A CORRELATION OF SFERICS CHARACTERISTICS AND ELECTRIC FIELD IN THUNDERSTORM DISCHARGE

By

WESLEY DANIEL WOODRUFF

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1959

Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1960

A CORRELATION OF SFERICS CHARACTERISTICS AND

ELECTRIC FIELD IN THUNDERSTORM DISCHARGE

Thesis Approved:

Herbert L. Jones

Thesis Adviser

Chas. F. Cameron

Robert T. MacVicar

Dean of the Graduate School

PREFACE

There is indisputably a very close association between unusually intense atmospheric electricity and the severe weather and tornados associated with thunderstorms. In the past ten years there has been much research devoted to study of the relationships between these two phenomenon, and it is important that such research and investigation be continued. If thunderstorms and tornados are closely associated with electrical mechanisms, a better understanding of these mechanisms should make it possible to increase the accuracy of tornado forecasts, to obtain warning of their presence, and conceivably to inhibit or prevent their formation.

This thesis is devoted to the collection and examination of simultaneously recorded sferics and electric field data derived from thunderstorm electrical activity. From such synchronized data it should be possible to understand better the physical basis of sferic activity and in turn to understand better the relationship of electricity and severe storms.

Research for this study was conducted at the Tornado Laboratory of Oklahoma State University using available equipment with some original adaptations. The work is a bit rough in some spots, but it is a satisfactory beginning step toward correlating electric field intensity and sferics.

The author has had considerable encouragement and help from the members of the Tornado Research Project, and to these men I give my thanks. My gratitude goes to Dr. Felix Boudreaux, Mr. George Lucky, Mr. Don Scouten, and Mr. Tony Flowers for their encouragement and technical assistance, and to Miss Barbara Benes, my typist.

Particular appreciation is extended to Dr. H. L. Jones. It is his strong encouragement, guidance and advice over the past several months which has made it possible for me to make completion of this thesis a reality.

Last, to my wife, Carol, loving thanks is given for her patience and invaluable aid, without which, preparation of this thesis would not have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

The thunderstorm and its effects that are manifest through lightning and associated phenomenon, have been known to mankind for at least as many years as we have recorded history. Biblical references to pillars of fire and forces of destruction can no doubt be attributed to the activities of the thunderstorm. The Norsemen attributed lightning to the magic hammer, Mjollner, of their fierce redheaded god, Thor. (1). To the Greeks and Romans, a lightning flash was one of the chief indications of the displeasure of either Zeus or Jupiter, the father of the gods of the respective nations. In other accounts one may read that certain African tribes claim that persons struck by lightning are unclean and attach other religious significance to thunderstorm activity.

Records of destruction by lightning as noted by Sir William Snow Harris in the early nineteenth century show some 150 British Naval ships severely damaged and 70 deaths and 130 wounded between 1799 and 1815. (1).

History of Atmospheric Electricity

Thus it is seen that the thunderstorm has been keen in the minds of men for centuries, but in the early years it was never noted that the strange phenomenon, lightning and its related behaviors, could be associated with electricity. Moreover, it was not even until 1600 that there occurred a man like William Gilbert who made the first scientific study of electricity; then it was not until 1708 that W. Wall (2) suggested an identity of lightning with electrical discharges.

Following the appearance of the ideas of Gilbert and Wall, the scientific exploration of the electricity in the atmosphere has proceeded steadily and more rapidly. In 1750, Benjamin Franklin suggested the possibility of obtaining electricity from thunderclouds and this he accomplished in 1752 with his now famous kite experiment. Also during Franklin's time, scientific study suggested that lightning was only one phase of an area of study of the physics of the earth, an area now known as atmospheric electricity. L. G. Lemonnier, (3) in 1752, set up a wooden pole with a pointed iron rod on the top. To this rod was attached an insulated iron wire which entered the laboratory and ended on a stretched silk fiber. With this experiment Lemonnier was able to observe, much to his surprise, that electrical effects were present even in fair weather. This was a finding perhaps even more important than the experiment of Franklin; it is an experiment that opened the second phase of atmospheric electricity, the phase of the electric field and fair weather conditions. In 1775 Beccaria confirmed Lemonnier's suspicion of a variation in the fair weather electrical effects, and in addition, he attributed a polarity to this electricity that was due to weather.

The preceding background and findings very briefly show some of the basic work on the two main phases of atmospheric electricity. Some more contemporary work combines these two phases into a solid system. This is the work of C. T. R. Wilson who in 1920 developed a theory that has survived all attacks to date and supposes thunderstorm cells to be likened to active batteries tied in parallel that maintain a charge on a leaky capacitor. (4). This capacitor is made up of the earth's surface, the atmosphere and the ionosphere. The atmosphere holds the place of the dielectric while the surface of the earth and the ionosphere are the two plates.

It is the field between these two plates that Beccaria confirmed and gave a polarity to, and it is a correlation of the charge of this field near thunderstorms and thunderstorm discharge that is dealt with in this dissertation. This correlation is achieved by synchronously recording lightning discharge characteristics, namely sferics and DF patterns, and the change of the electric field in close proximity to the discharge.

Contemporary Emphasis and Work

In the 1920's, the experiments of Wilson and George Simpson were carried out by working on the earth's electric field and the electric fields in and about thunderstorms. (4). More contemporary work now includes the findings of O. H. Gish, W. R. Wait, H. L. Jones, Ross Gunn and many others. For example, in 1952 on Mt. Worthington in New Mexico, where excellent thunderstorm formations occur, data was taken concerning potential gradient within and above the thunderstorm cell by means of aircraft and balloons. Observations in precipitation were made by radar. (5). The results of this experiment give some of the more important contemporary information. From this data reasonable conclusions are that appreciable electrification develops in a cloud before precipitation occurs, and this well confirms E. J. Workman's (6) view that charge separation is due greatly to convection while associated with precipitation. A very great assortment of other data is available, but the author finds no need to elaborate here. Findings pertinent to this discussion will be brought up as needed in later chapters, and the reader may wish to refer to the bibliography for further data.

Much of the modern findings is in search of answers to how a thunderstorm receives its electrical charge and characteristics and in search of clues to the definite characteristics and prediction of the worst result of the thunderstorm, the tornado.

Modern work leading up to the material presented in this discussion primarily centers around that of Dr. Herbert L. Jones and his staff at the Oklahoma State University School of Electrical Engineering. This is work that was started in 1948 after the Woodward, Oklahoma, tornado of 9 April 1947.

The early research was concerned mainly with investigating the frequency spectrum and waveform of atmospheric radiation [called sferics] in severe storms. This research was considerably hampered by lack of funds. In 1950 a band of sferics [150-250 kilocycles] was discovered by Jones and Hess (7) to be very active in the center of severe storms. The work continued and widened out after an initial boost in the way of an Army Signal Corps contract in 1951, and the work is presently continued under a contract with the United States Air Force. The Oklahoma State University laboratory work has far reaching effects and possibilities. The possibility closest to the heart of the author is the establishment of a sferic-electric field radar net for navigational assistance to aircraft pilots in severe weather.

In the winter of 1958 and spring of 1959 the study of the electric field and thunderstorms at Oklahoma State University was started by the work of Dr. Felix Boudreaux. In conjunction with Dr. Jones, Dr. Boudreaux set up instrumentation for recording the quasi-static electric fields near thunderstorms. Boudreaux (8) made possible the synchronous recording of the slow varying electric field with the rapid change due to electrical discharge.

To further the work started by Dr. Boudreaux, this author was able to acquire circuitry which allowed quite precise correlation of recordings of the above electric field with filmed data on sferics characteristics as received by the 150 kilocycle DF and the Q-3.

Much has been written in the way of thunderstorm history and accounts. Therefore, this chapter is not written to repeat that which can be found in scores of books; but the chapter is written as an introduction to a small area of thunderstorm research. It is hoped that the foregoing will serve as a locator in the vast subject of atmospheric electricity for this author's specific bit of research.

CHAPTER II

THEORY OF ATMOSPHERIC ELECTRICITY

It was stated in Chapter One that it is both feasible and convenient to regard the earth and its associated weather as a large electric circuit. Since it is the purpose of this study to correlate data taken on the weather's electrical discharge with data concerning the earth's electrical intensity or field, it is perhaps only proper to discuss the theory of the electric field and the thunderstorm electrification.

The Earth's Weather and Electric Current

The earth, its atmosphere and the ionosphere are held to be similar to a large spherical condenser with a poor dielectric. The earth by convention holds the position of the negative plate; the atmosphere, the dielectric; and the ionosphere, the positive plate. This is shown in Figure 1. The effective resistance of the atmosphere is roughly about 200 ohms. Its conductivity is found to be due to small ions that derive their energy from cosmic rays and radiation emitting from decomposing radio active particles of the earth. These atmospheric ions consist of clusters of molecules held together by the electric field of a central charged molecule. They have a high mobility and thus account for the greater part of the atmospheric

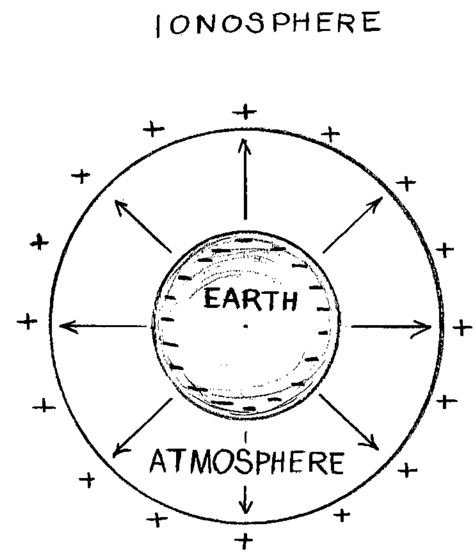

Figure 1. The Earth and Its Atmosphere as a Spherical Condenser

current. The ionization of the atmosphere is known to increase with altitude due to the increase of cosmic rays, and thus the conduction of the atmosphere also increases with altitude. (4).

It has been estimated that the earth's surface holds a negative charge of some 400,000 coulombs. This would place the potential on the earth-ionosphere capacitor at about 400,000 volts. With this high potential and the atmosphere's high conductivity, the earth's negative charge is continually and rapidly leaked off during fair weather by a steady downward flow of positive ions [electrically equivalent to upward leakage of negative charge]. Gish has estimated this leakage to be about 1800 amperes which would allow the earth to lose about ninety percent of its total charge in an hour.

The question raised by the German physicist, F. Linss, now arises. How does the earth, a charged body which is constantly and rapidly being drained, replenish its charge? The answer seems to lie in the large number of active thunderstorms continually present about the earth. It has been noted that during thunderstorms electric field intensities fluctuate widely and rise to high values. Beneath a thunderstorm the field is first noted to be negative [fair weather fields are positive]. When cloud-to-ground discharges occur, the field becomes less negative and at times goes positive. This change of field upon discharge is due to an electric current flow and charge displacement from cloud-to-earth and vice versa.

If, as Wilson suggested, the many thunderstorms scattered about the surface of the earth are thought of as a battery of electric cells in parallel, the earth's electric charge could be maintained. The lower poles of the cells funnel charge downward via lightning and point discharge currents from trees, poles and pointed objects while the upper thunderstorm poles are embedded in the high conduction region of the high atmosphere and leak positive charge upward. The upward charge is then dispersed and supplies the charge for the descending currents of fair weather.

A theory such as this has survived all attacks, and later findings even boost its validity. S. J. Mauchly of the Carnegie Institute of Washington D. C. has found that the maximum potential gradient of the earth occurs at about 7 P.M., G.M.T. The British meteorologist, F. J. W. Whipple has found that the most active period of combined thunderstorms about the earth is from 3-8 P.M., G.M.T. (4). A correlation thus exists.

