RAINDROP CHARGE AND ELECTRIC FIELD IN ACTIVE THUNDERSTORMS

By Ross Gunn and Charles Devin, Jr.

U. S. Weather Bureau [1]

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ABSTRACT

The electrical characteristics of two active spring thunderstorms are reported. Simultaneous surface measurements of the sign and magnitude of the free charge on individual raindrops, the electric field and precipitation rate have been made. More than 7000 drops, representing a continuous sample of the drops falling in the storms, show no important systematic dependence on the sign or magnitude of the instantaneous electric field. The measurements show that the convected current to the earth frequently exceeds the conduction currents by a large factor, and, therefore, the charged rain may determine the electric field at the surface.

The average measured free charge brought down by positively charged rain was 0.022 esu per drop, and by negatively charged rain was 0.031 esu per drop. The ratio of the negative free charge to the positive free charge brought down by rain was 1.2, while the ratio of the number of negative drops to the number of positive drops was 0.88.

1. Introduction

The fundamental mechanisms responsible for the separation of free electrical charge in the atmosphere, leading to the production of lightning, are poorly understood. Numerous explanations have been given for the selective transfer of free electricity to precipitation, but none of them are satisfactorily established. It seems clear that more observational information and systematic explorations of typical thunderstorms are necessary before theoretical descriptions are attempted. With the object of supplementing the meager information already available, complete data have been obtained for two active spring thunderstorms in Washington, D. C. All measurements were made on the ground, and provisions were made to trace simultaneously on an oscillogram the sign and magnitude of the free electrical charge on each droplet entering the apparatus, the precipitation rate, and the instantaneous electric field measured at the same instant and place where the droplet charges were collected. In two active electrical storms, covering an interval of more than two hours, measurements on over 7000 droplets were made.

2. Instrumentation

The apparatus employed in this investigation has been described in earlier publications [1; 2; 3].

The freely falling raindrops were caught in a well exposed and highly insulated cup, inside a shield, just below a round opening 9.8 cm in diameter. The apparatus was placed in an open area quite free of trees or other obstructions. The insulated cup was connected to a high-impedance vacuum-tube amplifier, and arranged to produce a pulse on a paper-tape oscillograph. The sign and magnitude of the charge on each droplet were determined by the direction and size of the pulse.

The electric field was measured by an induction electric-field meter of the general type described in [2] and [3]. The output from the electric-field meter was fed to a suitable amplifier, and the magnitude of the electric field was traced on the same tape as the pulses due to the droplet charge. Along one edge of the record was a third trace, connected to a tipping-bucket raingage that gave a pulse for every 0.01 inch of precipitation. In this way, a permanent, continuous record was available of the simultaneous values of free charge on the droplet, the electric field and precipitation rate.

3. Synoptic conditions

Both thunderstorms considered here were active, and data were collected only during the interval when thunder could occasionally be heard. The meteorological characteristics of these two storms may be summarized as follows:

Prior to the 5 May 1950 thunderstorm, a moist, unstable, maritime tropical air mass covered the southern states, with a deepening low in the southern plains. The winds aloft were from the southwest. The morning of 5 May, the front extended from western Pennsylvania southeastward, through Washington, to the southern Virginia coast. The thunderstorm accompanied this frontal passage.

A vigorous continental polar outbreak from western Canada and maritime polar air from the Pacific simultaneously entered the northwest early on 9 June. A well-developed cold front, oriented north-south, began moving eastward from the western plains. In advance of this front, there developed a squall line, accompanied by thunderstorms, which reached Washington in the early afternoon of 10 June.

[1] Physical Research Division, Washington.

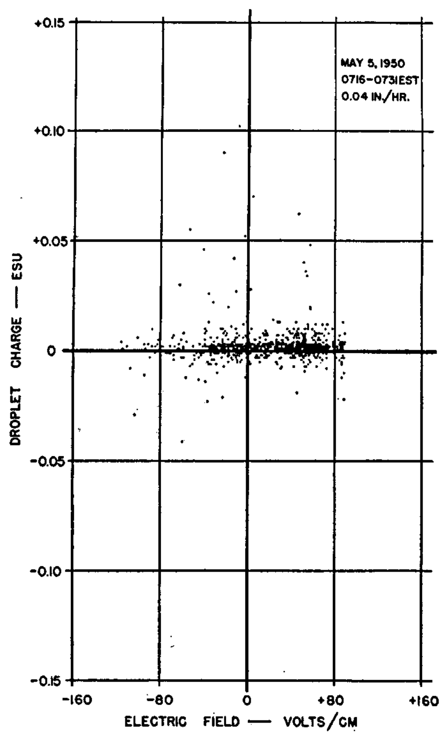

FIG. 1. Droplet free charge *vs.* electric field, 1216–1231 GCT 5 May 1950.

