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Recovery curves of the surface electric field after lightning discharges occurring between the positive charge pocket and negative charge centre in a thundercloud

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[1] Surface observations of the electric field recovery curves of the lightning discharges occurring between the positive charge pocket and negative main charge centre in an overhead thundercloud are reported. Such recovery curves are observed to have an additional step of very slow field-change observed at an after-discharge value of electric field equal to 5–6 kV m^{-1}. The behavior of recovery curves is explained in terms of the coronae charge and the relative efficiencies of the charge generating processes responsible for growth of positive charge pocket and main negative charge centre in the thundercloud. The charging currents responsible for the growth of charge in positive charge pockets is computed to be 2–4 times larger than that for the growth of the main negative charge. However, the charge destroyed in such a discharge is found to be comparable to that in a discharge between the main charge centres of the thundercloud. *INDEX TERMS:* 3324 Meteorology and Atmospheric Dynamics: Lightning; 3304 Meteorology and Atmospheric Dynamics: Atmospheric electricity; 0320 Atmospheric Composition and Structure: Cloud physics and chemistry; 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504). **Citation:** Pawar, S. D., and A. K. Kamra, Recovery curves of the surface electric field after lightning discharges occurring between the positive charge pocket and negative charge centre in a thundercloud, *Geophys. Res. Lett.*, *29*(23), 2108, doi:10.1029/2002GL015675, 2002.

1. Introduction

[2] Ions produced by coronae occurring at sharp elevated grounded conductors beneath thunderstorms can transfer more charge between the earth and thunderstorms than lightning or falling charged precipitation [*Schonland*, 1928; *Wormell*, 1930; *Livingston and Krider*, 1978; and *Williams and Heckman*, 1993]. These ions have also been suggested to contribute substantially to the electrification of thunderstorms [*Vonnegut*, 1955; *Wilson*, 1956]. The space charge formed due to the coronae ions can limit the absolute value of the electric field at the ground. Recognizing this fact and because of the lack of elevated objects, *Whipple* [1938] suggested that the behavior of electric field over water should be different from that over land. Observations of *Toland and Vonnegut* [1977] confirm the presence of more intense fields under thunderstorms occurring over water. *Winn and Byerley* [1975], *Standler and Winn* [1979], *Chauzy and Raizonville*, [1982], *Chauzy and Soula* [1987], and *Chauzy et al.* [1991] observe that the magnitude of the electric field a few hundred meters above the ground beneath thunderstorms is several times larger than at the ground. For example, *Soula and Chauzy* [1991] observe a field of up to 65 kV m^{-1} at 603 m while the surface field did not exceed 5 kV m^{-1}.

[3] Recovery curves of the electric field after a lightning discharge have often been used to study the electrification processes in thunderclouds [e.g. *Wilson*, 1920; *Wormell*, 1939; *Tamura*, 1959; *Freier*, 1962]. However, if there is sufficient space charge produced due to coronae ions in the sub-cloud layer, the inferences drawn about thundercloud electrification will be erroneous as the field at the ground will be the summation of fields due to charges in the thundercloud and the space charge in the sub-cloud layer. After a lightning discharge, the rate of change of the field at the ground is initially very fast and then decreases as the field approaches its pre-discharge value. However, observations of *Standler and Winn* [1979] and *Soula and Chauzy* [1991] show that the recovery of the field after a discharge is almost linear at a height of a few hundred meters above ground.

[4] To draw any inferences about the electrical processes in cloud from the field recovery curves at the surface far from a thundercloud can also be erroneous due to yet another factor even if the field there is less than that required for coronae to occur. *Illingworth* [1971, 1972] computed that the time variation of the surface field is also influenced by the conductivity of the air surrounding the cloud.

[5] Effect of coronae on the recovery curves has so far been studied for discharges in which a pre-discharge positive electric field (anti fair-weather polarity) reduces in magnitude or becomes negative (fair-weather polarity) after the discharge indicating thereby that the intra-cloud discharge has most probably occurred between the upper main positive charge and the lower main negative charge of the thundercloud. We report here the effect of coronae on the shapes of recovery curves of discharges in which the pre-discharge negative electric field changes to positive polarity after the discharge.

2. Observations

[6] The atmospheric electric field is measured at the Atmospheric Electricity Observatory at Pune, (18°32′N, 73°51′E) with an a.c. field mill kept in a pit with its stators flush with the ground. It can measure electric fields of upto ±12 kV m^{-1} with a sensitivity of 15 V m^{-1} and has response time of 10 ms.