O. H. Gish and W. R. Wait measured the net current exchange on the top of storms by the use of a United States Air Force B-29 airplane. They found that one-half ampere current flowed above each cell. This being true, it would require 3600 active cells to be present about the

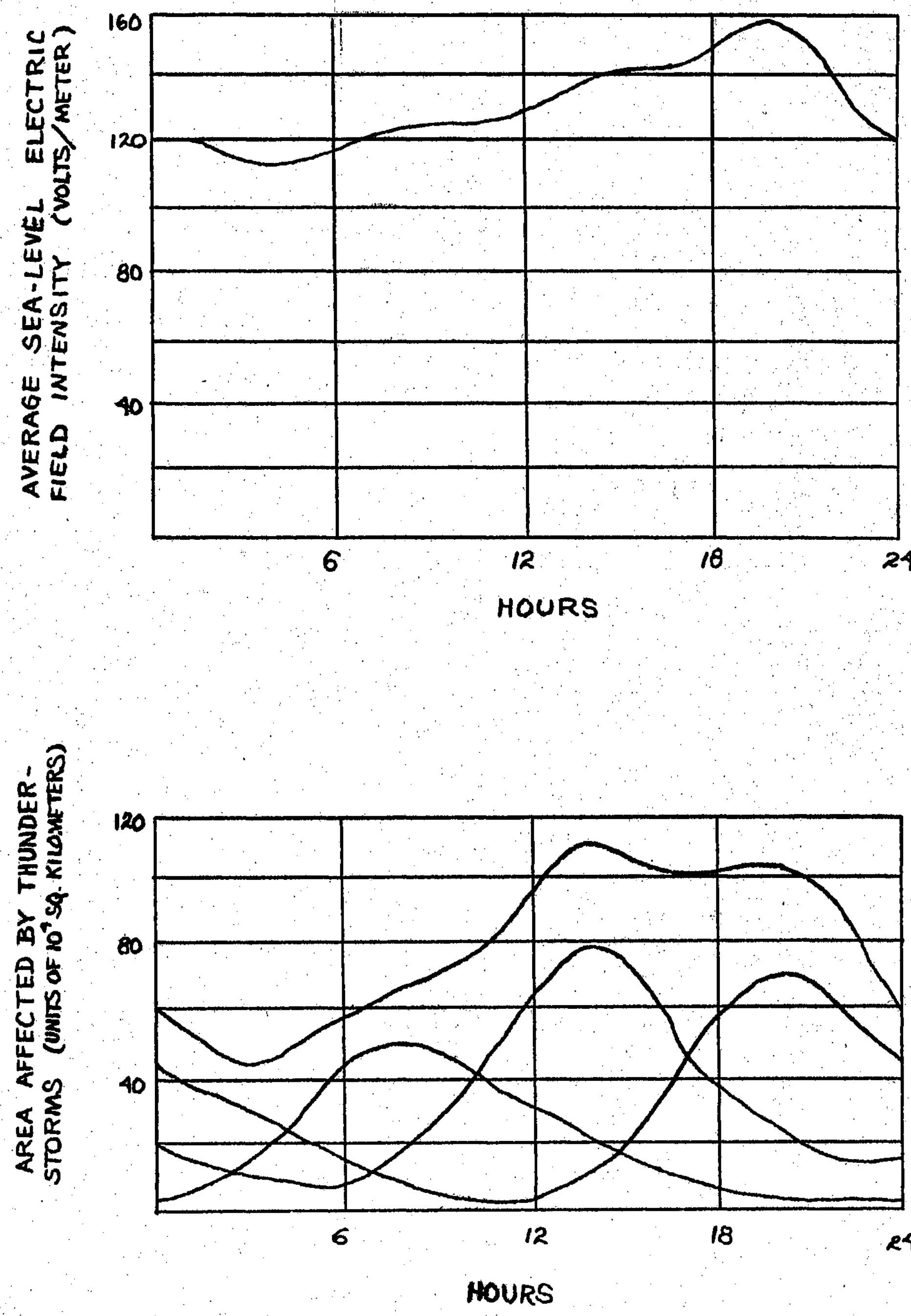

Figure 2. Daily Variation of Thunderstorms and Intensity of Electricity

earth at all times to maintain the assigned 1800 ampere leakage current. The presence of 3600 cells is quite feasible. Even though the B-29 crew could not measure current at great heights, the National Bureau of Standards has estimated that eighty-five percent of all current measured below 40,000 feet gets to the ionosphere. The stated theory then remains possible. Figure 3 depicts this theory of Wilson's.

The Thunderstorm Cell

The thunderstorm cell is the origin of the electricity in the earth's electrical system. From the cell comes the electrical discharge about which the technical data in this report has been taken. It might be well, then, to cover a bit on the original electrification of the thunderstorm cell and some important points on the electrical discharge. Brief mention might also be made of the formation of the cell to effect a better understanding of the electrical charges and of the great forces within the cell.

A thunderstorm will only form under certain meteorological conditions. These conditions appear to be unstable air of relatively high moisture content combined with some sort of lifting action. When these conditions are present the thunderstorm starts to form. There are several varieties of lifting action. The varieties commonly associated with the violent plains thunderstorms are the convection lifting [heating of a lower air mass in contact with a warm land or water surface] and the frontal lifting [warm air mass overriding a cold air mass]. (9).

The mature stage of development is reached when moisture begins to fall from the cloud. This stage occurs when the moisture of the rising air has been carried sufficiently high to bring about precipitation

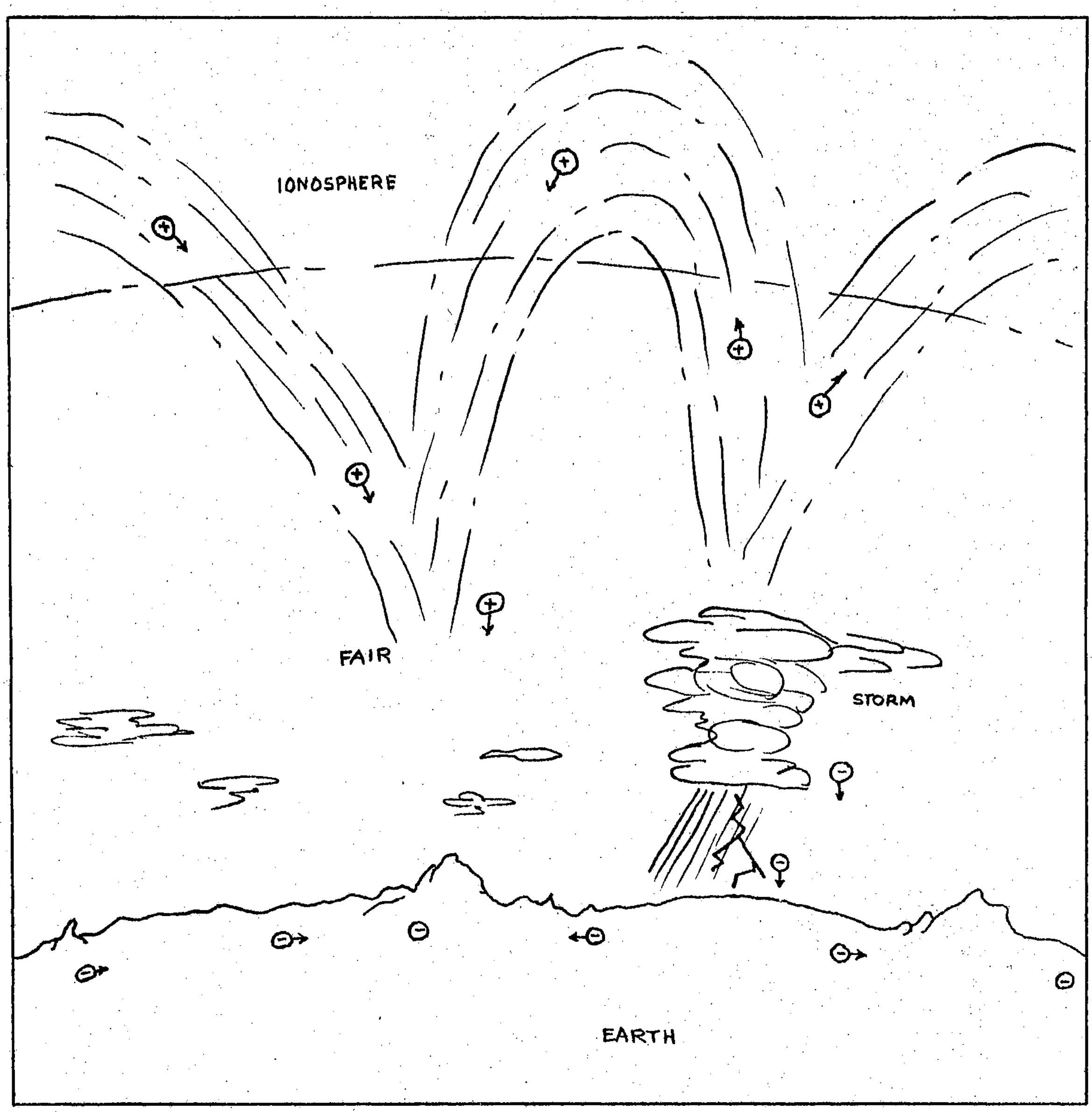

Figure 3. The Earth's Electrical Circuit

and its partial freezing into hydrometeors such as hail and snow. The updrafts are unable to support the moisture in this form and precipitation results. This falling precipitation in the mature cell is thought to be the origin of the violent downdrafts that are known to occur in thunderstorms, and it is these downdrafts that spread out upon reaching the surface of the earth and give rise to the gusty surface conditions under the cell.

An idea of the tremendous forces in the thunderstorm cell at the time of maturity may be had if one realizes that one cell can deposit one and one-half inches of rain over one square mile of the earth. This rain would weigh about 100,000 tons and the lifting action required to initially support such weight would be enormous.

As the vertical drafts subside and the thunderstorm cell deteriorates, the final stage occurs. But it is the mature stage of the cell that holds the greatest interest and the greatest electrical activity. A schematic of a mature thunderstorm cell at the height of its electrical activity is shown in Figure 4.

Thunderstorm Electrification

The methods of electrification of the thunderstorm cell are still under considerable debate, but the generally held view of cell charge distribution is as depicted in Figure 5. One of the more accepted means of cell charge is presented below.

Experiments have shown conclusively that when water of the purity

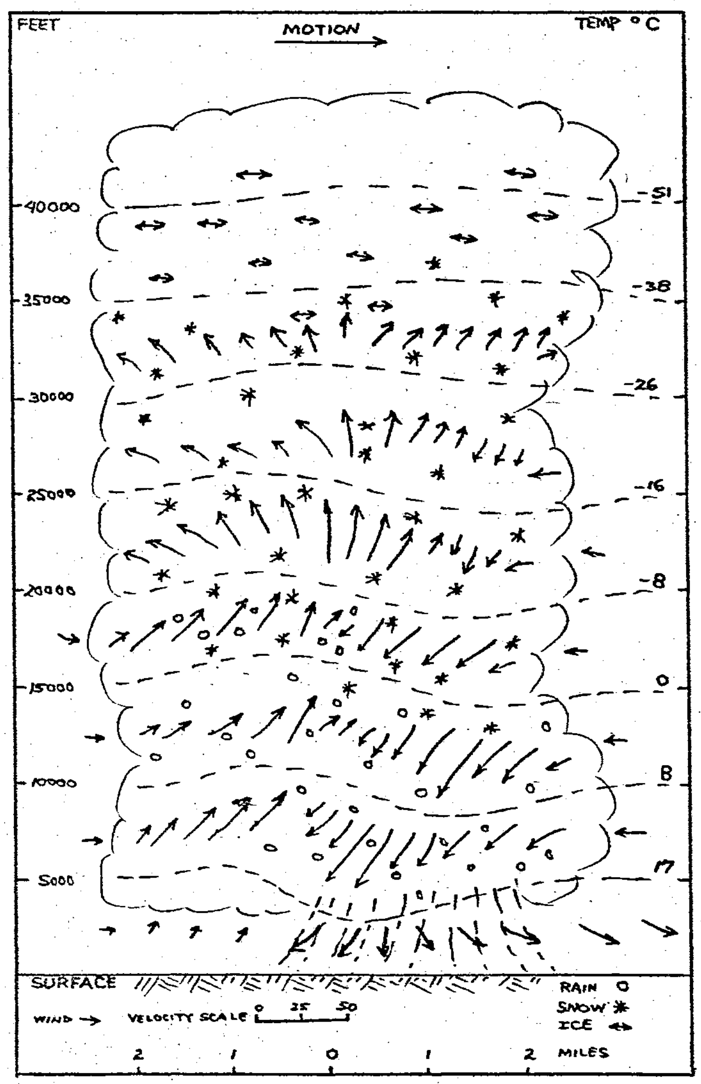

Figure 4. The Mature Thunderstorm at the Height of Electrical Activity

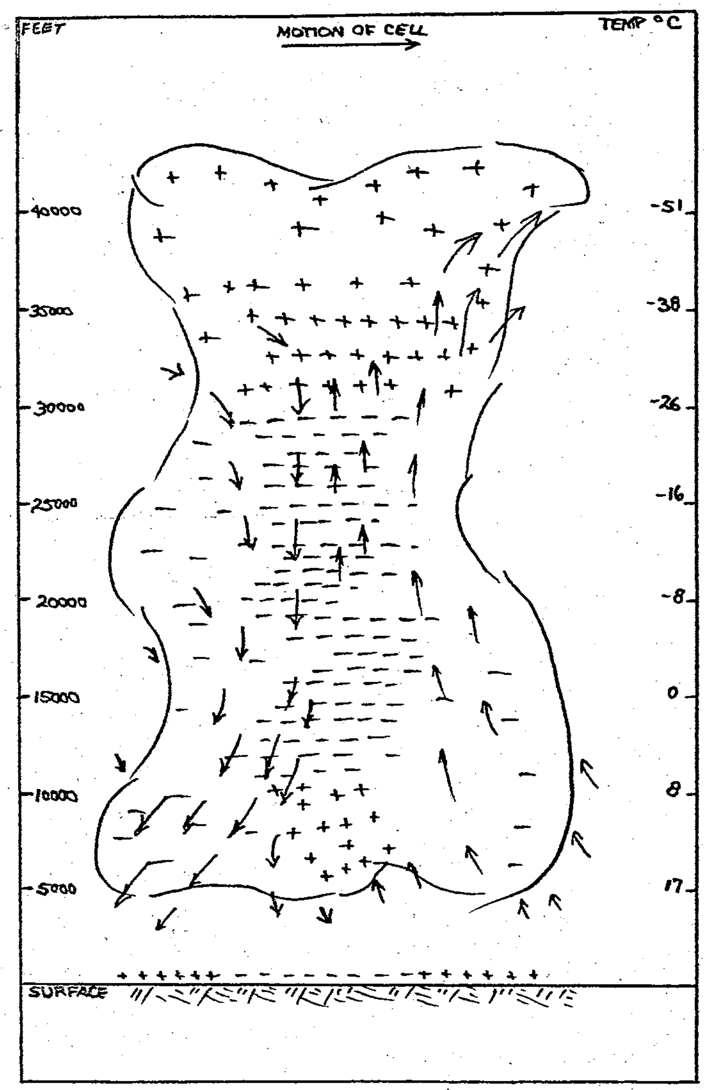

Figure 5. Charge Distribution in the Mature Thunderstorm

of raindrops freezes, very high electrical potential differences exist between the liquid and the solid state during the freezing. (6). A similar difference also occurs during melting. Because an electrical potential exists in these states, a difference in charge must be present on the two phases. If then, in some way the two phases of water mentioned could become separated, there would exist the separation of charges as occurs in the thunderstorm.

