CORRELATION OF THE INITIAL ELECTRIC FIELD AND THE RADAR ECHO IN THUNDERSTORMS

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ABSTRACT

The time of onset of the initial electrification in a thunderstorm cell has been correlated with the appearance of the initial radar (3 cm) precipitation-echo. The results show that precipitation is a necessary, but not sufficient, condition for the onset of thunderstorm electrification. The presence of radar-detectable precipitation does not lead to thunderstorm electrification, unless the precipitation echo evidences rapid vertical development. When this condition is fulfilled, the appearance of the initial electrification is almost coincident with the appearance of the initial radar precipitation-echo. On days when no precipitation echoes were present, no electric fields significantly different from the fair-weather positive fields were observed, although the clouds noted ranged from small fair-weather cumulus to clouds of considerable depth and active convection.

1. Introductory remarks

One objective of a field program carried out during the summer of 1954 was to study the relationship between the initial development of precipitation, as detected by APQ-13 (3 cm) radar, and the initial appearance of cloud electrification, as detected by an electric-field meter. Earlier studies [1], made during the summer of 1952, yielded one instance in which the initial radar echo could be related to the initial stages of cloud electrification. In this instance, the first evidence of cloud electrification was almost coincident with the first radar detection of precipitation. Confirmation of this relationship was highly desirable, since it has an important bearing on thunderstorm-electrification processes.

The radar set and a 16-mm lapse-time cloud camera were located on the St. Augustine Plain (7000 ft msl), 13 mi distant from the summit of Mt. Withington (10,270 ft msl). The radar set was equipped for automatic vertical scanning and for continuous photographic recording of the plan-position indicator. The elevation indicator and a small watch were also included in the field of the oscilloscope camera. A clock, synchronized with the radar watch, was placed in the field of the cloud camera. The camera was trained on Mt. Withington. An electric-field meter was located on top of the mountain, where a U. S. Forest Service lookout tower provided shelter for the operator and equipment. A U. S. Forest Service telephone line from the radar site to the tower provided the communication necessary for correlation of the records made at the two stations. The sensitivity of the field meter and its location were such that the fair-weather positive potential gradient caused a deflection amounting to about 8 per cent of full scale. An absolute calibration of the field meter was not made.

In four instances it was possible, with reasonable certainty, to relate the onset of cloud electrification to initial radar echoes in the vicinity of the mountaintop. The time of onset of cloud electrification is here defined as that time at which the field meter indicated a significant departure from the fair-weather positive potential gradient. The fair-weather gradient is usually from +1 to +2 volt/cm when measured on an extended plane at the surface of the earth.

2. Storm analyses

Storm of 30 July 1954.—Cloud electrification, in a storm approximately 6.5 mi distant from the field meter, was first observed at 1405 MST. The echo from this storm had appeared at least 30 min before the onset of electrification, but the height of the echo had remained constant at about 17,500 ft msl until 1405 MST. The height of the echo increased from 17,500 ft msl at 1405 MST to 23,500 ft msl at 1408 MST, which is a rise in height of 6000 ft in 3 min. The electric field began to depart from the fair-weather value, in the negative direction, at the time the echo began to rise. The first lightning stroke, as detected by the field meter, occurred about 12.5 min after the onset of electrification. The electric field *versus* time is shown in fig. 1. The storm lasted for a total of 60 min, during which time it slowly moved away from the mountain. The field remained strongly negative for about 40 min; then the sign slowly reversed to give a small positive value. An examination of the radar data indicates that, during this time, the storm receded from the field meter to a distance of about

[1] This research was sponsored by the Signal Corps of the U. S. Army.

10 mi south and east. At about 1445 MST, a new storm developed 8.5 mi directly south of the mountain. At these distances, positive dipoles (positive charge center at a greater height than the negative charge center) in either or both of the above precipitation centers would be expected to produce small positive gradients at the mountaintop.

The behavior of the precipitation echo, in remaining at a nearly constant height for an extended period of time before evidencing rapid vertical growth in a localized region, is typical of the "delayed action" storms described in an earlier study [2].