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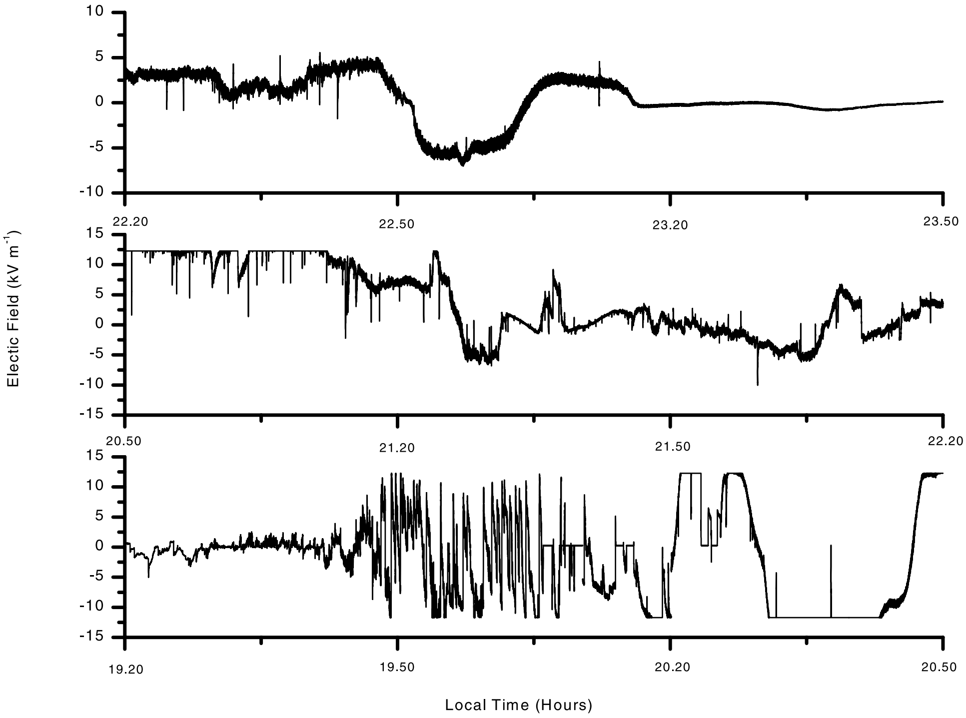

Figure 1. The surface electric field record during the thunderstorm of September 25, 2001. The excess fluctuations of electric field observed during the storm disappeared after the storm.

[7] Development of thunderstorms during the withdrawal period of the southwest monsoons is quite common in this area due to the southward shift of the trough from the foothills of the Himalayas. Bases of such thunderstorms are generally 1–1.5 kms above ground. On September 25, 2001, a thunderstorm developed northeast of the observatory, moved over it and gave a total rainfall of 28 mm over a period of about 4 hours; 23 mm of it coming down in the first one hour itself. Very low surface winds or almost lull prevailed for most of the period during which the storm stayed overhead and showed little or no horizontal movement. The storm exhibited 2 to 4 intra-cloud flashes per minute during its active period.

[8] Figure 1 shows the electric field record during the storm. Because of heavy rain, field mill failed to respond properly during 1930–1940 hours due to excessive splashing of raindrops on its stators. Excursions to the negative polarity at about 1942 and 1944 hours may be associated with the excursions associated with the precipitation [*Moore and Vonnegut*, 1977; *Standler and Winn*, 1979]. In the initial and final stages of storm, the field-record shows many negative field-changes (indicating the lowering of positive charge or raising of negative charge) typical of those observed during the intra-cloud discharges occurring between the main charge centers in a thundercloud. On the contrary, all discharges, about 30 of them, that occur from 1952 to 2020 hours when the electric field is of negative polarity show positive field changes indicating thereby that positive charge overhead has been destroyed. These discharges most likely occurred between the main negative charge and the positive charge pocket that is known to develop in the bases of thunderclouds in their matured stages. The negative electric fields at the ground can also be alternatively produced by an inverted dipole or the upper main positive charge in a cloud in case of the dipole is significantly inclined from the vertical. The negative electric fields can also occur due to some local effects or as a result of a movement of the storm. However, the large magnitude of the negative electric fields, the sequence of field changes in Figure 1, and the fact that the electric field eventually exhibits the usual end-of-storm-oscillation do not support such causes and strongly suggest that the storm had a usual positive dipole structure with a large positive charge pocket in its base [*Moore and Vonnegut*, 1977]. The signal noise of upto 0.7 kV/m around its rms value is observed almost throughout the storm period and nearly disappears before and after the storm. *Deaver and Krider* [1991] associate such noise in their observations to the movement of space charge in the atmosphere.

