A RADAR-SFERIC ANALYSIS OF THE TORNADOES OF MAY 25, 1955

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PREFACE

For the past eight years a research program toward the identification and tracking of tornadoes has been carried on at Oklahoma A & M College. In addition to a number of technical papers and reports concerning the progress of this investigation, several excellent theses have been written covering, for the most part, the development of laboratory equipment and the analysis of sferic waveforms. For the past three years an increased emphasis has been placed on the significance of sferic repetition rate with regard to azimuth. The investigation described in this thesis was concerned with a study of sferics and the direct correlation of the sferic results to the radar data. This is the first of its kind to be presented in thesis form.

Numerous obstacles handicapped the investigators when undertaking to obtain experimental data in the field of tornado research. A great deal of time was spent in watching a multitude of storms which failed to produce tornadoes. Even when tornadoes did occur, recorded data was often lost because of technical difficulties or unpredictable limitations in instrumentation.

It was unfortunate that the tornadoes that occurred during the evening of May 25, 1955 were responsible for the tragedy that killed over 100 people in Oklahoma and Kansas. Ironically this same storm produced scientific information which has been invaluable in furthering the knowledge of tornado phenomena. The Tornado Laboratory was fortunate to be in a position where local meteorological conditions were

sufficiently clear to allow the unobscured reception of both radar and sferic data from the areas affected by the storm.

A word of thanks is due Mr. Ruben D. Kelly, Project Engineer, and Mr. Melvin Oberst for the excellent maintenance of laboratory equipment, without which the data used in this thesis could not have been obtained.

A note of appreciation is made for the inspiration and helpful guidance of Dr. Herbert L. Jones in carrying out this research. The author is greatly indebted to Mr. Wayne F. Staats for his many helpful suggestions and opinions, and to Mr. T. Peyton Robinson for his assistance in the correction of the manuscript and for his many constructive comments.

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CHAPTER I

INTRODUCTION

For countless years in his eternal fight for survival, man has withstood the many forces of nature. Although these forces are made evident through a number of different modes, probably the one phenomenon that most affects his daily living is weather. Weather may described as the perpetual attempt of nature's forces to reach a state of equilibrium. This state is never reached, however, due to the constant consumption of energy from the sun.

Ordinarily, the process of force equalization, or change of state, has a beneficial effect; for example, the formation of crop-producing rain. It is the rate of energy exchange that causes various physical destructive effects. This destructive rate can vary widely from torrential rains that produce floods to the swift and almost instantaneous obliteration of a tornado. The degree of energy unbalance, or instability of the air system, seems to provide a clue to the speed and thoroughness with which destruction can take place.

For many years, the dream of man has been the evolution of a plan to control the weather to meet his desires and demands. To date, the numerous methods proposed to further this idea have greatly outnumbered the methods tried. Due to the energy magnitudes involved even those tried have netted, at best, questionable results on a very local basis. The natural alternative to weather control, then, would be a means of forecasting whereby protective measures could be taken to minimize property loss, and foremost, to eliminate human injury. During the past decade, research in the field of meteorology has produced a combination of knowledge and instruments which has brought the state of the art of this science to a degree of great reliability.

These developed methods and procedures have been put into practice on a continuous basis by the United States Weather Bureau. This has resulted in a routine of the regular accumulation of meteorological data together with the interpretation whereby the forecasts of oncoming storms may be made available to the areas concerned within hours or even minutes before the forecasted event. The fact that these warnings can be made with a high degree of certainty makes them of practical value.

Because of the many variables involved within a storm complex, no one can predict exactly how or where the storm will strike, even though the area of development has been determined. Exact details such as wind velocity, moisture concentration, hail size, and lightning intensity must usually come to storm warning centers via communications circuits, provided these circuits are still intact, if this information is to be of any value in warning an area in the path of a storm. These data may be obtained from aircraft reconnaissance in the case of slow moving storms, such as hurricanes, which usually exist for several days.

For detection of tornadoes the problem of gathering the necessary exact information for warning purposes is magnified many fold. Wire communication circuits are usually disrupted and radios in the stricken area made inoperative before they can be put into use. This makes reporting from a devastated area highly unreliable. The time between the sighting of the tornado and the time when a warning is issued to an area in the path of the tornado is critical. Thus far the only way of positively identifying the existence of a tornado is through observation of its physical structure. Even its positive identification may be mistaken by the many who become victims of a sort of hysteria during the approach of a precarious looking dark cloud.

Lateral ground speeds of thirty to forty miles per hour or higher are not uncommon to tornadoes, and tornado paths are very unpredictable. At present tornado alert areas determined by known meteorological information cannot be pinned down to much less than ten to twenty thousand square miles. This area, even in sparsely populated areas, may include a great number of people who experience only slightly severe weather. Repeated "false alarms" have been proved to create an air of skepticism which has resulted in serious consequences in the event of an actual tornado.

A tornado can vary in duration from less than five minutes as the incipient tornado[1] to one lasting several hours. The ones of longer duration are naturally the most disastrous since the probability of their hitting a populated area is much greater. It is obvious that with tornadoes which exist for less than five minutes the chances for warning of their approach becomes extremely small. If we therefore confine our study to tornadoes having existence of thirty minutes or longer, we should have a situation where issuance of a warning becomes feasible and has practical value.

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[1]Phillip N. Hess, "Installation and Operation of Electronic Sferic Detection Equipment". Unpublished Master's Thesis, Oklahoma A&M College, (1950), p. 50-52.

It can be seen from this discussion of problems encountered in tornado warning that time is a very important factor. A practical approach to a system of tornado warning would then be to devise a means whereby some characteristic of a tornado's existence could be detected at a remote point from its actual location. Once this characteristic is observed a warning could be forwarded to the area subject to the tornado's influence.

It was this idea that led Dr. H. L. Jones and associates at Oklahoma A & M College to institute a search for any unusual characteristics of tornadic type storms. Through their efforts, techniques have been developed throughout several years of research toward the establishment of a practical warning system.

CHAPTER II

BASIC RESEARCH AND DEVELOPMENT BEFORE 1955

Initial Research on Tornado Identification

Before an evaluation can be given to the specific work about to be presented, it is necessary to review the progress of the tornado program since its inception in 1947.

The Woodward, Oklahoma, tornado early in 1947 set a record in terms of loss of life and property. After this tornado much interest was generated pursuant to a method through which cognizance of such storms might be established in sufficient time to permit the operation of an effective warning system. The development of such a plan of research on tornado identification and tracking was undertaken at Oklahoma A & M College, Stillwater, Oklahoma, under the directorship of Dr. H. L. Jones and under the sponsorship of the Division of Engineering Research of the Oklahoma Institute of Technology.

Initial investigative work began with the study of accumulated data on the lightning or "sferics" that usually accompany any type of thunderstorm. From this study a hypothesis was reached that the characteristics of sferics from an ordinary thunderstorm are different from the characteristics of sferics generated by storm cells containing tornadoes. It appeared to be reasonable that the available energy in a tornado-type thunderstorm would be considerable greater than that of other types of thunderstorms. In addition, it was believed that the increased energy would be evident in generally two ways. First, there would be an increased number of strokes per unit time and second, each stroke would be more intense due to the increased amount of energy dissipated. This idea was supported by the generally accepted theory of separation of electrical charges in the generation of thunderstorm electricity.[1]

During the first two years of the tornado research the equipment used to investigate the characteristics of sferics consisted of a superheterodyne radio receiver whose output was connected to a cathode ray oscilloscope. The receiver was tuned in the band of frequencies near 400 kilocycles. The cathode ray oscilloscope was mounted on one end of a bench and an electrically driven sixteen millimeter camera was mounted at the other end of the bench and facing the oscilloscope screen. Extraneous light was prevented from reaching the oscilloscope by a metal tube that allowed the observer to view the screen while pictures of the screen were being recorded. Due to the very random nature of sferic activity it was necessary to make each recording for a period of from one to two minutes in order that sufficient pertinent data could be obtained.

One of the difficulties of securing sferic data of this type was in having the equipment in operation at the time such information was available. During the initial phase of research, schedules of operation were based on what little meteorological information was available concerning severe weather. Radio and newspaper forecasts provided the only tornado warnings or alerts that were made.

Despite the simplicity of the equipment and the difficulty of obtaining sufficient data, results of these efforts justified continued

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[1]Herbert L. Jones, "A Sferic Method of Tornado Tracking and Identification", Oklahoma Engineering Experiment Station Publication, No. 82, January, 1952, p.3.

investigation. The assumptions initially made regarding the characteristics of sferics as an index of storm severity were generally borne out in the early experiments. Further studies naturally dictated modification of the equipment as requirements were discovered. One of the most important changes in equipment design was made just prior to the Tornado Season of 1950. Since most of the waveform presentations were of the modulated type, it was decided to use a wide band video amplifier[2] instead of the tuned receiver.

After obtaining sufficient data with this modification, a rather interesting discovery was made concerning severe storms accompanied by tornadoes and hail. There appeared to be a pronounced high frequency component of sferics most prevalent in the band ranging from one hundred to two hundred and fifty kilocycles. This discovery was a very important factor in the design of the more elaborate equipment which is in use today.

Establishment of the Tornado Laboratory

The present Tornado Laboratory[3] was established in the Spring of 1950. It is located three miles northwest of the College at the Stillwater Airport which is operated by Oklahoma A & M College. The Tornado Laboratory is situated at the end of the southeast taxi strip at an elevation slightly higher than the surrounding terrain. This location

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[2] Hess, p. 13.

[3] "Research on Tornado Identification", First Quarterly Progress Report, Signal Corps Research, Project No. 172B-0, 1952, pp. 6-8.

was selected in order to attain freedom from local electrical static, sufficient elevation, and a road that is passable during the periods of bad weather that accompany severe storms.

Between 1950 and 1953 the main items of equipment located at the Tornado Laboratory consisted of the Harmonic Analyzer or Sferic Detector developed at Oklahoma A & M College, together with the APQ-13 radar and the AN/GRD-1A static direction finder borrowed from the Signal Corps Engineering Laboratories. A PE-197 Power Unit, also on loan, was installed in case of power failures, a not uncommon occurrence during local severe weather.

Beginning with the storm season of 1952, data was recorded from the equipment by the use of two cameras. Radar scope pictures were made with a 35 millimeter automatic single frame camera; since all data relative to sferic activity are displayed by a momentary light trace on an oscilloscope screen, sferic records were obtained by the use of a 35 millimeter continuous type motion picture camera. The instantaneous nature of sferic data thus permitted a continuous recording. Simultaneous recordings were made of: (a) the directional traces of the AN/GRD-1A Direction Finder; (b) the sferic wave form; (c) a coding system to indicate sweep speed on the waveform presentation; (d) a record of the time for each second; (e) a record of the date for each record. To insure that data was taken in regular sequence an electrical timing device was constructed to take both radar and sferic pictures automatically at preset intervals.[4]

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[4]"Research on Tornado Identification", Eighth Quarterly Progress Report, Signal Corps Research Project No. 172B-0, 1952, pp. 6-8.

It was not until the analysis of the records taken in 1952 that the value of the previous research had been realized. Material progress was evidenced in: (a) the discovery of a possible relationship between the severity of a storm and the rate of arrival of sferics from that storm; (b) the accumulation of experience relative to the observation of squall line and frontal movements peculiar to the Great Plains Area; and (c) the associated development of equipment and techniques necessary for the study of the sferic emissions from the related storm centers.

It was a fortunate turn of events that found meterological research pertinent to the forecasting of tornadoes developed simultaneously with the research at Oklahoma A & M College. A method of forecasting tornado areas in the Great Plains area was developed by Colonel E. J. Fawbush and Major R. C. Miller of the U. S. Air Weather Service at Tinker Air Force Base, Oklahoma[5]. It was through the cooperation between the Severe Storm Center at Tinker Air Base and the Sferic Research Group at the Tornado Laboratory that there was obtained an increased understanding of the individual storm movements and increased efficiency in the time spent in observations made at the Laboratory.

The forecast data from the Severe Storm Center made it possible to initiate operations at the Tornado Laboratory in time to observe the early formation of the squall line on the radar, and to record the initial sferics generated by the squall line during the preliminary growth of the individual thunderstorms. Subsequent forecasts during the period of activity made it possible to concentrate on specific areas of severe storm incidence as indicated by the changing meteorological conditions.

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[5]Major E. J. Fawbush, Captain R. C. Miller, and Captain L. C. Starrett, "An Empirical Method of Forecasting Tornado Development." Bulletin of the American Meteorological Society, January, 1951, PP. 1-9.

Early in 1953 when interest was mounting in rate of sferic arrival, the Evans Signal Laboratories shipped the Sferic Incidence Azimuth Integrator to the Tornado Laboratory for installation and testing. This device consisted basically of a photo-electric cell mounted behind a revolving slit. The slit was electrically driven so as to scan the azimuth scale of the Cathode Ray Tube of the Direction Finder. When a stroke occurred while the slit was in line with the azimuth from which the stroke arrived, the light from the oscilloscope screen was transmitted through the slit to the photo cell to form a voltage pulse. When several rapid successive strokes occurred from a given azimuth, which was usually the case, the resultant series of voltage pulses were counted in an electronic integrator. The output from the integrator was fed to a pen mechanism which plotted a continuous record of sferic activity over the entire 360° azimuth.

The accuracy of such a device is limited by some of the shortcomings of the AN/GRD-1A Direction Finder.[6] When a lightning discharge produces an electromagnetic wave with strength of a sufficient magnitude to overload the circuits of the direction finder, a family of concentric ellipses will result. The major axis of these ellipses may or may not coincide with the correct direction of arrival of the sferic. Such a display of light on the oscilloscope screen causes light to reach the photo tube erroneously and causes a subsequent error in the recording. This limitation also causes the sferic records taken by the continuous motion picture camera to be confusing to the analyst. A correlation between counts by the sferics integrator and those counted by the analyst is therefore difficult to obtain.

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[6]"Research on Tornado Identification", Final Report, Signal Corps Research Contract No. 172B-0, 1954, P. 22.

Basic Concepts of Lightning

According to Schonland[7], Normell[8], and others, a typical cloud to ground flash of lightning is initiated by what is commonly called a leader process, descending in discreet steps from the cloud through non-ionized air to the earth. As it travels downward it zig-zags and branches to form the characteristic of lightning discharges. When this stepped leader reaches the earth, the return streamer advances rapidly back along this ionized path to form the vivid lightning stroke commonly observed. Subsequent or multiple strokes are preceded by a dart leader which travels down the existing channel in a continuous streamer. The current carried by the initial leader process is known from field change studies to be in the order of 100 amperes. The peak current in the return stroke has been determined from various lines of evidence to be in the order of 20,000 amps, though in extremely heavy bolts it has been measured as high as 100,000 amps.

Appleton and Chapman[9] first analyzed the electrical field changes associated with a lightning stroke and demonstrated that such field changes are complicated by the superposition of electrostatic, induction and radiation effects represented respectively by the three terms on the

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[7] B. F. J. Schonland, "Thunderstorms and Their Electrical Effects", Physical Society of London, Proceedings, Vol. 55, Pt. 6, 1943. PP. 445-458.

[8] T. W. Wormel, "Lightning", Royal Meteorological Society, Quarterly Journal, Vol. 79, 1953.

[9] E. N. Appleton and F. W. Chapman, "On the Nature of Atmospherics IV", Royal Society of London, Proceedings, Vol. 158, January 1937, PP. 1-22.

right side of the equation:

$$E = \frac{M}{D^3} + \frac{1}{CD^2} \times \frac{dM}{dt} + \frac{1}{C^2D} \times \frac{d^2M}{dt^2}$$

where E = Electric field at the earth's surface
M = Electric moment
D = Distance
t = Time

For distances $D < 62$ miles, the first two terms $\frac{M}{D^3} + \frac{1}{CD^2}$ predominate; between 62 and 300 miles the middle or inductive term predominates; and beyond 300 miles the radiation or "atmospheric" effect $\frac{d^2M}{dt^2}$ is the greatest.

The major radiation pulse is of course produced by the high current return stroke. The original wave front generated by this stroke is aperiodic at its inception, however, at some distance from the point of origin the wave assumes a damped semi-sinusoidal character due to progressive reflections from the ionosphere. According to Schonland, the mean rate of speed of the return stroke is about 5×10^4 kilometers per second. When we consider that the average length of these strokes is from 3 to 5 kilometers, it follows that the average frequency of the maximum radiated pulse would be $\frac{5}{5x10^4}$ or 10 kilocycles per second. Adcock and Clarke[10] made some experiments to ascertain how the energy fell off below this frequency. It was found that the energy received was fairly well maintained down to 7.5 kilocycles per second but that a marked diminution occurred below this.

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[10] F. Adcock and C. Clarke, "The Location of Thunderstorms by Radio Direction Finding", Institute of Electrical Engineers, Journal Vol. 94, Pt. III, March, 1947.pp. 118-125.

Another source of radiated energy is in the stepped end dart leader processes. If we consider that the average length of each stepped leader is in the order of 30 meters and its effective rate of travel is about the same as the return stroke, namely 5×10^4 kilometers per second, we can calculate that the duration of these steps is in the order of 6 microseconds, thus giving rise to a radiation in the range of 150-200 kilocycles per second. The High Frequency Direction Finder was thus designed to have a peaked response in this vicinity.

Installation of High Frequency Direction Finder

At the close of the 1954 tornado season the construction of a new high frequency direction finder[11] was completed. This new equipment was designed to tune over a frequency range of approximately 100 to 150 kilocycles as compared with the ten kilocycle frequency of the AN/GRD-1A Direction Finder. Design considerations, as mentioned previously, were based in part on the accumulated data pertaining to high frequency characteristics of sferics from severe storms.

Subsequent testing demonstrated that elliptical pips encountered with the AN/GRD-1A Direction Finder were definitely reduced in recorded results taken with the high frequency direction finder. One of the logical explanations for this fact is that when two lightning strokes occur at almost the same instant, but at different locations, the direction finder must recover from one indication in the period of

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[11] "Research on Tornado Identification", Eleventh Quarterly Progress Report, Signal Corps Research Project No. 172B-0, 1954, pp. 4-14.

time that is sufficiently short to permit successful indication of the second stroke. This is accomplished by the increased frequency of operation. If a period of time corresponding to 50 cycles of the incoming wave train is required to indicate a given stroke, regardless of the operation frequency of the direction finder, then the 10 kilocycle system will require a period of 50/10,000 or 5 milliseconds to indicate the same stroke. Thus the high frequency system is capable of indicating strokes at a rate that is approximately fifteen times as fast as the 10 kilocycle system.