In the developing cell, moisture is raised upward through the freezing levels. As the moisture is raised it freezes and turns to various forms of hydrometeors. These in turn fall through the cloud and melt. As the freezing and melting takes place, gusty winds within the cloud blow the liquid away from the solid ice phase. The ice continues its fall and more melting occurs with more charge separation coming about. Usually the water is such that the solid ice becomes negative and the liquid becomes positive. The updrafts thus carry a positive charge, and the net effect as millions of ice particles go through this separation process is that a strong vertical field or dipole develops within the cloud. The positive charges are primarily at the top of the cell and the negative charges group towards the bottom layers. Once the dipole with the high electric field is created, its field may bring about further charging processes by polarizing falling raindrops and by ion movement. (1).

As was stated, the method of electrification is still under debate. However, there are some conclusive findings as mentioned and others that are of great interest and can be checked if desired. (10). The method of electrification presented here is a feasible and acceptable one if not <u>the</u> one. But the charge separation is known to exist as shown in

Figure 5, and such charge gives rise to lightning discharges that are of importance to this study.

One of the ultimate goals of thunderstorm research is to be able to determine the severity and path of a thunderstorm and its tornado so that human beings can have sufficient warnings and prepare themselves. The achievement of this goal quite possibly depends upon the study of the lightning discharge, its origin and its effects as a correlation with thunderstorm severity and movement.

Thunderstorm Discharge

Highly charged thunderstorms, either as isolated cells or in close proximity with other cells, have the possibility of various types of discharge. Intra-cloud discharge strokes are possible due to inner-cloud electric fields; cloud-to-ground strokes are possible when the negative charge at the base of the cell becomes great enough in relation to the induced positive charge on the earth's surface; inter-cloud strokes become possible between opposite types of charge in different cells when the proximity of the cells becomes sufficient. It is also thought that cloud-to-troposphere discharges occur occasionally due to the high positive charge on the upper portion of the cell. These four strokes are shown in Figure 6.

Regardless of the type of thunderstorm discharge stroke, its synthesis is essentially the same and the crooked electric spark of the laboratory has been turned to for aid in study. (10).

Most lightning strokes originate from the negatively charged cloud cell by first advancing an invisible pilot leader some 10-160 meters into virgin air along a meandering path. The length of the leader depends

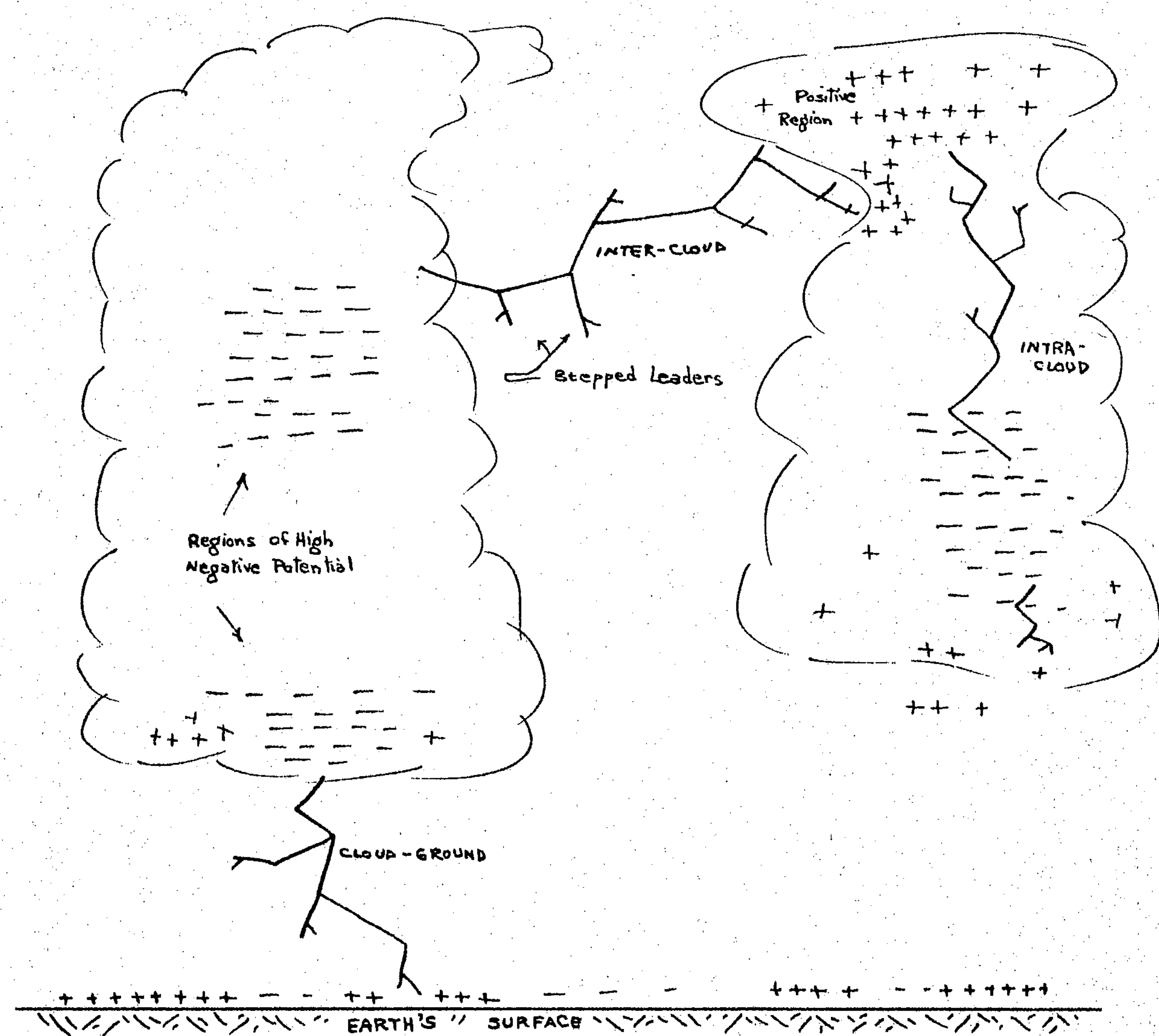

Figure 6. Primary Types of Lightning Discharge in Thunderstorms

upon the vigor of the stroke and its initiation depends upon local conditions producing a breakdown field. The pilot leader advances by a process of electron avalanche formations and moves at a minimum velocity of 62 miles per second as shown by Boy's camera. (1). After such an advance, decay of ionization and conduction in the pilot leader channel lead to an accumulation of electricity and an increase of electrical field at the negative cloud end of the path. This then launches a wave of ionization down to the tip of the slowing pilot leader. The wave moves at about 1.5×10^{-8} cm/sec and is quite visible. This second wave revitalizes the pilot streamer which again lurches ahead on another step. The electric current in the pilot and step leader will approach 50-600 amperes.

As the stepped leader approaches 10-40 meters from the earth or some positive charge, a return positive stroke comes to meet the leader and closes the gap. This return stroke accounts for the brilliant flash seen in lightning and contains electric currents as high as 500,000 amperes. (11). The sharp report or thunder that is normally heard is a low frequency rumble produced by the violent heating and adiabatic expansion of air caused by the enormous power carried in the return stroke.

One stroke does not necessarily completely discharge a cloud. In what seems to be a single lightning flash to the eye, several strokes exist with spacing of 30-40 milliseconds. The strokes, subsequent to the first, do not have a stepped leader but follow the already well ionized path towards the ground. The leaders of these strokes are termed dart leaders and are met by a return stroke as in the first.

Stepped leaders are of two types. The α leader has short and weakly luminescent steps. The ⊖ leader has the first part of its channel formed by longer and brighter steps. These steps are associated with extensive branching in the upper part of the channel. This branching suggests a stronger electric field at the beginning of the path than later on.

Although the synthesis of all lightning strokes is essentially the same there are two groups of strokes which should be separated. The cloud-to-ground stroke follows the procedure outlined above and includes the return stroke. However, observations have been made upon air discharges which do not reach the ground and flashes within the cloud; such observations show that these discharges consist in the main of stepped leader processes only, with occasional bright dart leaders up along channels already formed. Since these discharges make no contact with the ground, they show no return streamers. (1).

The Electric Field

The potential gradient, or rate of change of potential with distance, represents the force acting on a charged body when due respect is taken of polarity. Field or Electric Field is used to represent this potential gradient. When it is used in atmospheric electricity, the field is used to mean the mechanical force due to electrostatic effects acting on unit positive charge placed at the point. This field is vertical to the earth and adopted convention in atmospheric electricity states that the field is positive when the potential gradient is positive. Thus, in fair weather the earth holds the negative charge and the ionosphere the positive charge. (12).

If in an electric field a charged body or mass is moved about between the poles of the original field, this mass will effect the original field values and give considerably different values at locations near to the mass. Of course, if in some way a change occurs in charge on the boundaries or poles of this field it would change the electric field values completely. This is precisely the case with the thunderstorm.

The thunderstorm considerably effects the measured field of the atmosphere as the storm either forms or moves into an area. As a storm center moves into an area of fair weather the field changes from positive to distinctly negative values. The thunderstorm also alters the value of charge on the poles of this field by lightning discharge. The discharge carries negative charges to earth as stated earlier, and it is this charge transfer that gives the electric field recordings in this paper.

CHAPTER III

MEASURING SFERICS CHARACTERISTICS AND THE RELATED ELECTRIC FIELD

In the previous chapters an attempt has been made to furnish some basic background relating to the problems at hand. It is thought that an understanding of primary thunderstorm theory and theory of the earth's electrification is needed to understand what was done in the research that is presented here. Attention is now focused on the instrumentation and data of the specific problem.

When a lightning discharge occurs, two events of interest take place. One event is the transfer of electrical charge, and the second event is the emission of electromagnetic radiation of many frequencies in the form of radiation pulses known as sferics.

The basic problem to be investigated is an attempt to gain precisely synchronized recordings of the characteristics of these sferics and related changes in the earth's electric field. Perhaps from these recordings could come some decisive correlations which would give more reliable knowledge with which to predict thunderstorm activities.

The instruments selected for solution to this problem are the Q-3 equipment operated in conjunction with a 150 kilocycle direction finding unit, an electric fluxmeter of the rotating probe type and a stationary electric probe patterned after B. F. J. Schonland. (13). These instruments were modified to allow for necessary recordings and were used in connection with a monostable multivibrator triggered by a synchronizing pulse from a local oscillator.

The Q-3

The equipment used to receive and record the sferics characteristics has been furnished by the United States Air Force under a research contract and is designated the Q-3. It is designed to receive electromagnetic radiation energy at frequencies between 3 kilocycles and 10 megacycles and to photograph on 35 mm moving film the data received. The recorded data includes wave forms of the radiated energy and a notation of the level and direction of arrival of 10, 75 and 150 kilocycle energy. Time of arrival and recording is also noted by use of a clock that is synchronized with radio station W.W.V., Washington, D. C. The clock is photographed along with the incoming intelligence. (14).

Figure 7 shows an example of a film record from the Q-3 equipment. The data of particular interest on this record is the waveforms, time and 150 kilocycle direction finding traces. The DF or direction finding traces will often show the number of pulses as well as direction of origin of a stroke. This also gives a clue as to the type of lightning stroke. (15). The waveforms may be analyzed for amplitude, frequency content, type and many other characteristics. The time recording is, of course, used to synchronize the film with related data taken from other instruments.