[9] Figure 2 shows a typical record of field-changes during lightning discharges that occur when the surface electric field is high and negative. After the discharge, the electric field generally changes its polarity and attains a magnitude which in most cases, is a little higher than its pre-discharge value. The field recovery curve after a lightning discharge in this period consists of four distinct parts. In part I, immediately after a lightning, the field has very fast recovery for 5 seconds until its value drops down to ~5–6 kV m^{-1}. In part II, the field recovery is very slow or nil or even changes its sign for a period of ~5–15 s. In part III, the field recovery is almost linear for 5–10 s and the electric field changes its polarity during this period. In part IV, the field recovery slows down and the increase in field is almost exponential until the field reaches its pre-discharge value and the next discharge occurs. The rate of change in electric field (dE/dt) in part I averaged for 14 flashes observed during this period is

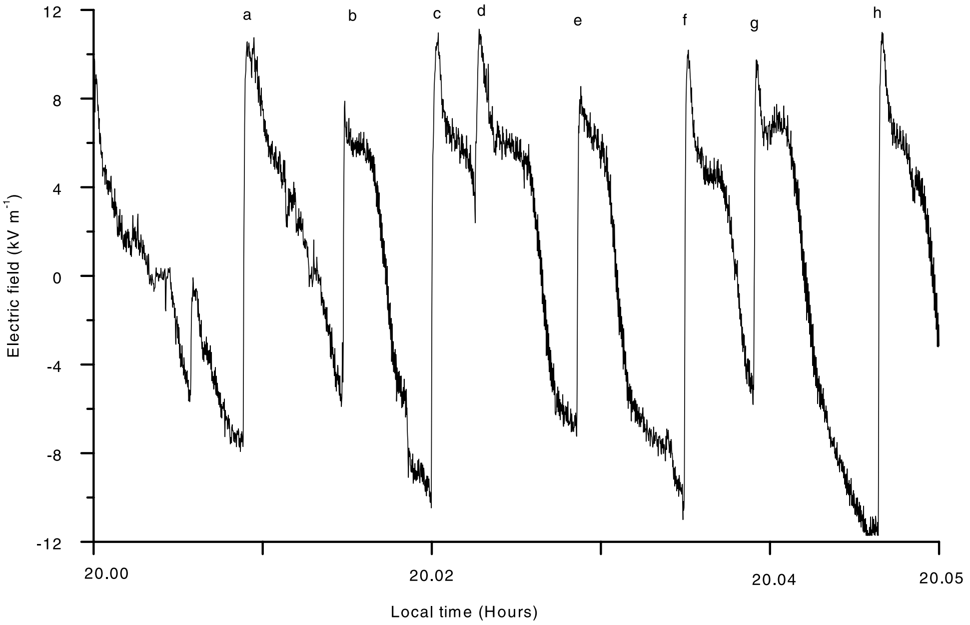

Figure 2. Recovery curves of the positive field-changes due to lightning.

1590 V m^{-1} s^{-1} and is approximately 20, 2 and 8 times faster than in II, III and IV parts, respectively.

3. Discussion

[10] The recovery curves for positive field-changes differ from those for the more frequently observed negative field-changes in the respect that part II of the recovery curves as described above, is missing in the later case. This part II of the recovery curves always occurs when the value of the after-discharge electric field drops down to 5–6 kV m^{-1}. This value of electric field roughly corresponds to the value at which coronae starts at the elevated points at the ground surface. As discussed below, the slower field recovery in part II may be due to the comparable but opposite effects of the growth of the lower positive charge pocket and the main negative charge of the thundercloud, on the surface electric field.

[11] Electric field at the surface below a thundercloud is the superposition of two fields, one from the charges inside thundercloud and the other from the space charge produced by corona discharge near the ground. Pre-discharge large negative electric fields in Figure 2 are indicative of the positive charge pocket overhead in the thunderstorm base. These negative electric fields introduce negative coronae charge into the atmosphere. A lightning discharge destroys all or part of the positive charge in thundercloud so that more of the lower main negative charge in the thundercloud is exposed to the surface electric field. Immediately after the discharge, field becomes large and positive which will introduce positive coronae charge into the atmosphere. Recovery of the electric field to its pre-discharge value occurs mainly because of the build-up of the positive charge pocket in the base of thundercloud and the readjustment of the coronae charge below thundercloud. Based on our observations and the knowledge gained from earlier observations [e.g. *Standler and Winn*, 1979; *Chauzy et al.*, 1991], we postulate the following explanation for the recovery curves of the positive field-changes reported above.

[12] Polarity of the charge being introduced into the atmosphere close to ground suddenly changes from negative to positive when the pre-discharge negative field changes to the after-discharge positive one following a lightning flash. Positive ions generated in the after-discharge field will not only combine and neutralize the surrounding negative ions but create a positive space charge close to ground. Mobility of the coronae-generated small ions is about 1.5×10^{-4} m^2 V^{-1} s^{-1} until they get attached to an aerosol particle and lose their mobility. According to *Willet* [1983] this attachment occurs after about 30 s. During this period these ions are located in an electric field of about 10 kV m^{-1}. So in 30 s the movement of positive ions under electrical forces can form a layer of ~45m thickness above ground which can significantly decrease the electric field at the ground surface. We propose that formation of this positive charge layer may be the dominant process responsible for the fast field-recovery in part I of the recovery curves. Supporting our proposal is the field recovery curve shown in Figure 3 where the positive electric field attained after the discharge is not large enough to initiate positive coronae at the ground. Consequently no positive ions are introduced from the ground and the electric field recovers exponentially to its pre-discharge value without part II appearing in the recovery curve.

