Electrical and Microphysical Measurements in Warm Cumulus Clouds Before and After Seeding

A. S. RAMACHANDRA MURTY, A. M. SELVAM, R. VIJAYAKUMAR, S. K. PAUL AND BH. V. RAMANA MURTY

Indian Institute of Tropical Meteorology, Poona—411 005

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ABSTRACT

Electrical and microphysical measurements were made in warm maritime and inland cumulus clouds, before and after seeding, by repeated aircraft penetrations at a single level, a few hundred meters above cloud base. Such measurements were also made in non-seeded clouds by single penetrations during transient flights.

The electric field initially was negative in the maritime clouds which developed rain. In the cloud case which dissipated without rain it was initially positive. The field showed sign reversal with time, occasionally preceded by intensification, in all maritime clouds. The field initially was positive in inland clouds. It showed no time variation except in one cloud case where both positive and negative fields were recorded during the period of heavy rain.

The droplet charge, droplet median volume diameter and liquid water content showed no marked time variation in either maritime or inland clouds. However, in the cloud case which developed heavy rain marked increases in droplet median volume diameter and liquid water content were recorded.

The time variations of electrical and microphysical parameters following seeding are in general within the range of their natural variability.

1. Introduction

Simultaneous measurements of electrical and microphysical parameters in seeded and non-seeded clouds will contribute significantly to our understanding of seeding effects (MacCready and Takeuchi, 1970; Mogila, 1972). Such measurements will also be valuable for understanding the interaction between cloud physical and atmospheric electrical phenomena. Several studies reported in this regard were reviewed (Imyanitov *et al.*, 1971). The possible application of electrical forces in warm cloud modification was theoretically examined (Shvarts, 1972). However, simultaneous measurements of electrical and microphysical parameters in warm cumulus clouds subjected to seeding are scanty. The present authors have had an opportunity of making aircraft measurements in warm maritime and inland cumulus clouds as part of the salt seeding experiments conducted at Bombay (18°51′N, 72°49′E, 11 m MSL) and Rihand (24° 12′N, 83°03′E, 310.5 m MSL) in the summer monsoon of 1974. A summary of the measurements is presented below.

2. Experiments

The details of the salt seeding experiments have been described elsewhere (Krishna *et al.*, 1974; Kapoor *et al.*, 1974). The points relevant in the present context are mentioned here. When isolated cumulus clouds were present in the area, repeated aircraft penetrations were made at a single level, a few hundred meters above the cloud base. Commencing from either the second or the third traverse seeding material was released into the cloud, through a special gadget fitted to a DC-3 aircraft, at the rate of 20–30 kg per 3 km of flight path, until the termination of the final traverse.

Several transient flights were also made in the two regions before the beginning of the experiments. During these flights in-cloud measurements were made at different altitudes. These observations represent the natural conditions of the clouds in the two regions. The values corresponding to the flight levels of the measurements in seeded clouds were considered in the present study.

3. Measurements

The parameters measured are 1) vertical component of the atmospheric electric field, 2) droplet charge, 3) liquid water content and 4) drop size distribution. Since these measurements were made within a few hundred meters above the cloud base, they represent only the conditions in the lower regions of the clouds. Also, visual observations were made on the development of rain, cloud dissipation, etc.

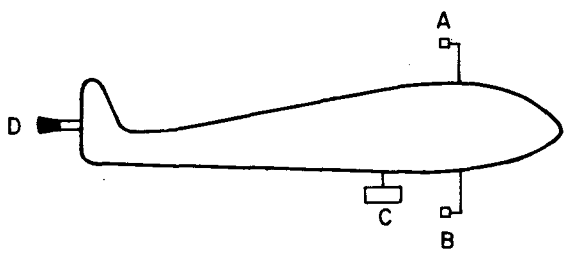
4. Equipment

The instruments used for the measurements were designed and fabricated. Their details have been described elsewhere (Selvam *et al.*, 1976). The locations of the different sensors on the aircraft are shown in Fig. 1. The important details of the instruments are given below.

The electric field was measured with dual radioactive probes using a 500 μCi auto-pilot source (P 210) supplied by M/S Radio Chemicals, U.K. The probes were fitted symmetrically, one at the top of the fuselage and the other vertically below the belly of the aircraft. The measuring apparatus is similar to the one used by Vonnegut and McCaig (1960) and its output was monitored on a four-pen heated stylus recorder. It measures the field in the vertical direction at right angles to the line of flight. The values of the field have not been corrected for distortion by the aircraft.