The 150 kilocycle DF information is received by a separate narrow band 150 kilocycle receiver and amplifier. This receiver uses two loop antennas which are fed to a set of deflection plates in a cathode ray tube on the Q-3. With this arrangement directional information can be

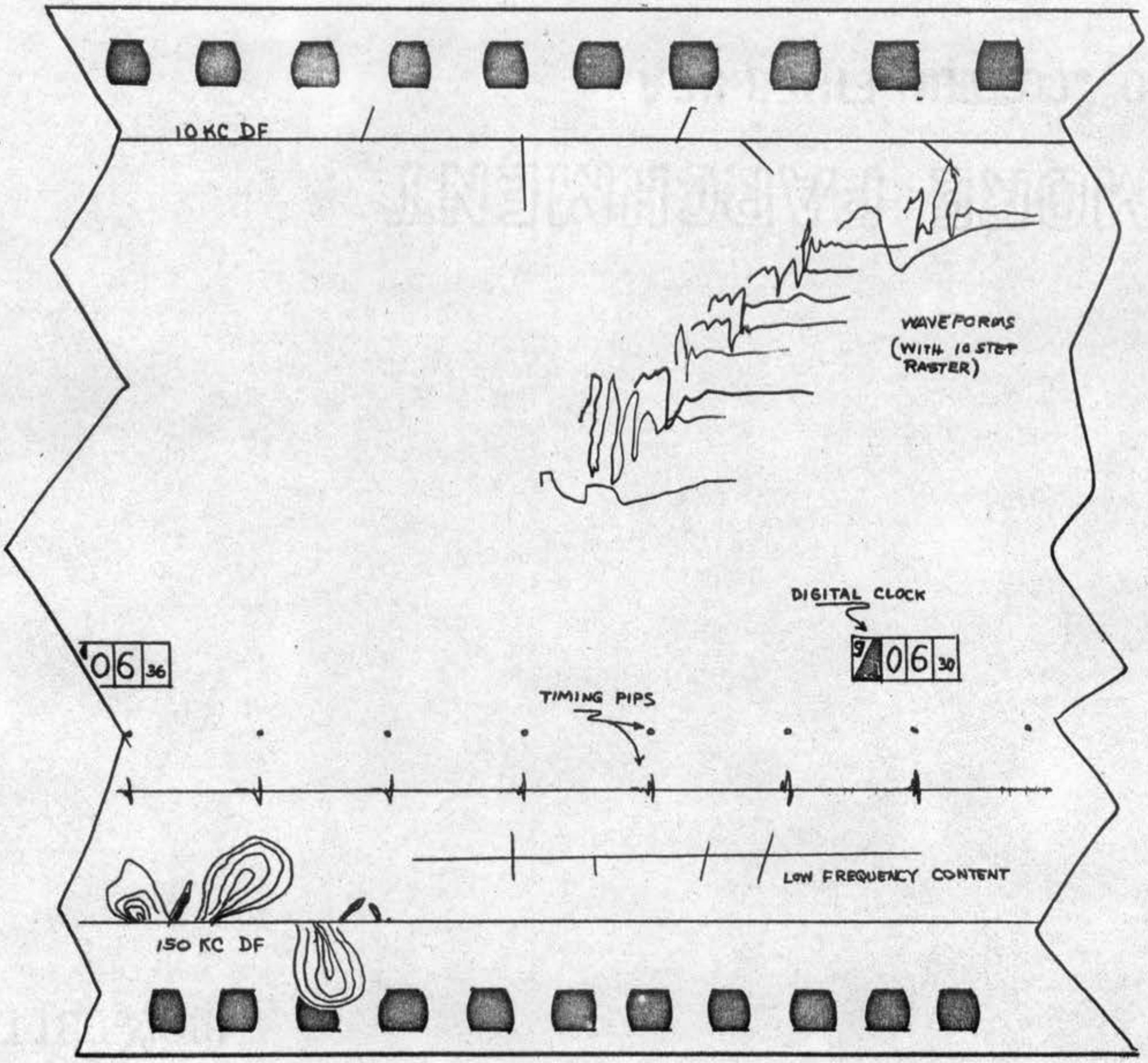

Figure 7. Typical Film Record From the Q-3 Equipment
Showing Waveforms, Timing Pips, and DF

had.

The Q-3, itself, uses two loop antennas and a vertical sending antenna. The two loop antennas are turned to a frequency of 10 kilocycles and the information is amplified and solved for directional ambiguity much in the way a radio direction finder works. The 10 kilocycle signal is then presented, through the use of proper controls and units, on a two-beam cathode ray tube. Thus the amplitude and angle of arrival of the 10 kilocycle component of signal is known. The sensing or verticle antenna is used to send a signal to a broadband 3-300 kilocycle receiver for use in wave forms and to two narrow band receivers of 20 and 75 kilocycles which are used to present the energy content of the sferic pulse at the specific frequency.

The actual waveform of a sferic pulse contains many frequencies, but by using the broadband receiver of 3-300 kilocycles a fair reproduction of the original waveform can be made. These waveforms are amplified and presented on the cathode ray tube for photographing.

To allow for clarity in reading the many waveforms and pulses presented, the camera has a variable speed control which allows for horizontal spacing of the waveform images. Also a stepped raster system is used whereby the reference for each successive waveform locates slightly to the right [slightly lower on the film presentation] of the preceding reference until nine relocations have been made. The reference then moves completely to the left and the cycle repeats. All information lined up on the film with the start of the waveform can be considered to hold true for the complete sweep of the waveform, since the film speed runs at about 600 feet per minute and the cathode ray tube sweep is 500 microseconds. The positioning error is therefore negligible.

A timing section in the Q-3 provides accurate timing information for photographing. A frequency standard provides a 100 cycle per second voltage to the motor of a synchronous clock. One and six second switch contacts on the clock are used to provide one and six second indicator pulses on one of the cathode ray tubes. The six second pulse is used to illuminate the clock face for photographing. Thus, one second pulse marks show on the film as does the printed time every six seconds. The local timing system is compared and synchronized with WWV by use of a receiver and calibrator unit capable of detecting WWV. The one second pulse of the timing section is also used to trigger the event marker on the strip chart recorder that is mentioned later.

Stationary Electric Probe

The equipment used to detect both the slow and rapid changes in the electric field of the earth was designed and built at the Oklahoma State University laboratories by Dr. Felix Boudreaux. While the idea of the two pieces of equipment was not original with him, the building, trouble shooting and perfecting of the circuits is original.

To detect and record the very rapid field changes from thunderstorm discharge an instrument of a high time discrimination is necessary. For this reason the stationary electric probe is selected as it will discern changes on the order of milliseconds.

The essential features of the probe are shown in Figure 8 in which C_A and R_A represent the capacitance and resistance through air, S represents the metal sphere or probe, R_R represents the input resistance of the recorder and C_S represents the capacitance in parallel with the recorder.

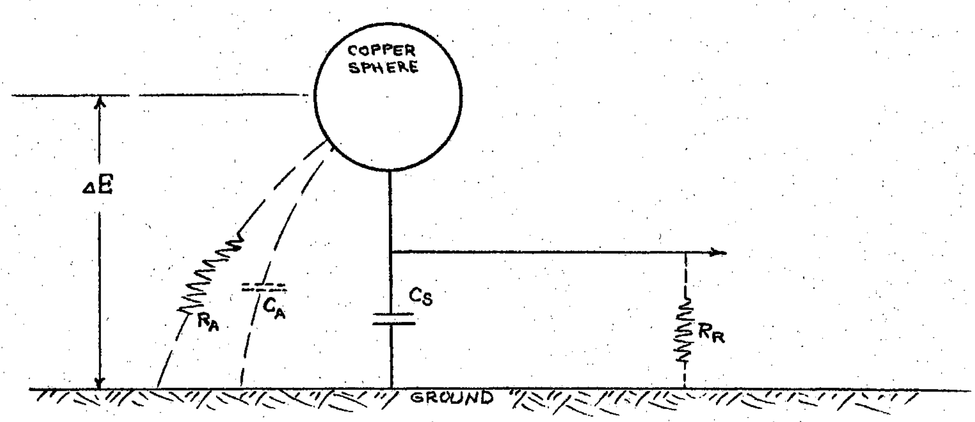

Figure 8. The Electric Probe

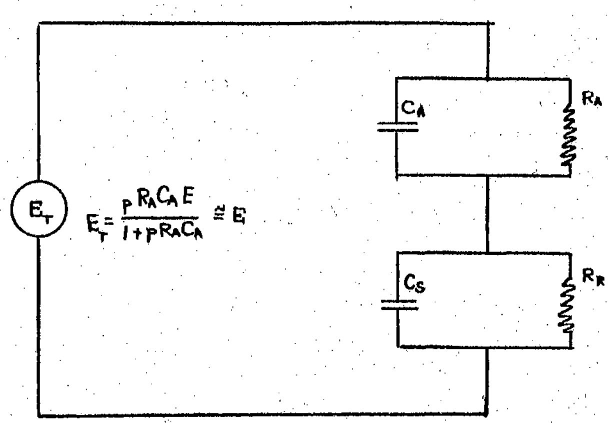

Figure 9. Thevenin's Equivalent of the Electric Probe

Alternating current circuit theory states that if an alternating voltage is applied to two impedances in series that have the same sign, magnitude and phase angle, the voltage across the two impedances will always be of the same ratio. In the case of the electric probe the change in the earth's electric field will provide a change in potential between the sphere and the ground. This change of potential can be used as the alternating voltage in the above statement. When the values of C_A and R_A are calculated and the values of R_R and C_S adjusted so that $R_R C_S = R_A C_A$, an equivalent circuit can be drawn as in Figure 9. The required situation of an alternating voltage across series impedances is present and the voltage across the $R_R C_S$ combination is in proportion to the voltage across the $R_A C_A$ combination.

Since the system is driven by the electric field change, a recording of the voltage across $R_R C_S$ will be an accurate representation of the field change. If the time constant of the system is long enough, faithful recordings of all but comparatively slow changes of field can be made. A slow or steady change on the recording means nothing, but rapid changes are fine representations of the rapid field change due to lightning discharge.

A copper sphere 12 inches in diameter and 1.5 meters above the ground was used in this instrument. The capacitance was calculated to be 17.6 microfarads and the air resistance to ground was calculated to be about 5 megamegohms. (8). The time constant figures to be 88 seconds.

One channel of a two channel Brush Recorder was used for recording and the input resistance of this channel was 5 megohms. Thus, C_S must have a value of 17.6 microfarads so that $C_S R_R$ will also yield the 88 second constant.

As mentioned, a Brush Recorder was used. This recorder has variable speeds from 1 millimeter per second through 125 millimeters per second. The 125 millimeter speed was used throughout the recording of data in the research as it is a speed fast enough to allow the individual strokes of the recorder pen [that are due to separate field charge pulses] to be well separated for reading. This separation also allows for fine accuracy when the recordings are compared with the film from the Q-3 equipment.

Electric Fluxmeter

The important instrument in looking for correlations in this research is the electric probe. The probe, however, is only capable of detecting rapid field changes. For this reason the electric fluxmeter was used to record the slow changes and steady values of the electric field.

The schematic for this meter is shown in Figure 10 and the recorder noted is the second channel of the Brush Recorder. It is unnecessary to cover the theory and details of the meter at this time.

Simply, the meter is a straight probe rotated about its midpoint. One-half of the path of the probe is shielded to ground and the other half is vertical in free air. Since the potential field to be measured is vertical to the earth's surface, the probe cuts the lines of this field in its rotation and develops a two cycle per revolution sine type current. This current is passed through a resistor and the resulting voltage is amplified, rectified, filtered and presented to the recorder as a representative of field change.

Ambiguity of polarity is solved by developing a reference voltage of the same frequency as the probe and comparing the two voltages. This is done by an induction generator operating from the same shaft that drives the probe.

Synchronized Event Marker

The basic problem is to gain precisely synchronized recordings of the electric field changes and the sferics characteristics. This reduces to synchronizing the Brush Recorder records with the Q-3 equipment film. The Brush Recorder has an event marker pen coupled with the unit. This pen can be triggered by an independent low voltage source. The solution of the problem, then, is to synchronize these possible event marks with the Q-3 film.

One of the main contributions arising from this author's work is the operation of the synchronized event marker. This is accomplished by constructing a monostable multivibrator with a relay in the plate circuit. The multivibrator is wired so that the one-second pulses from the Q-3 timing section will trigger it. This in turn actuates the relay and marks the recorder strip. Thus, the event pen's markings coincide with the one-second pulses on the Q-3 film. The error between the timing pulse and the event marker due to electrical and mechanical delay was checked and found to be negligible on the scale on which the recordings are read.

The multivibrator circuit is mounted on the chassis of the flux-meter amplifier. The unregulated side of the amplifier power supply is tapped for power to the multivibrator. A disabling switch on the incoming signal is also installed. The only difficulty experienced with the multivibrator circuit is some feedback or interference to the time pulse. This interference is discernable if the pulse source is

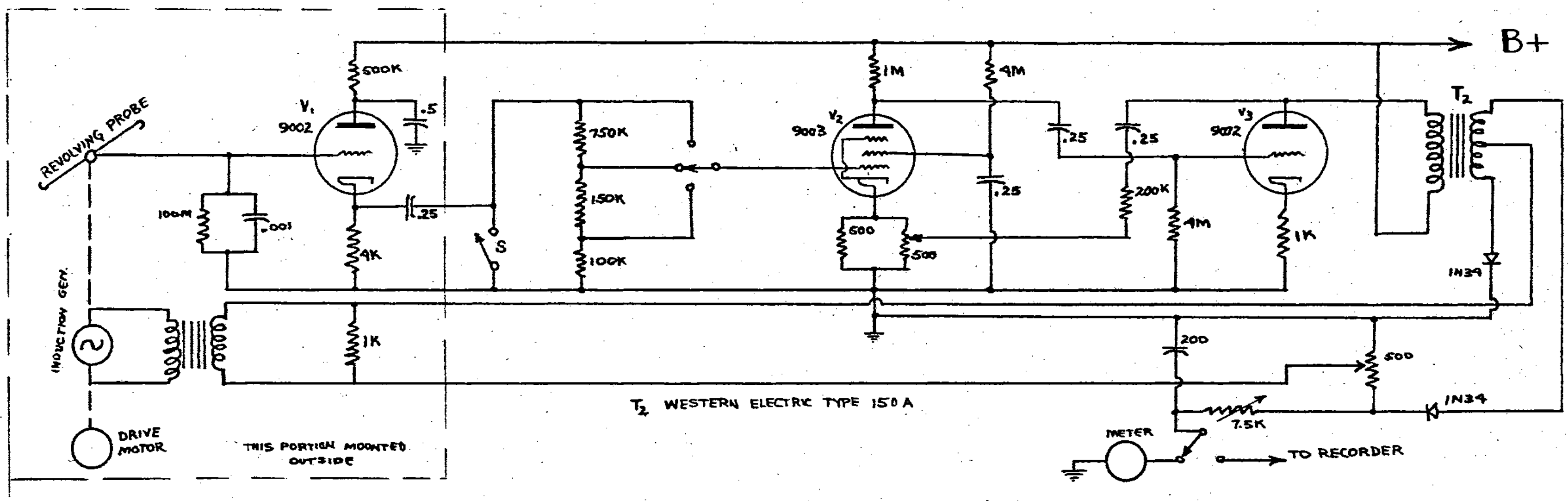

Figure 10. Schematic of the Electric Fluxmeter

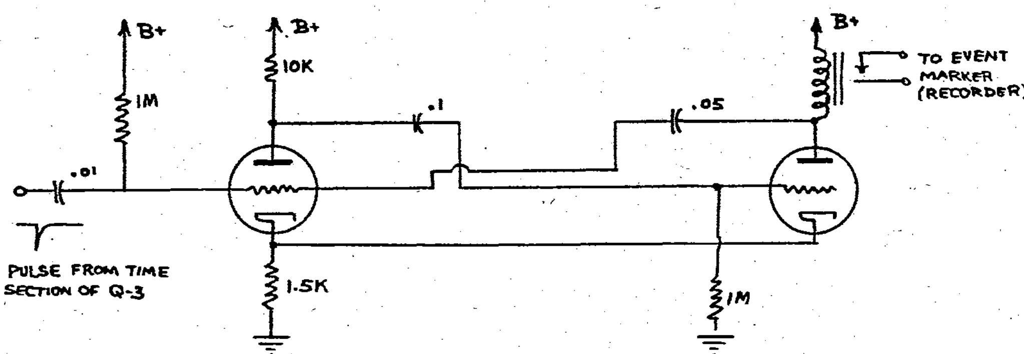

Figure 11. Schematic of the Multivibrator

monitored with an oscilloscope, but it does not seem to effect the functioning of the timing pulse and its dependencies.

