Indian Journal of Radio & Space Physics
Vol. 24, December 1995, pp. 297-307

Estimation of electrical charges deposited to the ground by lightning in thunderstorms at Pune

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Received 25 July 1994; revised received 15 May 1995; accepted 2 June 1995

Ground-based data of electric field measured at Pune during lightning events of nine thunderstorms have been analysed to obtain the spatial and temporal variation of the charges that are deposited to the ground. The results are based on some assumptions such as the large transient changes in electric field of at least 1 kVm^{-1} for which the flash of lightning was visible and the subsequent sound of the thunder was well heard. The inter-storm average charge per flash varied in the range -19 to -147 and $+19$ to $+44$ C and the storms aggregate mean values were -42 and $+37$ C per flash. The spatial variation suggested that the radial distance of the lightning-strike underneath the storm tended to cluster within the distance of 6 km. The time variation of the charge and strike distance underneath the storm showed localization of radial strike distances associated with the increase in charge values. The study has also permitted one for the direct validation of the analytical result of Malan [*Physics of Lightning* (The English Uni Press, London), 1963, p. 30] that the value of the electric field ($\sin\theta \cos^2\theta$) at a fixed location due to the vertical motion of the charge exhibits maxima when $\tan\theta$ ($= H/D$) is 0.707.

1 Introduction

Lightning and the accompanying sound of thunder are the two most spectacular and horrifying phenomena which are usually noticed in a thundercloud during its life cycle. Studies[1-5] on the observations of lightning-associated electric field have yielded information on the characteristics of the field changes, average estimates of charge deposited to the ground and the recovery patterns of electric field following the lightning. These studies[6-13] were carried out more regularly in different parts of the world. Similar studies at low latitudes and, especially, in the southern parts of Indian subcontinent appeared to be infrequent[14-21]. This study proposes to illustrate the observed records of electric field accompanying the events of lightning and furnishes the results derived therefrom at Pune (lat., 18°32'N; long., 73°51'E, 559 m a.s.l.), a station on the Deccan Plateau region of Indian peninsula.

2 Electric field observations

Atmospheric electric potential was measured by the potential equalization method[22,23]. The details of the electronics and the accuracy of the measurement of this system are described elsewhere[24-26]. During the thunderstorm conditions, the magnitude of the surface atmospheric electric potential gradient is usually high and, occasionally, the extreme value may be about ± 10 kVm^{-1}. To accommodate such extreme values, the probe (Po-210; 6 μCi) height was maintained around 20 cm above the surface[23] of the open terrace of the observatory building at Pune during observation period. The potential of the probe was noted with respect to the ground and expressed as potential gradient. The fair weather convention of potential gradient is positive and the potential gradient data, in this study, are termed as electric field. The chart drive speed during observation period was ≥ 1 cm per minute. The 1 s time constant of the recorder was too slow to resolve the individual leader and return strokes of lightning flash, but it was probably[3] adequate to represent the entire flash since the chart drive speed was ≥ 1 cm per minute. The notings of sudden transition in field record, visible glow of lightning and the times of thunder heard after lightning were made carefully. The results in this paper are derived from the large field changes that are produced by the entire flash.

Table 1 presents information on dates of thunderstorms, times of observation, number of flashes studied of either polarity and average

Table 1—Observations of lightning activity during thunderstorms at Pune

Date of thunderstorms	Time of observation hrs IST	Negative lightning flashes			Positive lightning flashes		
		No.	Av. charge per flash C	Av. strike distance per flash km	No.	Av. charge per flash C	Av. strike distance per flash km
31 May 1973	1625-1715	15	−25.8 (21.3)	4.82 (2.4)	3	+18.5 (7.8)	2.1 (1.3)
14 May 1974	1530-1645	6	−55.55 (55.1)	6.6 (2.6)	3	+42.2 (12.7)	3.2 (2.0)
16 May 1974	1352-1630	0	—	—	10	+43.0 (11.7)	4.2 (1.0)
22 May 1974	1458-1710	25	−28.6 (15.5)	4.3 (2.3)	8	+27.6 (14.1)	3.5 (1.5)
24 May 1974	1140-1230 and 1510-1540	29	−33.8 (15.2)	5.4 (3.5)	25	+36.9 (12.5)	4.1 (2.9)
27 May 1974	1230-1305	11	−56.7 (50.9)	6.73 (4.6)	7	+42.0 (17.8)	2.8 (1.2)
7 June 1977	1625-1658	13	−19.3 (10.8)	3.8 (2.4)	5	30.0 (6.0)	3.3 (1.6)
14 June 1977	1430-1555	26	−67.5 (48.1)	6.4 (2.5)	0	—	—
16 June 1977	1559-1642	1	−146.8	9.0	4	43.6 (8.1)	6.0 (0.6)

Note:
(i) Weighted mean of 126 negative flashes: −41.2(30.98) coulomb charge per flash is deposited at 5.4 km (1,5)
(ii) Weighted mean of 65 positive flashes: +37.3(10.8) coulomb charge per flash is deposited at 3.8 km (1.5)
(iii) Figures in parenthesis indicate standard deviation

charge and strike distance per flash at Pune. Figures 1 and 2 present a few samples of records of electric field associated with lightning studied by other workers elsewhere, and those at Pune, respectively.