Additional experience has shown that the range of the high frequency direction finder is such that the sferics received are confined to storms within about a 250 mile radius of the Tornado Laboratory. This range is comparable to the normal operating range of the radar. From an analytical point of view this is quite advantageous since pips appearing on the scope can usually be assumed to be originating from echos displayed on the radar scope rather than from some storm several hundred miles away.

CHAPTER III

PLAN OF LABORATORY OPERATION

Procedure Prior to Storm

In Oklahoma the approximate time between February 15 and June 15 is considered a period when tornadoes are most likely to occur. A very unique feature of the weather during this period is the almost weekly occurrence of an active squall line with the associated thunderstorms.

A typical storm cycle during the spring months begins with the formation of an active cold front in eastern New Mexico and Colorado. The required time to complete the cycle varies from two to four days, after which the system has moved across Oklahoma and Kansas and well into Arkansas. Although sferic data is available from the very start, the squall line usually does not come into operating range until sometime during the first or second afternoon or evening. Redevelopment of severe activity in the vicinity of the Tornado Laboratory is not uncommon during the following day. Most activity begins about 11 A.M. and continues until 4 A.M. or 5 A.M. the following morning. The collection of data through such an extended period of time is indeed a feat of physical endurance.

Approximately 48 hours previous to the development of a storm system, radio and television provide the necessary forecast as to when the Oklahoma area is to affected. On the morning of the expected day of activity, contact is made with the Severe Weather Center at Tinker Air Force Base regarding the time and location of the expected outbreak. The Tornado Laboratory is then opened for operation a few hours previous to this time.

The equipment placed in operation during the 1955 tornado season was the APQ-13 radar, the High Frequency Direction Finder, and the wave form presentation. The AN/GRD-1A Direction Finder was not operated due to the fact that it was in the process of modification during the entire season.

In placing the laboratory equipment in operation all apparatus is turned on a few hours before the expected outbreak time to insure proper functioning and to make necessary adjustments or replacements. During this time all cameras are loaded, clocks are set at standard time, and date cards are placed in their respective holders. A log sheet is started on which all pertinent information is entered at regular intervals regarding the progress of the storm.

Data Collection During Storm

When all equipment is functioning properly, the automatic timing device which controls all cameras is activated. During normal procedure a set of pictures is taken for each five minute period throughout the duration of the storm. When the radar camera is triggered into operation at each of these periods, a relay mechanism operates the single frame camera for each two revolutions of the antenna until a set of three consecutive pictures is taken of the radar presentation. A duplicate radar scope is available for viewing purposes. There is a manually operated button beside the viewing scope that makes it possible to obtain additional sets of pictures if desired.

Once the sferic camera is started it will photograph incoming sferic information continuously until another automatic pre-set timing circuit turns it off. The sferic camera can be set to record data for intervals ranging from two seconds to 30 seconds, depending upon the amount of data required. Usually ten to fifteen seconds is sufficient. Twenty second intervals were used, however, in the storm investigation to be presented here. During the running time of the sferic camera, the film is advanced at the rate of one and seven-eights inches per second. Each second of elapsed time is recorded on the film by a neon marker bulb. The timing circuit that controls the neon bulb also triggers a stroboscopic flashing tube which illuminates an electric clock. Information recorded during each interval takes the form of a line of directional pips resulting from sferics received at that particular time by the High Frequency Direction Finder. Waveform presentations can be switched, by a switching device, onto the same cathode ray tube that presents the directional pips. This is usually done for a period sufficient to record a set of waveform pictures. The camera is operated manually for this purpose.

CHAPTER IV

THE TORNADOES OF MAY 25, 1955

Meteorological Conditions of May 25, 1955

On May 25, 1955, meterological conditions were typical of a tornado situation in Oklahoma. As a result there was considerable instability throughout the state. The components of the storm mechanism were a complex low pressure system and a mass of Pacific air moving through Arizona behind a front of maritime tropical air that had already progressed northward across the state[1]. This tropical air had covered the entire state at the surface by 1830 CST and the low pressure system had advanced to the extreme western tip of the Oklahoma Panhandle. The pacific front extended from the point of low pressure southward through the Panhandle and Big Bend areas of Texas. Widely scattered thunderstorms, some with damaging wind and hail, were reported from the western two-thirds of the state throughout the day. A damaging storm occurred as early as 0755 CST in the Blackwell-Newkirk area of north-central Oklahoma. A little after 1500 CST, a tornado was reported on the ground in the Texas Panhandle moving northeast into west-central Oklahoma and funnels were also sighted about 1800 CST in the general area but about 75 miles to the north.

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[1]Wayne F. Staats and Charles M. Turrentine, "Some Observations and Radar Pictures of the Blackwell and Udall Tornadoes of May 25, 1955", Bulletin of the American Meteorological Society, 1956, Scheduled for Publication.

Path of Blackwell and Udall Tornadoes

The echo that was subsequently associated with the Blackwell and Udall tornadoes developed on the station radar at 1850 CST and proceeded northward. Figure 1 is a composite radar tracing showing the initial development of the storm 45 miles southwest of Stillwater near Oklahoma City together with the approximate movement of this echo at one-half hour intervals during its existence. The relative position of towns along its path are also shown on the figure along with the position of the station radar.

Figure 2 shows a map of the area traversed by the two tornadoes with the dotted line representing the approximate paths of each. The multiple dots at the terminal areas of each path represent areas of widespread partial destruction.

A severe tornado developed from this isolated thunderstorm complex about 26 nautical miles north northwest of the Tornado Laboratory at about 2100 CST and moved in a northerly direction. It then crossed U. S. Highway 60 about one mile east of Tonkawa, Oklahoma, at 2115 CST and headed in a direction a little east of north to a point two and one-half miles southeast of Blackwell. The storm then curved to the northwest, more or less following the Chikaskia River into the southeastern part of Blackwell. As it passed through the eastern section of Blackwell at about 2130 CST, the funnel curved to the north again and continued in this direction to a point some three and one-half nautical miles south of the Kansas-Oklahoma border. Here the tornado, now of somewhat diminished intensity, assumed a northwesterly direction, passing into Kansas and dissipating in the vicinity of South Haven, Kansas, at about 2200 CST.

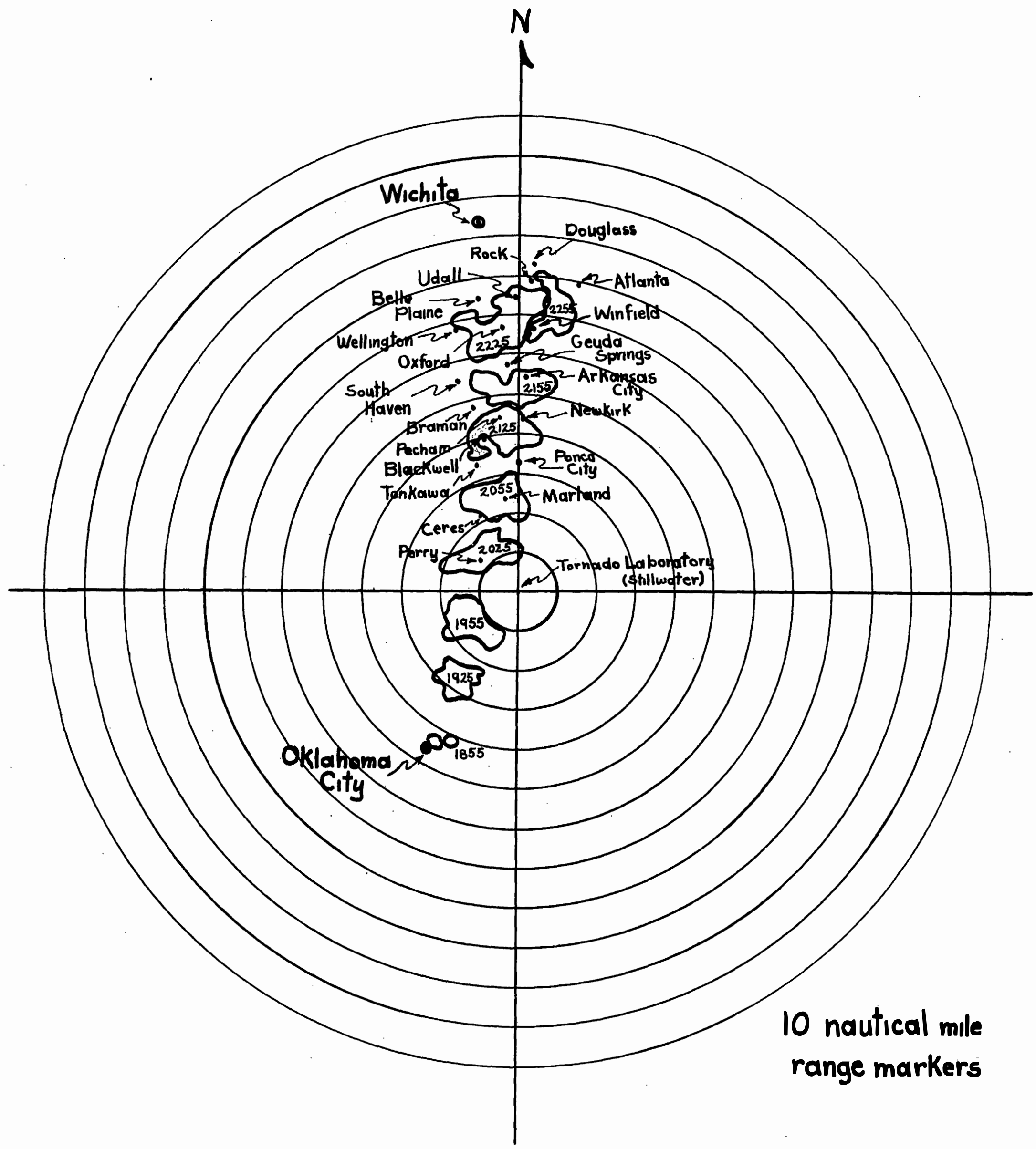


Figure 1. Composite Tracing of Tornado Radar Echo. May 25, 1955

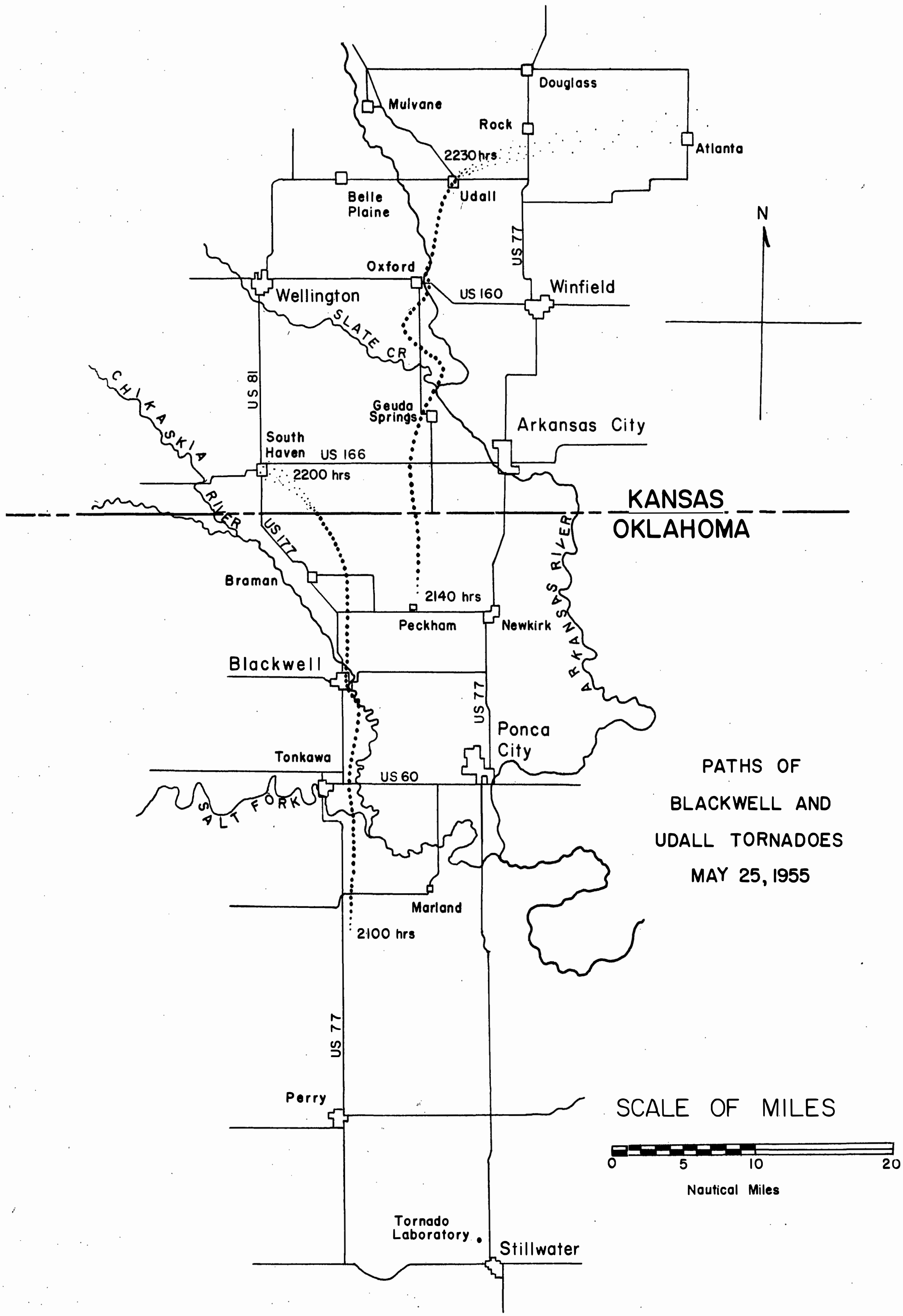


Figure 2. Map Showing Paths of Tornadoes of May 25, 1955

About twenty minutes before this tornado dissipated, another funnel touched the ground about five nautical miles east of the path of the Blackwell funnel and approximately one nautical mile north of Peckham, Oklahoma. This funnel moved in a slightly north northwesterly direction, then curved northeast passing just west of Geuda Springs, Kansas, a little after 2200 CST. It continued to move in a northeast direction for a few miles, then curved to the northwest for several miles and back to the northeast again until it reached the Arkansas River southeast of Oxford, Kansas. Here it followed the river in a general northerly direction for about three miles, passing one-half mile east of Oxford at 2220 CST. After leaving the river two miles north of Oxford, it curved again to the northeast, passing directly over Udall, Kansas at 2230 CST. Immediately after leaving Udall, it apparently began to dissipate as it continued curving to the east. Beyond Udall there was little evidence of total destruction but rather a wide belt of partial destruction extending an additional 10 miles.

Radar Results of May 25, 1955

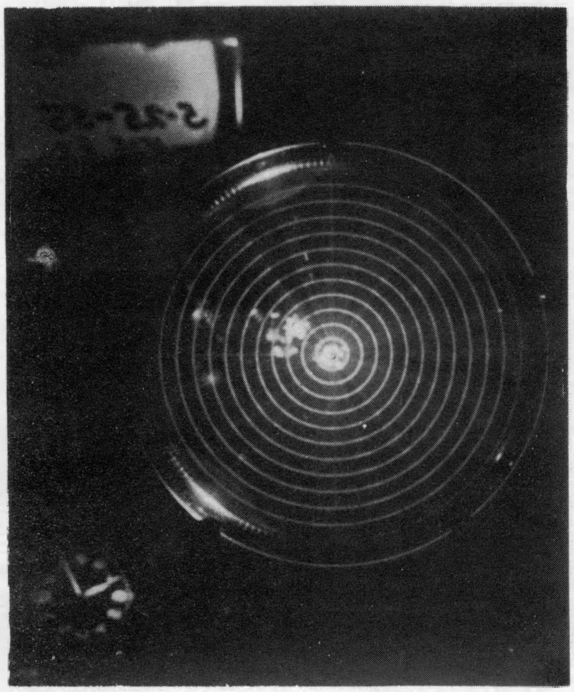
A series of consecutive radar pictures was obtained throughout the evening of May 25 by the automatic recording procedure outlined in the preceeding sections. Although radar scope pictures are available for each five minutes during the entire storm, the pictures presented here are the most revealing and are so spaced as to illustrate the progress and development of the tornado echo. Since there are several echos present in each photograph, the specific tornado echo may be identified by reference to the composite tracing in Figure 1.

On all radar scope prints the displayed range markers represent ten nautical miles on the ground. The mechanism of the radar camera is such that the date card and clock are shown as mirror images with the date card in the northwest quadrant. It should be noted that the peripheral azimuth scale is 13° in error, but that the cross hairs are oriented at the true cardinal directions with the cross-hair arrow pointing north. At the time of these exposures, the radar transmitter was double pulsing, causing spurious images of most echos more distant than about 50 miles. All apparent echos occurring at the same azimuth but about 50 miles nearer the station should be regarded with suspicion although it is possible to distinguish the spurious echos from the actual echos after careful investigation.

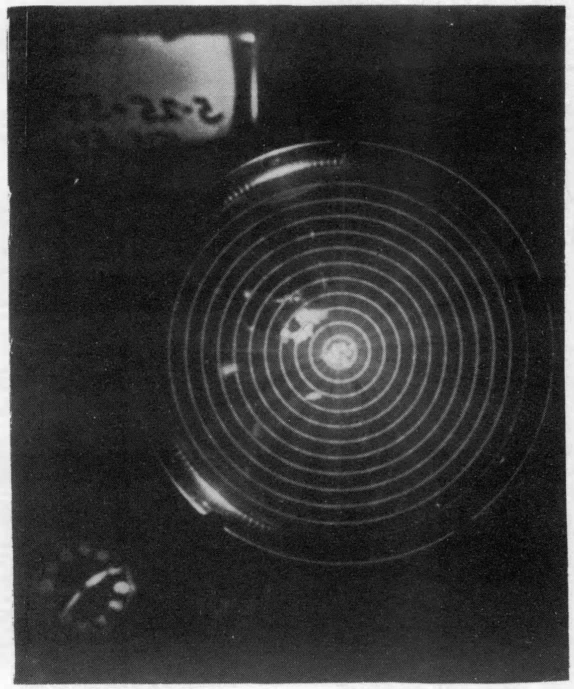
The radar echo from which the Blackwell and Udall tornadoes ultimately developed came into existence near Oklahoma City at about 1850 CST. It is barely perceptible in Figure 3A at an azimuth of 203°, 56 miles from the Tornado Laboratory. The echo is shown 20 minutes later in Figure 3B, and is located at 210° at 35 miles. Figures 3C and 3D at 214°, 29 miles and 220°, 20 miles respectively, show the north-northeasterly course and the increasing dimensions of the echo during the time intervals indicated.