An interesting point came to light when the event marker was first actuated. The marker showed the recorder to be running at 123 millimeters per second rather than the theoretical 125 millimeters per second. A schematic of the multivibrator circuit is shown in Figure 11.

CHAPTER IV

DATA AND ANALYSIS

Synchronization of a record of electric field changes with the waveforms and DF characteristics of sferics due to lightning discharges was effected in the process of working on this research. This accurate synchronization allows for the two types of data to be compared for a number of independent lightning strokes.

It is not possible to make an immediate study of the waveforms of the DF characteristics as they are received on the Q-3 equipment, because the information is recorded only on film and this film must first be developed. However, a continuous monitor and an immediate study of incoming information is possible with the electric field recording equipment. Therefore, if a correlation between the data from the Q-3 and the electric field data exists, it would be possible to make an immediate determination of the type of Q-3 information being received by monitoring the field meters. It would then be possible to know the type of discharge occurring. This immediate knowledge might be used for predicting, warning or whatever is necessary. These same correlations might also be used to learn more about the contents of lightning discharges. H. L. Jones (16) has shown that the 150 kc DF is quite active during severe storms. It is possible that a correlation between this DF and the electric field could yield valuable information about the 150 kc energy content in the sferic.

Obtaining the Data

When one attempts to obtain data of the type presented here, he must prepare his equipment and then wait patiently for nature to play its role. This author was fortunate to have been prepared to receive such data in the spring and summer of 1959. Several excellent and severe storms containing considerable electrical activity passed over the laboratory. The only thing that did not occur and would have no doubt given valuable information was the passage of a tornado oscillator. However, several funnels were sighted on the ground within a number of miles of the laboratory.

The data presented here was obtained primarily during four separate storm periods. The first two periods occurred on the 13th and 15th of July, 1959, and covered the advance and passage of thunderstorms traveling northeast to southwest. These were of the frontal type storm and preceeded a cold front. The third and fourth periods occurred on the 21st of July, 1959, and covered the movement of the most violent of the storms in its movement from southwest to northeast.

The procedure for obtaining data was to monitor the approach of a storm both visually and on the electric field recorder that was running at slow speed. As the thunderstorm action approached close enough for the electric probe to show indications and the lightning discharges became quite frequent, the camera of the Q-3 was turned on and the recorder shifted to the high speed of 125 millimeters per second. An attempt was made to turn down the sensitivity of the Q-3 so that many of the discharges that were too distant to effect the electric probe would not be recorded on the waveform trace of the Q-3. This attempt was primarily successful. However, some undesirable waveforms were still recorded as is pointed out in later portions of this chapter. Runs were made with the camera and the recorder covering periods of about five minutes each. These runs were made at different film speeds. The exact time of a run and the date are noted on the data shown.

When the film from the Q-3 was developed it was viewed on a Diebold 35mm microfilm reader and compared with the strip recordings from the electric fluxmeter and probe. About 150 fine examples of field change were found on the strip recordings. Of these 150 changes, some ninety field changes were found that synchronized and compared favorably with the sferics films. These ninety synchronizations were studied for characteristics and possibilities, and nine of the best synchronizations are presented in Figures 12 through 20. Of these figures, numbers 13 through 15 show good correlation with the 150 kc DF.

Presentation and Analysis

It is quite difficult to select the exact waveform that coincides with a particular spot on the field recording as several separate waveforms can coincide with what appears to be one field change. However, the beginning of each wavetrace has a specific time, and an attempt can be made to compare this time with the corresponding time on the electric field data. By pinpointing corresponding times on the film and the recorder strip, it is possible to locate the wavetraces that occur during a field change interval. When the ninety examples of synchronization are compared, it appears that specific types of waveforms are characteristic of specific electric field action.

Figure 12 is presented to give a picture of the distribution and occurrence of the many types of waveforms related to one overall field change. Perhaps some of the waveforms are from discharges that were too distant to effect the electric probe, but the variety of waveforms in a severe storm can be seen. It will be noted that the fluxmeter shows that the electrostatic field changes from a negative value towards zero and the positive side. The overall change in the electric field is caused by many individual changes due to separate electrical discharges. These immediate changes in the electric field are shown on the electric probe trace.

The film strip of Figure 12 synchronizes well with the electric field recordings. Electric field action starts at 15:06:12.1 as do the waveform traces. It can then be said that most of the electrical discharges that produced the waveforms must be responsible for the electric field changes.

Air discharges as well as cloud-to-ground discharges occur in Figure 12. This can be seen by the sferic waves with and without severe return pulses and smooth or rapid changes on the probe trace.

In the waveform of the cloud or air discharge, one does not expect to find a sharp pulse as would follow a heavy return stroke. It will be remembered that the cloud discharge does not normally contain these heavy returns. These cloud discharges then lead to a smooth change or rate of change in the electric field, and this is demonstrated by the waves and field recordings in Figures 16 through 19.

In Figure 13 there are seven prominent and abrupt changes in the electric probe trace. These positive pulses indicate seven rapid cloud-to-ground strokes with relatively high mean field. The effect of these

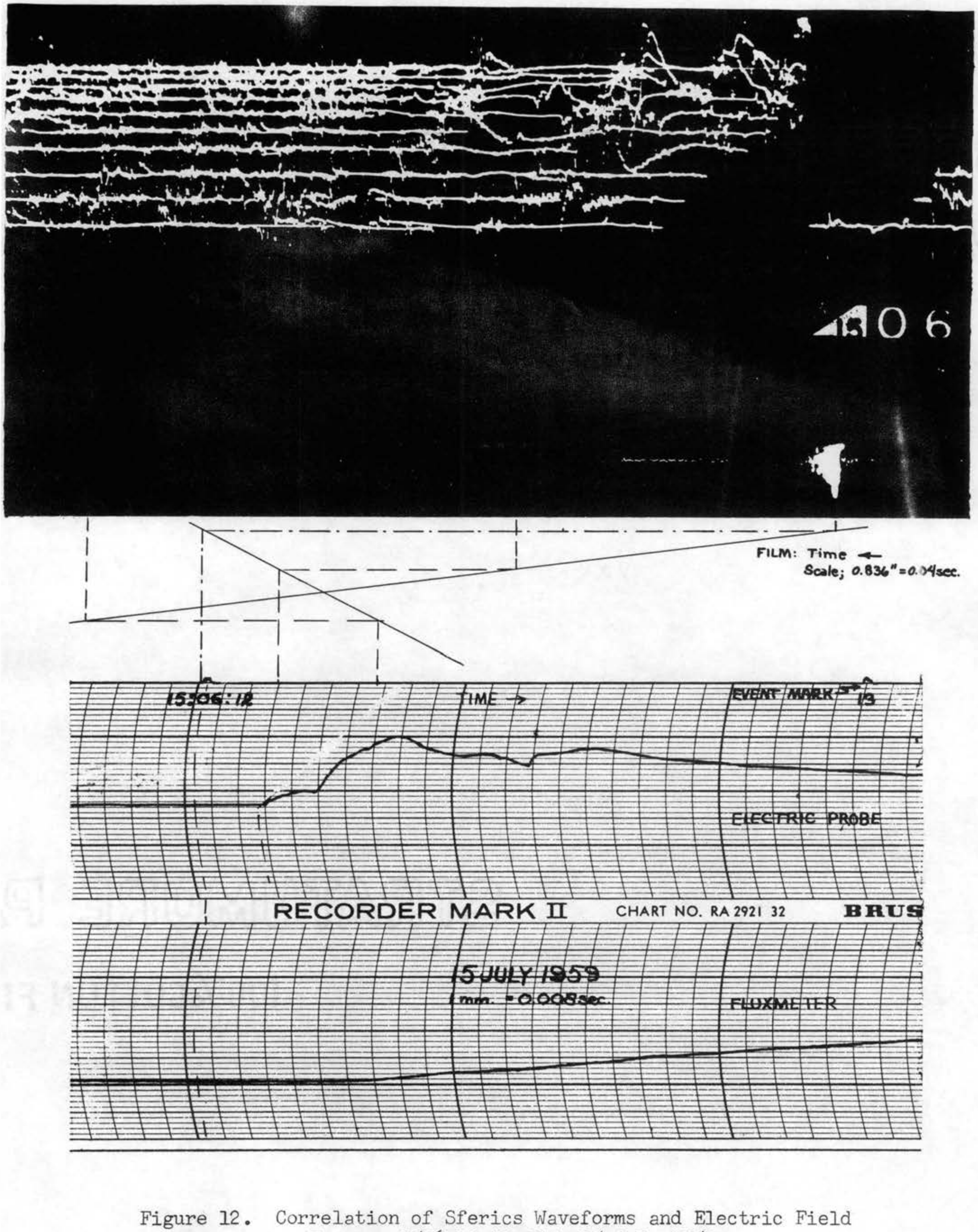

Figure 12. Correlation of Sferics Waveforms and Electric Field Traces, 1506:12-13 CST, 15 July 1959.

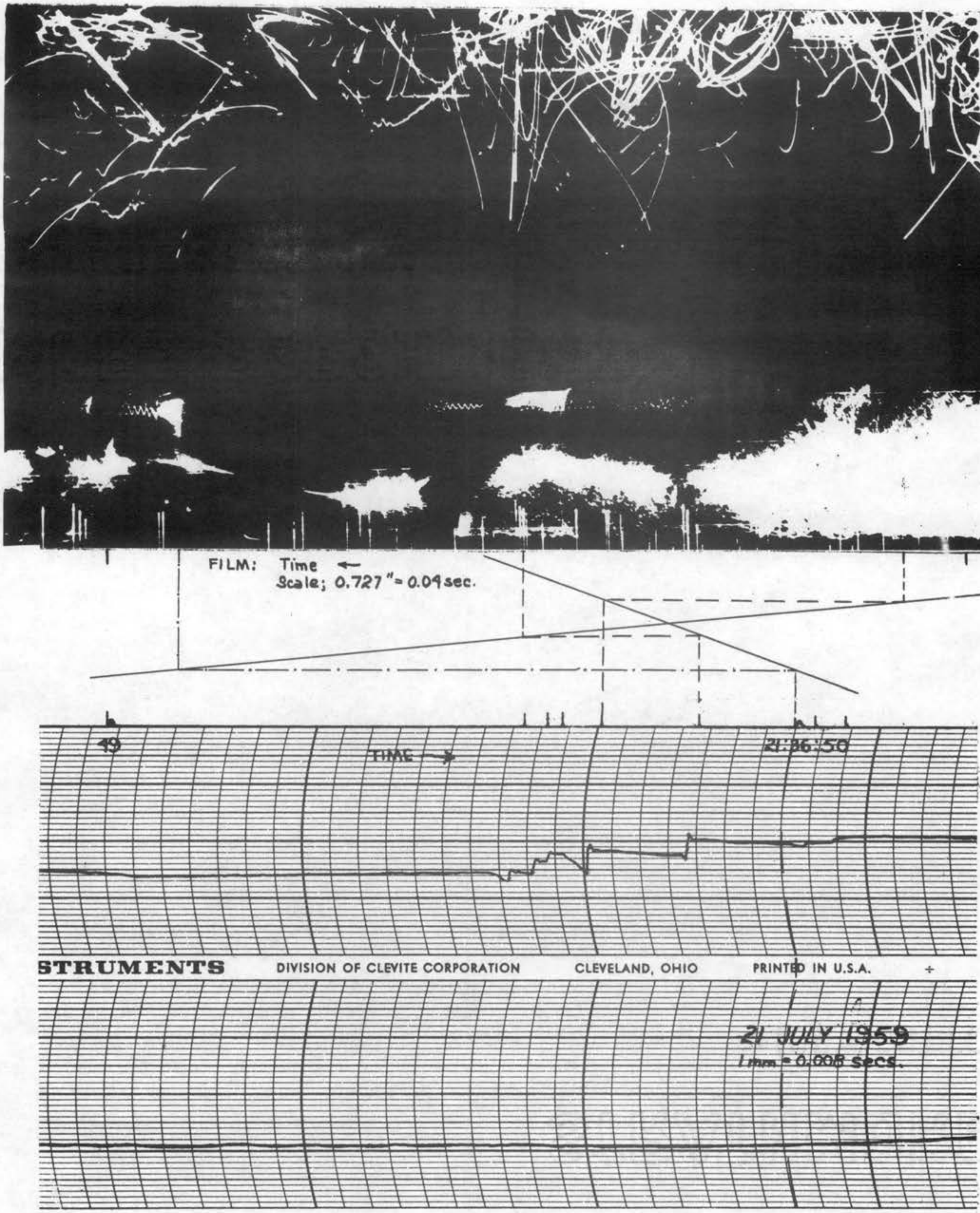

Figure 13. Correlation of Sferic Characteristics and Electric Field Traces, 2136:49-50 CST, 21 July 1959.

strokes on the electric field can be seen as the fluxmeter trace moves towards the positive. The time relationship of the recorder strip and the film is excellent.