Storm of 1 September 1954.—This storm also is an example of what have been called "delayed action" storms. For a period of at least 5 min preceding the appearance of electrical activity (the radar set was inoperative prior to this time), precipitation was detectable by the radar set over a large area approximately 3 mi south and southwest of the mountain. The echoes remained relatively constant in height at about 18,000 ft msl, until sometime between 1346 and 1350 MST, when the echo in one small region of the storm began to ascend. The time at which the ascent began cannot be stated more accurately, because of a brief period of faulty operation of the automatic vertical scan. This echo reached a height of 28,000 ft at 1359 MST. The initial discharge in the cloud was indicated between 1401 and 1402 MST. As can be seen from the plot of fig. 2, the onset of cloud electrification was indicated at about 1348 MST. A particularly good sequence of lapse-time cloud photographs, from which cloud-growth data could be plotted, was obtained for this storm. Plots of cloud height and radar-echo height *versus* time are also shown in fig. 2. These plots show the increase in height of the top of a single cumulus tower whose azimuth from the radar site was coincident with the azimuth of the growing radar echo. This cumulus tower was first distinguishable from surrounding and higher cloud masses at 1347 MST. It should be noted that the height of the echo and the height of the cloud top are virtually the same at this time, and that the rate of growth of the cloud exceeds that of the echo. The rate of vertical growth of the echo was generally greater than that of the cloud in the earlier study [2]. It is interesting to note a flattening of all three of the cloud parameters plotted in fig. 2 in the period from 1352 to 1356 MST.

Storm of 11 September 1954.—This storm was complicated by a multiplicity of almost simultaneous, initial echoes occurring within a 6-mi radius of the mountain. The analysis is complicated further by faulty operation of the radar automatic vertical scan, which makes it impossible to trace accurately the development of echoes. At 1105 MST, scattered low and very weak echoes were detectable in the region southeast of the mountain at distances of from 3 to 10 mi, and strong echoes were present at from 10 to 25 mi to the west. At 1109 MST, two echoes developed, one about 2 mi east of the mountain and the other about 8 mi west-northwest of the mountain. At 1113 MST, a new echo appeared about 6.5 mi northwest of the mountain, and at 1115 MST two new echoes developed 5 and 6 mi southeast of the mountain. At the time of initial detection, the tops of all three of these echoes were at from 20,000 to 22,000 ft msl (−10 to −14C approximately). The radar camera was inoperative in the period from 1115 to 1118 MST. By 1118 MST, two new echoes had developed 2 mi east and 4 mi south of the mountain.

Of this group of seven echoes, only the one occurring at 1115 MST and 6 mi southeast, and the one occurring in the period from 1115 to 1118 MST about 2 mi east, showed evidence of vertical development. In the period from 1115 to 1121 MST, the first of these grew upward at the rate of about 1000 ft/min; the second echo showed the same rate of development in the period from 1118 to 1121 MST. These two echoes reached heights of at least 30,000 and 25,000 ft msl, respectively. Rain began to fall on the mountain at 1125 MST. By 1133 MST, the rain was heavy; and at 1136 MST, graupel pellets about 1/8 in in diameter were observed.

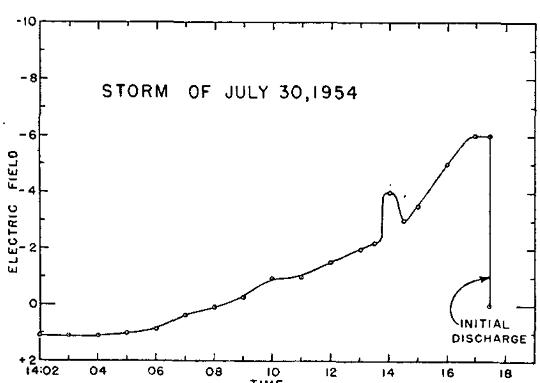

FIG. 1. Plot of electric field *versus* time for storm of 30 July 1954.