The corona current was measured through a static discharger mounted on the tail of the aircraft. Measurements of corona current were made use of in the present study only to the extent that field values recorded during periods of corona were *not* considered in the analysis. The distortion effect on the electric field by corona discharge was thus avoided.

Droplet charges were measured by the double-sheath induction technique, using an apparatus similar to that described by Latham and Stow (1969). The output from the two induction rings was measured as a continuous current using two Keithly Model 310 operational amplifiers and recorded on the two adjacent channels of the heated stylus recorder. The charges on individual drops were computed from the drop charge current and the computed number concentration of droplets passing through the cross sectional area of the induction ring. Only the droplet charge values obtained from the recordings relating to the rear ring were made use of in the study. The values relating to the front ring were not considered in order to avoid any possible errors due to the direct impact of the cloud droplets on the ring. The absolute values of the computed droplet charges are not precise because of the low frequency response of the recorder (20 Hz).



A & B : Po-210, 500 microcurie radio-active probes for measurement of the atmospheric electric field.

C : Induction ring for measurement of cloud droplet charges.

D : Static discharger for measurement of corona current emitted by the aircraft.

FIG. 1. Locations of sensors on the aircraft.

Liquid water content was measured with a J-W Hot Wire Meter Model LWH having a range of 0–3 gm m^{-3}.

A spring-loaded droplet sampler containing magnesium-oxide coated glass slides was used for sampling cloud droplets. The details of the drop size distribution measurements were reported by (Kapoor *et al.*, 1976).

5. Results

Measurements were made in five maritime clouds in the region off the coast at Bombay during 22–25 September 1974 and in five inland clouds at Rihand during 10–11 September 1974. The depth of the maritime clouds varied from 0.9 to 1.2 km and that of the inland clouds from 1.2 to 2.1 km. Measurements were made before and after seeding in all the cloud cases at Bombay and in four out of the five clouds at Rihand. In the remaining single case at Rihand, measurements were made but no seeding was done. The cloud base at Bombay and Rihand, during the period of measurements, was generally at 600 and 1500 m MSL, respectively. The diameter of the cloud at the penetration level ranged from 5–10 km at Bombay and 5–15 km at Rihand.

The number of traverses made through each cloud varied from 3 to 7. Measurements were made along all traverses, but seeding commenced during either the second or the third traverse. Because all the sensors on the aircraft were forward of the location of release of the seeding agent, measurements during the first seeding traverse were considered to represent natural conditions. Thus measurements made during the first two traverses through clouds 3 and 4 at Bombay and clouds 1, 2, 4 and 5 at Rihand and during the first three traverses through clouds 1, 2 and 5 at Bombay were taken to represent natural conditions. These traverses are hereafter referred to as initial traverses. Cloud 3 at Rihand was not seeded in any of the traverses.

Only single traverses were made in the clouds which were sampled in the transient flights. Measurements in these flights were made use of for estimating the natural variability of the different parameters in the clouds in each region although they cannot serve as random controls.

a. Bombay (*maritime clouds*)

The maximum and minimum values noted of the electric field, droplet charge and liquid water content (LWC), the values of droplet median volume diameter

TABLE 1. Electrical and microphysical observations in clouds off the Coast of Bombay.

