Characteristics of Raindrop Charge and Associated Electric Field in Different Types of Rain

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ABSTRACT

Simultaneous measurements of raindrop charge, atmospheric electric field and rain intensity were made at Poona using fast response, continuous recording surface instruments during four types of rain: pre-monsoon (thunderstorm rain), monsoon rain type I (light intermittent rain), monsoon rain type II (heavy continuous rain) and post-monsoon (thunderstorm rain). Measurements were also made of the conductivity of rainwater samples collected during the monsoon season. On some days of this period data on cloud thickness as obtained from the aircraft flights in the region were also available.

The electric field associated with negatively charged raindrops was less negative than that associated with positively charged drops. The raindrop charge spectrum showed different characteristics during the four types of rain studied. It was broadest during the pre-monsoon rain when the convective activity was a maximum. It followed a log-normal distribution during the monsoon rain type I and it was peaked and skewed to the positive side during the monsoon rain type II. Rainwater conductivity was inversely correlated with the cloud vertical thickness. The results of the present study support the warm cloud charge generation mechanism proposed by Takahashi (1974).

1. Introduction

Several studies have been reported of the electrification processes in cold convective clouds (Gunn and Devin, 1953; Smith, 1955; Krasnogorskaia, 1965; Bradley and Stow, 1974) as well as in warm clouds (Takahashi and Fullerton, 1972; Takahashi and Craig, 1973; Takahashi, 1974). In addition, some investigations on the electrical state of monsoon clouds in India have appeared (Sivaramakrishnan and Selvam, 1967; Selvam *et al.* 1976; Ramachandra Murty *et al.*, 1976). Present knowledge of the role of cloud electrical activity in precipitation formation is far from satisfactory. Any information on the electrical characteristics of different types of clouds will be of value in advancing our knowledge. The authors have undertaken a study of the electrical characteristics of different types of rain at Poona (18°32′N, 73°51′E, 559 m ASL[1]). Simultaneous surface measurements of raindrop charge, atmospheric electric field and rain intensity were made on a number of occasions during thunderstorms of pre- and post-monsoon periods of 1973 and the quiet continuous rain during the monsoon of 1973. The conductivity of rainwater was also measured, using samples collected during the monsoon. Aircraft measurements of cloud thickness were also taken in 1973.

[1] Above (mean) sea level.

2. Measurements

a. *Raindrop charge*

The raindrop charge was measured using the induction ring technique (Ratcliffe *et al.*, 1969). The instrument was fabricated out of an alloy of aluminum. The first stage of the electronic measuring circuit consisted of an electrometer operational amplifier (Analog Devices Model 310 K) in the virtual earth configuration. Further amplification of the electrical pulses due to the drops was achieved in the second stage of the circuit through another operational amplifier (Model 118K) of the same make. Three sensitivity ranges were provided in the circuit which could be operated manually through a band switch arrangement. The absolute values of the raindrop charge were evaluated using calibration curves constructed from the data obtained by measuring the deflections produced by drops of known charges. The minimum drop charge which the instrument could detect was 10^{-13} C and the maximum value 3×10^{-13} C. In order to minimize the simultaneous occupation of the Faraday tube by raindrops at any given time, inlet tubes of different diameters were used in different intensities of rain. However, no estimates of the probability of simultaneous occupation were made. The instrument was installed on the terrace of the Institute building on a stand. It was, as far as possible, maintained perpendicular to the mean rain direction with a suitable tilting device fitted to its base. The sampling errors in the collection of raindrops due to tilt of the instrument (Griffiths, 1975) were not estimated in the present study.

b. Electric field

The electric field was measured with a 6 μCi polonium-210 radioactive sensor. The electronic measuring circuit consisted of an Analog Devices, electrometer operational amplifier Model 311 K. The radioactive sensor was connected to the electronic measuring circuit through a $10^{12}\ \Omega$ 100:1 voltage divider (Victoreen).