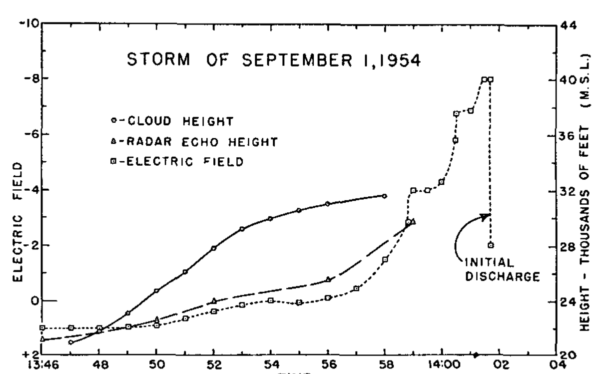

FIG. 2. Plot of electric field, cloud height, and radar-echo height *versus* time for storm of 1 September 1954.

At 1105 MST, when the field meter was placed in operation, a very slight positive field and occasional small negative deflections characteristic of distant discharges were noted. This electrification is attributable to the strong echoes 10 to 25 mi west. At 1109 MST, the indicated positive potential gradient was about the value of the fair-weather gradient. From 1109 to about 1116 MST, the field remained relatively constant at about the value of the fair-weather positive gradient. Between 1116 and 1117 MST, the indicated field began to depart significantly from the fair-weather value. A plot of field *versus* time is shown in fig. 3. The first discharge was indicated at about 1126 MST, and the time to thunder reveals that this discharge occurred in the nearest echo, which was first detected at 1118 MST. This time lapse of 8 to 11 min from echo to first discharge is in good agreement with earlier findings [2].

Since a significant departure from the fair-weather gradient occurred between 1116 and 1117 MST, it is not unreasonable to associate this electrification with either or both of the radar echoes which showed vertical development beginning at some time in the period from 1115 to 1118 MST.

Storm of 12 September 1954.—In the period from 1115 to 1138 MST, a positive field of from two to four times the value of the fair-weather gradient, with occasional discharges, was indicated. This electrification undoubtedly was caused by a large region of precipitation centered about 15 mi west of the mountain. At 1138 MST, a new echo was detected about 2 mi east-northeast of the mountain, with its top at 21,000 ft msl (about −12C). In the period from 1138 to 1141 MST, the height of the echo top increased to about 26,500 ft msl, or at the rate of about 2500 ft/min. The fact that the field was disturbed by the distant storm makes it difficult to determine precisely the time of onset of electrification in the nearby cloud, but the first electrification attributable to the nearby echo is indicated at some time between 1138 and 1140 MST – perhaps closer to 1138. The field became zero at 1144 MST and reached the off-scale negative value at 1150 MST. The time of the initial discharge cannot be determined with certainty, because of frequent discharges occurring at distances of 10 to 15 mi. A plot of field *versus* time, which has been smoothed to eliminate the effect of these distant discharges, is shown in fig. 4.

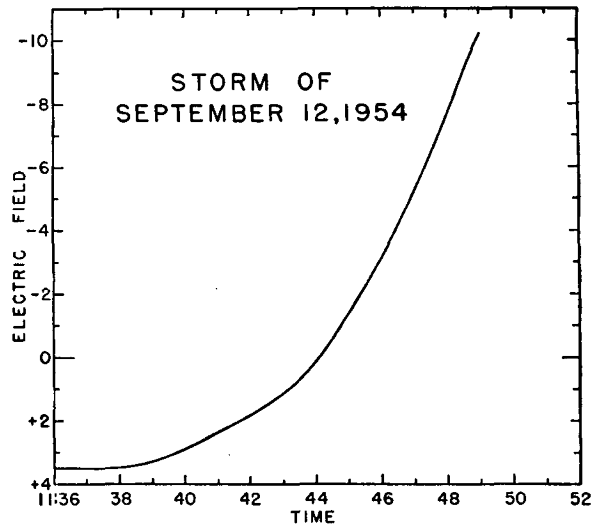

FIG. 4. Plot of electric field *versus* time for storm of 12 September 1954.