3 Nomenclature

The usually noted types of lightning flashes have been described as (a) cloud to air flashes; (b) cloud flashes or intra-cloud flashes (IC); and (c) cloud-to-ground (C-G) flashes. Of these, the C-G type flashes are of prime importance because they measure the free electrical charge transferred to the surface of the earth. For such flashes, the sound of the thunder is heard almost invariably and the more intense and closer the flash, the more violent is the sound of the thunder[19]. The net effect of the C-G flash is to remove electrical charge from the cloud and dissipate it to the ground[2,5,11]. Under such circumstances the electric field at the ground exhibits a series of frequent transient changes in the field polarity caused by lightning flashes. Fig. 1 [(a)-(d)] shows one high-frequency-fast-resolution record and a few fast-resolution records of lightning-associated electric field taken from elsewhere. In the C-G lightning studies the commonly assumed cloud charge model is the point charge model[5]. With this assumption the field change (ΔE) is expressed as:

$$\Delta E_{\pm} = \frac{2\Delta QH}{4\pi\varepsilon_0(H^2+D^2)^{3/2}} \qquad \ldots (1)$$

Since C-G lightning flash could transfer either positive or negative charge to ground, following sign convention is adopted in the literature. Accordingly, a flash that dissipates positive charge (ΔQ_+) to the ground is termed as a flash of positive (P) polarity and the one that dissipates negative charge (ΔQ_-) is termed as a flash of negative (N) polarity. Consequently, the net change caused underneath a storm in the ground electric field (ΔE) is negative for a positive flash and positive for a negative flash. The net change in the field ($\Delta E_{\pm}$) was obtained as the difference of field value at the end (F_B) and the beginning (F_A) of the flash (see record for 27.5.1974 in Fig. 2). Thus, it is noted that a positive change in the field (ΔE_+) corresponds to dissipation of negative charge (ΔQ_-) to the ground and vice-versa.

4 Criteria adopted for the identification of C-G lightning flash and method of analysis

Many workers[5,9,10,12,13] have examined the C-G lightning flash events in detail in relation to the ground electric field records. Accordingly, in order to minimize the possible uncertainties in the present results and to ensure that the results are more realistic and meaningful the following conditions were imposed as threshold bias for the

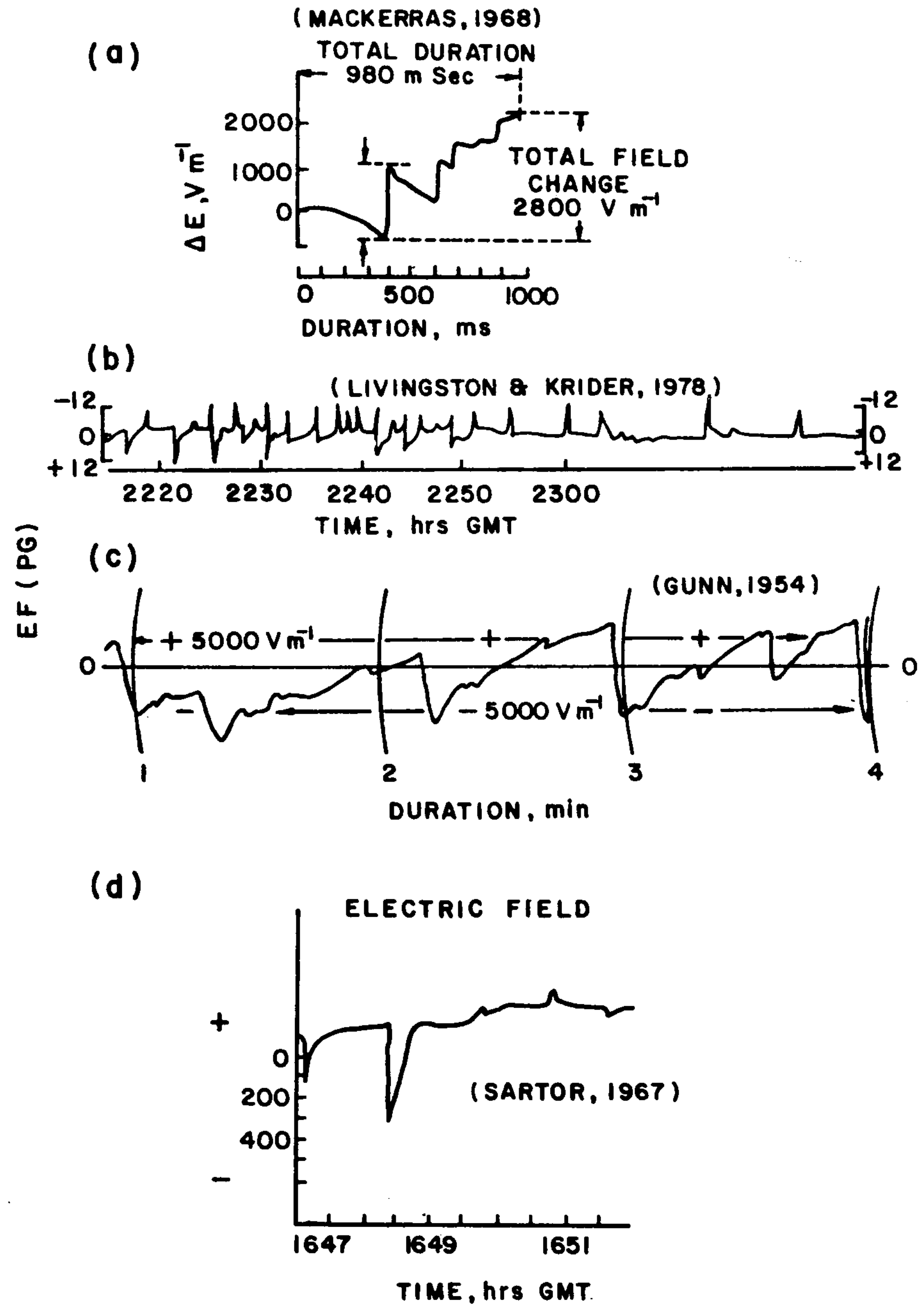

Fig. 1—Sample records of a series of frequent transient changes in the ground electric field due to lightning activity [Ordinate in these records indicates scale of electric field while abscissa shows time. Record at (a) is a high frequency fast speed record. Field responses of individual leader and return strokes, the total field change ($\Delta E = 2800$ Vm^{-1}) and the total duration (980 ms) of flash are seen. Rest of the records (b-d) are fast speed records].