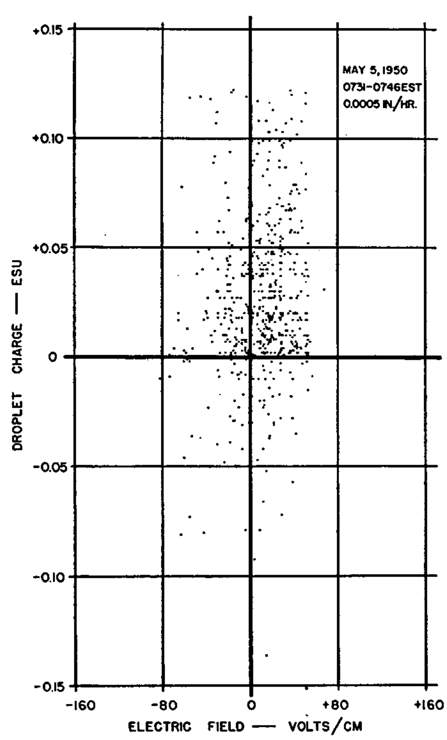

FIG. 2. Droplet free charge *vs.* electric field, 1231–1246 GCT 5 May 1950.

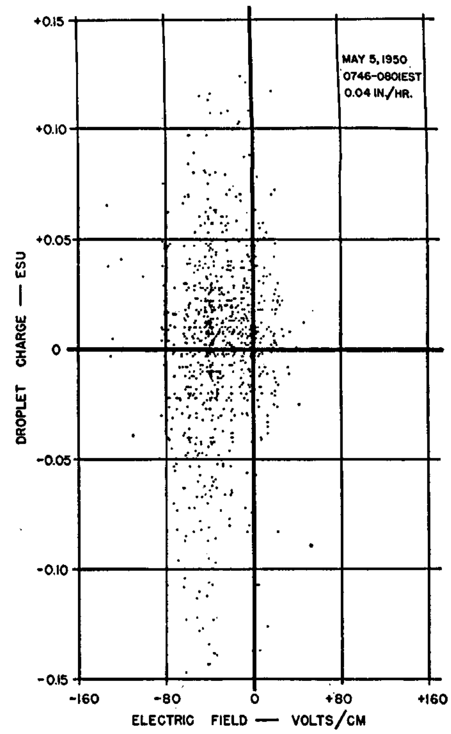

FIG. 3. Droplet free charge *vs.* electric field, 1246–1301 GCT 5 May 1950.

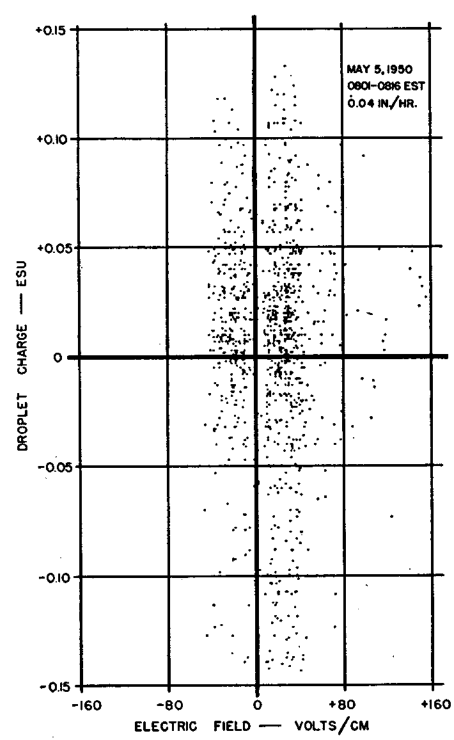

FIG. 4. Droplet free charge *vs.* electric field, 1301–1316 GCT 5 May 1950.