The gain of the lower frequency DF on the upper part of the film is too high so that the return overruns the waveforms. But the interesting data here is the correlation of the 150 kc DF. Time intervals were measured on the film and DF activity was found to be present at intervals that equal those between the probe trace pulses. These intervals are from 28 to 144 milliseconds. The 150 kc DF activity appears as sprays from particular centers that synchronize with the probe pulses. This is in contrast to the DF activity accompanying the smoother probe changes in some of the later figures. The discernible waveforms that correspond to the DF activity are predominantly of the sharp pulse, low frequency variety.

Figure 14 is one of the best examples of the alignment of a series of cloud-to-ground strokes and the accompanying DF activity and waveforms. Note again that there is a center of DF activity timed perfectly with each electric field pulse. Again the conclusion is that the same lightning discharge is responsible for the DF sprays, the electric field pulses and the wavetraces. The DF activity occurs as sprays from discernible centers.

Figure 15 shows centers or sprays of DF activity which correspond to sharp pulses from the electric probe trace that are due to cloud-to-ground strokes. The DF traces as shown in the film reproduction in the figures are not as clear as the actual film. In the film the centers definitely can be seen and the fine spray is clear and distinct rather than a blob.

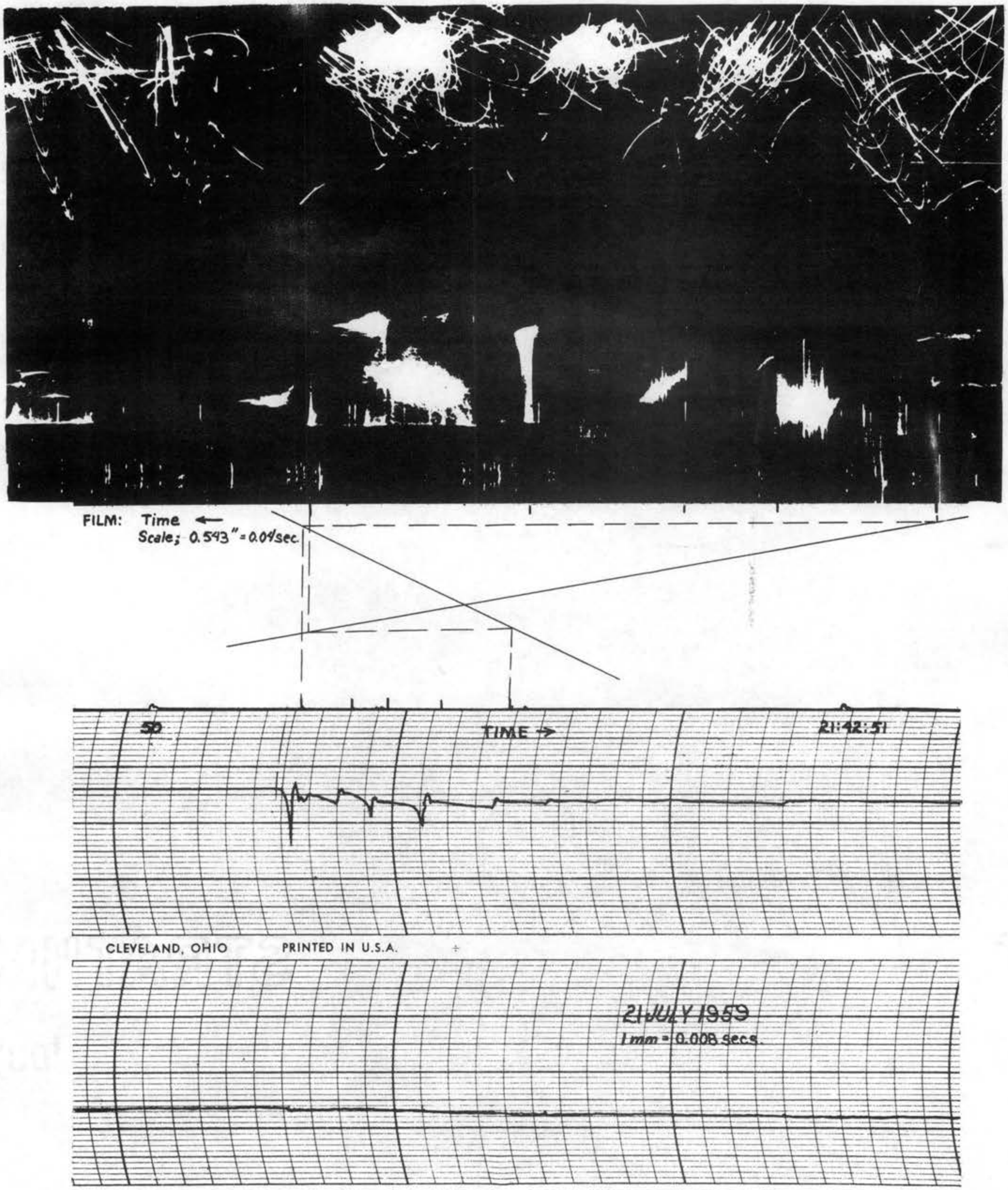

Figure 14. Correlation of Sferics Characteristics and Electric Field Traces, 2142:50-51 CST, 21 July 1959.

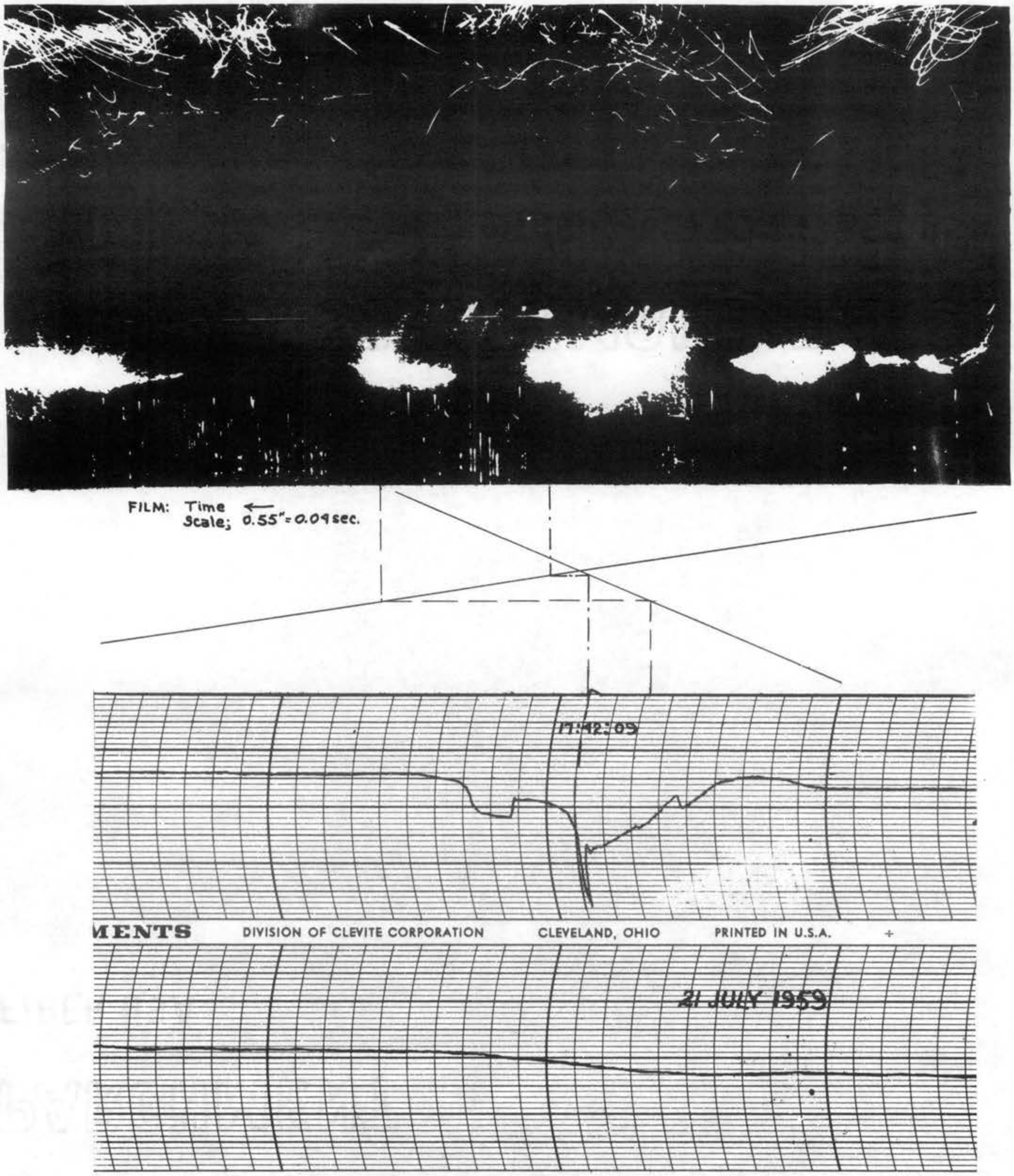

Figure 15. Correlation of Sferics Characteristics and Electric Field Traces, 1742:09 CST, 21 July 1959.

The waves in Figures 16 and 17 are predominantly an irregular high frequency type of atmospheric. They are due to pulses radiated during step processes. (17). The atmospherics of Figure 17 show peaked waveforms with extended long-train series of oscillations. The 150 kc activity accompanying this figure is quite steady and continuous compared to that which accompanies the cloud-to-ground strokes of Figures 13 to 15. In Figure 16 the DF was turned off. In both Figures 16 and 17 the rate of change of the electric field is slower. Research reports state that extended long-train oscillations of the sferic waveform and slow change of the electric probe trace both correspond to higher frequency activity. (17). Since these two types of information correspond to the same point of time in the figures, correlation can be assumed.

All of the data presented in this chapter was obtained during severe storms and periods of high electrical activity. The majority of the data is of the variety of Figures 16 through 20. Thus, the severest storms and highest electrical activity seem to coincide with the cloud and air type discharge and they lack somewhat in the cloud-to-ground strokes. The energy content of these waveforms seems to be mainly of the higher frequencies.

In Figures 13 and 15 DF pulses occur regularly for every major field change. The figures contain waveforms from cloud-to-ground strokes which have a bright and powerful return stroke. This return stroke is responsible for the sudden electric field change as there is an extreme change in the rate of current flow. This return stroke also provides the atmospheric with a large and sudden pulse. These figures are good examples of the sharp pulse atmospheric and electric field recording.

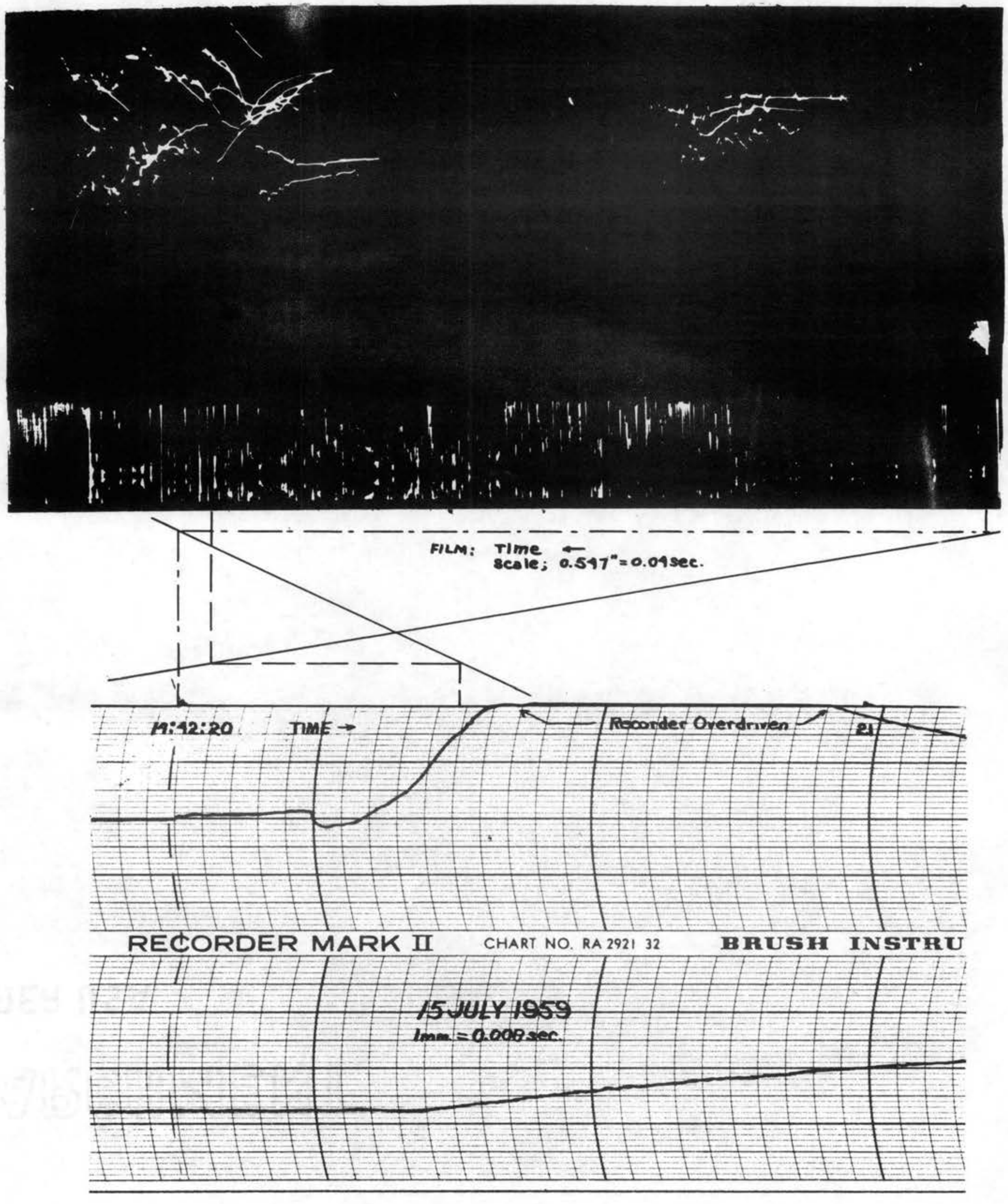

Figure 16. Correlation of Sferics Waveforms and Electric Field Traces, 1442:20-21 CST, 15 July 1959.