Although the analysis of this storm is somewhat complicated by the field disturbance of a distant storm, the correlation of negative electrification with the onset of precipitation in the nearby cloud is unambiguous.

Storm of 1 August 1954.—On 1 August, the field meter was operated while the radar observation station was not manned. The field meter indicated cloud electrification, but it is not possible to state the time or place of occurrence of the precipitation associated with the electrification. A few drops of rain fell intermittently at the mountain site before, during and after the indicated electrification. A plot of field *versus* time for this instance is presented in fig. 5, since it provides additional information concerning the rate of growth of initial thunderstorm gradients.

No abrupt field change suggestive of a discharge was

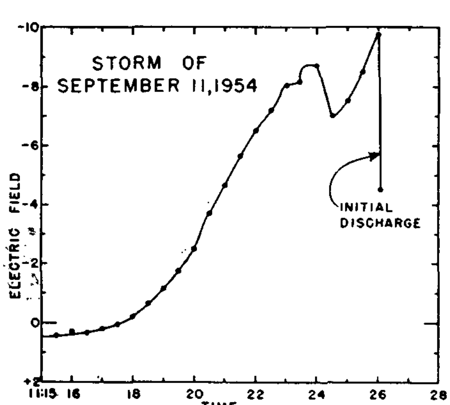

FIG. 3. Plot of electric field *versus* time for storm of 11 September 1954.

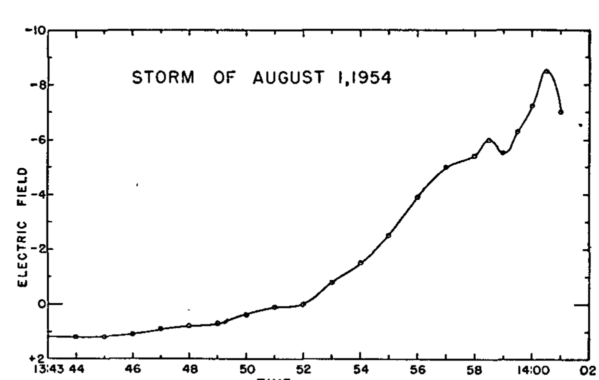

FIG. 5. Plot of electric field *versus* time for storm of 1 August 1954.

noted during the period shown in fig. 5; but, as can be seen, there were several relatively rapid but smooth fluctuations in the value of the field.

3. Correlation of electrical data with cloud conditions

The study of initial electrification and its relation to the initial radar precipitation-echo necessarily involved a large number of days during which no storms were present within 30 mi of the mountain. On these days, notes were made of the types of clouds which appeared, their relative depth, and whether active convection was apparent. The degree of convection was determined from lapse-time cloud photographs, when available. These observations were then compared with the electric-field record, to establish whether or not electric fields had been recorded. Data were taken for about 75 hr during which there were no precipitation echoes within radar range. The records show that, during these hours, the clouds varied from small fair-weather cumulus to clouds of considerable depth characterized by active convection. In no instance were the fields significantly different from the fair-weather positive gradient.

4. Summary and conclusions

The data presented in this article show clearly that precipitation (as detected with 3-cm radar) is a necessary, but not sufficient, condition for significant cloud electrification. The many hours of observation on non-precipitating clouds establish the necessity for precipitation. Despite the fact that these non-precipitating clouds varied from small fair-weather cumulus to clouds having considerable depth and very active convection, they gave no evidence of electrification. The storms of 30 July and 1 September, in which precipitation echoes were detectable for from 5 to 30 min prior to electrification, demonstrate that the occurrence of precipitation in cumulus clouds is not a sufficient condition for electrification.[2] In both of these storms, no electrification was detected until the radar echo showed rapid vertical development. Cloud photographs of the storm of 1 September show that this rapid vertical development was coincident with a strong updraft and a consequent rapid increase in the height of the cloud top. In the storms of 11 and 12 September, the radar echoes were characterized by rapid vertical development from the time of their first detection, and the first appearance of significant electrification was almost coincident with the first appearance of the echo.