The field values were corrected for ideal exposure by multiplying it with a suitable reduction factor (Chalmers, 1967) determined previously. The minimum value of the electric field which the instrument could record was 2 V m^{-1} in the highest sensitivity range.

c. Rain intensity

A standard float-type self-recording raingage with a funnel diameter of 203 mm (India Meteorological Department) was used for the measurement of rain intensity. Continuous records of rainfall were obtained by converting the vertical displacement of the raingage float to electrical signals through a LVDT (Linear Voltage Differential Transformer) arrangement and an electronic circuit. The resolution of measurement of rainfall was 0.1 mm.

d. Rainwater conductivity

Samples of rainwater were collected over 24 h intervals in polyethylene bottles previously cleaned and rinsed with double-distilled water. The conductivity of the rainwater samples was measured on the day of collection using Philips, India, Model No. PR 9500/90 conductivity meter. The maximum relative measuring error of the instrument as specified by the manufacturers was 0.5%.

e. Cloud thickness

The thickness of the clouds over Poona during the monsoon season was obtained from aircraft pressure altimeter readings corresponding to the cloud base and cloud top level flights made in the region during the monsoon season. The measurements were made as a part of the cloud seeding experiment in the region, 40 km downwind of Poona. The values of cloud thickness are accurate to 20 m.

Synchronization of the first three sets of measurements was obtained by simultaneous recording of the parameter on a four-pen heated stylus recorder. The frequency response of the recorder used was 20 Hz which is adequate for recording the parameters with sufficient resolution.

3. Meteorological conditions at Poona

Poona is situated on the lee side of the western Ghats. The hottest period is the pre-monsoon season (March–May). From the third week of April to the first week of June the weather at Poona is characterized by intensive convective activity. Cumulonimbus development takes place on some of these days during the afternoon hours and thunderstorms with squalls, heavy precipitation and sometimes hail occur. The post-monsoon season (October–November) is characterized by frontal type thunderstorms. During the monsoon season (June–September) the region is under the influence of strong westerly air flow in the lower troposphere (up to 500 mb) which brings moist air from the Arabian Sea. Under the influence of large-scale convergence due to synoptic systems the region gets light rain with mostly overcast sky conditions. During the monsoon season more than 90% of the low cloud tops lie below the freezing level and the most frequent range of occurrence of the cloud tops is between 2.0 and 3.0 km. The average meteorological conditions at Poona are listed in Table 1.

The light and intermittent rain which is frequent during the monsoon has been classified as monsoon rain type I. The heavy and continuous rain which occurs occasionally during the strong monsoon conditions has been classified as monsoon rain type II.

4. Results

The individual raindrop charges, the associated electric field values recorded simultaneously and the

TABLE 1. Average meteorological conditions at Poona.

	Pre-monsoon (March–May)	Monsoon (June–September)	Post-monsoon (October–November)
Cloud type	Towering Cu, Cb	Sc and St	Towering Cu, Cb
Cloud base height (km, ASL)	2.1	1.5	2.1
Freezing level (km, ASL)	5.2	5.8	5.4
Percentage frequency of low clouds extending beyond freezing level	12	2	5
Normal (1901–1950) rainfall (mm)	44	503	107
Rainfall (mm) for 1973	42	639	95

TABLE 2. Average seasonal and annual values of raindrop charge (pC) and associated electric field (V m^{-1}).*