Cloud	Traverse	Sign†	Vertical field (V m^{-1}) Max positive	Min positive	Max negative	Min negative	Sign†	Cloud droplet charge (10^{-7} esu) Max positive	Min positive	Max negative	Min negative	Medium volume diameter (μm)	Liquid water content (g m^{-3}) Max	Min	Visual observation
1	I*	−			99.2	17.7	±	3.09	0.21	2.67	0.30	16.96	0.9	0.1	No rain
	II*	−			99.2	14.2	±	3.09	0.51	2.67	0.84	16.34	1.0	0.1	No rain
	III*	−			99.2	35.2	±	1.02	0.09	1.56	0.21	17.06	1.0	0.1	No rain
	IV	−			105.6	24.8	±	3.39	0.21	2.01	0.21	18.50	1.3	0.3	Rain
	V	+	135.0	45.0			±	3.30	0.30	2.07	0.30	18.24	1.0	0.1	Rain
	VI	+	225.0	67.5			±	0.09	0.00	0.21	0.09	19.83	0.8	0.1	Rain
	VII	+	225.0	180.0			+	0.00	0.00	0.21	0.00	19.90	0.7	0.1	No rain
2	I*	−			99.2	16.0	−	2.28	0.21	0.84	0.21	—	0.9	0.2	No rain
	II*	−			112.5	7.1	∓	3.60	0.21	1.35	0.30	—	0.9	0.2	No rain
	III*	−			225.0	45.0	∓	3.09	0.30	1.23	0.09	20.46	1.4	0.4	No rain
	IV	−			22.5	0.0	∓	3.60	1.02	0.84	0.30	—	0.8	0.4	No rain
	V	+	225.0	157.5			+	0.21	0.00	0.09	0.00	26.30	1.0	0.1	No rain
	VI	−			96.6	9.6	±	3.60	0.21	0.63	0.21	24.54	1.0	0.1	Rain
	VII	+	90.0	22.5			+	3.81	0.42			—	1.3	0.1	Rain
3	I*	+	35.2	9.6			+	0.21	0.00			20.28	0.9	0.1	No rain
	II*	∓	24.8	3.3	17.7	3.5	Nil					—	0.8	0.1	No rain
	III	−			48.0	3.5	Nil					18.46	0.6	0.1	Dissipating
	IV	−			67.2	24.8	Nil					18.47	0.5	0.1	Dissipating
	V	−			83.2	25.6	−			0.42	0.09	16.13	0.9	0.1	Dissipating
	VI	−			51.2	7.1	±	0.51	0.09	0.21	0.00	—	0.3	0.1	Dissipating
4	I*	−			24.8	7.1	+	0.42	0.21			19.87	0.7	0.1	No rain
	II*	−			51.2	32.0	+	0.42	0.21			17.92	0.5	0.1	No rain
	III	−			10.6	3.5	+	0.30	0.09			19.34	0.5	0.1	No rain
	IV	−			48.0	10.6	+	0.42	0.09			24.06	0.5	0.1	No rain
	V	±	32.0	7.1	24.8	10.6	+	0.21	0.09			—	0.6	0.1	No rain
	VI	∓	16.5	9.9	24.8	10.6	+	0.30	0.09			—	0.7	0.1	Rain
	VII	∓	40.4	9.9	10.6	7.1	+	0.21	0.09			21.62	0.7	0.1	Rain
	VIII	±	29.4	9.9	35.2	7.1	+	0.21	0.09			—	0.7	0.1	No rain
	IX	∓	13.2	6.6	24.8	14.2	+	0.42	0.09			21.34	0.6	0.1	Rain
5	I*	−			17.7	3.5						15.79	0.5	0.1	No rain
	II*	−			14.2	33.5						—	0.4	0.1	No rain
	III*	−			8.9	3.5						16.42	0.6	0.1	No rain
	IV	+	33.1	9.9				No data				18.54	0.6	0.1	No rain
	V	+	21.8	3.3								18.70	0.5	0.1	No rain
	VI	−			54.4	7.1						21.18	0.8	0.1	Rain
	VII	±	16.5	3.3	28.8	14.2						18.12	—	—	No rain

* These traverses represent natural conditions.
† Values shown as ± indicate initial field is positive, ∓ that initial field is negative.

(MVD), and the salient points of the visual observations are given traverse-wise, for the five seeded clouds in Table 1.

1) Electric field

The value varied from a few tens to a few hundreds of volts per meter. In the initial traverses, it was negative in four cases (Clouds 1, 2, 4 and 5). In the subsequent traverses, it showed a sign reversal, occasionally preceded by intensification. Rain was noticed in these four cases. In the fifth case (Cloud 3), the field was positive in the initial traverse. It showed sign reversal and intensification with time. This cloud dissipated without rain.

2) Droplet charge

Measurements were available in four cases (Clouds 1–4); the value was in the range 0.02 to 0.39×10^{-6} esu. Positive charges or a combination of positive and negative charges were noticed in the initial traverses. In the subsequent traverses, either positive or predominantly positive charges were noted in the three cases (Clouds 1, 2 and 4) which developed rain. In the case of Cloud 3, which dissipated without rain, there were no detectable charges in some traverses.

3) Median volume diameter

The value ranged from 15.8 to 26.3 μm. It was slightly higher (up to 1.2 times) in the subsequent traverses than in the initial traverses in the cloud cases which developed rain. They decreased in the subsequent traverses of the cloud case which dissipated without rain.