4. Data

Complete analyses of these two thunderstorms have been carried out, and the results are summarized in the accompanying figures, which give the values for droplet charge as a function of the electric field measured at the same place where the droplets were captured. In order that the reader may independently appraise the reality of any systematic correlation

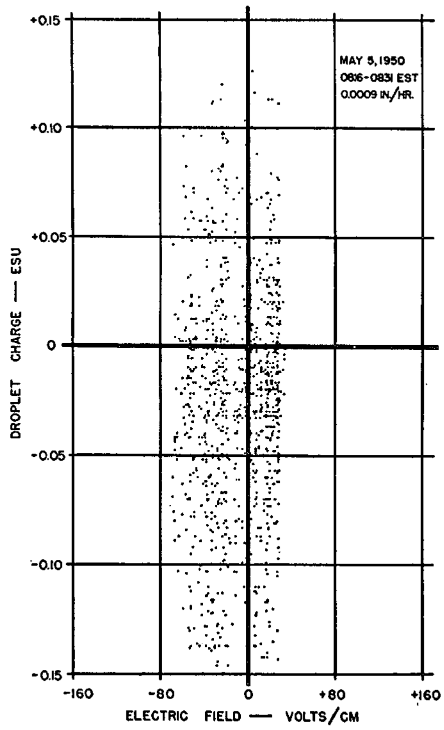

FIG. 5. Droplet free charge *vs.* electric field, 1316–1331 GCT 5 May 1950.

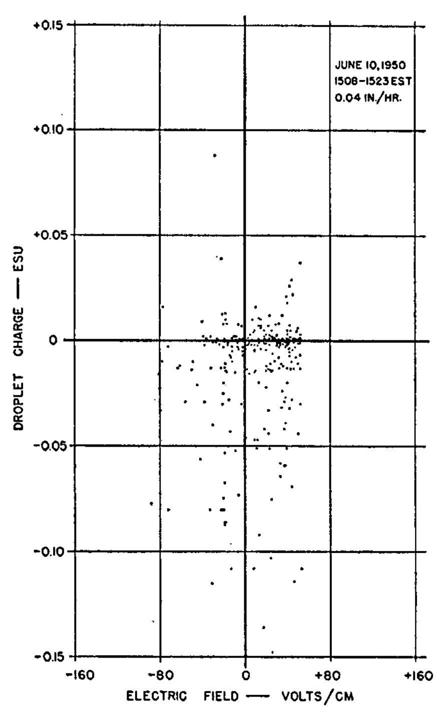

FIG. 6. Droplet free charge *vs.* electric field, 2008–2023 GCT 10 June 1950.

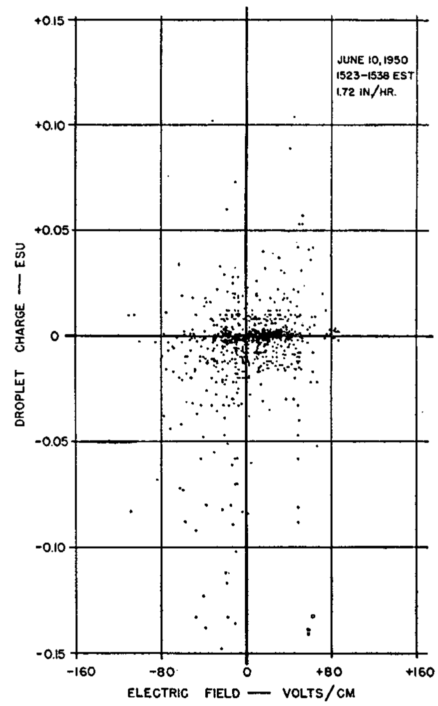

FIG. 7. Droplet free charge *vs.* electric field, 2023–2038 GCT 10 June 1950.