Season	Number of rain occasions studied	Charge per drop Negative	Charge per drop Positive	Charge per drop Net charge	Ratio of number of positively to negatively charged drops	Percentage number of positively charged drops	Mean electric field associated with drop carrying Negative charge	Mean electric field associated with drop carrying Positive charge	Net electric field
Pre-monsoon	16	−1.78 (4090)	1.79 (3505)	−0.130 (7595)	0.9	46.1	193 (196)	−419 (260)	−156 (456)
Monsoon Type I	3	−0.45 (231)	0.37 (341)	0.040 (572)	1.5	59.6	−57 (225)	−117 (334)	−93 (559)
Monsoon Type II	6	−0.66 (727)	0.66 (2713)	0.380 (3440)	3.7	78.9	−280 (727)	−508 (2713)	−461 (3440)
Post-monsoon	9	−0.73 (4894)	0.74 (4850)	0.005 (9744)	1.0	49.8	−478 (4725)	−707 (4613)	−591 (9338)
Annual	34	−1.15 (9942)	1.03 (11409)	0.016 (21351)	1.1	53.4	−415 (5873)	−605 (7920)	−171 (13793)

* Values in parentheses denote the number of observations of which the given value is the mean.

rain intensity values at 1 min intervals were read from the continuous recordings obtained during a number of rain occasions during the pre-monsoon, monsoon (type I and type II) and post-monsoon seasons of 1973. The average values of raindrop charge and electric field are given for the three seasons in Table 2. The data were further stratified into 13 arbitrary rain intensity groups (0–2, 2–5, 5–10, 10–15, 15–20, 20–25, 25–40, 40–60, 60–80, 80–100, 100–120, 120–140 and 140–160 mm h^{-1}) and the average values for the different groups for the three seasons are shown in Figs. 1 and 2 and Table 3.

The average raindrop charge spectra were also obtained by grouping the data into 10 arbitrary groups (0–5, 5–10, 10–15, 15–25, 25–50, 50–75, 75–90, 90–150, 150–180 and 180–270$\times10^{-13}$ C). Fig. 3 gives the distribution of the logarithm of the raindrop charge (ln$Q$) for positively and negatively charged drops for the three seasons. Raindrop charge data obtained during periods of lighting strokes were not considered in the study.

The coefficient of skewness and kurtosis have been computed for the ln Q distributions for different rain intensities for monsoon rain type II and post-monsoon rain for which adequate data over different rain intensity ranges are available. These distributions are not shown in the figure, but the values of the coefficients computed for these distributions are given in Table 4.

A plot of the cloud thickness versus rainwater conductivity is shown in Fig. 4.

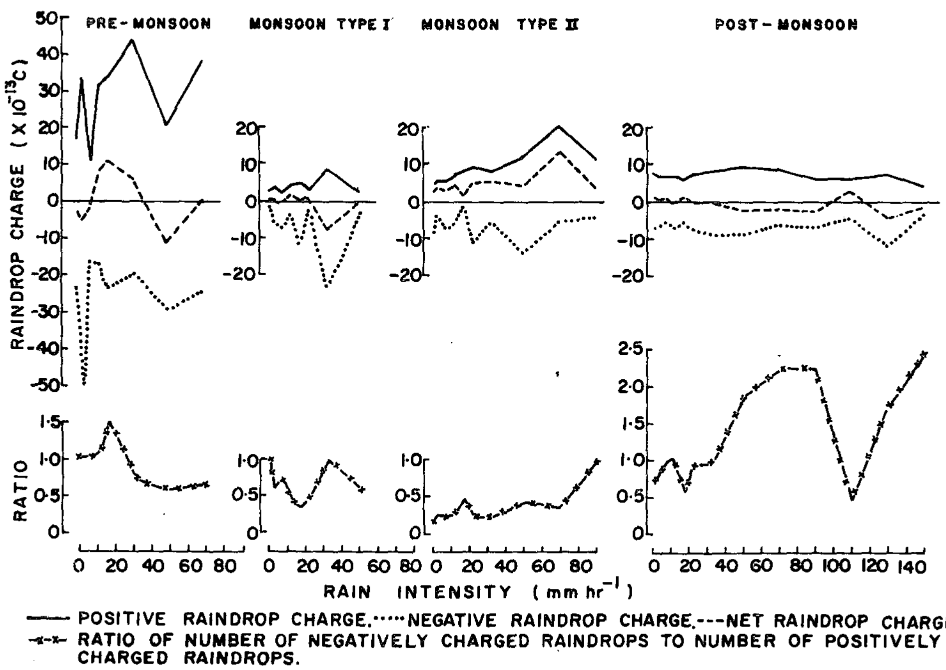

FIG. 1. Average values of the raindrop charge for the four types of rain.