The photographs in Figures 4 A, B, C, and D show the radar echos at approximately 15 minute intervals during the next 60 minutes. The tornado echo is seen passing just west of the station with its eastern edge extending into the ground clutter. In Figures 5 A, B, C, and D, the progress of the echo between 2053 CST and 2109 CST is shown. The western edge of the tornado echo should be noted with regard to its peculiar and rapidly changing shape. The tornado was formed and on the ground at

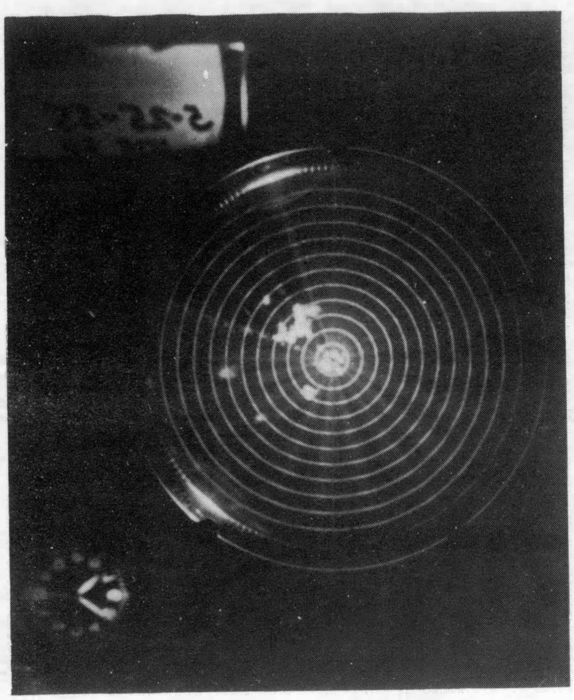
Figure 3. Radar Photographs, May 25, 1955



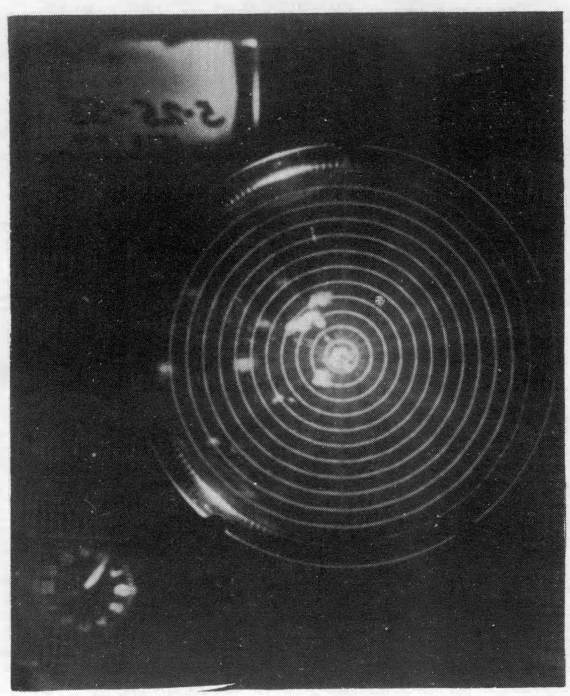
A. 1850 CST



B. 1909 CST

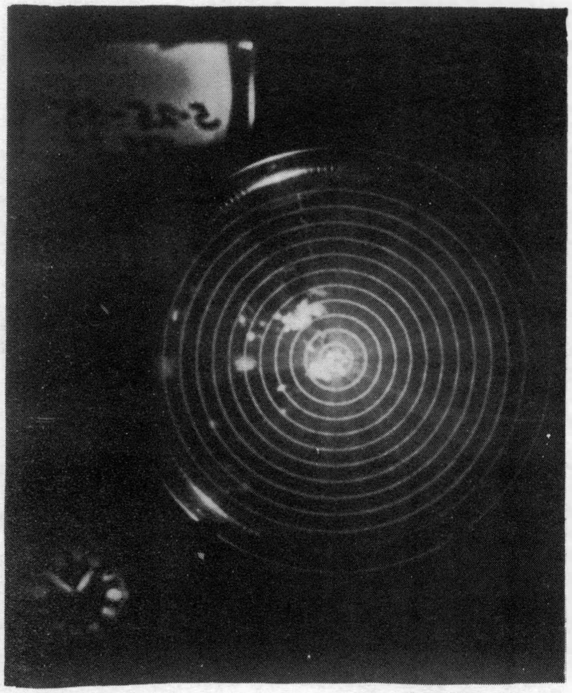


C. 1924 CST

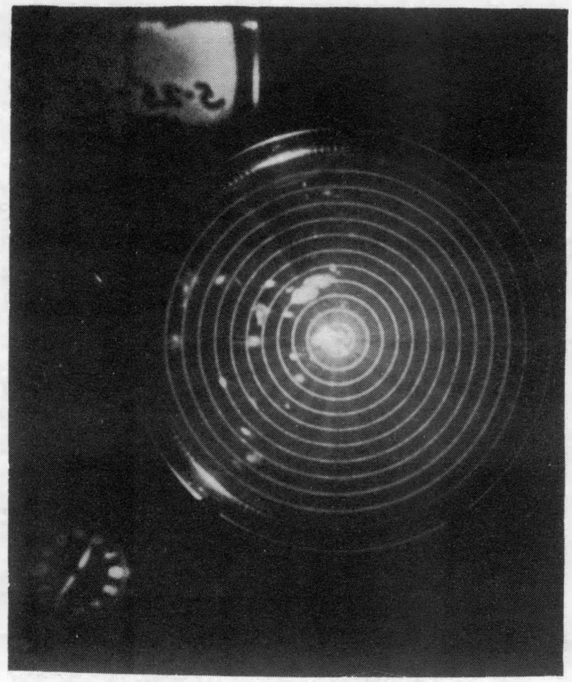


D. 1939 CST

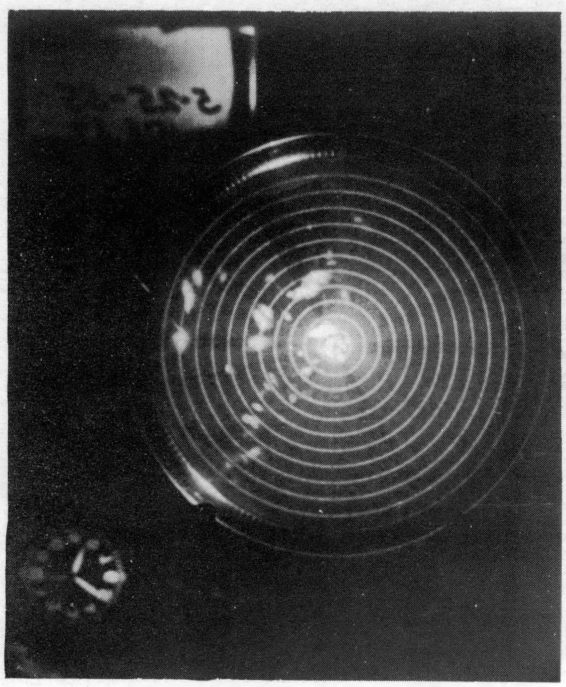
Figure 4. Radar Photographs, May 25, 1955



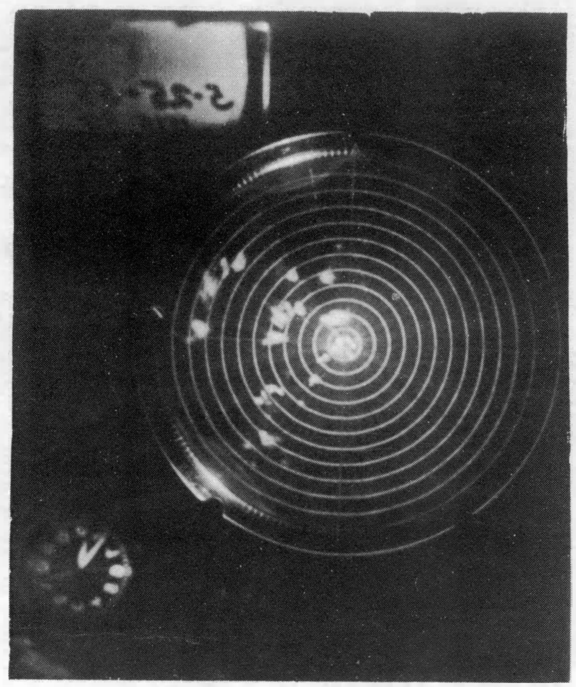
A. 1954 CST



B. 2009 CST

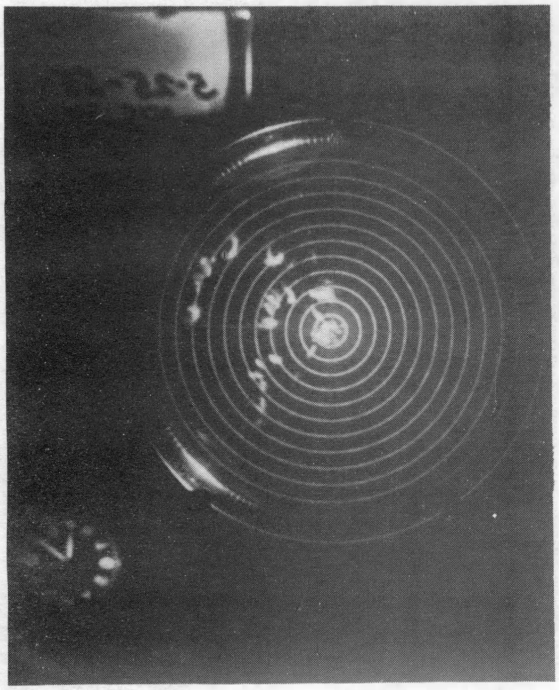


C. 2024 CST

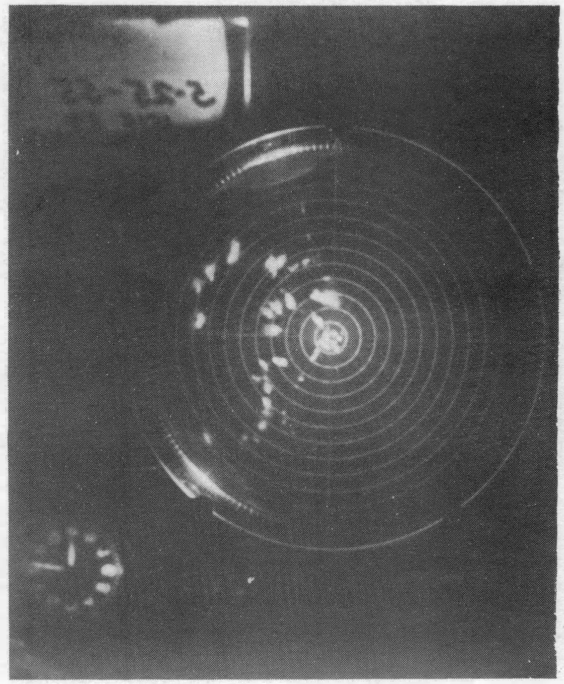


D. 2039 CST

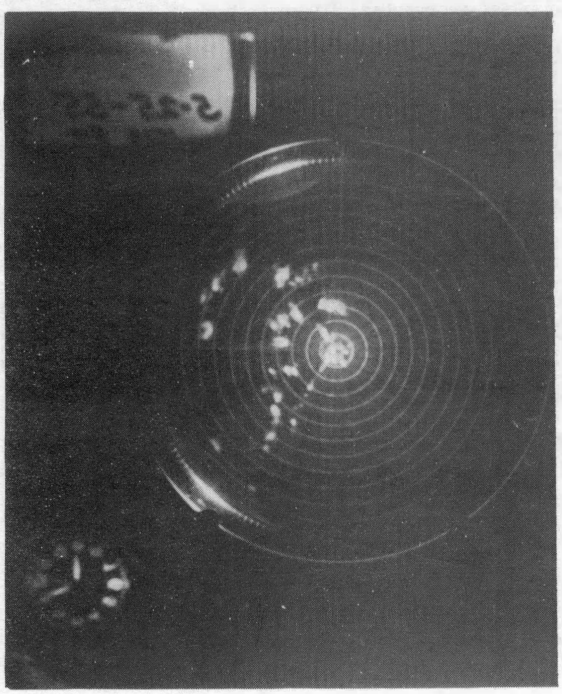
Figure 5. Radar Photographs, May 25, 1955



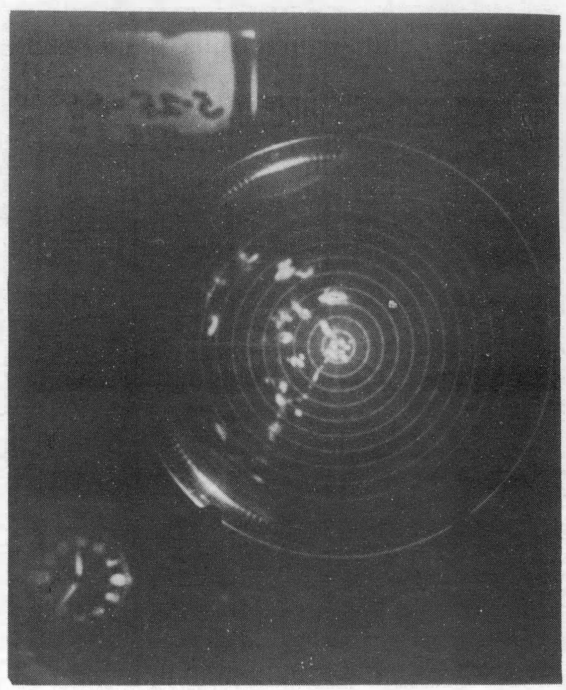
A. 2053 CST



B. 2059 CST



C. 2104 CST



D. 2109 CST

2104 CST and was located at 339°, 25½ miles from the station, or about four miles south of the echo boundary in Figure 5C. The first evidence of the development of the cyclonic protuberance or hook on the echo is similar to those previously observed in the Illinois[1] and Massachusetts[2] tornadoes. This is shown in Figure 5D.

Figures 6 A,B,C, and D show clearly the counter-clockwise folding action of the cyclonic hook until its closure at 2129 CST, the same time the tornado struck the south side of Blackwell, Oklahoma. From the time of the tornado passage reported by witnesses along its path, it was found that the tornado was on the ground very near the tip of the protuberance in Figure 6A and 6B, and near the bulb of the protuberance at 346°, 38 miles in Figure 6C.

The completion of the cyclonic folding of the protuberance into the parent echo is shown in Figure 7A, as the tornado moved north out of Blackwell. The dark portion at the left of the echo in Figure 7B and 7C is possibly the hollow core believed to be associated with the vortex of the tornado funnel. From the ground path survey it was assumed that the Udall tornado developed near the right side of the core in Figure 7C.

There is a striking similarity in the development of the Blackwell and Udall tornadoes as compared with the Massachusetts tornadoes of

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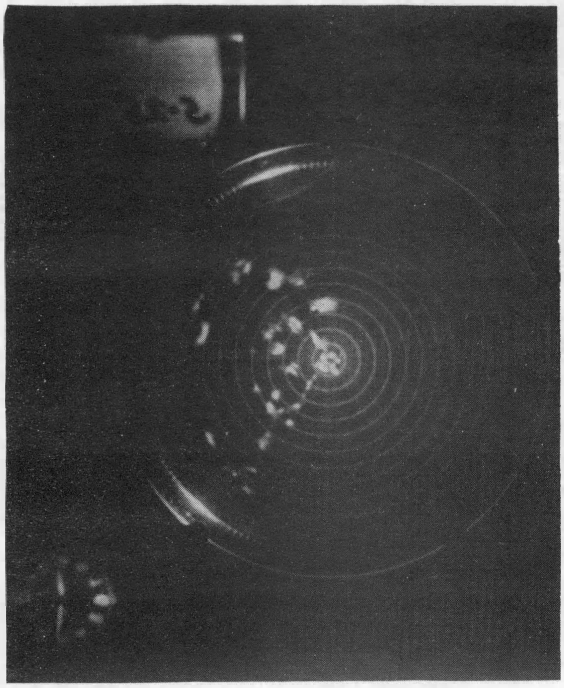
[1]G. E. Stout and F. A. Huff, "Radar Records Illinois Tornadogenesis", Bulletin of the American Meteorological Society, June, 1953, pp. 281-284

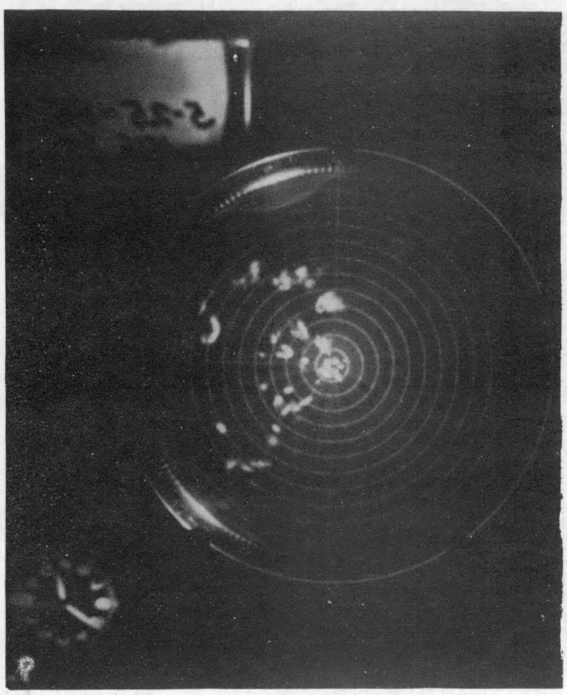
[2]S. Penn, C. Pierce, and J. K. McGuire, "The Squall Line and Massachusetts Tornadoes of June 9, 1953", Bulletin of the American Meteorological Society, March, 1955, pp. 116-122.