identification of a C-G flash:

(i) The electric field record should show a transient change in electric field.

(ii) The transient change should be simultaneously associated with the visible flash of lightning.

(iii) The flash of lightning should be followed by a loud sound of thunder.

(iv) The transient change in electric field should be $\geq 1\ kVm^{-1}$.

It is believed that these requirements help in eliminating mostly all small discharges and many distant flashes. It is, therefore, assumed that the

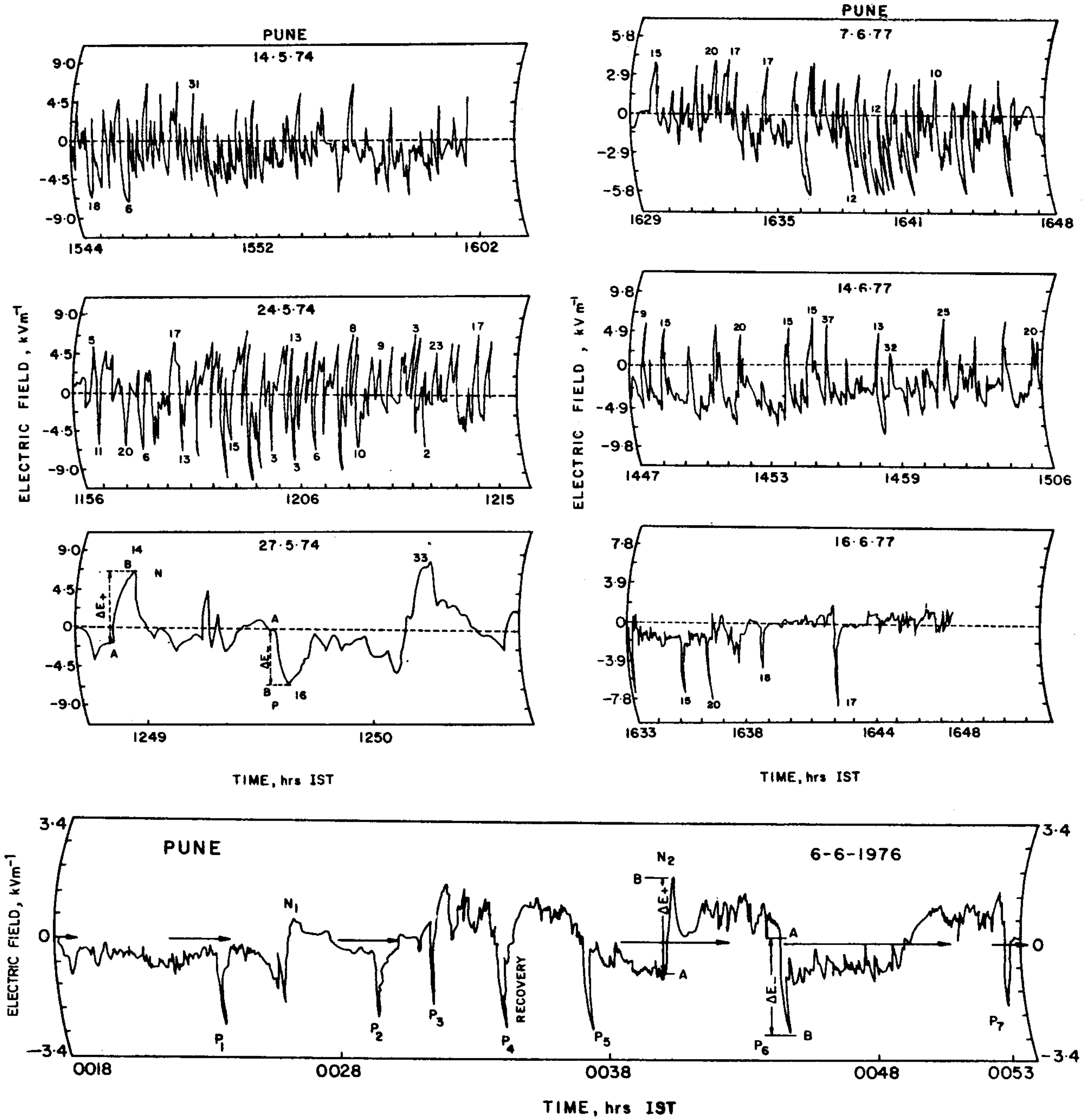

Fig. 2—Sample records of lightning associated ground electric field at Pune on different dates [Record on 27 May 1974 is a fast speed (10 cm per minute) record. It is seen that just prior to 1249 hrs, transient change from A to B takes place in the electric field. This change in electric field ($F_B - F_A = \Delta E$) is positive and relates to a flash of negative (N) polarity, while in the subsequent flash the electric field change is negative, this relates to a flash of positive (P) polarity. The times of the thunder heard after lightning for these flashes are 14 and 16 s, respectively. Information in the rest of the records are likewise].

errors and uncertainties involved in following this procedure are minimum. For brevity, Table 2 furnishes details of flashes only for two (24 and 27 May 1974) out of nine thunderstorm days. Last three columns of Table 2 provide information on charge deposited (ΔQ in coulomb); and values of $\tan\theta$ ($=H/D$) and $\sin\theta.\cos^2\theta$ per flash using the expression provided by Malan[2].