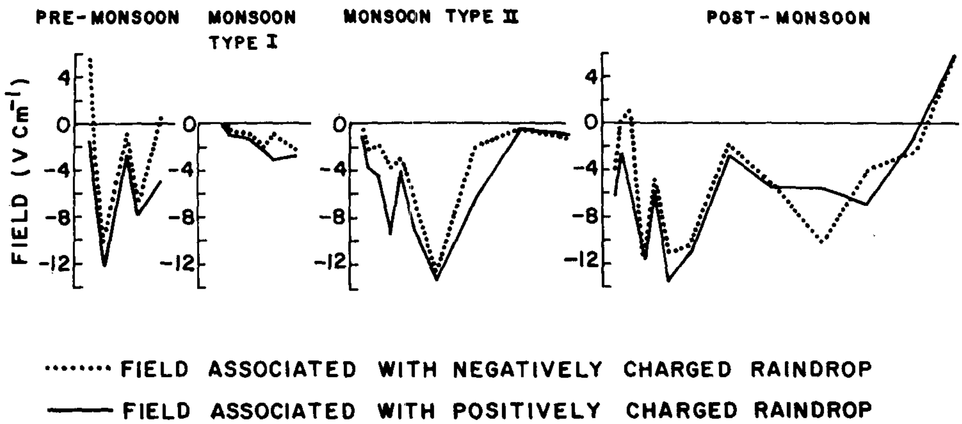

FIG. 2. Average electric field recorded simultaneously when positive and negative raindrop charges were noticed during various rain intensities.

5. Discussion

a. Raindrop charge

The average raindrop charge is significantly higher during the pre-monsoon season than during the other two seasons (Table 2). During the pre-monsoon season the convective activity is maximum due to surface heating. At any given observation time the raindrops carry charges of either sign and the magnitude of the charges vary widely during the pre- and post-monsoon seasons. However, the average magnitude of the positive and negative charges in any season is nearly equal. The average net charge per raindrop for the year is positive and small (0.016 pC). The seasonal average ratio values of the number of raindrop charges of either sign is close to unity except in case of monsoon rain type II when the raindrops carrying positive charge are predominant (Table 2). However, average values of the ratios for different rain intensity ranges (Figure 1) showed departures. These departures, however, are obscured in seasonal mean values.

b. Rain intensity, raindrop charge and electric field

The magnitude of the raindrop charge is not related to rain intensity except during monsoon rain type II when the average positive charge shows an increase with rain intensity (Fig. 1). The net average charge is positive for all the rain intensities studied. This result is consistent with earlier rain current measurements at Poona (Sivaramakrishnan, 1962).

The frequency of occurrence of negative field associated with drops of either sign is always higher. The electric field is less negative when raindrop charges are negative than when they are positive. The ratio of the number of negative field cases to the number of positive field cases is in general higher for positively charged drops (Table 3). For drops of either sign the electric field tends to become less negative and even positive on occasion at higher rainfall intensities.

c. Raindrop charge spectra

The ln Q (logarithm of raindrop charge) distribution is symmetric and platykurtic during the pre- and post-monsoon seasons (Fig. 3). It is skewed to the positive side for monsoon rain type II when about 80% of the drops carry positive charge (column 7, Table 2). Monsoon rain type I shows a normal distribution (Table 4). The distribution for monsoon rain type II is most peaked (leptokurtic) and the one for the pre-monsoon is broadest (platykurtic).