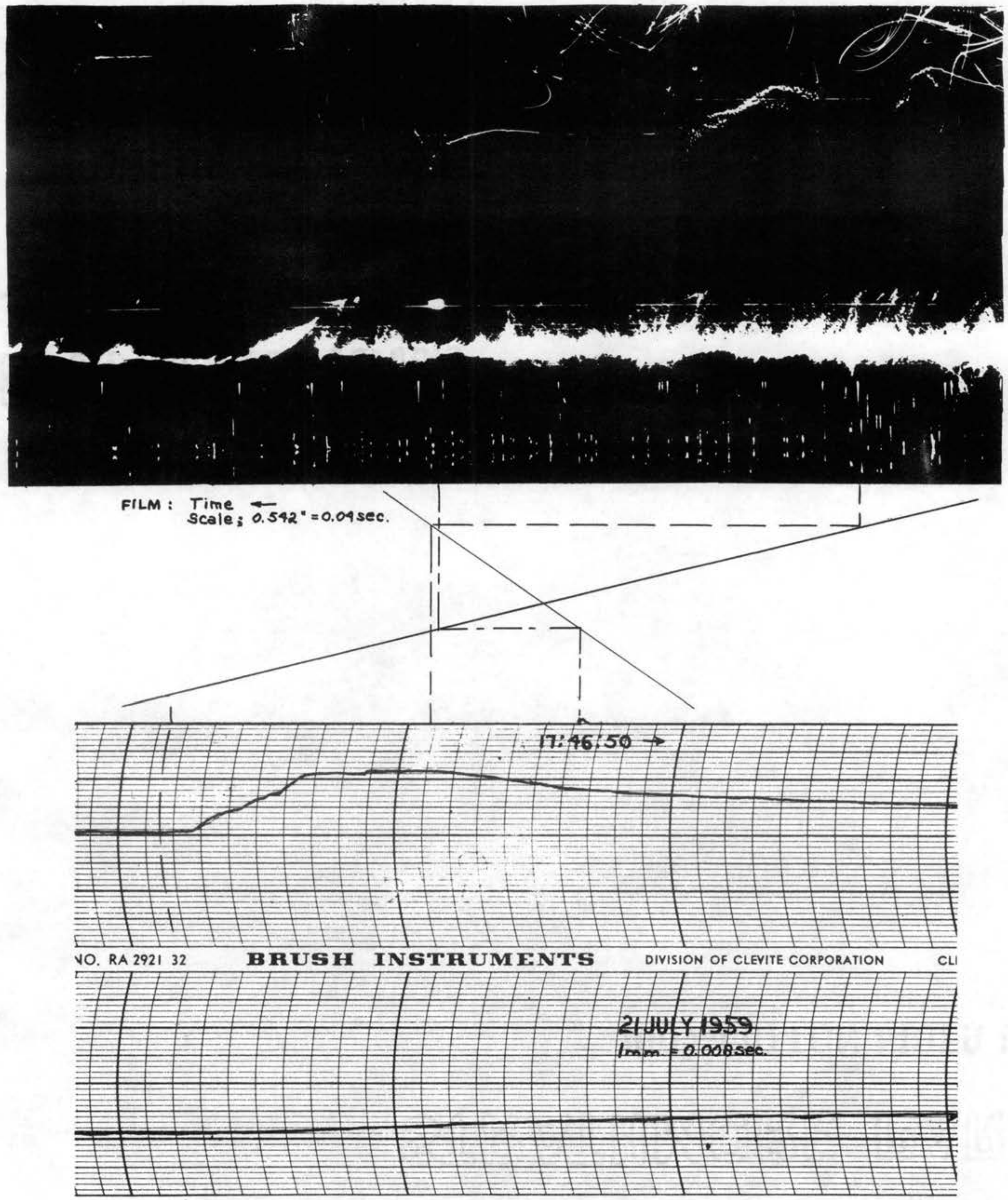

Figure 17. Correlation of Sferics Characteristics and Electric Field Traces, 1746:50 CST, 21 July 1959.

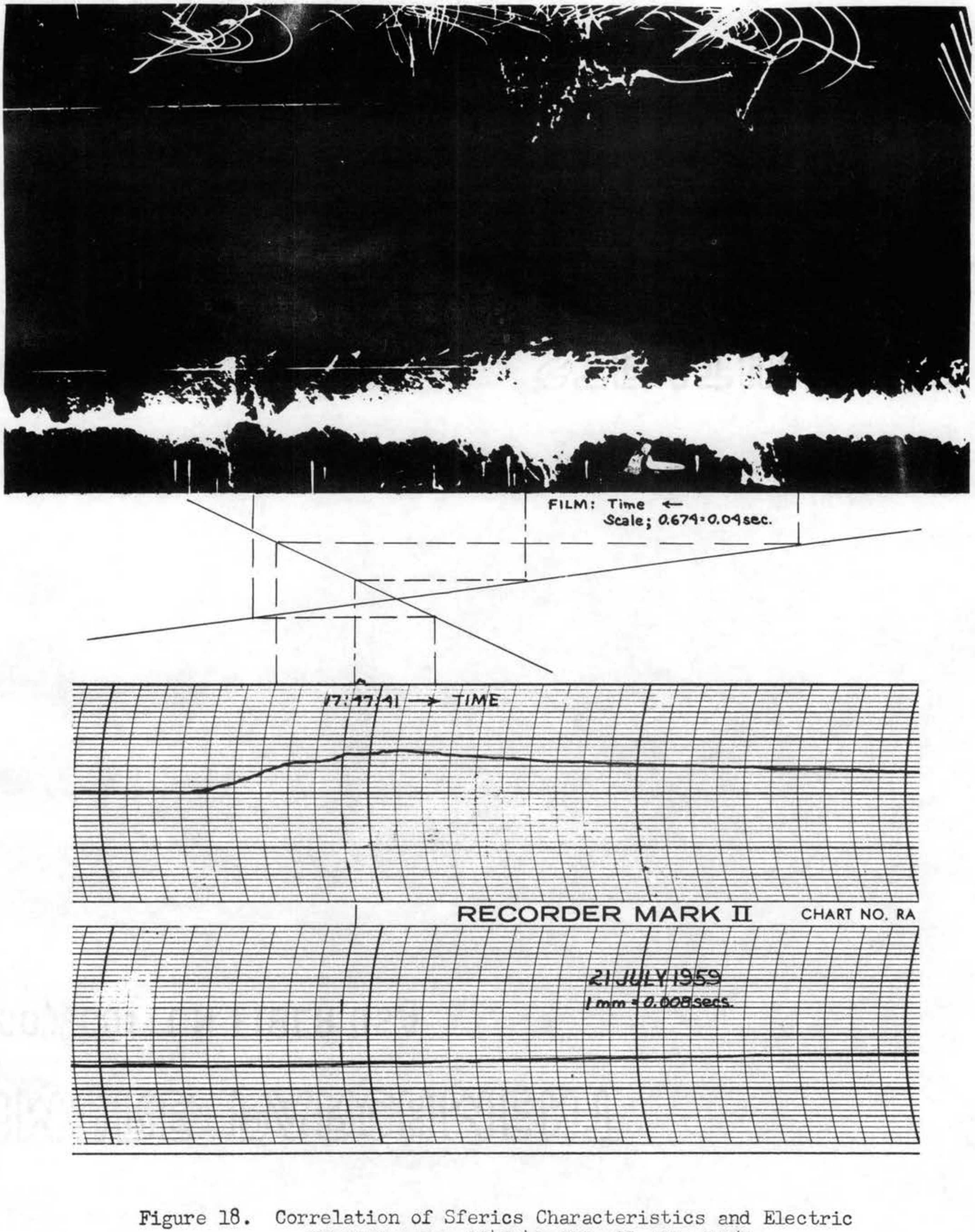

Figure 18. Correlation of Sferics Characteristics and Electric Field Traces, 1747:41 CST, 21 July 1959.

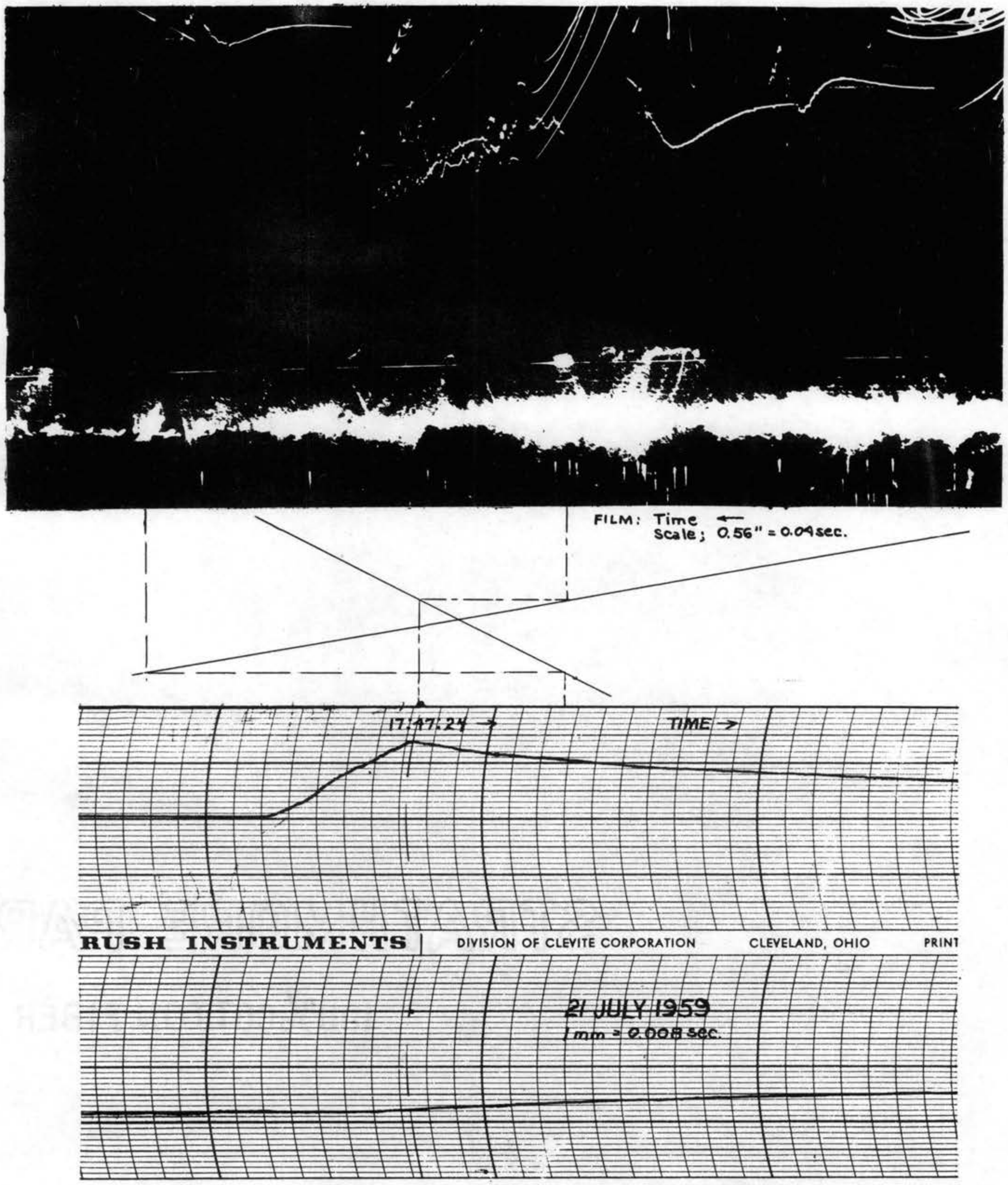

Figure 19. Correlation of Sferics Characteristics and Electric Field Traces, 1747:24 CST, 21 July 1959.