Figure 6. Radar Photographs, May 25, 1955

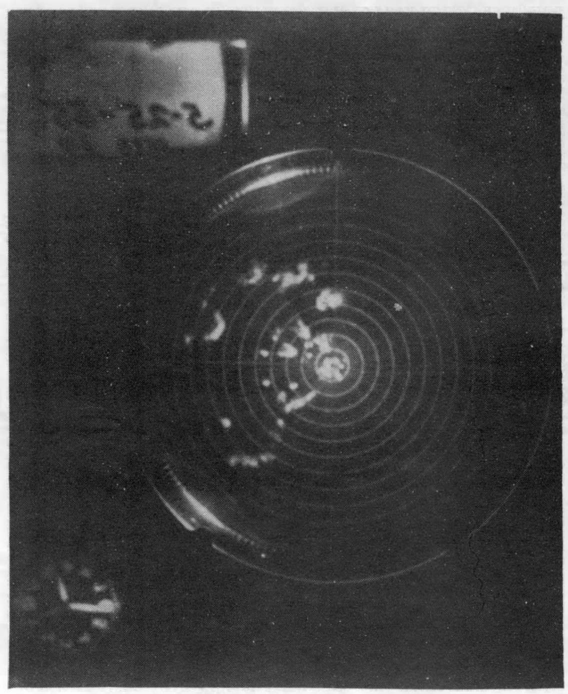


A. 2114 CST

B. 2119 CST.



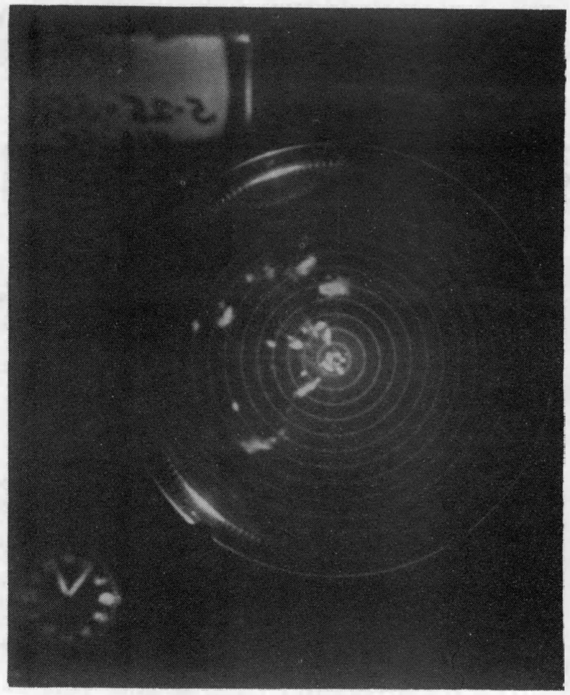
C. 2123 CST



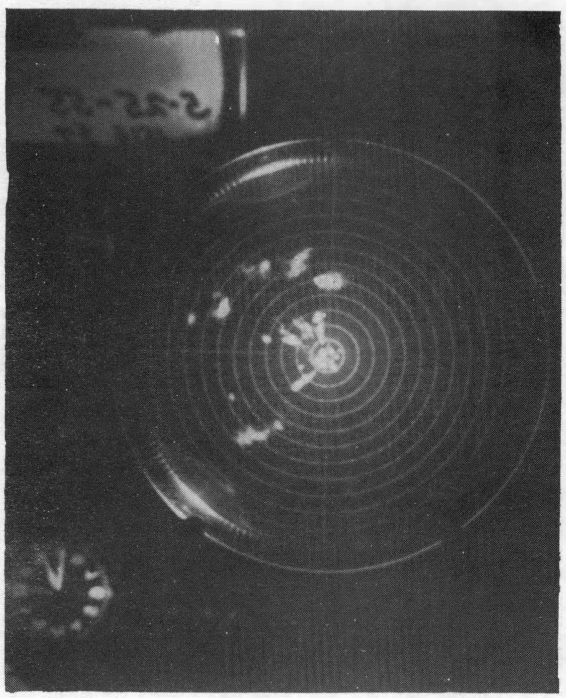
D. 2129 CST.

Figure 7. Radar Photographs, May 25, 1955

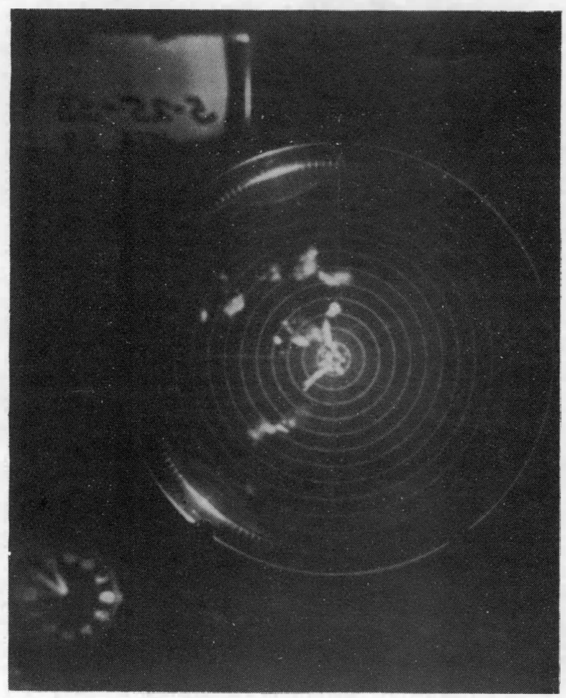
A. 2135 CST



B. 2140 CST



C. 2145 CST



D. 2155 CST

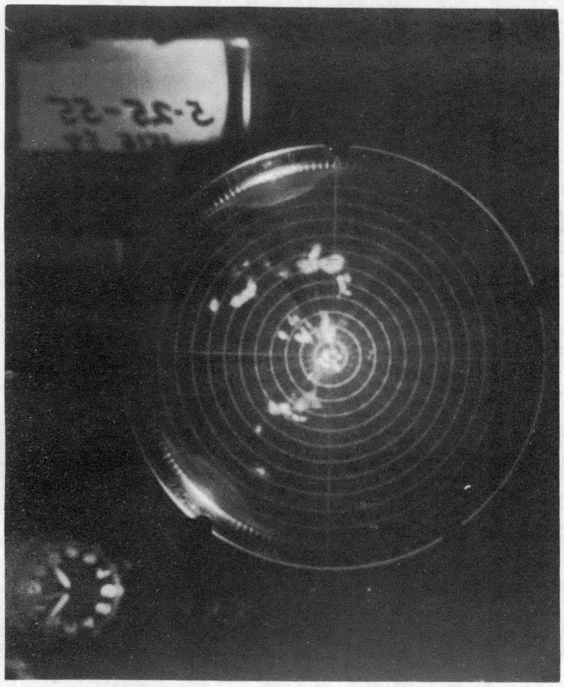
June 9, 1953. In both cases an initial hook developed on the radar echo some 20 to 30 minutes after the formation of the first tornado. This is followed by the development of another tornado a few miles to the right of the first at about the time that the first funnel begins to curve to the left, and some 15 minutes before the first tornado dissipates.

Figures 8A, B, C, and D show the progress of the tornado echo after it had crossed the state line into Kansas. In Figure A the tornado echo centered at 359°, 60 miles and moved in a north-north-easterly direction to apparently meet with another echo centered at 348°, 65 miles that was moving along an east-northeast course. From the ground damage survey it was near this point of intersection that the tornado began to intensify. Figures 8B and 8C show the combined echos coincident with the tornado at Udall, Kansas, at 359°, 75 miles. In Figure 8D, some fifteen minutes later, the echos have almost dissipated.

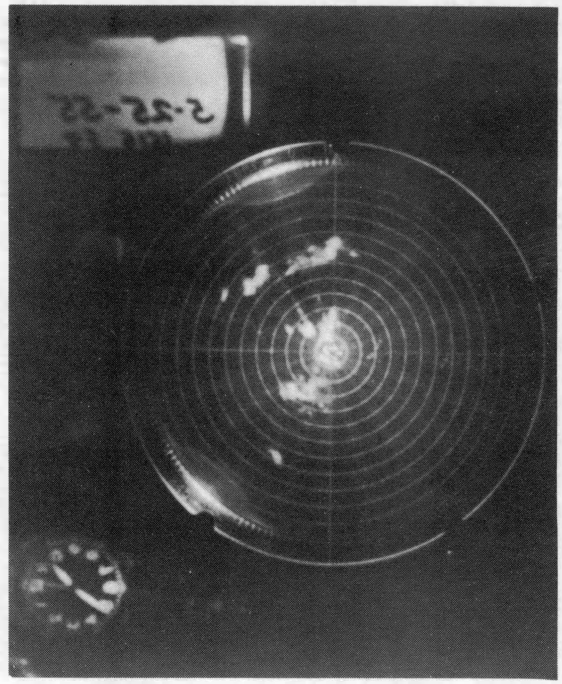
Sferic Results of May 25, 1955

The tornado season of 1955 was highlighted on May 25th by a major storm with accompanying tornadoes. This was the first major storm that occurred subsequent to the installation of the high frequency direction finder. Sferic records in the form of directional pips were obtained by using the procedure already described. Examples of the type of sferic information recorded are shown in Figure 9 A and B and Figure 10 A and B. Waveform records of incoming sferics were also taken. An analysis of these data is not included in this thesis.

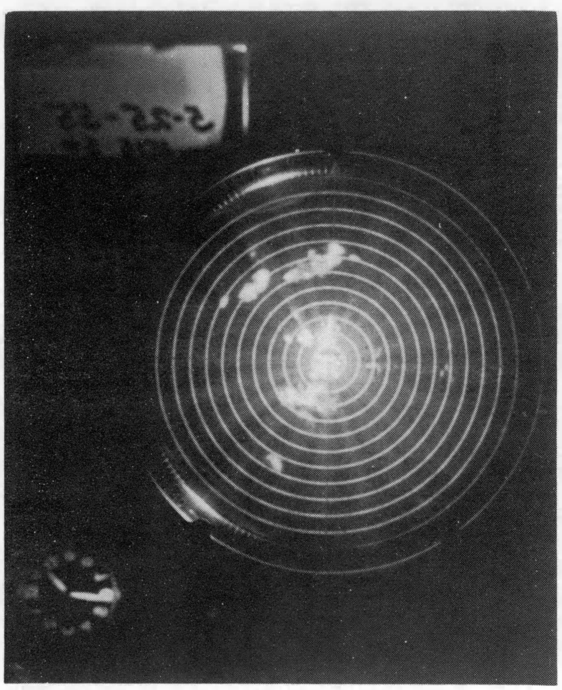
Figure 8. Radar Photographs, May 25, 1955



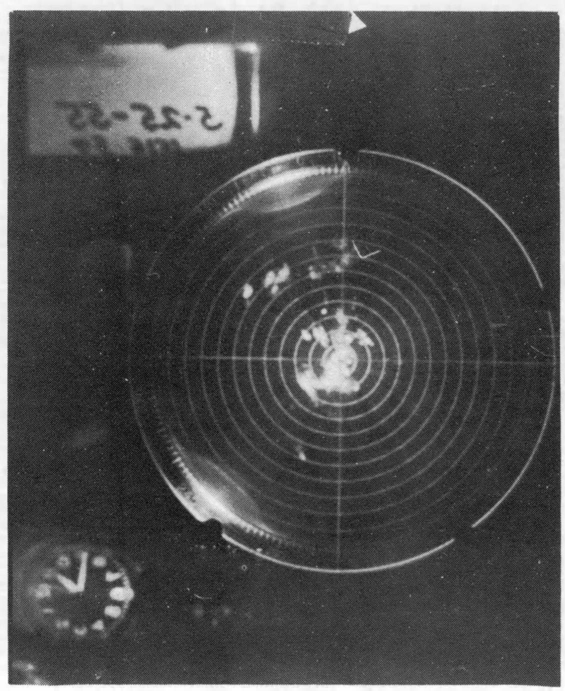
A. 2209 CST



B. 2224 CST



C. 2229 CST



D. 2244 CST

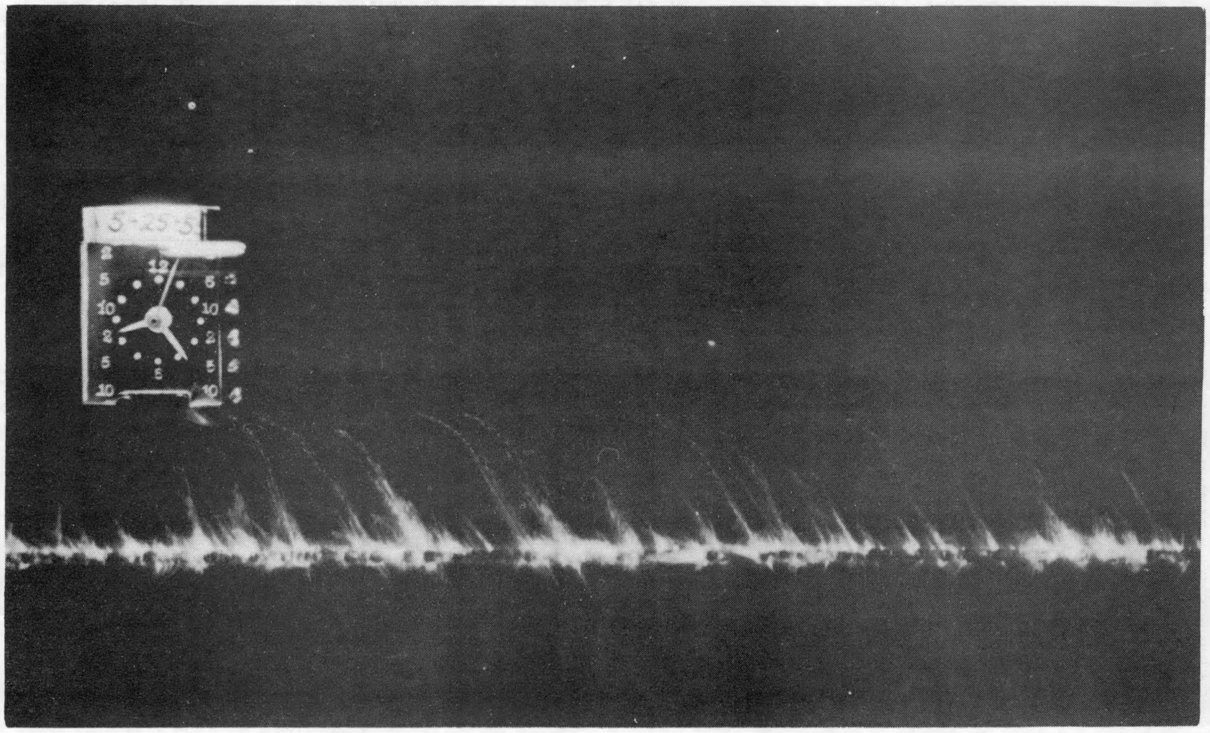


Figure 9A. Film record of sferics. May 25, 1955. High intensity.

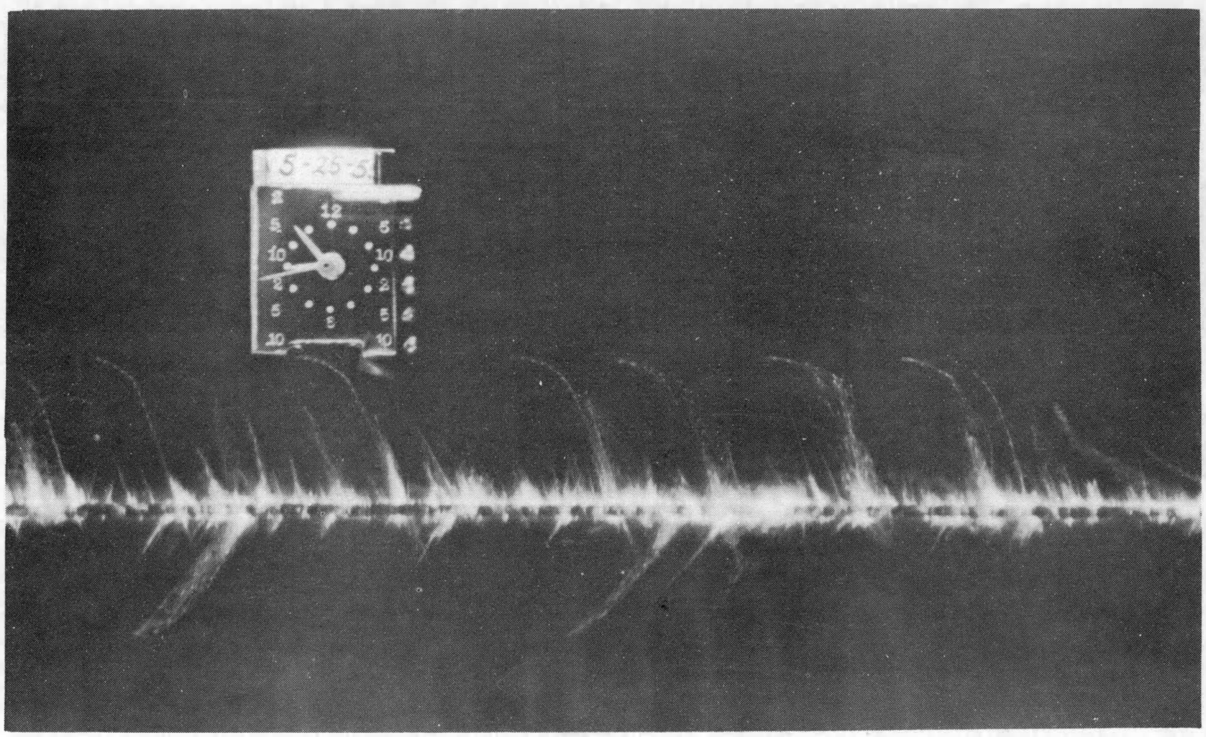


Figure 9B. Film record of sferics. May 25, 1955. High intensity.