4) LIQUID WATER CONTENT

The value ranged from 0.1 to 1.4 g m^{-3}. The time variation was similar to that of the median volume diameter. The liquid water content increased (up to 1.6 times) in the subsequent traverses in the cloud cases which developed rain.

b. Rihand (inland clouds)

The data for the five cloud cases studied are given in Table 2.

1) ELECTRIC FIELD

The value varied from a few tens to a few hundred volts per meter. The field was positive in all the traverses of Clouds 1, 3, 4 and 5. However, Cloud 2, which developed heavy rain, contained both positive and negative fields in traverses IV and V.

2) DROPLET CHARGE

The value was in the range 0.01 to 0.33$\times 10^{-6}$ esu. The charges were negative in all the traverses made in Cloud 3. In the other cloud cases, both positive and negative charges were present in the initial as well as in the subsequent traverses.

3) MEDIAN VOLUME DIAMETER

Measurements were available only in Cloud 2. The value decreased (up to 0.4 times) in the subsequent traverses.

4) LIQUID WATER CONTENT

The value ranged from 0.1 to $>$3.0 g m^{-3}. Cloud 2 showed a marked increase and Cloud 5 a marked decrease in the subsequent traverses.

c. Natural variability versus variations following seeding

The computed mean values of the different parameters and their standard deviations for the non-seeded clouds during the transient flights at Bombay and Rihand are given in Tables 3 and 4, respectively.

1) BOMBAY

Examination of Tables 1 and 3 points out that, except for the electric field, the parameter time variations following seeding are not significant. The increases noticed in the electric field are significant at the 5% level in Clouds 1 and 2 only.

TABLE 2. As in Table 1 except for clouds at Rihand.

			Vertical field (V m^{-1})					Cloud droplet charge (10^{-7} esu)				Medium volume diameter	Liquid water content (g m^{-3})		
Cloud	Traverse	Sign†	Max positive	Min positive	Max negative	Min negative	Sign†	Max positive	Min positive	Max negative	Min negative	(μm)	Max	Min	Visual observation
1	I*		No data				±	0.42	0.21	3.09	0.42	No data	0.8	0.1	No rain
	II*	+	186.7	133.3			±	0.51	0.21	3.09	0.72	No data	0.7	0.1	Rain
	III	+	186.7	77.1			±	3.09	0.09	3.09	0.21	No data	1.0	0.1	Rain
	IV	+	186.7	106.7			±	3.09	0.09	3.30	1.35	No data	1.1	0.2	Rain
2	I*	+	186.7	133.3			∓	3.09	0.21	3.09	0.72	28.64	0.8	0.1	No rain
	II*	+	160.0	77.1			±	0.30	0.09	3.09	0.21	42.00	2.0	0.1	No rain
	III	+	160.0	77.1			±	3.09	0.30	3.09	0.72	40.00	>3.0	0.1	Heavy rain
	IV	±	160.0	51.4	90.0	22.5	−			3.09	1.56	No data	2.0	0.1	Heavy rain
	V	±	186.7	26.7	12.9	0.0	∓	3.09	0.21	3.18	0.42	15.32	0.5	0.1	Heavy rain
3	I*	+	186.7	51.4			−			2.88	0.21	No data	0.4	0.1	No rain
	II*	+	160.0	77.1			−			1.14	0.30	No data	0.3	0.1	No rain
	III*	+	160.0	51.4			−			3.00	0.21	No data	0.3	0.1	No rain
4	I*	+	240.0	51.4			±	0.30	0.30	3.09	3.09	No data	0.4	0.1	No rain
	II*	+	240.0	106.7			±	3.09	0.63	3.09	0.21	No data	0.7	0.1	No rain
	III	+	240.0	51.4			±	3.00	0.21	2.67	0.63	No data	0.8	0.1	No rain
5	I*	+	240.0	77.1			±	3.00	0.84	3.09	0.42	No data	0.6	0.1	No rain
	II*	+	240.0	51.4			±	3.09	1.44	3.00	0.30	No data	0.9	0.1	Dissipating
	III	+	240.0	133.3			±	3.09	0.21	3.09	0.30	No data	0.4	0.1	Dissipating
	IV	+	240.0	106.7			−			3.09	0.42	No data	0.3	0.1	Dissipating

Footnotes as in Table 1.