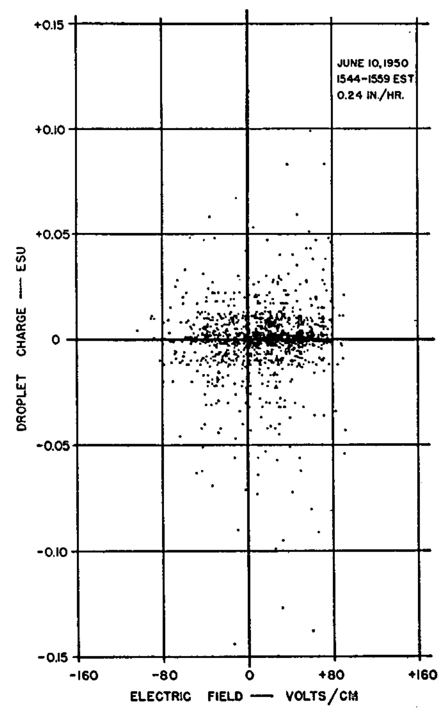

FIG. 8. Droplet free charge *vs.* electric field, 2044–2059 GCT 10 June 1950.

between the electric field and droplet charge, the values for each individual droplet are plotted. The 5 May 1950 storm was a morning storm, lasting over an hour. Rates of precipitation for the intervals covered are indicated on each figure.

Figs. 1 to 5 are in continuous time sequence, and show a marked increase in the free charge carried by the droplets as the storm developed. All measurements exhibit the usual mixture of positive and negative droplets, observed in earlier experiments [4].

The afternoon thunderstorm of 10 June 1950 lasted more than an hour, and gave values for the free charge

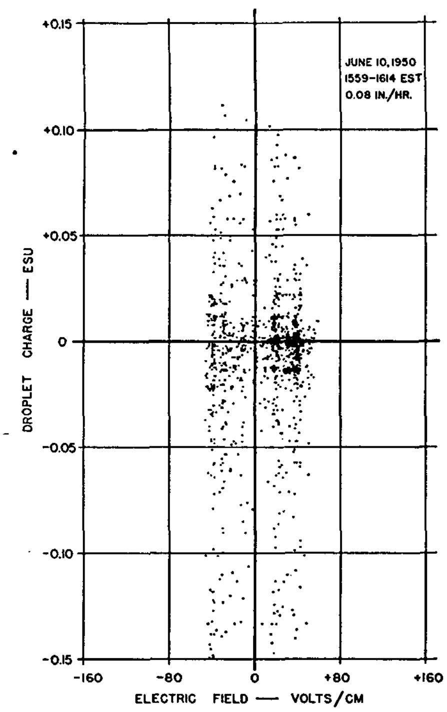

FIG. 9. Droplet free charge *vs.* electric field, 2059–2114 GCT 10 June 1950.

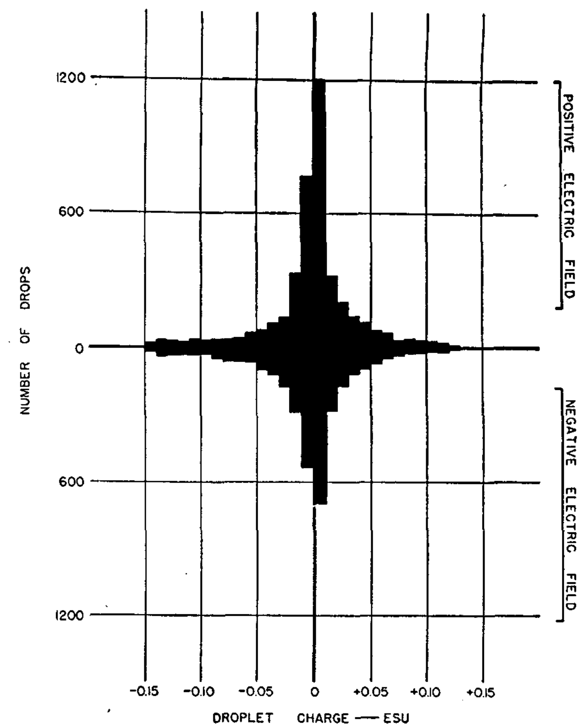

FIG. 10. Number of droplets measured in free-charge intervals of 0.01 esu, when electric field was positive and when negative.

and electric field as summarized in the time sequence given in figs. 6 to 9. Both storms exhibit about the same characteristics, and figs. 10 and 11 are composite diagrams for all measured droplets. Fig. 10 summarizes the relative numbers of droplets collected under positive and negative electric fields as a function of the charge carried by each. An analogous plot of the number of drops collected as a function of the electric field, and separated into positive and negative free-charge classifications, is given in fig. 11. The distribution about the origin of both is, perhaps, more symmetrical than one might expect.