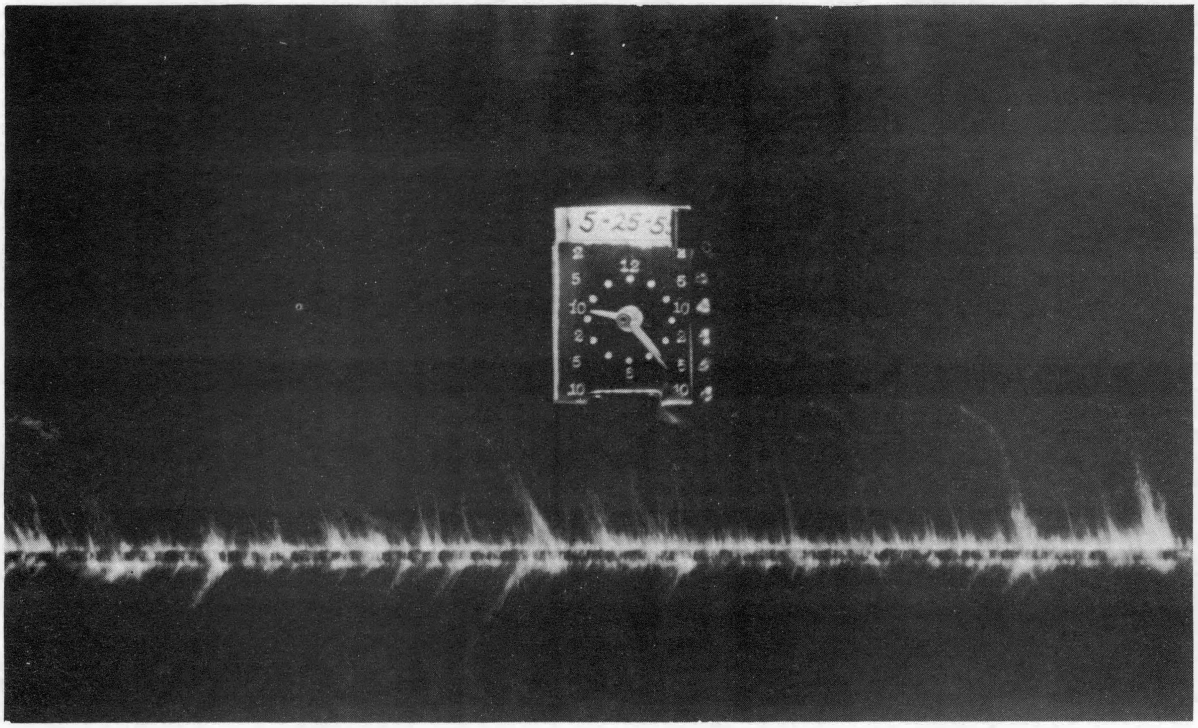


Figure 10A. Film record of sferics. May 25, 1955. High intensity.

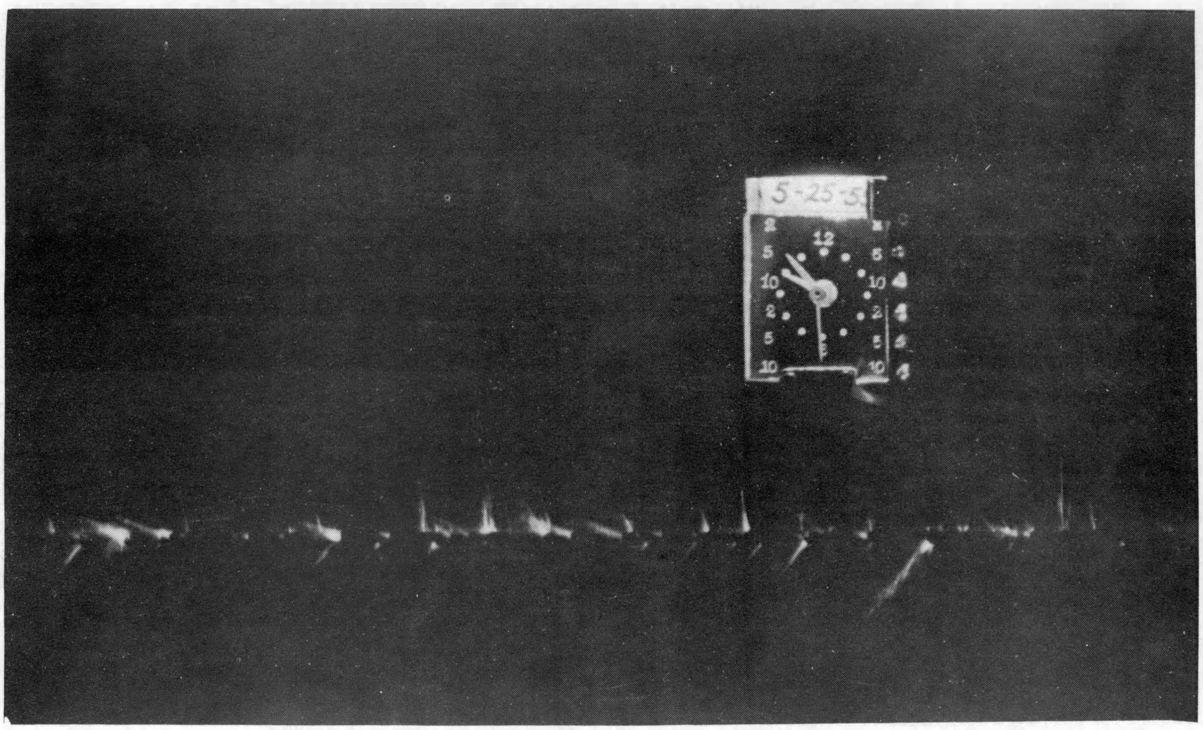


Figure 10B. Film record of sferics. May 25, 1955. Low intensity.

Since the camera used to record sferic information is of the continuous recording variety, the line of directional pips shown may be considered as a time axis. On the 35mm film this time base would correspond to one and seven-eighths inches of film advance per second of elapsed time. Since the photographs shown are enlarged portions of the 35mm film, the time interval for each print shown would represent between one-half and two-thirds of a second.

It will be noticed that the rate of sferic arrival is very high in Figure 9A and 9B and Figure 10A, compared to that in Figure 10B. At about 2125 CST, just before the tornado struck Blackwell, the gain and scope intensity of the High Frequency Direction Finder were reduced in an attempt to provide a better film record. It was found on developing the film that both the gain and scope intensity had been cut too much. Therefore, the sferic records before 2125 CST are referred to as "high intensity" and those after 2125 CST as "low intensity".

In the analysis of this recorded sferic information, each directional pip that was sufficiently long enough to permit the establishment of a direction was evaluated as to its azimuth to the nearest two degree sector. It was found that due to halation effects of the phosphor coating on the cathode ray tube, a single pip commonly occupies more than a one degree sector. Consequently, evaluation of pips to the nearest two degree sector was used through the analysis. Considering the comparatively broad sector of sferic activity of any storm, it has been found that two degree resolution of pips provides a useful representation of the different sferic intensities within a storm complex.

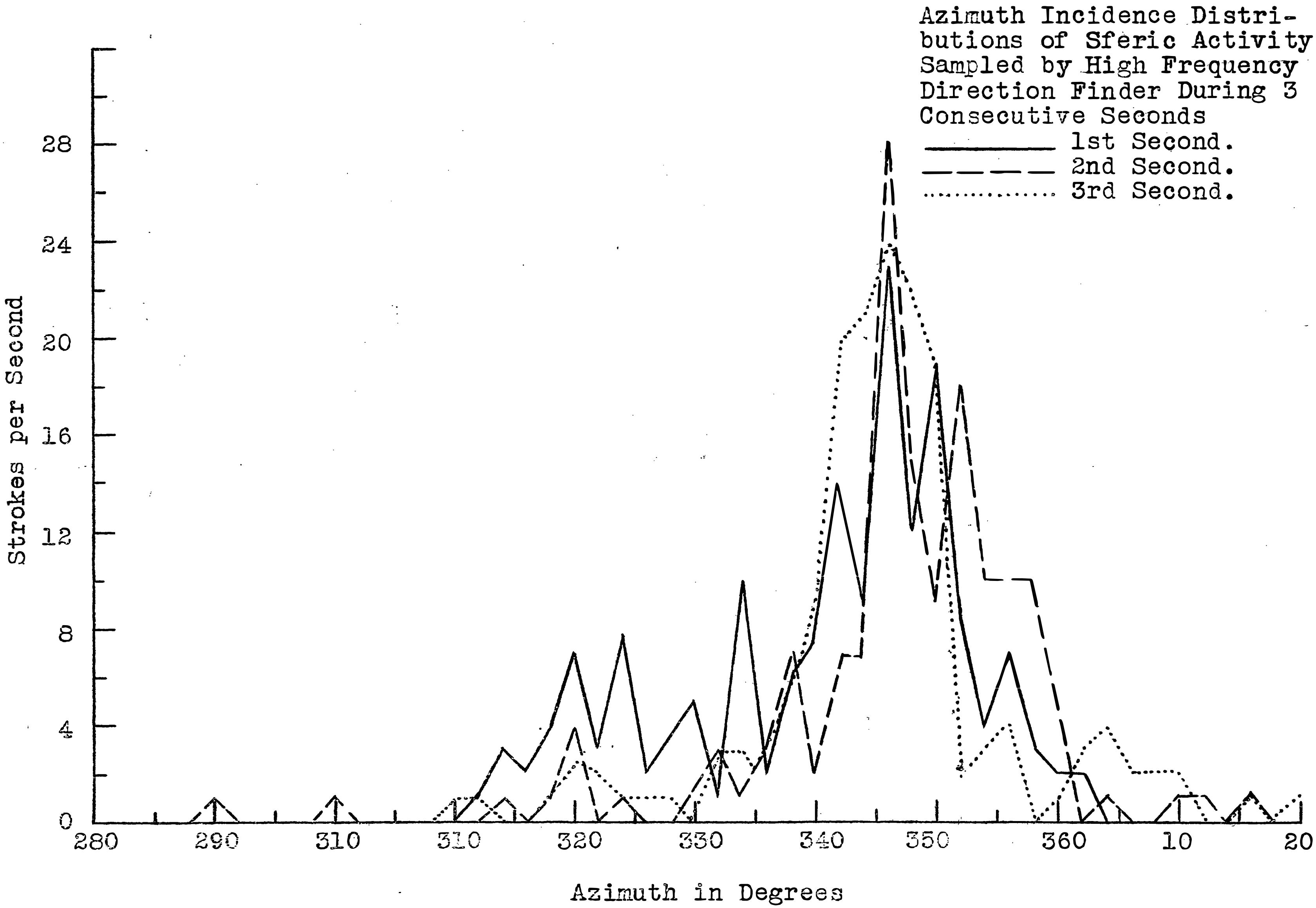
The directional pips recorded on a 35mm film strip are necessarily quite small. By the use of a Recordak microfilm viewer, located in the Oklahoma A & M College Library, it was possible to magnify the sferic information about fifteen times, thus providing sufficient size to permit an accurate evaluation. An ordinary transparent protractor was used to determine the angle of each pip relative to the east-west base line established by the cathode ray trace in quiescent position. Standard compass references were used to assign an azimuth to a pip, with zero degrees at the north.

In order to systematize the tabulation of the results of sferic evaluation, a data sheet was prepared with horizontal columns listing the two degree sectors and the vertical columns listing seconds of a given time interval. As the azimuth of each pip was measured it was recorded in the block representing the azimuth and time of appearance. For a given time interval all pips along a given two degree sector were totaled and averaged over the particular time interval counted. All sectors averaging less than one half stroke per second were disregarded. The averaged rates of sferic arrival were than plotted on graphs with the horizontal and vertical axis showing azimuth and stroke rate respectively. Sferic plots of this type are shown in Figures 11 to 21 inclusive.

From Figures 9A and B, and 10A, it can be seen that the sferic activity was very heavy and than an accurate count of lightning strokes was extremely difficult to obtain. The resolution of pips obtained with a film speed of 1 7/8 inches per second, which necessitated running the film transport mechanism at nearly top speed, was inadequate for the high stroke rates found in a storm of such high intensity. It is evident that opportunities to acquire data of this nature are rare indeed and that instrumentation deficiencies cannot readily be rectified in a repeated experiment. It therefore becomes a problem of identifying each individual stroke from the sferic records at hand by increased resolution through the use of optical equipment available and the exercising of careful judgment by the analyst.

With these limitations in mind, an attempt was made to count the multitude of sferics recorded during the Blackwell-Udall storm. The end results justified the time and effort required in making the necessary counts. The counts from one second to the next were reasonably consistent as well as those from one period to the next. Figure 11 illustrates the results of counting and plotting the directional pips for three consecutive seconds, with the average of the three seconds shown in Figure 19. Considering the broad sector of activity, it is apparent that there is not too much difference from one second to the next. In addition it should be mentioned that two of these three second periods were counted by one analyst and one period by another. The consistency of the stroke-azimuth distributions indicates that there was little difference in the criteria used by each analyst. To further test this aspect of the analysis, a count of the strokes occurring during the same second was made by the two analysts, each without reference to the results of the other. Azimuth distributions of these counts are shown in Figure 12.

As mentioned earlier, a 20 second run was made each five minutes for the duration of the storm. Due to the limitations in the number of personnel available and equipment for analysis, it was an impossible task to count all strokes recorded. It was found that during the height


Azimuth Incidence Distributions of Sferic Activity Sampled by High Frequency Direction Finder During 3 Consecutive Seconds
1st Second.
2nd Second.
3rd Second.
Strokes per Second
0
4
8
12
16
20
24
28
280
290
310
310
320
330
340
350
360
10
20
Azimuth in Degrees
Figure 11

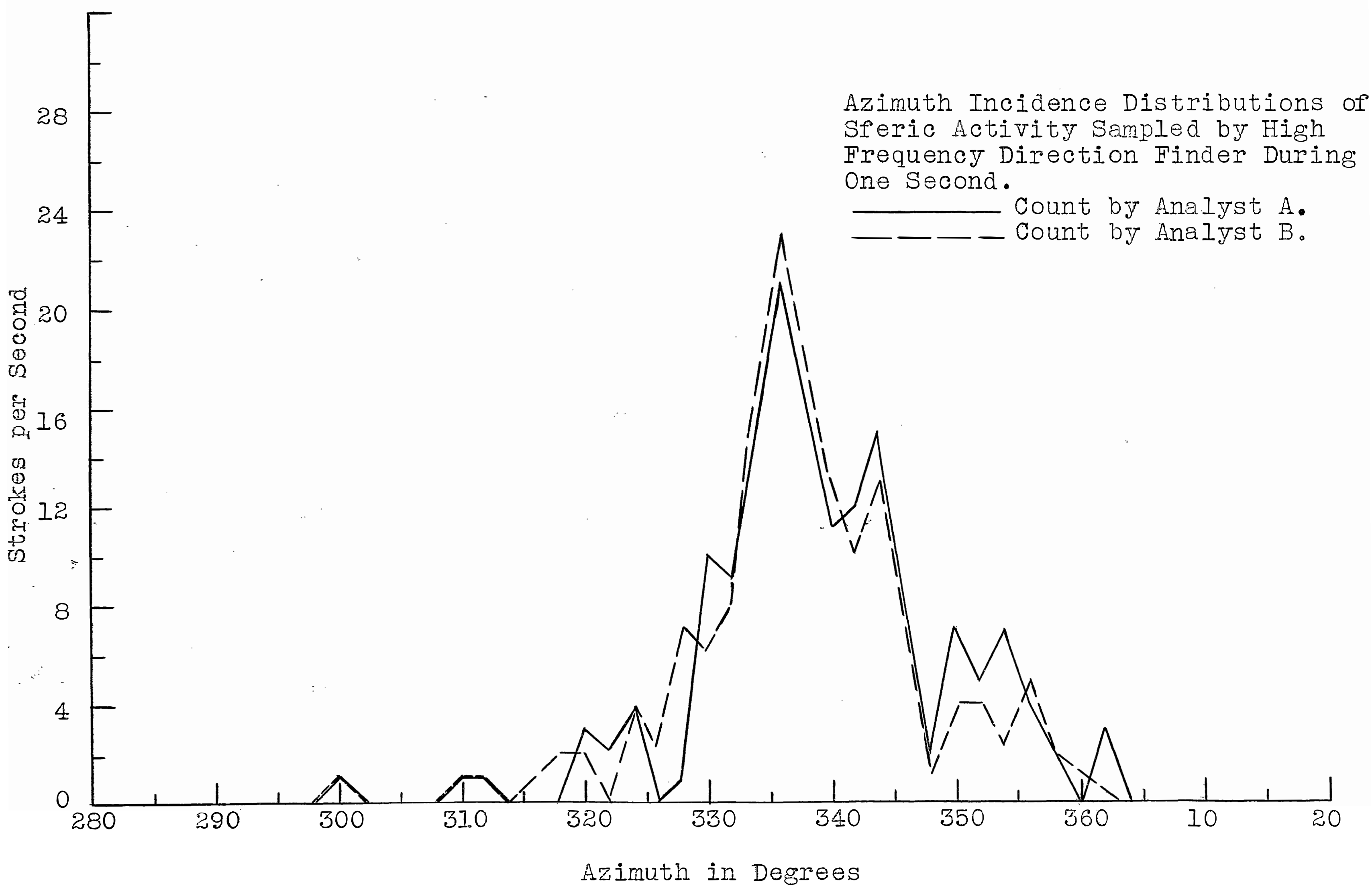

Azimuth Incidence Distributions of Sferic Activity Sampled by High Frequency Direction Finder During One Second.
Count by Analyst A.
Count by Analyst B.
Strokes per Second
0
4
8
12
16
20
24
28
280
290
300
310
320
330
340
350
360
10
20
Azimuth in Degrees

Figure 12

of the storm when "high intensity" film records were taken, there were between 150 and 200 pips occurring during one second. Average time to accurately identify, evaluate, and tabulate this number of strokes was about one-half hour.

Since the primary interest of this investigation is to identify the conditions consistent with the inception of tornadoes and with subsequent tracking of the tornado path, the main area of interest was selected as the time period from which practical warning information could be obtained. With this in mind, it was decided to examine the time period between one hour before and one hour after the inception of the tornado. In addition, it was decided to evaluate the data for three consecutive seconds at regular 15 minute intervals during this two hour time period under analysis, with full 20 second counts to be made at regular 30 minute intervals beginning with one half hour prior to the inception of the tornado. The latter counts were made to establish some form of a reference to ascertain the validity of the three second count.

The resulting plots made of the stroke counts during the time interval mentioned above are shown in Figure 13 to 21 inclusive. It will be noticed that only the sector between 280° and 20° is included during each time interval, except for 2053 CST, shown in Figure 17. Since almost all sferics were originating between the azimuths indicated, only the one plot was made of the much less active sectors of azimuth. This plot is typical of the sferic activity from these sectors during the period of these analyses. No sferics were received at the Tornado Laboratory during this period from 30 to 180 degrees azimuth.

The radar echo associated with the thunderstorm complex that subsequently developed into the Blackwell and Udall tornadoes was positioned almost due west of the Tornado Laboratory at the time of the stroke count shown in Figure 13. The resolution of pips is always most difficult along the east-west axis in the film recording. It was, however, possible to make an approximate evaluation. This evaluation shows that very little lightning was coming from that echo at this time. The sferic activity which shows a peak at about 325 degrees was apparently originating from the large echo located in the azimuth sector from 308° to 350°.

At 2024 CST the radar echo from which the tornado originated had moved to about ten nautical miles northwest of the Tornado Laboratory. It will be noted from Figure 14 that the peak of sferic activity had shifted to about 335°. Here both radar echos were now in line with the station radar and it must be concluded that the sferics coming from this direction were the total emanating from the two echos. However, since the total number of pips shows only a slight decrease, there is a good possibility that the more distant was beginning to dissipate at a rate that just about balanced the increasing rate of sferic activity of the tornado echo.