For monsoon rain type II, the drop charge spectrum width increases with intensity and approaches normal

TABLE 3. Ratio of number of negative to number of positive field cases associated with drops of either sign.*

Season	Raindrop charge sign	Rain intensity intervals (mm h^{-1}) 0–2	2–5	5–10	10–15	15–20	20–25	25–40	40–60	60–80	80–100	100–120	120–140	140–160
Pre-monsoon	+	1.4	2.0	21.5	—	*	*	6.5						
	−	0.7	0.7	9.5	—	2.0	*	0.3						
Monsoon	+	5.4	85.6	130.5	59.9	236.0	*	34.4	74.0	*	*			
	−	1.7	24.3	50.0	140.0	*	*	61.0	30.0	*	*			
Post-monsoon	+	2.7	3.0	3.1	4.0	3.5	9.0	5.7	1.7	6.2	4.2	*	1.4	0.5
	−	1.6	1.3	0.9	2.1	1.5	4.8	2.5	1.1	2.6	6.0	*	0.4	0.5

Asterisks indicate no cases of positive electric field.

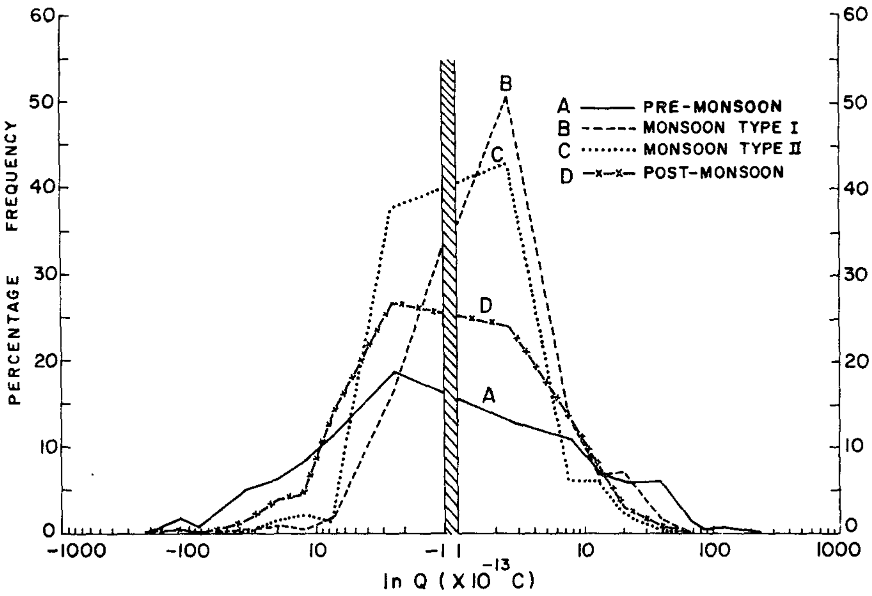

FIG. 3. Distribution of raindrop charge Q.

distribution (Table 4). During the post-monsoon season, the distribution is normal for most of the intensities above 10 mm h^{-1}. The distribution is platykurtic for the lower intensities. Charge distribution was found to be normal in cold frontal systems (Bradley and Stow, 1974).

d. Rainwater conductivity

An inverse relation is noticed between conductivity and cloud thickness (Fig. 4), in agreement with the results of Takahashi and Fullerton (1972).

There was heavy continuous monsoon rain type II during 6–8 July 1973. The average value of the conduc-

TABLE 4. Characteristics of ln$Q$ distribution for different rain intensities during the three seasons.

Season	Rain intensity range (mm h^{-1})	Total number of drops in each distribution	Skewness	Kurtosis	Remarks
Pre-monsoon	T*	7595	0.068	−1.156	S, P
Monsoon type I	T	572	−0.407	0.587	normal
Monsoon type II	T	3440	−0.677	1.037	+AS, L
Post-monsoon	T	9744	−0.021	−1.004	S, P
Monsoon type II	0–10	1967	−0.704	1.745	+AS, L
	10–20	858	−0.585	0.531	+AS, normal
	20–40	488	−0.818	0.608	+AS, normal
	40–60	106	−0.692	−0.560	+AS, normal
	60–80	19	−0.817	−0.878	+AS, normal
Post-monsoon	0–10	4486	−0.083	−1.048	S, P
	10–20	1681	−0.126	−0.979	normal
	20–40	1668	−0.133	−0.889	normal
	40–60	1119	0.291	−0.838	normal
	60–80	377	0.482	−0.546	normal
	80–100	292	0.453	−0.736	normal
	100–120	13	−0.709	−0.619	+AS, normal
	120–140	67	0.179	−1.209	S, P
	140–160	41	0.635	−0.564	−AS, normal

