not seen in the beginning stage of thunderstorm it was noticed towards the dissipating stage and in some cases, the simultaneous presence of melting band and adjacent growing radar echoes was noticed suggesting that ice phase must be involved in tropical thunderstorms.

4. The limitations of using radar alone to study the initial stage of precipitation development and the nature of possible physical processes have been emphasised. The stage in the development of the precipitation process at which a radar echo will first appear will obviously depend upon the range and reflectivity of the cloud and upon the performance, characteristics of the particular radar. It is emphasised that in order to obtain really conclusive information about the development of precipitation process, a knowledge of the initial electrification of the cloud is also necessary, coupled with the visual observations of the cloud.

5. The nature of electric charge carried by rain also decides whether the rain is due to ice crystal mechanism or coalescence mechanism.

6. It is concluded, that a simultaneous study of the initial electric field activity, sensitive radar observations, the charge carried by rain, point discharge current, intensity of rainfall, drop size measurement and radiosonde ascents is necessary for the understanding of precipitation process in thunderstorms and for evaluating charge generating mechanisms in thunderstorms.

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