It will be noticed that the graph for the twenty second interval peaks at an azimuth that is very close to that for the count taken over the three second interval, although the former peak is of smaller amplitude and broader than the latter. The explanation for this difference is that a single thunderstorm cell does not in general continuously produce lightning. A highly active cell might produce as high as one burst per second. This is probably true also for a tornado type

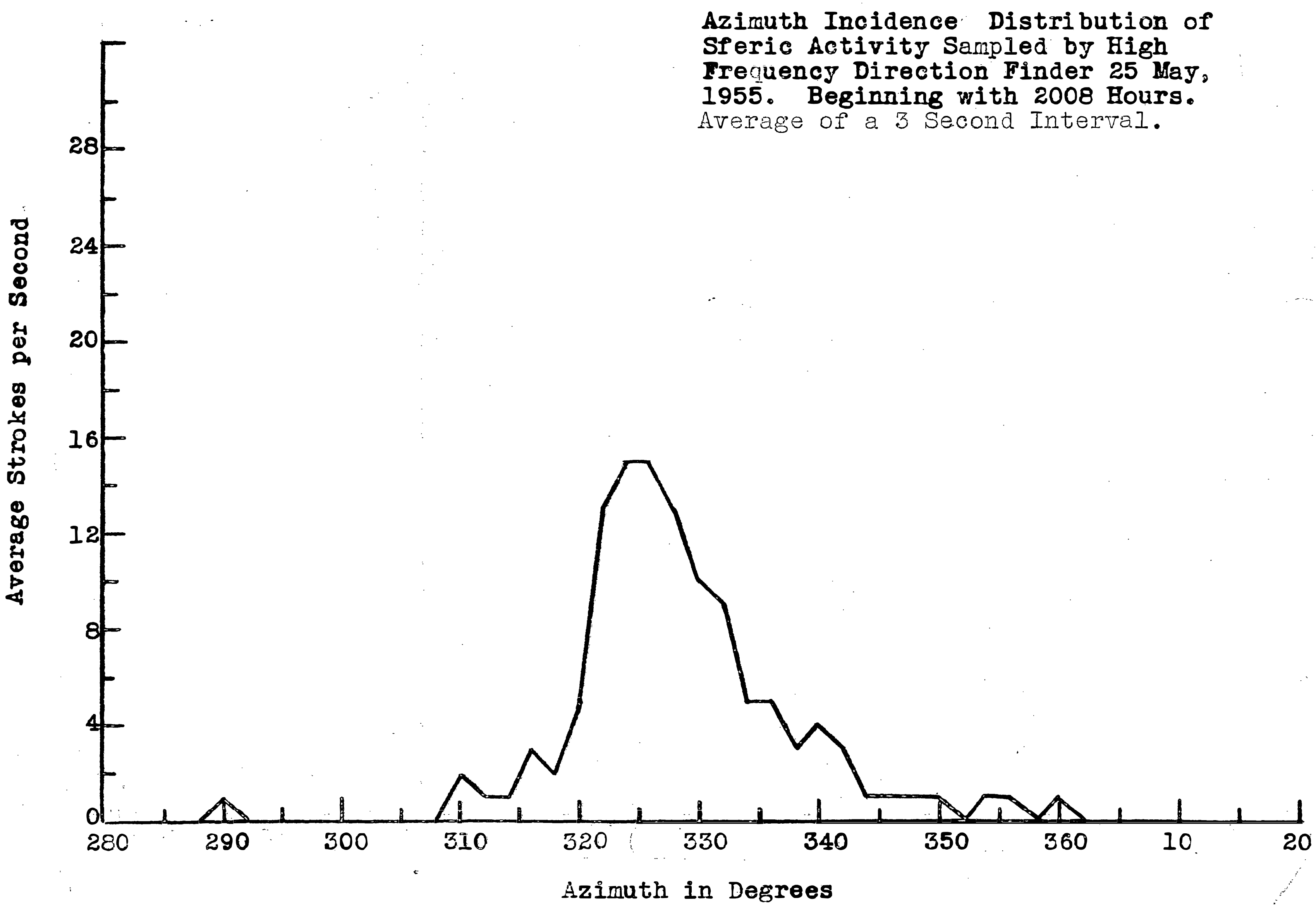

Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder 25 May, 1955. Beginning with 2008 Hours.
Average of a 3 Second Interval.
Average Strokes per Second
0
4
8
12
16
20
24
28
280
290
300
310
320
330
340
350
360
10
20
Azimuth in Degrees

Figure 13

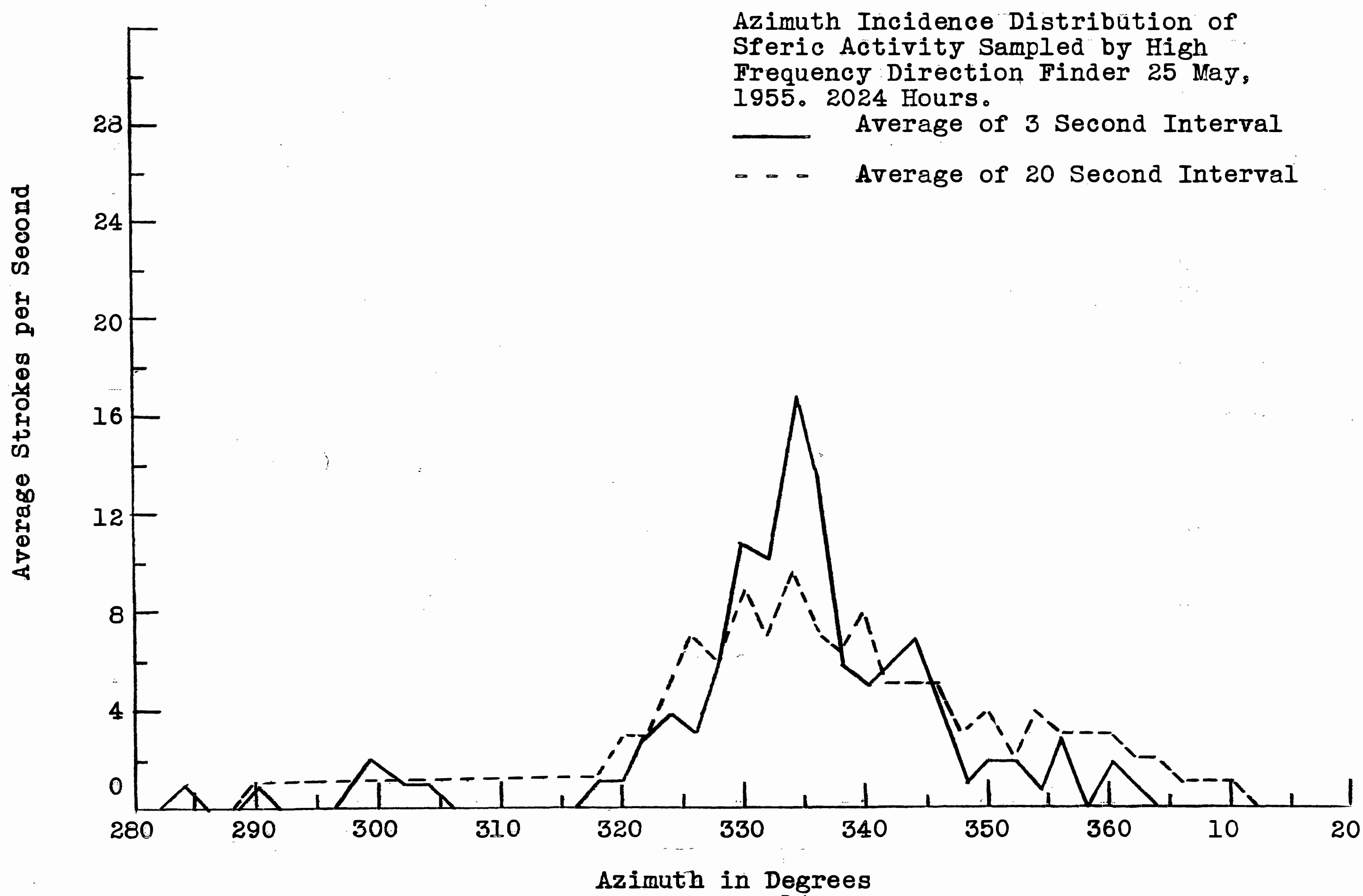

Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder 25 May, 1955. 2024 Hours.
Average of 3 Second Interval
Average of 20 Second Interval
Average Strokes per Second
28
24
20
16
12
8
4
0
280
290
300
310
320
330
340
350
360
10
20
Azimuth in Degrees

Figure 14

thunderstorm cell, and would explain why the curve for the three second count always seems to peak at the same azimuth as the tornado echo. In the curve of the 20 second count, all cells within the storm complex have been represented in the total count. There may have been several seconds of elapsed time between successive bursts in the minor thunderstorm cells. This would account for the average sferic rate of arrival being relatively low when averaged over a 20 second period. Most certainly the peak sferic activity would be lower for the 20 second average than for the three second average, when the latter was made over an interval of relatively high activity.

The sferic distribution at 2038 CST is shown in Figure 15. Although there is a slight drop in peak value, the total sferics in the active sector has increased slightly. Also the azimuth of the peak of sferic activity is not very pronounced, although it might be estimated as 336 to 338 degrees by the vertical extension of sides of the triangle formed by the curve as the sector of maximum activity is approached.

In Figures 16, 18, and 19, showing the time periods of 2053, 2108, and 2123 CST respectively, the total sferics received over the sector of maximum activity levels off to a rather constant value. The peak of sferic activity continues to increase slightly and becomes more pronounced. These three time periods are illustrations of sferic distributions during the inception of the tornado and 30 minutes thereafter. The most remarkable feature of these curves is that the azimuths of the peaks of sferic activity coincide closely with the actual position of the tornado at the time of occurrence.

The sferic records taken after 2125 CST are of the "low intensity" type due to the reduced gain and scope intensity of the High Frequency

Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder 25 May, 1955. Beginning with 2038 Hours.
Average of a 3 Second Interval

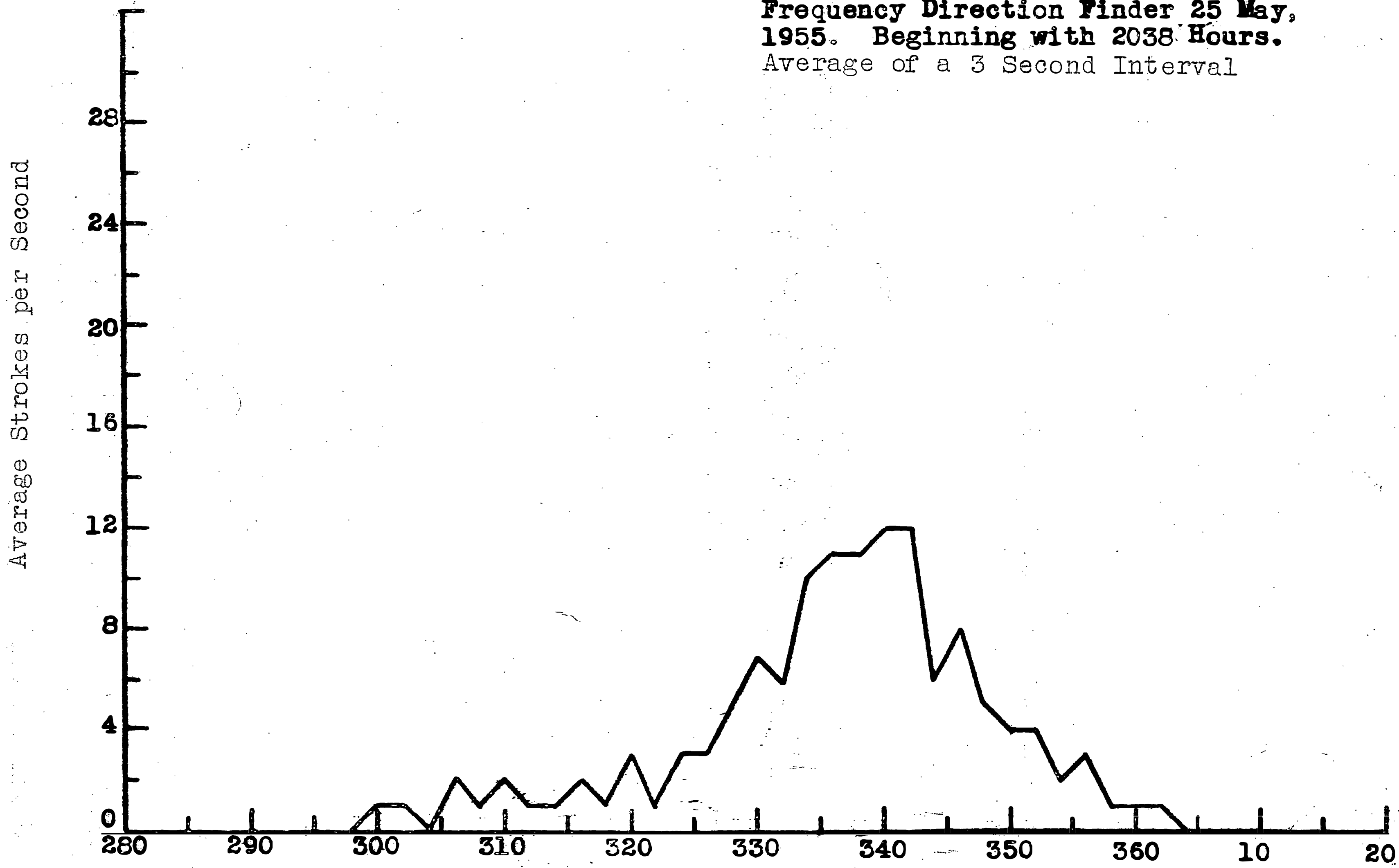
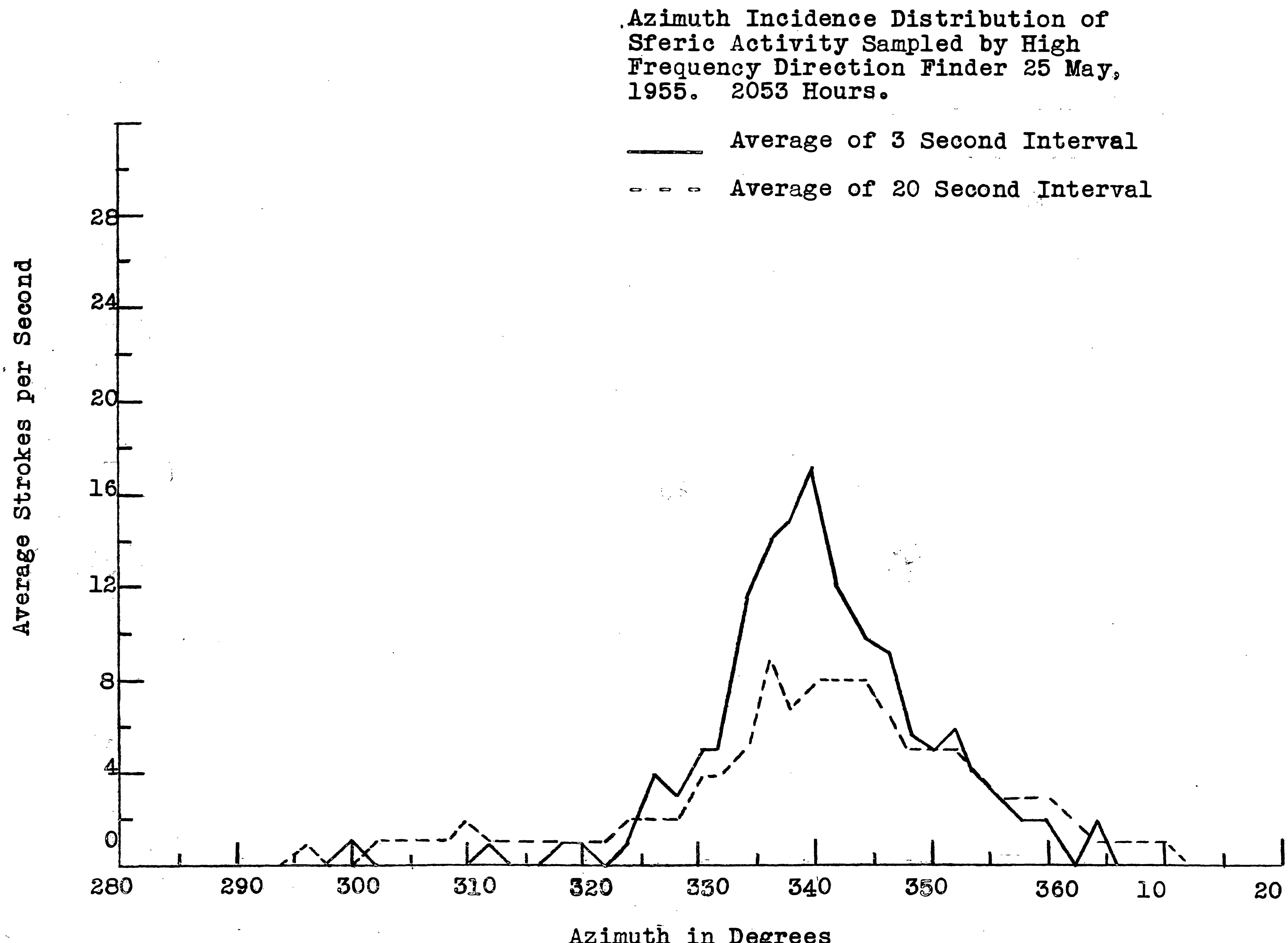


Figure 15



Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder 25 May, 1955. 2053 Hours.
Average of 3 Second Interval
Average of 20 Second Interval
Average Strokes per Second
0
4
8
12
16
20
24
28
280
290
300
310
320
330
340
350
360
10
20
Azimuth in Degrees

Figure 16

Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder 25 May, 1955. Beginning with 2053 Hours. Average of a 3 Second Interval.