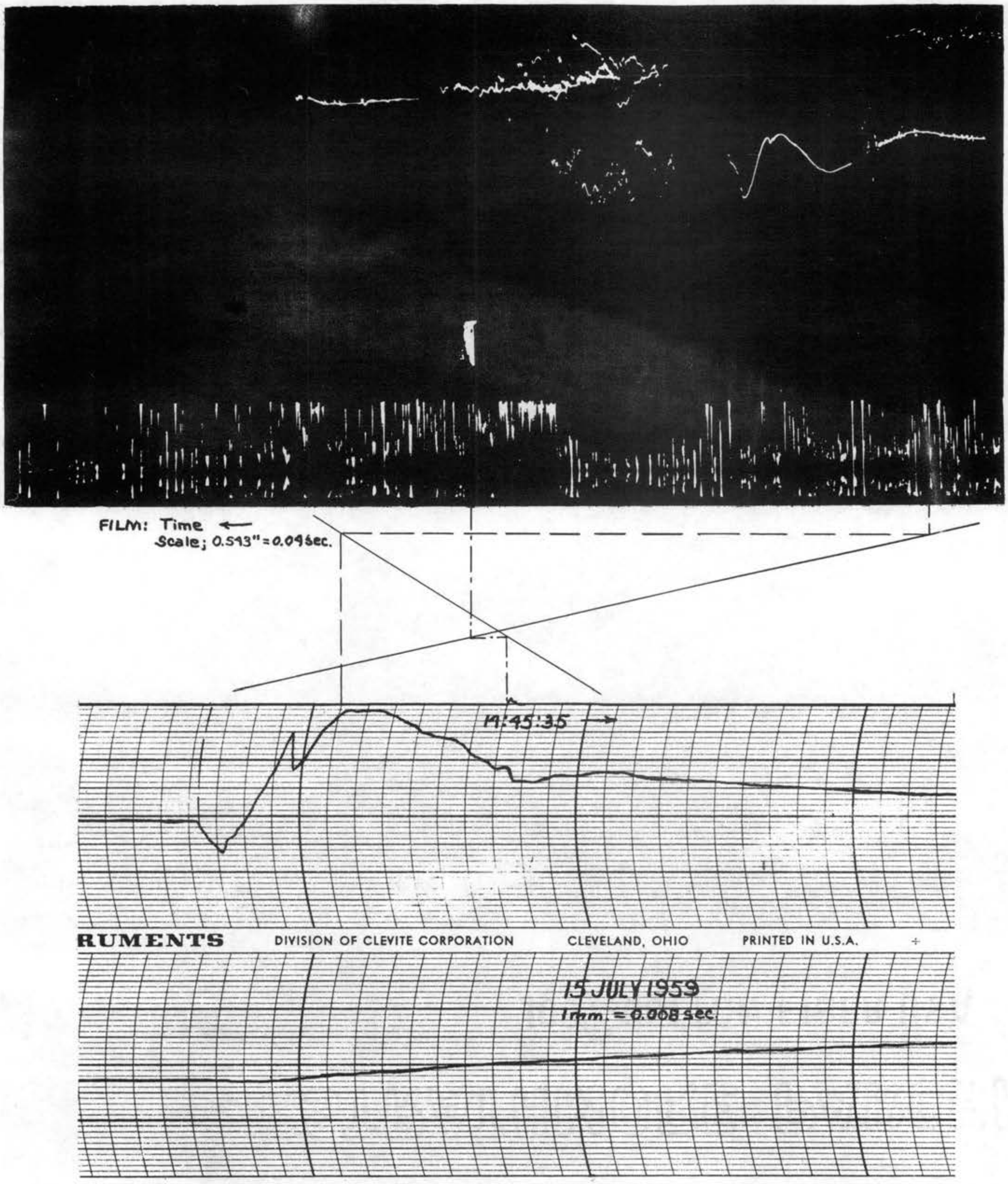

Figure 20. Correlation of Sferics Waveforms and Electric Field Traces, 1445:35 CST, 15 July 1959.

It might be pointed out that the same atmospheric could accompany a change in the field in either the positive or the negative direction. This is due to the fact that a discharge that produces a positive field change can produce a negative change when the discharge is at a greater distance.

In Figures 18 and 19 there is a very smooth change of the electric probe trace. This is again interpreted as an electric field change due to intense inner-cloud discharge. Note that the 150 kc activity is in almost continuous action. This activity starts off of the figure at the right at 17:47:40.78 which is a time that corresponds to the beginning of the change in the probe trace. The DF activity continues throughout the field change interval.

During the film run for Figure 20, the DF again was turned off, but the waveforms were quite good. The timing pulse is clearly shown and the wavetraces are shown as they synchronize with the electric field traces.

The 150 kc DF presented some problem because the directional reliability of the DF equipment is not good under a distance of two or three miles. Most of the electrical activity recorded in this data occurred directly overhead or within one to two miles from this station. In such a case the DF appears for the most part as omnidirectional. The DF spray is quite heavy due to the close proximity of the origin of the energy. However, the DF does occur reliably and the appearances correlate with the electric field changes due to a common discharge. Figures 13 to 15 best show the correlation of the DF burst with the electric field recordings of cloud-to-ground discharges.

It was noted that in all the ninety some cases studied the 150 kc activity was heavy. This is particularly so in the case of the smoother, slower field change recordings. The DF sprays were continuous in many cases while the field changes were being recorded. Attention is drawn also to the 150 kc activity in Figures 17 to 19. Here the basic sferic waveform is seen to be modulated by what this author believes to be 150 kc or higher frequency energy that shows up in the form of long-train series oscillations.

Consistently the higher frequency and oscillating type strokes with few sharp pulses coincide with the smooth field changes. The sharp pulse sferic waves can be synchronized with sharp 150 kc pulses and abrupt field changes denoting cloud-to-ground strokes or strokes with high current return. The more intense electrical activity seems to be associated with cloud and air discharges which show up in the form of the above mentioned comparisons.

The amplitude of radiated pulses are determined by rate of change of electric current. Rate of change of current effects rate of transfer of charge and this in turn effects rate of field change. Thus the amplitudes of the radiated pulses and the pulses of the electric field traces are related.

CHAPTER V

SUMMARY AND CONCLUSIONS

It has been the purpose of this thesis to obtain and examine synchronized recordings of sferics characteristics and electrostatic field changes in an effort to find a correlation between these two types of data. This work is meant to be a step in the intensification of the tornado-sferics research effort initiated by the staff of the Atmospherics Laboratory.

There is a very close association between unusually intense atmospheric electricity and severe thunderstorms and tornados. It is important that any investigation possible be made to determine the relationship between these two phenomenon. The work of this thesis leads toward relating electric field measurements to other measurements such as visual, photographic or sferics.

Conclusions

Based on a study of the correlated records thus far examined, several conclusions can be reached.

1. Accurate synchronization between electrostatic field information and sferics information can be made. The synchronizations in the data of this thesis verify the existence of a correlation between the two types of information.

2. The correlations show that a rather smooth and relatively

slow electric field change can be associated with high frequency and primarily inner-cloud discharge. The data shows that the smooth field changes are accompanied by intense 150 kc DF activity and high frequency long-train type waveforms. The DF patterns are somewhat omni-directional, but this is not completely indicative of anything since the azimuth indications are not accurate when the origin of the electrical energy is in close proximity to the station.

3. A sharp change in the electric field is due to an intense return stroke in a lightning discharge. A single directional stroke of the DF or a center of DF spray often synchronizes with the pulse of the electric field change and a sharp pulse sferic waveform. This type of waveform is known to accompany the return stroke of a lightning flash. When the range of the discharge is great enough to make the DF azimuth reliable, the single azimuth of the DF indicates the single direction of the origin of the energy which in turn indicates a cloud-to-ground or vertical inner-cloud stroke.

4. The start in sferic-electric field correlation made in this thesis provides encouragement to further pursue the work with refinements such as quantitative measurements of electric field change and closely calibrated DF information.

5. It should be feasible to understand better the physical basis of sferics action by use of sferics observations and electric field observations that are taken at the same time. These observations should now be made with the greatest accuracy concerning magnitude of DF returns and sferic energy content.

Recommendations

Research of the type conducted for this thesis was relatively new at this laboratory and was largely exploratory. While gaining the data for this work, some unwanted material was obtained that clouded the desired information. Also some desirable information was not obtained due to the widely different sensitivities of the electric field meters and the Q-3. However, insight was gained in methods of obtaining synchronization of recordings and their correlations. As a result of this work, several recommendations can be made for further research.

1. A more sensitive electric probe should be developed that would receive information from storms several miles from the recording station. This would place the electric field instruments on a more equal basis with the Q-3. Comparing the data from the probe with the DF data would then be greatly aided since directional characteristics of the DF are poor when the electrical activity originates close to the station. In turn, the Q-3 could be tuned to be sensitive only to discharges in very close proximity of the station.

2. Calibrated measurements of the amount of field change should be obtained to compare with calibrated Q-3 information.

3. Electric field measurements should be made simultaneously at several stations. Through these measurements one may be able to obtain an estimate of the charge transferred in a lightning stroke and the rate at which electrical energy is being released.

4. Simultaneous observations should be made with photographic

equipment, the naked eye, sferics receiving equipment and the electric probe and fluxmeter.

5. Adjustment of the various sensitivities and careful calibration of the Q-3 equipments should be made to obtain exactly the information desired for study. When this is done, much extraneous data can be left out of the recorded data and the information of interest can be more easily read. The 150 kc DF tracings on the Q-3 should be carefully calibrated for energy content. The 150 kc energy of a lightning discharge could then be closely compared with the exact change of field due to this discharge and measured on the probe. In this way, perhaps, electric field readings could be used to give close indications of energy content in storm activity.

A SELECTED BIBLIOGRAPHY

1. Schonland, B. F. J. The Flight of Thunderbolts. Oxford: Oxford Clarendon Press, 1950.

2. Wall, W. Phil. Trans. Roy. Soc. 26 (1708), p. 69.

3. Lemonnier, L. G. Mem. de l'Acad. des Sci. 2 (1752), p. 233.

4. McDonald, J. E. "The Earth's Electricity." Scientific American, 188 (April, 1953), pp. 32-37.

5. Moore, C. B., B. Vonnegut, and A. T. Botka. Results of an Experiment to Determine Initial Precedence of Organized Electrification and Precipitation in Thunderstorms. Cambridge: Arthur D. Little, Inc., The Air Force Cambridge Research Center.

6. Workman, E. J. and S. E. Reynolds. "Electrical Activity as Related to Thunderstorm Cell Growth." American Meteorological Scoiety Bulletin, 30, No. 4 (April, 1949), pp. 141-144.

7. Jones, H. L., and P. Hess. "Identification of Tornadoes by Observation of Waveform Atmospherics." Proc. I.R.E., 40, No. 9, (September, 1952), pp. 1049-1952.

8. Boudreaux, Felix. A Study of the Quasi-static Electric Fields of Severe Thunderstorms. Unpublished Ph.D. dissertation, Oklahoma State University, August, 1959.

9. Air Force Manual 105-5. Weather for Aircrew Trainees, May, 1956.

10. Houghton, H. G. Atmospheric Explorations. New York: John Wiley & Sons, Inc., 1954, Chapters 2-5.

11. Loeb, Leonard B. "Thunderstorms and Lightning." Modern Physics for the Engineer. New York: McGraw Hill, 1954, Chapter 13.

12. Chalmers, J. Alan. Atmospheric Electricity. London: Pergamon Press, 1957.

13. Schonland, B. F. J. Atmospheric Electricity. London: Methuen and Company, Second Edition, 1953.

14. Air Force Manual 16H-86-1. Operation and Maintenance Instructions Q-3 Equipment, 1 November 1958.

15. Stearns, C. D. Identification of Intercloud Lightning Discharges of Sferic Waveforms. Unpublished Masters dissertation, Oklahoma State University, August, 1959.

16. Jones, H. L. "The Identification of Lightning Discharges by Sferic Characteristics." Recent Advances in Atmospheric Electricity. New York: Pergamon Press, 1959, pp. 543-556.

17. Byers, H. R. Thunderstorm Electricity. Chicago: The University of Chicago Press, 1953.

VITA

Wesley Daniel Woodruff

Candidate for the Degree of

Master of Science

Thesis: A CORRELATION OF SFERICS CHARACTERISTICS AND ELECTRIC FIELD IN THUNDERSTORM DISCHARGE

Major Field: Electrical Engineering

Biographical:

Personal Data: Born in Eureka, California, February 4, 1931, the son of James H. and Grace Titus Woodruff.

Education: Attended grade school in Oakland, San Jose, Pacific Grove, and San Francisco, California; graduated from George Washington High School, San Francisco, California, in 1948; attended Chapman College, Orange, California, 1948-51; attended University of California, Berkeley, California, 1951-52; received Bachelor of Science degrees from the Oklahoma State University, with majors in Electrical Engineering and Air Science, in May, 1959; completed the requirements for the Master of Science degree in Electrical Engineering in January, 1960.

Professional Experience: Employed as Manager of the Chapman College Book Store from September, 1949, to June, 1950; employed as Assistant Station Manager for Standard Stations Inc. from June, 1950, to June, 1951; entered the United States Air Force as an Aviation Cadet in February, 1953, and was commissioned a Second Lieutenant and rated a Pilot in May, 1954; performed the duties of All-weather Intercepter Pilot from June, 1954, to September, 1957; is now holding the rank of Captain.

Member: Institute of Radio Engineers, Phi Kappa Phi, Eta Kappa Nu, Air Force Association.