In that expression H refers to the mean height[27] (a.g.l.) of the main positive (8500 m) and negative (6200 m) charge regions, which is probably involved in a lightning flash. In the same expression D refers to the distance in kilometres of the lightning strike from the observation point which is the origin of reference system. This distance (D) is obtained from time lapsed between thunder heard following lightning. Since $\tan\theta=H/D$, $\sin\theta.\cos^2\theta$ is derived from $\tan\theta$, which is proportional to the electric field[3]. This procedure is similar to the one adopted by Winn and Byerley[7]. The procedure for the estimation of charges deposited to the ground during lightning events is described elsewhere[2-3].

Table 2—Details of lightning flashes for 24 and 27 May 1974

Sl. No. of flashes	Polarity of flash (P or N)	Time of flash h	min	s	Flash-thunder heard time (T) and distance (D) T s	D km	Change in field (E) due to flash Vm^{-1}	Amount of charge (Q) lowered during flash C	$\tan\theta$	$\sin\theta\cos^2\theta$
					24 May 1974					
1	N	11	55	42	18	5.976	+6975	−39.94	1.0374	0.3464
2	N	11	56	48	5	1.660	+6525	−15.47	3.7349	0.0645
3	N	12	00	27	17	5.644	+8100	−42.81	1.0985	0.3348
4	N	12	05	36	12	3.984	+5400	−19.38	1.556	0.2457
5	N	12	06	24	12	3.984	+5175	−18.57	1.556	0.2457
6	N	12	08	24	8	2.656	+11025	−30.34	2.3343	0.1424
7	N	12	09	42	9	2.988	+4275	−12.49	2.074	0.1697
8	N	12	10	15	18	5.976	+7425	−42.52	1.037	0.3464
9	N	12	11	18	3	0.996	+6750	−14.98	6.224	0.0248
10	N	12	12	18	23	7.636	+5850	−49.92	0.8119	0.3796
11	N	12	14	12	17	5.644	+10350	−54.70	1.098	0.3348
12	N	12	14	48	15	4.980	+9000	−40.59	1.244	0.3054
13	N	12	15	30	8	2.656	+8325	−22.91	2.334	0.1424
14	N	12	17	12	10	3.320	+11925	−37.20	1.867	0.1962
15	N	12	19	12	14	4.648	+14760	−61.58	1.333	0.2876
16	N	12	20	15	9	2.988	+15120	−44.20	2.074	0.1696
17	N	12	21	30	9	2.988	+5400	−15.78	2.074	0.1697
18	N	12	21	48	3	0.996	+14760	−32.77	6.224	0.0248
19	N	12	22	30	13	4.316	+15480	−59.85	1.4365	0.2676
20	N	12	24	00	12	3.984	+14040	−50.39	1.556	0.2456
21	N	12	25	48	10	3.320	+8280	−25.83	1.867	0.1962
22	N	12	28	09	5	1.660	+13320	−31.58	3.734	0.0645
23	N	12	29	21	15	4.980	+12960	−58.45	1.244	0.3054
24	N	15	22	00	40	13.280	+1644	−46.41	0.4688	0.3470
25	N	15	29	36	35	11.620	+1771	−36.28	0.5506	0.3661
26	N	15	32	00	38	12.616	+1012	−25.21	0.4914	0.3549
27	N	15	37	00	28	9.296	+1012	−12.66	0.6669	0.3837
28	N	15	40	00	34	11.288	+1265	−24.23	0.5492	0.3695
29	N	15	41	00	30	9.960	+885	−12.81	0.6224	0.3807
30	P	11	42	30	10	3.320	−4275	+21.25	2.560	0.1231
31	P	11	43	54	20	6.640	−4725	+38.78	1.280	0.2984
32	P	11	46	15	10	3.320	−4050	+20.13	2.560	0.1232
33	P	11	47	33	16	4.312	−4275	+28.16	1.600	0.2379
34	P	11	49	51	14	4.468	−9450	+56.20	1.8288	0.2018

Contd.