* Total for all rain intensities.
Standard error for skewness = 0.244. Standard error for kurtosis = 0.489. S: Symmetric. P: Platykurtic. L: Leptokurtic. +AS: skewed to the positive side. −AS: skewed to the negative side.

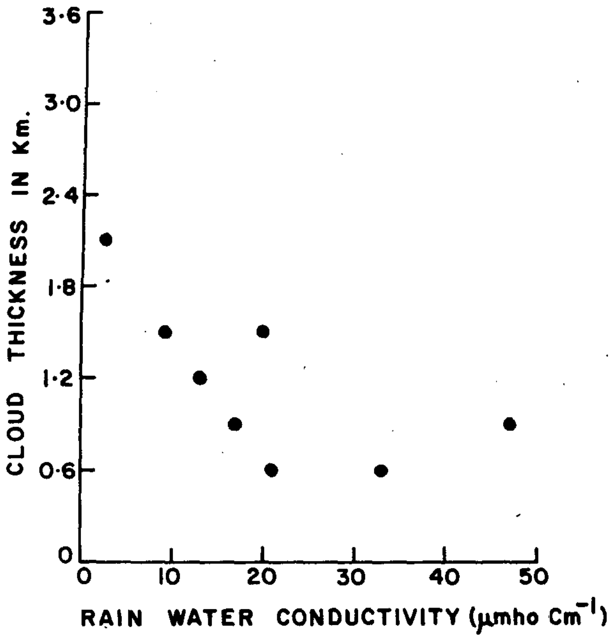

FIG. 4. Rainwater conductivity and cloud thickness for monsoon rain type I.

tivity of rainwater samples collected during the period was as low as 4.2 μmho cm^{-1} as compared to the average value of 34.0 μmho cm^{-1} for monsoon rain type I. The very low values of rainwater conductivity noticed during monsoon rain type II indicate that the heavy continuous rain could be from clouds with greater vertical extent. The larger values of raindrop charge and electric field recorded during monsoon rain type II (Table 2) are consistent with the above result.

6. Conclusions

A study of the raindrop charge, the associated atmospheric electric field and the rain intensity during pre-monsoon, monsoon and post-monsoon seasons suggests the following:

1) The electric field associated with negatively charged raindrops is less negative than that associated with positively charged drops. This could be a manifestation of the mirror image effect (Chalmers, 1967).

2) The charge distributions are significantly different for the four types of rain studied. The spectrum shows a platykurtic distribution during the pre-monsoon and post-monsoon seasons. It is broadest during the pre-monsoon when the convective activity was maximum. The raindrop charge spectrum is log-normal for monsoon rain type I and is peaked and skewed to the positive side for monsoon rain type II.

3) The log-normal distribution observed during monsoon rain type I with weak electrification could be due to the raindrops acquiring their charges by the Wilson's ion capture process from naturally occurring space charges between the cloud base and the ground.

4) The positively skewed charge distribution associated with the thicker clouds of monsoon rain type II with stronger electrification would help corroborate the warm cloud charge generation mechanism proposed by Takahashi (1974).

The raindrop charges as measured at the surface may not be exactly representative of in-cloud conditions. However, the results may prove useful for the understanding of the cloud electrification mechanisms in the region. Simultaneous raindrop size measurements would have greatly increased the value of the results, especially in explaining the distributions of raindrop charge in different rain types.

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