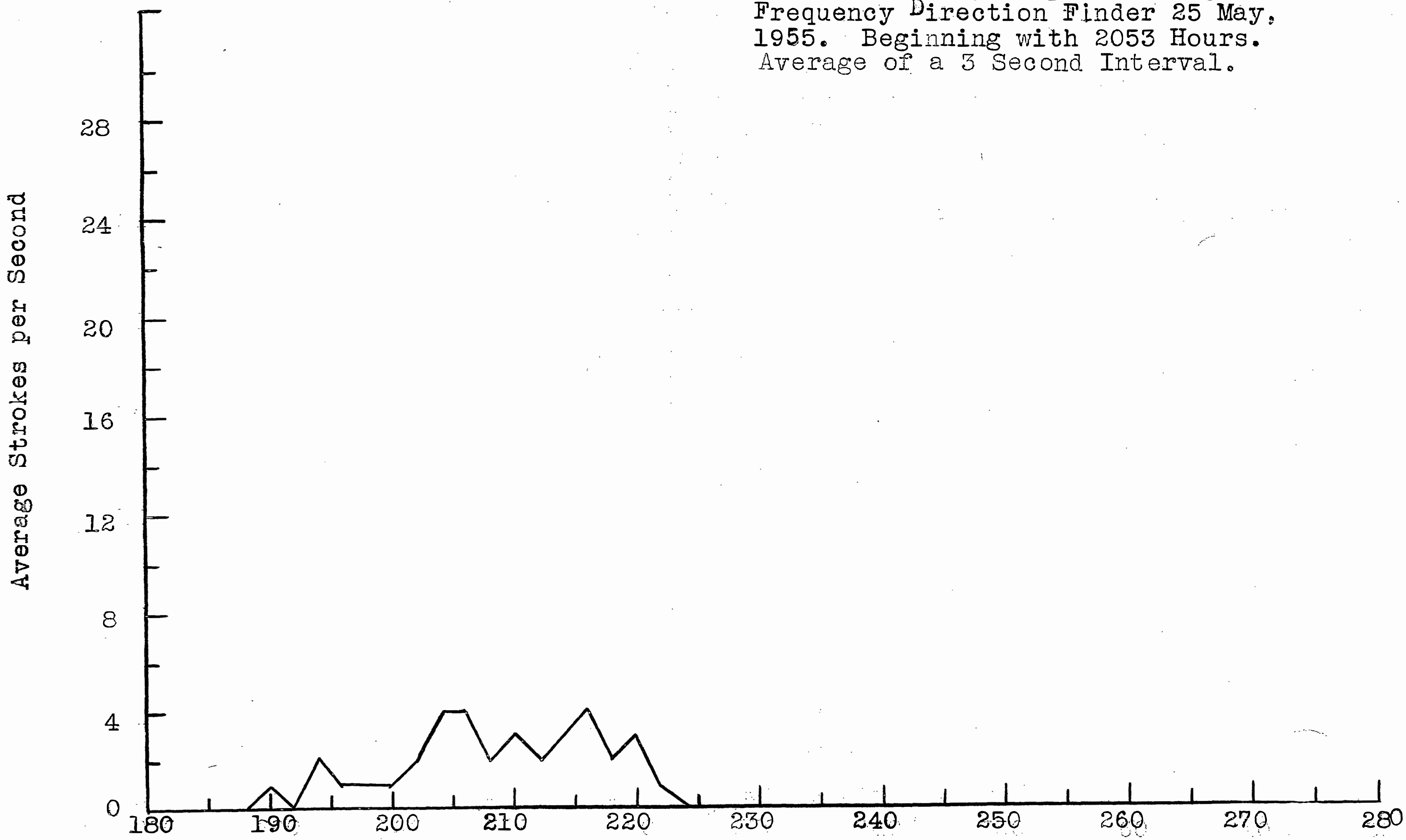


Figure 17

Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder 25 May, 1955. Beginning with 2108 Hours.
Average of a 3 Second Interval.

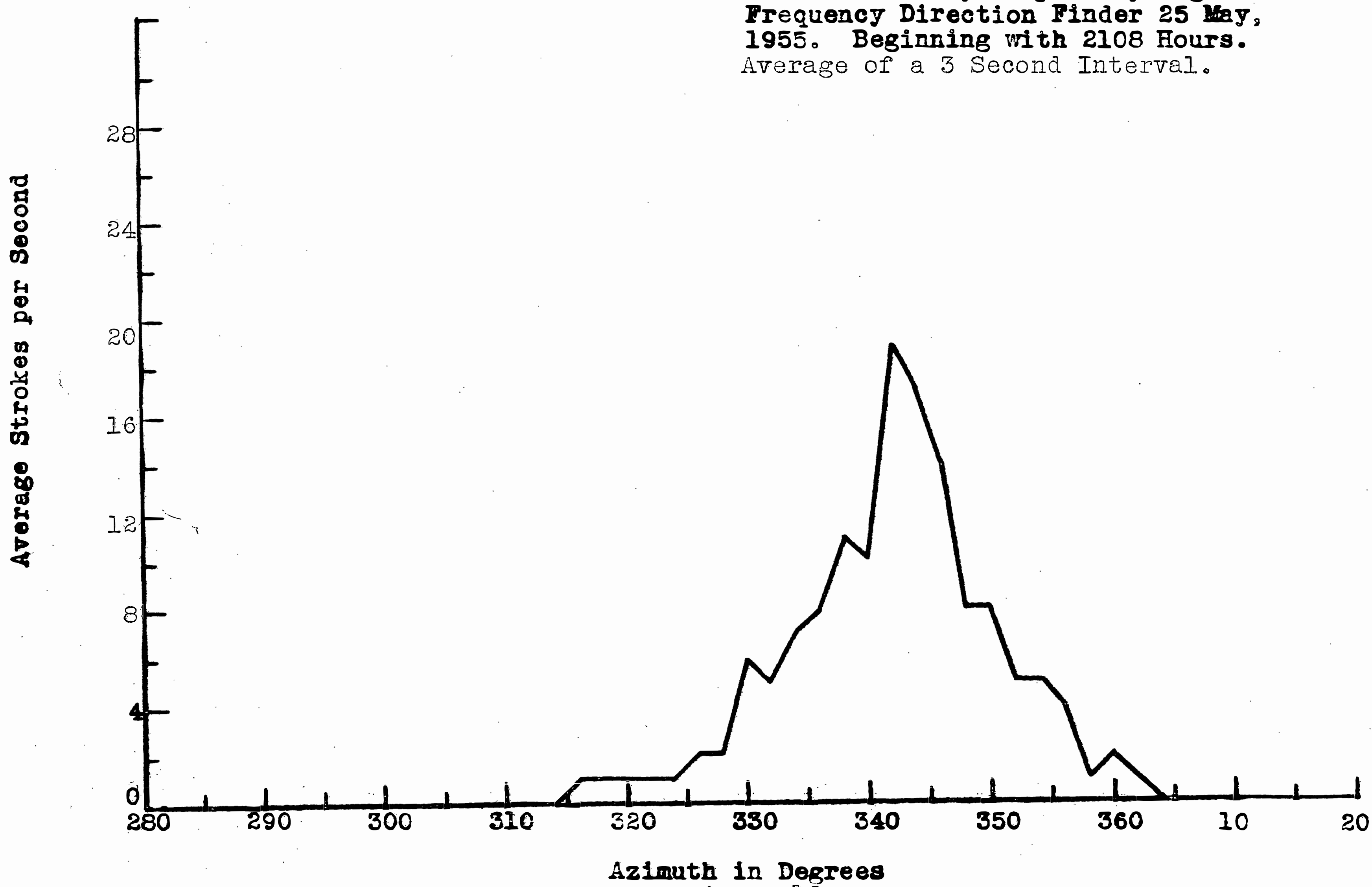
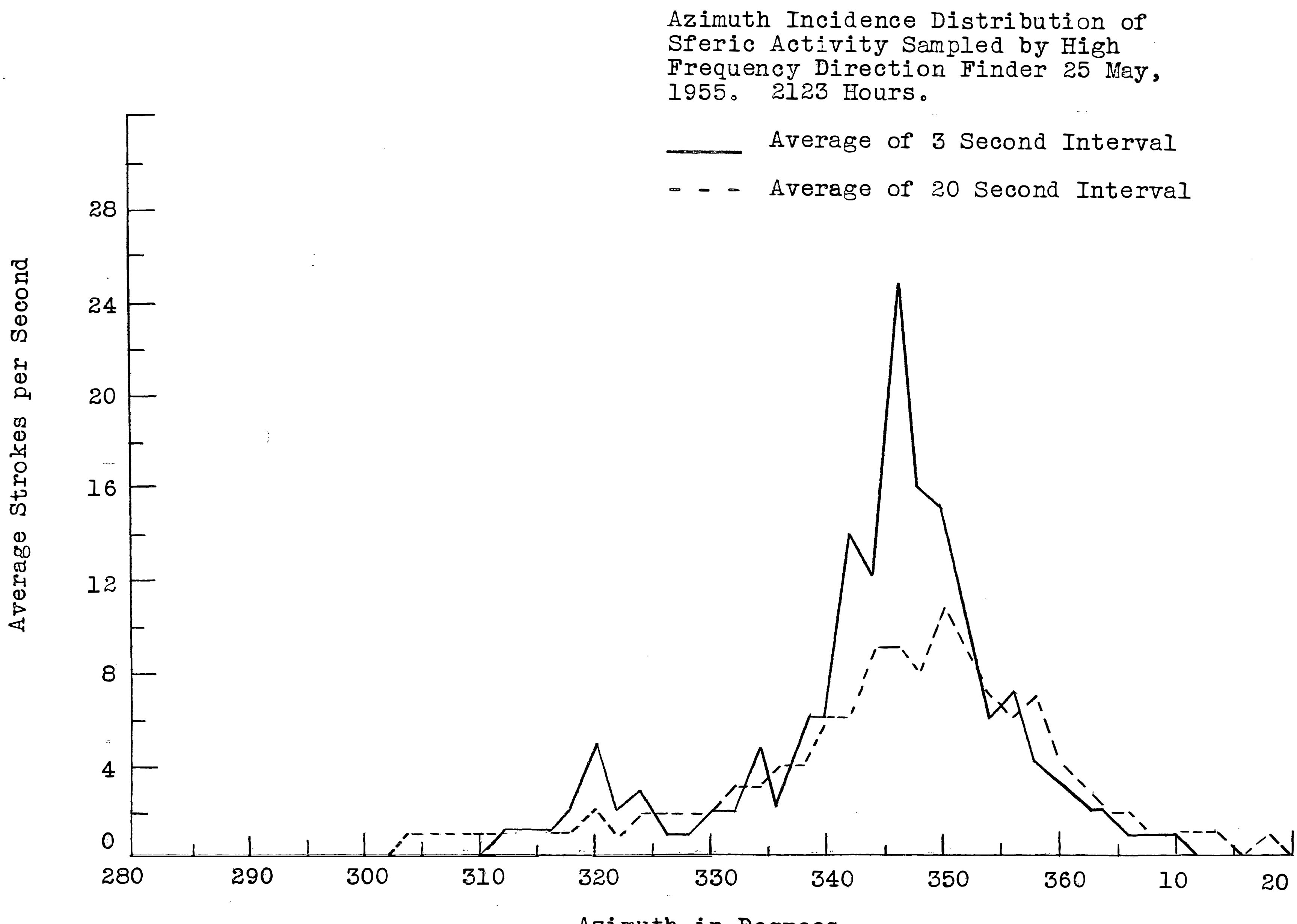


Figure 18


Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder 25 May, 1955. 2123 Hours.
Average of 3 Second Interval
Average of 20 Second Interval
Average Strokes per Second
0
4
8
12
16
20
24
28
280
290
300
310
320
330
340
350
360
10
20
Azimuth in Degrees
Figure 19

Direction Finder. The stroke counts made from these records therefore were not directly comparable to the evaluations made from "high intensity" records. In order to make the graphs taken after 2125 CST appear similar to those of the earlier periods, a total count for five seconds was used rather than an average stroke rate per second as previously described. The significance of the curves made on such a basis lies in the azimuth of peak sferic activity rather than the total sferic count. The rates of sferic arrival from a given azimuth should be viewed relative to another azimuth rather than to some absolute value.

In Figures 20 and 21 sferic distributions from "low intensity" counts are shown. These graphs show a marked shift of peak sferic activity to the right, near 354°. Refering to Figure 20 it will be noted that this shift of activity is concurrent with the time of inception of the tornado which subsequently passed through Udall, Kansas. This shift of activity to the right may be indicative of the development of this new tornado six miles to the right of the waning Blackwell tornado.

Correlation of Radar and Sferic Results

While several references were made to the positions of the radar echoes in the discussion of sferic results, it is indeed difficult to readily identify pertinent azimuths on the small radar photographs shown in Figures 3A to 8D, inclusive. In order to facilitate the necessary correlation between the radar and sferic results, radar photographs made at certain intervals were enlarged to such an extent that they might be compared directly with the sferic distributions at corresponding times. Reversals of the radar photographs were made in the enlargements to permit the addition of sferic distribution curves

Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder, 25 May, 1955. Beginning with 2138 Hours.

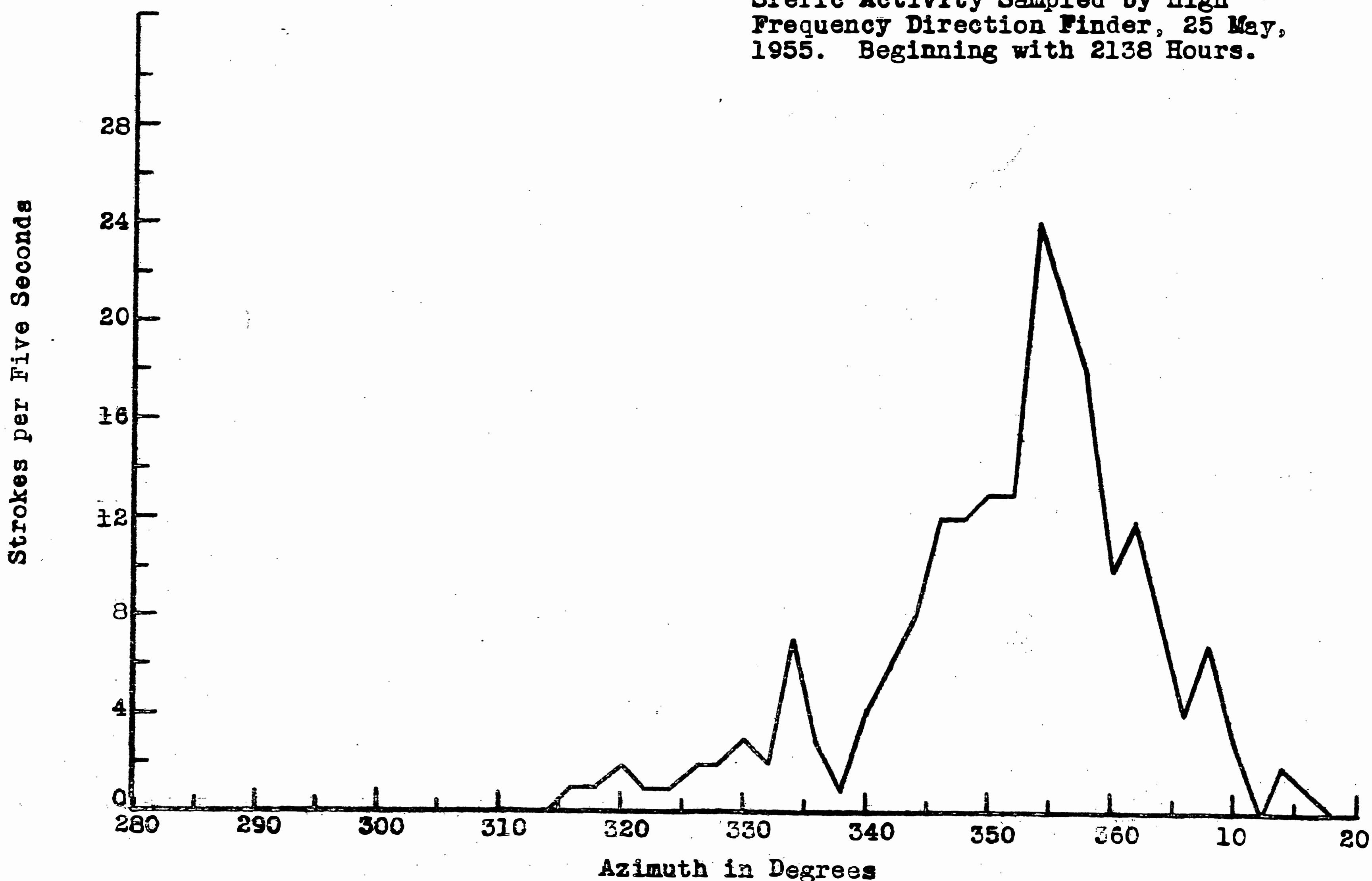


Figure 20

Azimuth Incidence Distribution of Sferic Activity Sampled by High Frequency Direction Finder, 25 May, 1955. Beginning with 2153 Hours.