5. Discussion

It has been suggested [5] that, for moderately large electric fields, the free electrical charge acquired by falling droplets is due to charging by corona currents released by surface objects like trees or grass. If such a mechanism were active, the charge on the droplets should be the same sign as the instantaneous free charge on the surface of the earth. Positive electric fields would, therefore, produce positive charges on the droplets. Clearly, if this mechanism were important, the study of the free electricity brought down by rain could hardly yield information on the electrical characteristics within clouds. The data of figs. 1 to 9 do *not* show a significant correlation of the free charge and the electric field. Moreover, it appears to the writers that the mixture of positive and negative charges almost always observed in thunderstorms, and

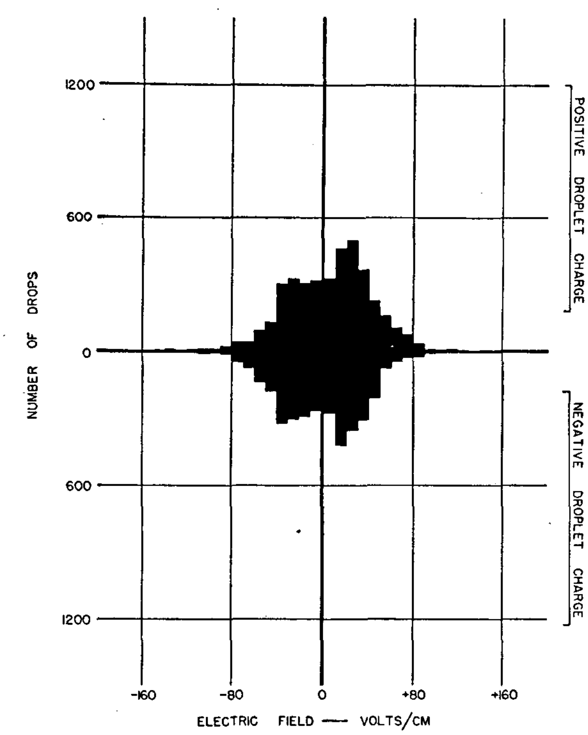

FIG. 11. Number of droplets measured in electric-field intervals of 10 volt/cm, when free charge was positive and when negative.

verified by a number of writers, shows that the systematic charging of droplets by corona from sharp points at the surface of the earth can play only a negligible part in precipitation electricity. The reader

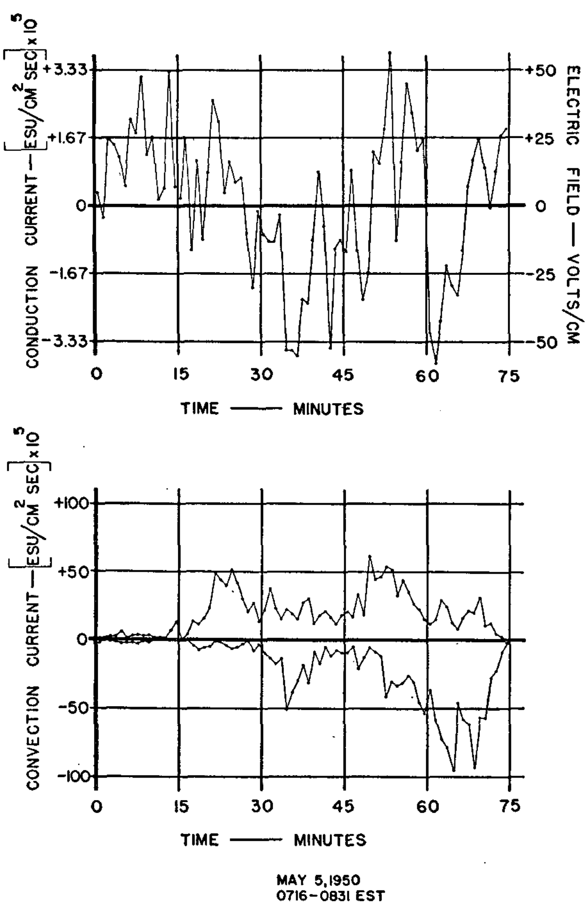

FIG. 12. Top: Electric field averaged over one minute intervals during storm of 5 May 1950; also conduction current density, if conductivity is 2×10^{-4} esu. Bottom: Convected current density; charge transported by positive and negative droplets plotted separately; net convected current density is sum of plotted curves.