[13] Because of the reduction in electric field, further addition of coronae charge to the atmosphere is much reduced during part II of the recovery curve. Meanwhile, the negative main charge and the positive charge pocket keep building-up in the thundercloud above. Very slow recovery of the electric field during this period indicates that the effect due to the growth of the main negative charge almost equals or sometimes even exceeds (e.g. during flashes b and g in Figure 2) the sum of effects due to the growth of positive charge pocket and that due to coronae charge. It may be concluded that at least in those periods where dE/dt is positive, the charging rate of the mechanism responsible for charge generation in main dipole is greater than that responsible for charge generation in positive charge pockets. Supporting this conclusion are the recovery

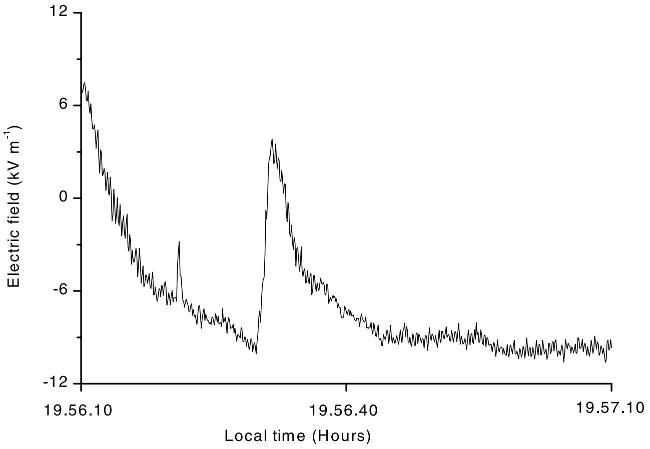

Figure 3. Recovery curve of a lightning discharge where the after-discharge electric field is below its critical value to initiate corona at the ground.

curves for the flashes b and g in Figure 2 where the pre-discharge negative electric field is not large enough to initiate coronae at the ground. Consequently no negative ions are introduced from the ground.. Since the charging current for the main negative charge remains constant between the two lightning discharges [*Krider and Musser*, 1982], any change in trend in part II of the recovery curve indicates a change in the growth rate of the positive charge pocket which in turn is determined by the charging and dissipating currents flowing into it. Contribution of the updraft current carrying coronae charge into a thundercloud depends on the magnitude and polarity of the electric filed and on the vertical wind speed and so will certainly vary over a large range. The above conclusion, however, needs to be taken with caution that although Maxwell current between the lightning discharges has been observed to be constant in large thunderstorms, it shows some rapid and reproducible time-variations in small thunderstorms [*Deaver and Krider*, 1991]. Although, the flash rate observed in our thunderstorm classifies it as a small thunderstorm, the displacement current (as calculated below) and duration of the storm are comparable to that of a large storm.

[14] In part III of the recovery curve, the electric field passes through its zero value and changes polarity. No generation of coronae charge is expected at these low fields and the field change during this part of the curve reflects the charging current in thundercloud [e.g., *Krider and Musser*, 1982]. The value of displacement current calculated from the field changes observed during 13 flashes in our measurements varies between 4 and 15 nA m^{-2} with an average value 8.9 nA m^{-2} . It is much higher than the average values of 0.4 to 3.5 nA m^{-2} observed by *Standler* [1980] and 1 to 4 nA m^{-2} computed by *Krider and Musser* [1982] but is comparable to the values (upto 15 nAm^{-2}) observed by *Krider and Blakeslee* [1985] for the negative field-changes during intra-cloud discharges.

[15] As the negative electric field increases in magnitude, the negative corona charge is introduced into the atmosphere close to the ground. This coronae charge suppresses further growth of the surface electric field in part IV of the recovery curve and it grows almost exponentially till the next lightning discharge occurs.

[16] Since the height of the thundercloud base in this area is $\sim$1 km in this season, the charge center of the dipole formed by the positive charge pocket and the main negative charge in an overhead thunderstorm can be assumed at a radial distance of approximately 3 km from the measuring site. The charge destroyed in a flash estimated from our measurements of positive field-changes during 16 flashes varies from 9 to 24 C with an average of 17 C per flash. This estimate is comparable to the charge destroyed in discharges which occur between the main positive and negative charge centres in thunderclouds.

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