TABLE 3. Mean values and standard deviations of the given parameters based on measurement in transient flights (unseeded clouds) at Bombay. Figures in parentheses denote the number of cloud cases of which the given value is the mean.

	Field (V m^{-1}) Positive	Field (V m^{-1}) Negative	Cloud drop charge (10^{-7} esu) Positive	Cloud drop charge (10^{-7} esu) Negative	Medium volume diameter (μm)	Liquid water content (g m^{-3})
Maximum	22 (25)	−96 (24)	3.660 (11)	−2.391 (14)		0.70 (39)
Standard deviation	8	95	1.356	0.804		0.30
Average	14 (25)	−65 (24)	3.093 (11)	−1.350 (14)	17.17 (9)	0.40 (37)
Standard deviation	7	72	1.728	0.582	2.67	0.15

TABLE 4. As in Table 3 except for unseeded clouds at Rihand.

	Field (V m^{-1}) Positive	Field (V m^{-1}) Negative	Cloud droplet charge (10^{-7} esu) Positive	Cloud droplet charge (10^{-7} esu) Negative	Medium volume diameter (μm)	Liquid water content (g m^{-3})
Maximum	146 (44)	Nil	1.335 (26)	−2.196 (29)		0.84 (35)
Standard deviation	63		1.026	1.182		0.65
Average	86 (44)	Nil	0.831 (26)	−1.659 (29)	40.9 (86)	0.44 (35)
Standard deviation	60		0.771	1.110	27.9	0.20

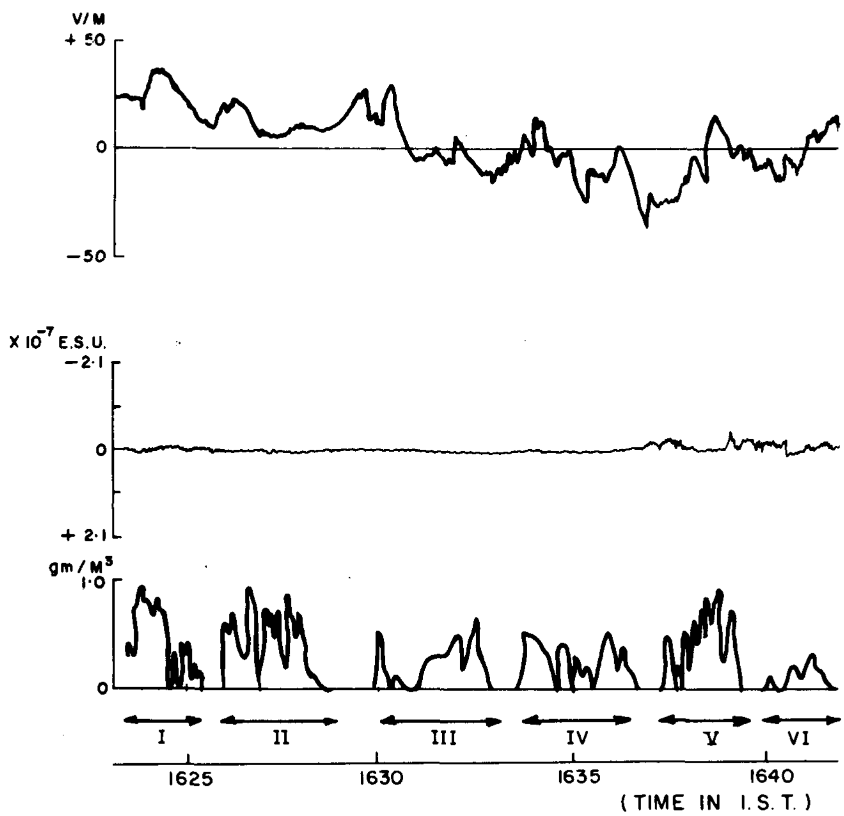


FIG. 2. Variations of potential gradient, cloud droplet charge and liquid water content during cloud traverses I–VI case 3, dissipation, at Bombay on 24 September 1974.

2) RIHAND

Examination of Tables 2 and 4 points out that, except for liquid water content, the parameter time variations following seeding are not significant. The increase noticed in liquid water content is significant at 5% level in traverse III of Cloud 2.

d. Sample data

Sample variations of electric field, droplet charge and liquid water content along the flight path of each traverse for one cloud case each of dissipation and rain are given in Figs 2 and 3 respectively.