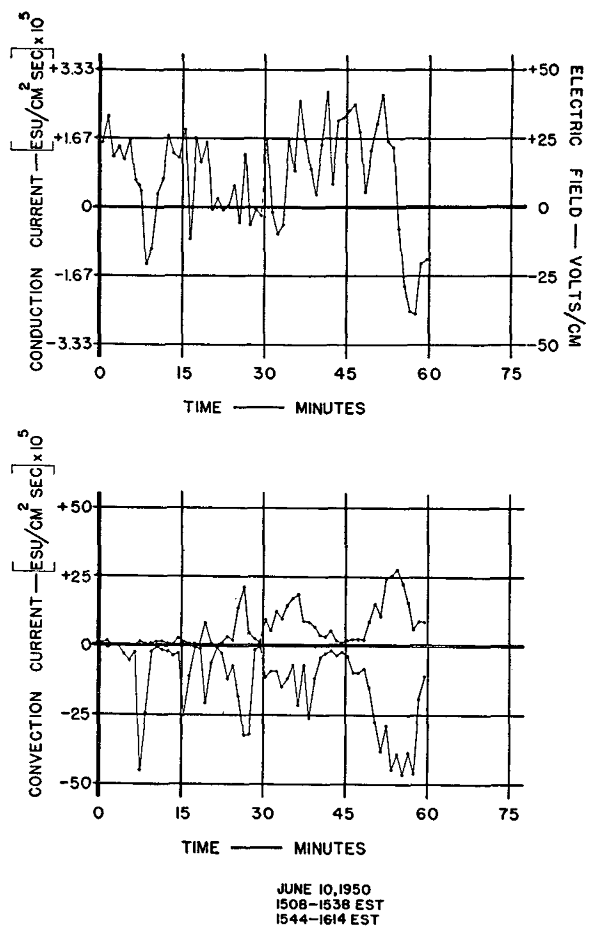

FIG. 13. Same as fig. 12, except for storm of 10 June 1950.

may verify this conclusion by a critical examination of figs. 1 to 9, which summarize the data on more than 7000 droplets.

To compare the current per unit area transferred to the earth by electrical conduction with that convected by the falling rain, simultaneous plots have been made of the mechanically transported and electrically conducted current in both storms. To clarify the details of behavior, the convected charges carried down per unit area by the positive and by the negative droplets are given independently for the two storms in the bottom portions of figs. 12 and 13. The net current density may be found by simply adding the positive and negative current densities. In the top portions of figs. 12 and 13, the plot of the electric field averaged over one minute intervals is given as a function of time. The electric field in these storms was subject to wide excursions and more than 300 changes of sign. Thus, these measurements afforded a rather critical test for the reality of any systematic correlation between the free charges brought down by droplets and the electric field. The estimated conduction current is given by the top portions of figs. 12 and 13, with use of the scales on the left side of the figures. Whipple and Scrase [6] quote Mr. Starr of the Kew Observatory as finding no abnormality in the conductivity of the air near the ground during thunderstorms, save for a few seconds immediately following a lightning flash. Thus, the conduction currents estimated above assume that the conductivity of the earth's atmosphere is its normal value of 2×10^{-4} esu. If corona discharge from surface objects is important, the resulting charge transfer by conduction may be underestimated.

The average free charge brought down by the rain in these two storms is summarized in table 1. The results summarized are generally consistent with earlier and less extensive measurements, except for the

TABLE 1. Summary of free charge brought down by rain. Q_- and Q_+ are respectively total amounts of negative and positive charge.

Date of storm	Number of drops +	Number of drops −	$\frac{Q_-}{Q_+}$	Average charge per drop (esu) +	Average charge per drop (esu) −
5 May 1950	2391	1643	1.0	0.028	0.041
10 June 1950	1457	1726	2.0	0.012	0.021
Both	3848	3369	1.2	0.022	0.031

fact that in the 5 May 1950 storm apparently just as much negative charge as positive charge was deposited on the earth by the rain. The larger average charge carried by the negative droplets and reported in earlier measurements is confirmed.

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