A single instance in which the initial cloud electrification was coincident with the initial radar echo in the cloud was reported from the 1952 observational program [1]. It was thought that confirmation of this relationship might yield important information about the charge-separation process in thunderstorms. If the concentration of precipitation particles in the cloud is of the order of 10^4 M^{-3}, and if the cloud is from 10 to 15 mi from the radar set at the time of detection of the initial echo, the radius of the reflecting particles must be about 200μ. It is unlikely that particles of this size could be involved in the "glaze ice" charge-separation mechanism [3]; therefore, another process must be involved, at least in the initial stages of cloud electrification.[3] The near-coincidence of radar-detectable precipitation and cloud electrification (when the first echo is characterized by rapid vertical growth) is confirmed by the storm observations of 11 and 12 September.

The "delayed action" storms of 30 July and 1 September are not directly comparable to the 1952 storm. Although the initial electrification was not coincident with the initial echo in these storms, it was nearly coincident with the fulfillment of the second condition for electrification, *i.e.*, rapid vertical development.

It is gratifying that, in most cases where the data are available in the study reported here, the temperature level of the top of the initial radar echo and the time lapse between the initial discharge are consistent with the mean values (−10C at the top of the initial echo and 12 min time lapse from the initial echo to the initial discharge) found in the 1947 study [2].

Most of the records of initial electrification shown in figs. 1 to 5 are characterized by small but relatively rapid deflections a few minutes before the deflection designated as the initial discharge. The nature of the process causing these small negative deflections is uncertain. The magnitude of the deflections and the time constant of the Esterline-Angus recorder used in these studies are such that the time constant of the process cannot be stated even approximately. It is possible that these rapid increases in the negative field value prior to the main discharge are due to the spread of charge from the main region of negative charge to regions in the lower part of the cloud. Such discrete redistributions of charge would appear as increases in the negative field measured at the surface of the earth. It is also possible, in the cases of both the 30 July and 11 September storms, that the small negative deflections were caused by the discharge of a small positive dipole sufficiently distant from the gradient recorder that its existence caused a positive-field indication superimposed on the larger negative indication of closer dipoles. This explanation seems less likely for the small negative deflections in the

[2] There were, actually, several other instances in which precipitation echoes were observed in the vicinity of the mountain without significant electrification being recorded. It seems unnecessary to discuss these instances in detail.

[3] Laboratory investigations of a process which seems capable of accounting for electrification under the conditions described have been discussed elsewhere [4].

record of 1 September, since in this case the echo is much closer to the instrument site.

Some interest has been evidenced recently in the precise formulation of the time-rate of growth of initial thunderstorm fields. Such information, it is thought, would be diagnostic of the electrification process involved [5]. Although the curves of field growth *versus* time do appear to be exponential in some instances, the growth curve in most cases deviates considerably from an exponential law. This is not surprising, since the field as measured at the surface is a function not only of the charge associated with the dipole, but also of the space coordinates of the dipole and the distance between the dipole charges themselves. Obviously, it is not possible to evaluate all three variables simultaneously with a single field meter.

REFERENCES

1. Reynolds, S. E., and H. W. Neill, 1955: The distribution and discharge of thunderstorm charge-centers. *J. Meteor.*, **12**, 1–12.
2. New Mexico School of Mines, 1947: *Thunderstorm electricity.* (Prog. Rep. 4, Contract W-36–039-sc-32286), Socorro, N. M. School Mines, 26 pp.
3. Workman, E. J., and S. E. Reynolds, 1950: Electrical phenomena occurring during the freezing of dilute aqueous solutions and their possible relationship to thunderstorm electricity. *Phys. Rev.*, **78**, 254–259.
4. New Mexico Institute of Mining and Technology, 1954: *Compendium of thunderstorm electricity.* (Signal Corps Res. Proj. 172-B), Socorro, N. M. Inst. Mining Tech., 100 pp.
5. Vonnegut, B., C. B. Moore, and M. Blume, 1955: *Preliminary investigation of the distribution of space charge in the lower atmosphere.* Unpubl. paper read at "Conference on physics of clouds and precipitation particles," Woods Hole, Sept. 7–10.