Table 2—Details of lightning flashes for 24 and 27 May 1974—*Contd.*

Sl. No. of flashes	Polarity of flash (P or N)	Time of flash			Flash-thunder heard time (T) and distance (D)		Change in field (E) due to flash Vm^{-1}	Amount of charge (Q) lowered during flash C	$\tan\theta$	$\sin\theta\cos^2\theta$
		h	min	s	T s	D km				
35	P	11	51	24	18	5.976	−6300	+46.23	1.422	0.2703
36	P	11	53	00	5	1.660	−5175	+21.99	5.120	0.0360
37	P	11	55	21	8	2.656	−6075	+28.06	3.200	0.0848
38	P	11	56	24	15	4.980	−3150	+19.70	1.7060	0.2203
39	P	11	57	12	11	3.652	−7650	+39.62	2.327	0.1430
40	P	11	58	21	20	6.640	−6075	+49.86	1.2805	0.2984
41	P	11	59	00	6	1.992	−9000	+39.17	4.2670	0.0506
42	P	11	59	36	12	3.984	−7452	+40.17	2.133	0.1629
43	P	12	01	00	13	4.316	−7650	+43.35	1.9692	0.1826
44	P	12	06	55	06	1.992	−12375	+53.86	4.2672	0.0506
45	P	12	08	00	04	1.328	−13725	+57.16	6.400	0.0235
46	P	12	08	55	10	3.320	−10350	+51.44	2.5600	0.1232
47	P	12	11	42	05	1.660	−10350	+43.98	5.1203	0.0360
48	P	12	12	00	02	0.664	−6975	+28.27	12.80	0.0060
49	P	12	13	36	04	1.328	−7200	+29.99	6.40	0.0235
50	P	12	15	48	06	1.992	−6075	+26.44	4.267	0.0506
51	P	12	23	18	05	1.660	−3240	+13.76	5.120	0.0360
52	P	12	27	51	18	5.976	−7200	+52.83	1.422	0.2703
53	P	15	12	18	28	9.296	−2403	+31.41	1.204	0.3672
54	P	15	14	42	43	14.276	−1391	+41.73	0.5954	0.3774
						27 May 1974				
1	N	12	35	21	48	15.936	+2533	−113.579	0.3890	0.31464
2	N	12	36	09	10	3.320	+2533	−7.9023	1.8674	0.19628
3	N	12	39	57	18	5.976	+7650	−43.8084	1.0374	0.3464
4	N	12	50	53	4	1.328	+3510	−8.0243	4.6686	0.0428
5	N	12	51	35	6	1.992	+8640	−21.3990	3.1124	0.0890
6	N	12	54	47	13	4.316	+6300	−24.3700	1.4375	0.2675
7	N	12	55	19	10	3.320	+8100	−25.2828	1.8674	0.1961
8	N	12	55	55	14	4.648	+8100	−33.8155	1.3339	0.2874
9	N	13	00	43	40	13.280	+6300	−177.956	0.4668	0.3468
10	N	13	03	08	32	10.624	+5800	−96.8622	0.5835	0.3754
11	N	13	03	49	28	9.296	+5625	−70.414	0.6669	0.3835
12	P	12	40	42	06	1.992	−13050	+56.80	4.2673	0.0506
13	P	12	43	03	07	2.324	−13950	+12.44	3.657	0.0670
14	P	12	44	13	11	3.852	−10800	+43.38	2.206	0.2052
15	P	12	45	24	06	1.992	−4500	+19.58	4.2670	0.0506
16	P	12	49	36	16	5.312	−6525	+42.98	1.600	0.2379
17	P	12	52	53	06	1.992	−13950	+60.72	4.2676	0.0506
18	P	12	53	36	07	2.324	−13050	+58.41	3.657	0.0670

5 Results and discussion

5.1 Spatial variation of the mean magnitude of the charges

Table 1 shows the storm average charge and the strike distance per lightning flash deposited to the ground for the nine storm days at Pune. The weighted mean charge, using the storm average values, is also given in the same Table at the end. The above result shows that the inter-storm daily averages show substantial variation (−19 to −147 C; +19 to +44 C), but the average strike distance (4-9 and 2-6 km, respectively, for either-polarity), exhibits appreciable localization[5]. In thunderstorms environment, this information is always useful for taking safety measures of the power transmission lines and wireless technology. In view of this, the charge per flash of either polarity was classified in distance range 0-1, 1-2, 2-3, ... km. From the number of charges falling in each 1 km class interval, the mean and standard deviation was obtained. Figure 3 shows the result of the spatial variation of the mean charge and its percentage of occurrence. Vertical bars show the standard deviation of the mean charge. It is seen from Fig. 3 that the magnitude of the charge in either case increases with the increase of distance from the origin and the standard deviation indicates the variability of mean charge. This gives an impression that the observed charge pattern is a reflection of the choice of threshold bias mentioned earlier. Figure 3 also suggests that the average positive charge deposited in 1 km range up to about 7 km from the point of observation is higher than the corresponding negative one. It is clear from Fig. 3 that the negative lightning-strike activity extends up to a distance of 10-11 km underneath a storm, but positive flashes occur only up to 6-7 km. These plots show that nearly 65% of the negative activity takes place between 1 and 6 km; 25% within 6-11 km and much less ($\leqslant$5%) within the first 1 km. While in case of positive charges, 83% of the activity takes place within first 1-6 km and about 6% beyond 6 km and ~ 3% in the first 1 km. In this study the spatial pattern obtained from negative and positive lightning-strike points is limited to a few thunderstorms in Pune area. The result of this analysis suggests that the radial range of lightning strike points underneath a cloud is in the order of ~ 10 km. This result is in good agreement with those of Krider[28], Hatakeyama[29] and Feteris[30]. Pierce[1] and Illingworth[6] have studied the lightning channel geometry and suggested that, underneath a storm, at closer distance, the occurrence of lightning strike is usually small, because at closer distance the lightning channel gets a very small solid angle which is required for its horizontal development during its vertical propagation to the ground.