6. Discussion and conclusion

A study was made of the time variations of the electrical and microphysical parameters in warm clouds before and after seeding. The features in maritime and inland clouds differed in some respects.

In the maritime clouds which developed rain the vertical electric field was initially negative. The field showed a sign reversal, occasionally preceded by intensification, before the onset of rain. In the inland clouds the field initially was positive and showed no time variation except in the cloud case which developed heavy rain during which period both positive and negative fields were noticed. Insofar as the other parameters (cloud drop charge, droplet median volume diameter and liquid water content) are concerned, there was no systematic or marked time variation in either maritime or inland clouds.

The maximum value of the electric field recorded was 225 and 240 v m^{-1} in maritime and inland clouds, respectively. The minimum value was zero in maritime clouds. The maximum value of cloud droplet charge recorded was 3.81 and 3.30×10^{-7} esu, respectively, in maritime and inland clouds. The minimum value was zero in maritime clouds. The median volume diameter ranged between 15.79 and 26.30 μm in maritime clouds. The maximum liquid water contents recorded in maritime and inland clouds were 1.3 and >3 gm m^{-3}, respectively. These values are within the range of those reported in the literature (Takahashi 1973, 1975; Takeuchi, 1972; Sax, 1974).

The size of the data sample (Tables 1 and 2) is quite small and the variability of the several parameters is

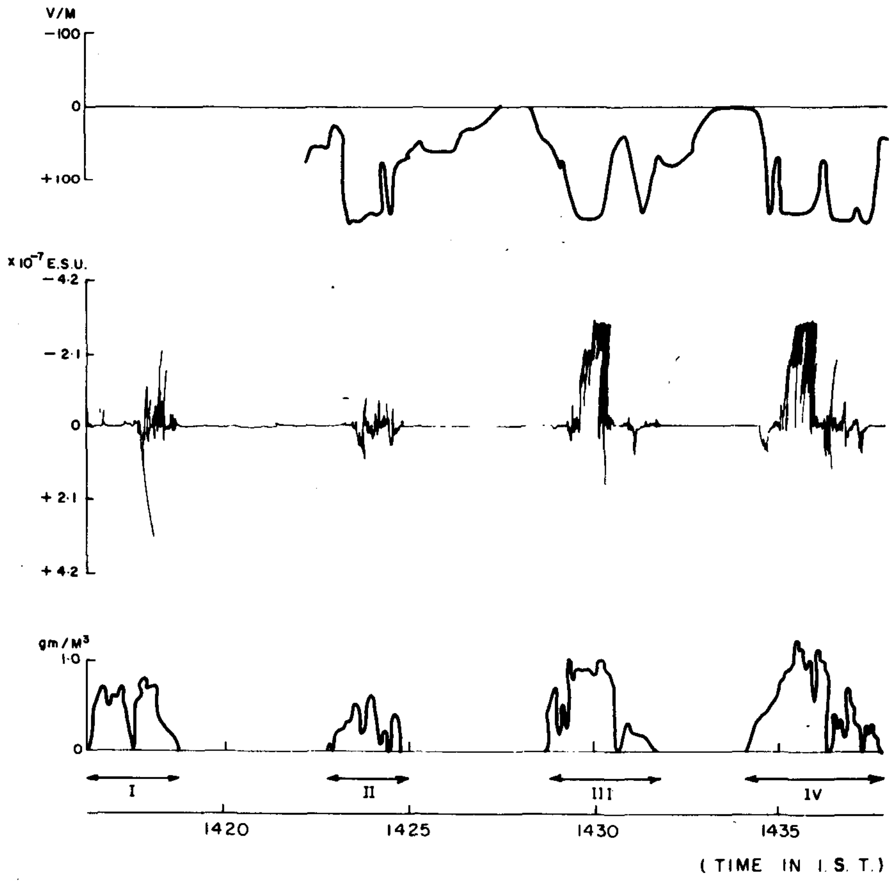


FIG. 3. As in Fig. 2 except for cloud traverses, I–IV, in Cloud 1, rain development, at Rihand on 10 September 1974.

quite large (Tables 3 and 4). The time variations of these parameters following seeding are not significant in most of the cases. It is therefore difficult to evaluate the seeding effect from the present measurements, since the natural variability of the parameters measured masks any implied seeding effect in the small sample available.

Observations are required in several seeded clouds as well as in control clouds for a better understanding of the time variations of cloud electrical and microphysical parameters following seeding.

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