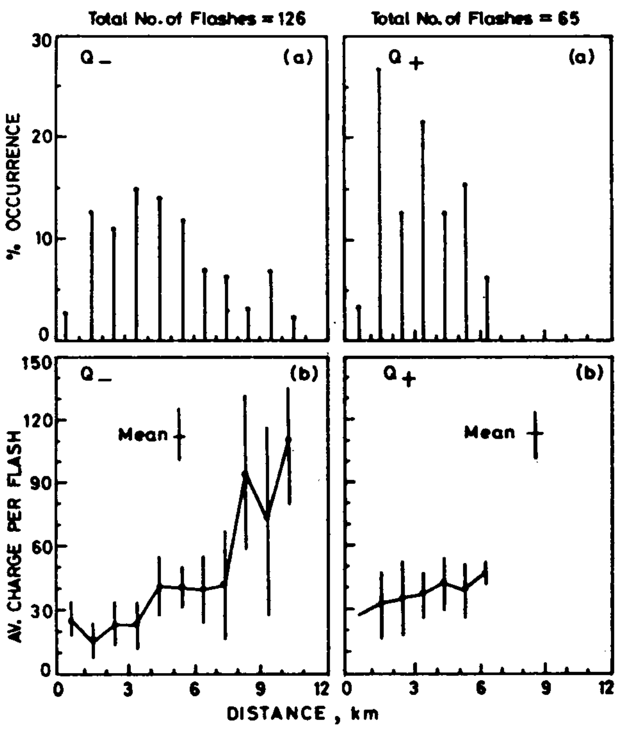

Fig. 3—(a) Percentage occurrence of charge with distance and (b) spatial variation of the average charge per flash of either polarity from the point of observation [The vertical bars show the standard deviation in the averages].

5.2 The relationship of electric field change with flash distance

For this purpose the data on the changes in the electric field ($\Delta E_{\pm}$) and flash distances are considered. The values of field changes in each 1 km range were clubbed and the mean $|\Delta E|$ and its standard derivation for each range were obtained (see Fig. 4).

It is noted from Fig. 4 that all the field changes are more than 1 kVm^{-1} and most of them lie within 10 km from the point of observation. The slant line drawn through these data points using a trend technique of the computer graphics suggests

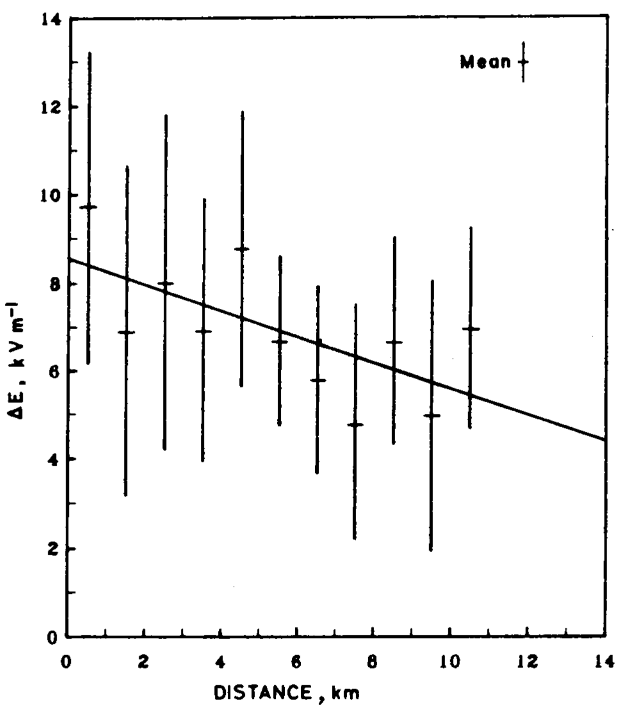

Fig. 4—Relationship of average change in ΔE with flash distance from the point of observation [The vertical bars show the standard deviation in the averages].

the inverse relationship between distance and ΔE. Earlier workers[1,3,20] also obtained similar relationship.

5.3 Time variation of charge and strike distance of lightning flash

The time variation of the charge and strike distance during storm evolution have been presented in this subsection. The data on lightning strike distance and charge per flash were considered for four individual days, i.e. 31 May 1973, 22 and 24 May 1974 and 7 June 1977. The choice of these days was arbitrary. From the daily data of lightning flashes (Table 2), the values of charges (ΔQ) of either polarity and their strike distances were plotted against the time lapsed with respect to the initial time of the storms (Fig. 5). For all the storms mentioned above, it was noticed that with the increase in the time lapse, the lightning-strike distance reduced, while the magnitude of the charge increased. This feature was observed for all the storms under study. Figure 5 shows the result for the storm on 24 May 1974 at Pune. The main feature of the above result can be seen from the straight line trend between strike distance and charge versus time lapse. This analysis may provide some insight into the sequence of the lightning activity from the beginning to the end of the storm. The variation in the charge and strike distance may appear to be consistent if consideration of the developing, mature and decay phase of the storm is made. From radar studies of the thunderstorms, Fuquay[10] reported that usually during the developing-to-mature stage of the storm the radar echo dimensions are at their maxima and the development of its electrical activity is on its increase, while during the mature-to-decay stage, the storm occupied area dwindles but the electrical activity is at its peak. These features are reflected from the above analysis. It can also be argued that the observed tendency for lightning to cluster towards the end of the storm may be a side-effect of the Q model, if the storms consistently move towards the measuring site. This consideration appears to be consistent with the fact that the location accuracy of the Q model tends to improve as flashes come closer to the measuring site. With reference to the results reported in this paper, more information on the typical synoptic situations responsible for the development of thunderstorms over Pune region and their average characteristics are deemed to be essential to

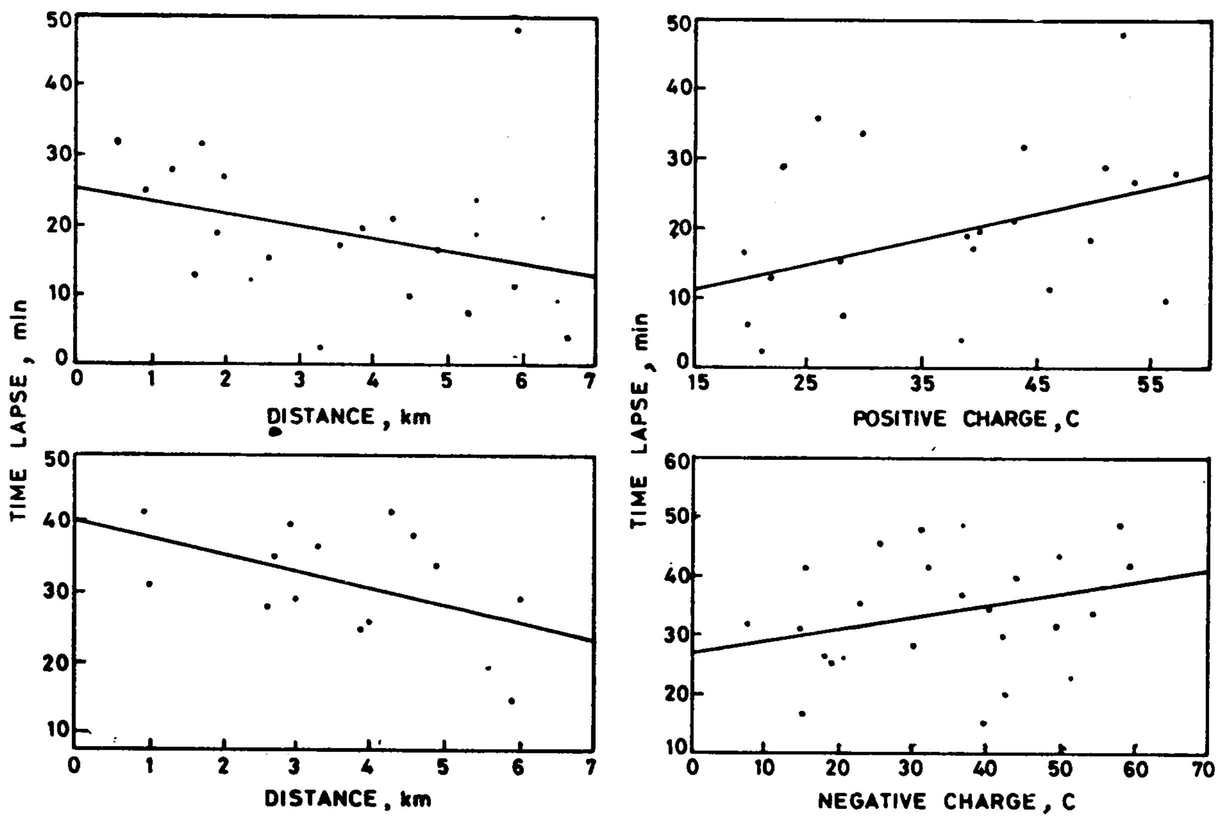

Fig. 5—Temporal variation of the charge and strike distance of the flash during storm evolution on 24 May 1974.

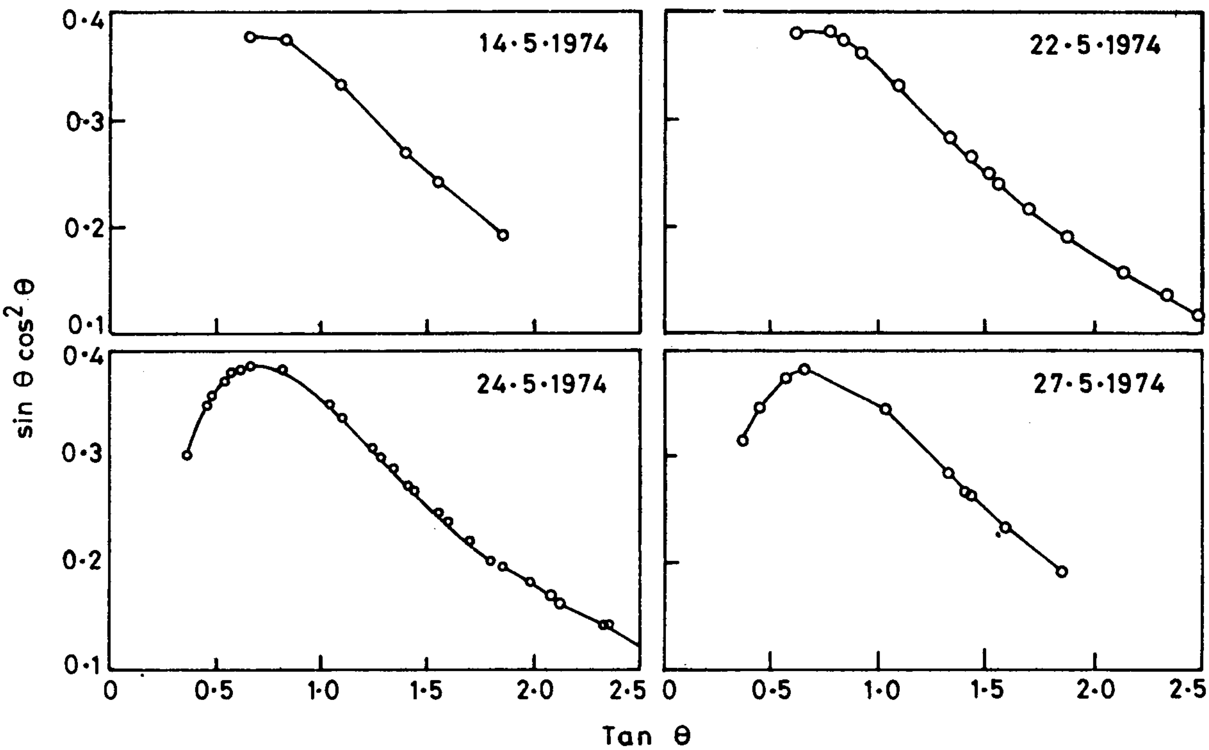

Fig. 6—Variation of $\sin\theta\cos^2\theta$ with $\tan\theta$ ($=H/D$) for 14, 22, 24 and 27 May 1974. [The value of $\sin\theta\cos^2\theta$ which is proportional to the field passes through a maximum when the charge passes through a height $H=D/\sqrt{2}$, i.e. when $\tan\theta=0.707$].

complement the above results. Although, these characteristics may not identically occur each time in thunderstorms at Pune, these information (see Appendix) may help to understand/identify the average conditions which may be prevalent in such studies.

5.4 Comparison of the analytical result of electric field due to vertical motion of the cloud charge

Data on the field changes caused by lightning flashes at various distances (D in km), permitted us for the direct validation of the analytical result[2] that the value of the electric field ($\sin\theta\cos^2\theta$) at a fixed location due to the vertical motion of the charge, exhibits maxima when $\tan\theta$ ($=H/D$) is 0.707. This aspect was verified by plotting $\sin\theta\cos^2\theta$ against $\tan\theta$ for four dates (14, 22, 24 and 27 May 1974 in Fig. 6). The choice of these dates was arbitrary. It is clearly seen that on all the occasions the field produced at the ground showed a maximum when $\tan\theta=0.707$. This is in agreement with the analytical result mentioned above.

Acknowledgements

The authors express their sincere gratitude to the anonymous referee of this paper for taking special interest in this work and for offering constructive suggestions to improve the text. They are also thankful to Dr (Mrs) A M Selvam and Dr A S R Murty for their constant support and suggestions.

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Appendix

(A) Synoptic situations favourable for the development of pre-monsoon thunderstorms over Pune region

Synoptic situation such as wind discontinuity in the lower troposphere (up to 1.0 km a.s.l.) extending from south Kerala to eastern Vidarbha, associated with migratory cyclonic disturbance is the most common reason for the development of thunderstorm. In addition to the above mentioned discontinuity, when one or more cyclonic circulations are embedded in it and when an induced low pressure forms over the central parts of the country, the situation is more favourable for the development of widespread thunderstorm activity in this region. The formation of troughs in the mid-upper tropospheric westerlies and their southward extension also occasionally give rise to large scale thunderstorm activity over the peninsula. Sometimes the prevalence of a jet maximum in the strong westerlies over the peninsula is also reported to be responsible for the development. A combination of two or more of the above mentioned synoptic situations may, sometimes, take place giving rise to well-marked thunderstorm activity over the peninsula[1,2].

Over the Indian region, the period from March till early June constitutes the hot weather (premonsoon) season. During this season, thunderstorms are most frequently observed. Over the peninsular India, comprising Pune region, the annual average number of thunderstorm days is ~ 22. Nearly 60% of this activity takes place in the premonsoon season, of which most activity is usually experienced in April-May[3-5].

(B) Some characteristic features of thunderstorms

Information on spatial distribution of thunderstorms, their preferred directions of motion, heights attained by them over a region, etc. are of crucial importance for the understanding of their genisis zones and preferred regions of activity[6]. Documentation of these information is made by the deployment of meteorological radar, satellite imageries, and a net-work of lightning detector and radio-sonde systems[2,7]. Wind and temperature structure at the upper tropospheric levels and ground-based observations of point discharge current are also useful for the above studies[7,8].

Investigations of thunderstorms over Pune region using some of the above techniques are done by different groups[9-13] in the past and by Manohar[14,15] in the recent years. All these investigations reveal that the most favoured region for thunderstorm activity around Pune was the sector extending from northwest to south through east. Results of studies[10,11] done by using radar observations and lightning counters at Pune, pointed out that the storms locations appeared to be quite stable and the associated cells grew and dissipated over almost the same area. It is reported[10] that the seasonal average height of zero degree isotherm is ~ 4800-4900 m (a.s.l.) and heights attained by the super cooled water drops varied between 9500 and 13100 m (a.s.l.). Results of aircraft observations[13] of tops of Cb clouds suggested that over this area, Cb tops were generally in the range 12.7-13.3 km (a.s.l.).

(C) Diurnal variation of thunderstorm activity over Pune region

The most obvious results of these studies[3-5] concluded that the diurnal period of thunderstorms activity is mainly confined to 1500-2100 hrs IST, although on rare and typical occasions it may be traced even until midnight. Another important conclusion of the above studies was that the period from early morning until around 1400 hrs IST is mostly free from pre-monsoon thunderstorms. Further, from the records of electric field and point discharge current for the pre-monsoon season thunderstorms of years 1973, 1987 and 1988 at Pune their mean beginning and end times were obtained. It was noted that, for about 12 thunderstorms during each of the above years, the mean beginning and end times were $\frac{1537}{1943}$, $\frac{1612}{1900}$ and $\frac{1630}{2000}$ hrs IST, respectively. It was noted that the range of the timings fits well within the major period quoted earlier.

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