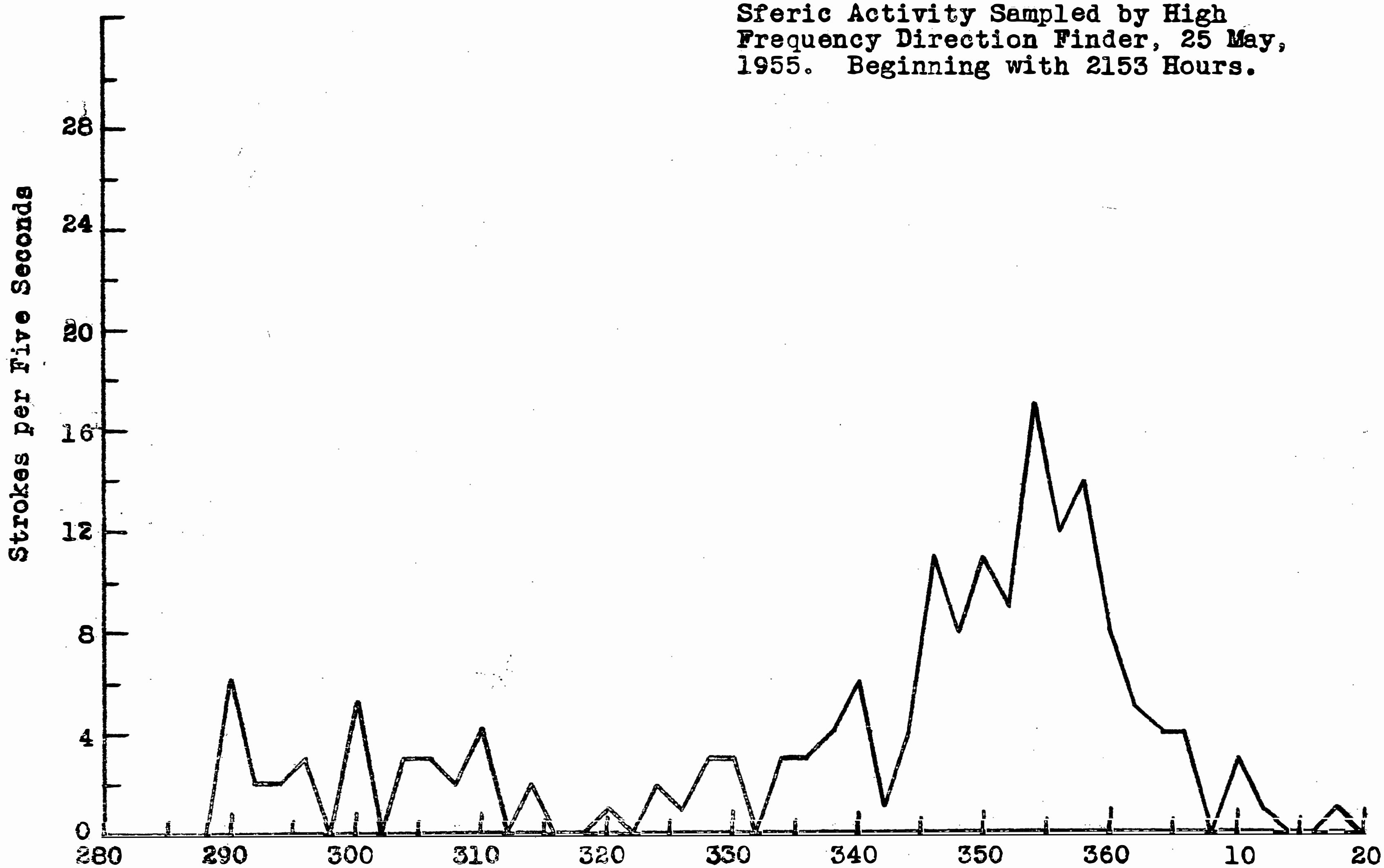


Figure 21

and marginal information. These additions were made in India ink. This method of presentation shows not only the portion of the radar echo that is most active, but also how sferic activity is confined to a given echo within a storm complex that bears surveilance. Correlative photos were made at appropriate time intervals before, during, and after the inception of the Blackwell tornado.

As mentioned previously the large echo situated between 40 and 50 miles northwest of the Tornado Laboratory at 2024 CST was in line with the closer echo that produced the Blackwell tornado. This situation is shown in Figure 22. The peak sferic activity is concentrated along a 334° azimuth and was coincident with the center of both echos. The sector of maximum activity seems to cover the same sector occupied by the larger and more distant echo, whereas the tornado echo covered a much larger sector. It is believed that the sector of maximum activity would have been considerably broader if the tornado echo had been the most active at the time, due to the proximity of this latter storm to the Tornado Laboratory. This partially substantiates the belief already expressed that most of the lightning at that time was emanating from the more distant echo.

In Figure 23 the distant echo has practically dissipated and most of the sferics appear to be originating from the sector encompassing the tornado echo. It was estimated that about this time period, approximately 2053 CST, the tornado came into existence. The azimuth of peak sferic activity is about 340°, with the higher stroke rates occurring at azimuths to the left of the peak. This would indicate that the western portion of the echo was most active. From eye witnesses and damage surveys it was found that the firstevidence of tornado existence was in

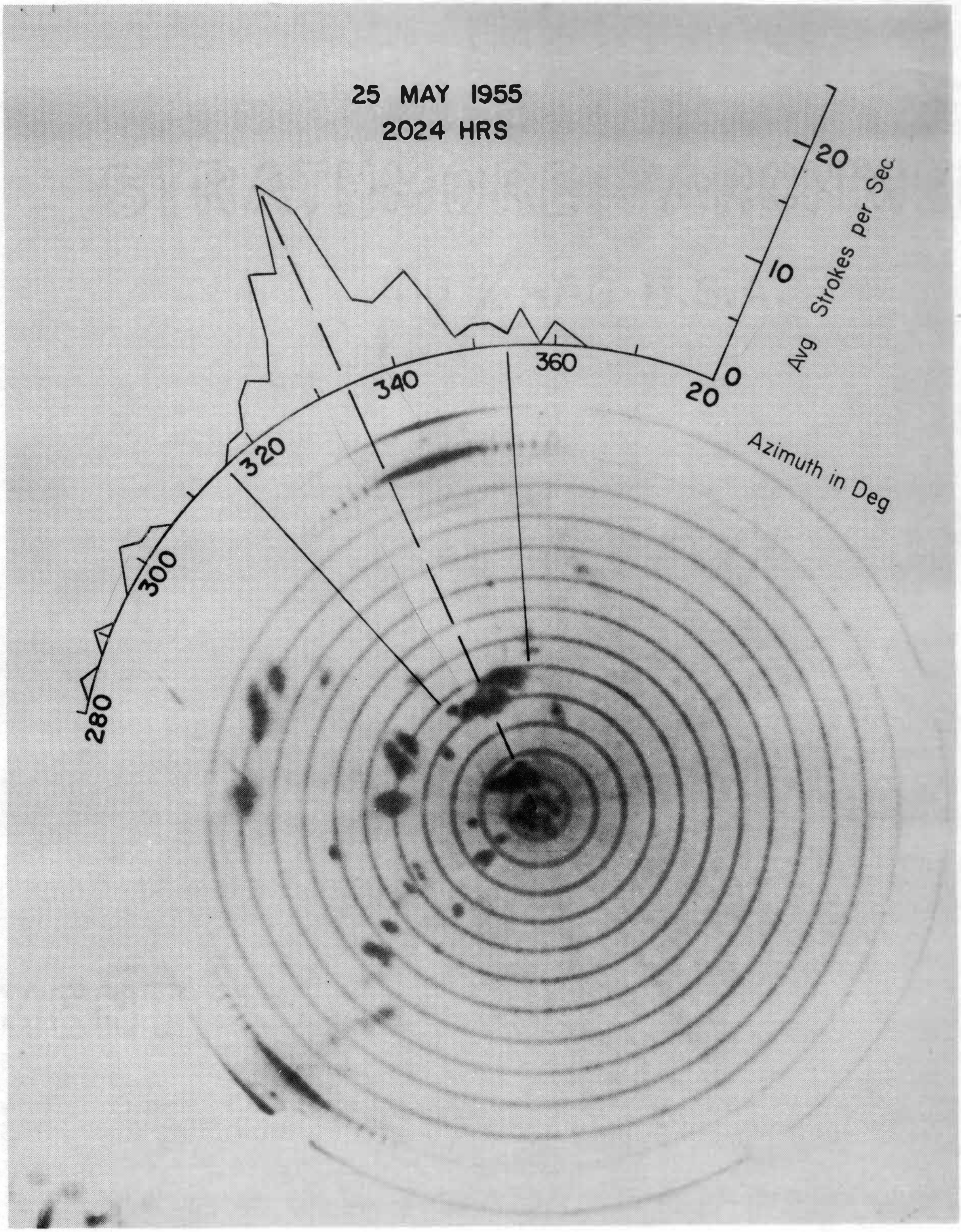


Figure 22. Correlation of Radar Sferic Records, 2024 CST

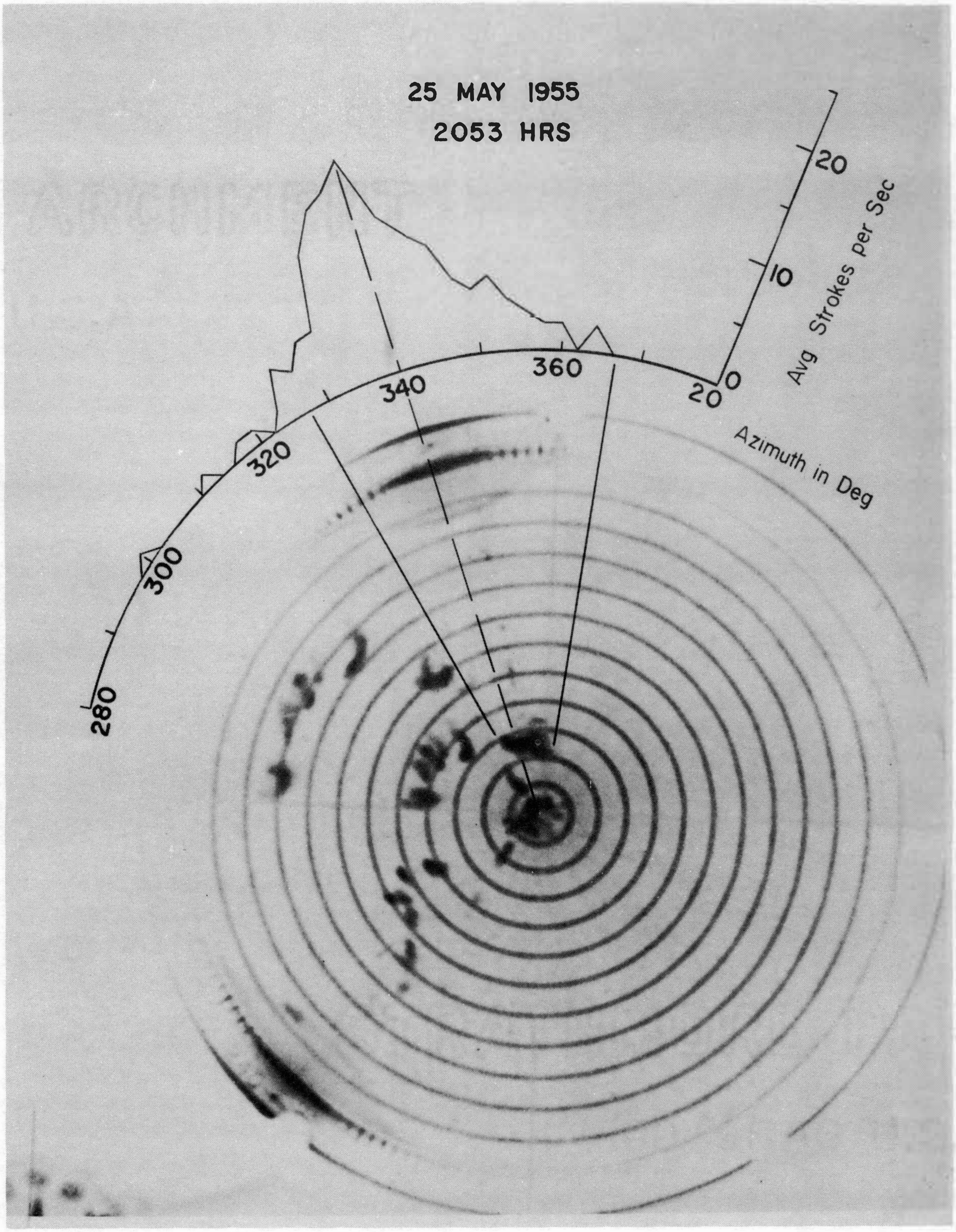


Figure 23. Correlation of Radar Sferic Records, 2053 CST

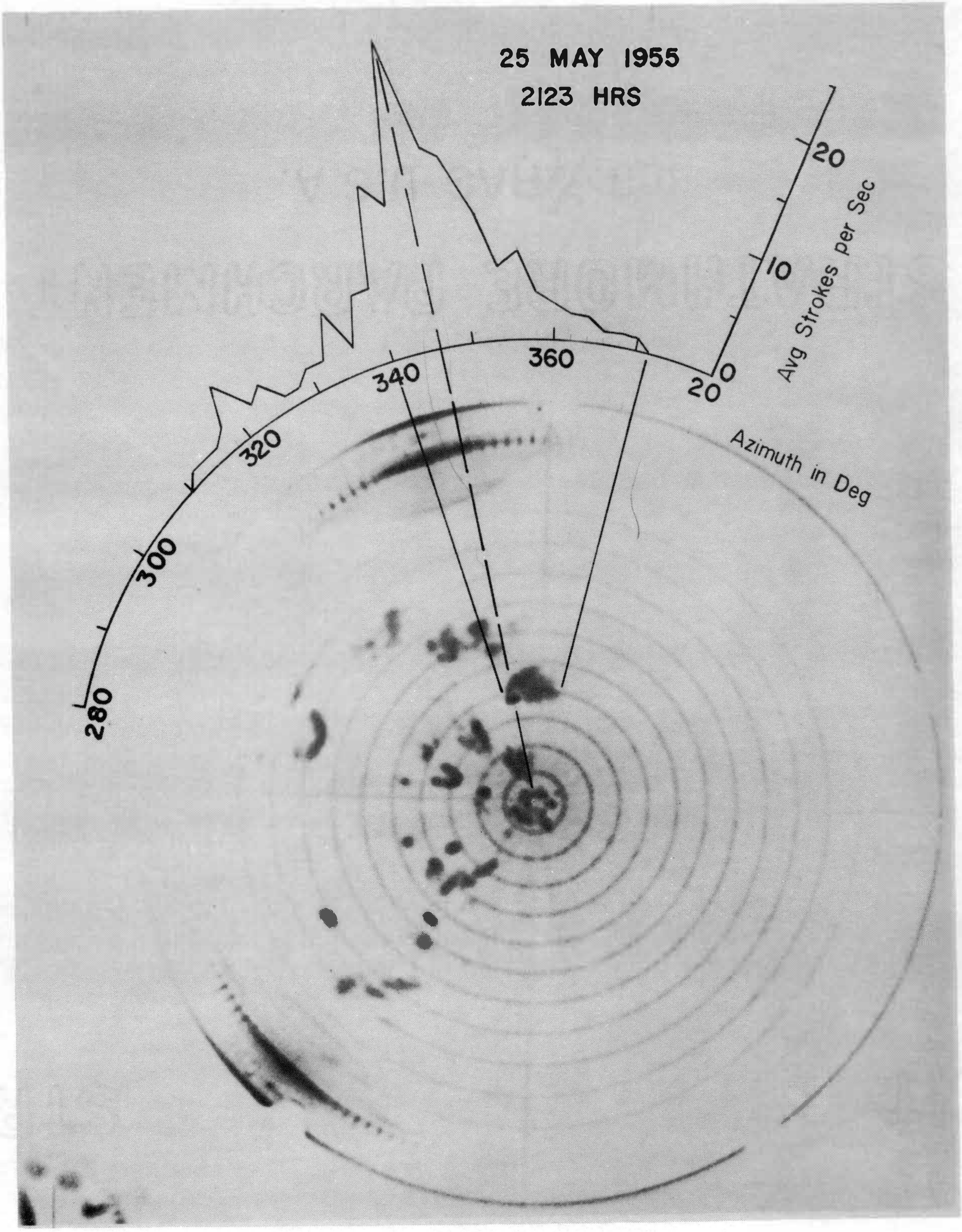


Figure 24. Correlation of Radar Sferic Records, 2123 CST

the area under the western portion of the echo.

The tornado echo is shown with its characteristic hook on the southwestern portion of the echo in Figure 24. At this time the tornado was on the ground, some two to three miles southeast of Blackwell, Oklahoma. Damage surveys indicate the tornado had become most intense near this point. Since the tornado funnel is believed to be within the bulb of the echo protruberance, it is quite interesting to find that not only does the azimuth of peak sferic activity coincide with the center of the bulb, but that the stroke rate has reached a maximum value along this same azimuth. It should also be noted that the sferic distribution curve rises rather sharply at the left of the peak and tapers off more gradually to zero at the extreme right edge of the echo. The relatively low stroke counts appearing between 310° and 340° are believed to be coming from the squall line appearing just northwest of the tornado echo.

CHAPTER V

Summary and Conclusion

In the foregoing analysis an attempt was made to find some characteristics from the radar and sferic records taken on May 25, 1955, that could be used to locate and track a severe storm and to identify the possible existence of a tornado within this same storm. Based on the present day knowledge of the unique features of severe storms and the mechanisms of tornadoes, several pertinent facts were found within the analysed data that would support these proposed theories. Where possible, comparisons of results were made with the findings of other allied research projects in this field of study.

In summarizing, the analysis of results appear to indicate that the radar provided an accurate indication of the size, intensity, speed, and direction of all thunderstorm cells existent in the area under observation. It was found also that in the portion of the radar echo believed to contain the tornado funnel, reflectable material was impelled in such a fashion that it appeared on the radar screen as a counter-clockwise folding hook. One of the criteria being currently used as a verification of tornado occurrence is the evidence of rotation in the resultant damage. This rotational aspect was dynamically demonstrated in the radar photos.

Although these characteristic hooks have appeared on radar scopes in a few other instances where tornadoes have occurred, it would be erroneous to rely on radar as a primary method of tornado identification.

One limitation of radar is that frequently many ordinary precipitation echos take on appearances of hooks or appendages through the random movement of rain particles within a thunderstorm cell. These echos could easily be confused with the echo phenomenon associated with a tornado. In the May 25th storm the hook did not develop until some 15 to 20 minutes after the tornado was on the ground, whereas in other recorded occasions the hook was either concurrent with or before the inception of the tornado. At this time, it is not known positively that a hook or appendage will develop with every tornado, or if there is a relationship between hook development and tornado magnitude.

From the results of the sferic analysis it was found that, within limits of visualevaluation, azimuths of maximum stroke counts were consistent with the movements of the tornadoes when checked against the actual path of travel determined by physical survey. Sectors of maximum sferic activity were confined to the same azimuth boundaries as sectors defined by limits of the tornado echo. Sferic activity in the thunderstorm system that generated the tornadoes apparently increased very rapdily during the 30 minute period prior to the development of the Blackwell tornado, and it reached a maximum count for the entire storm at 2123 CST, when the tornado was believed to be at the highest intensity. While these observations do not necessarily constitute a positive method of tornado identification, they do demonstrate a definite trend toward the identification of the nucleus of a severe storm by the radar-sferic method.

The sferic activity associated with the tornado echo was very high as compared with that from other thunderstorm cells in the area, although it was not appreciably greater than the sferic activity from the large echo in the Blackwell area about one hour before the tornado echo. This echo, shown in Figure 22, between 40 and 50 miles northwest of the Tornado Laboratory, failed to produce any known tornadoes. Although it would only be speculative at this time, there is a reasonable possibility that high sferic activity and possible tornado inception are, to a great extent, a function of local meteorological conditions and that the thunderstorm serves as a triggering mechanism for the generation of the tornado. Many meteorological measurements must be made, with more emphasis on detail, in the vicinity of a tornado area before a definite relationship can be established. These meteorological measurements should be accompanied by sferic recordings taken simultaneously. It is of interest to note that the non-tornado echo moved through the Blackwell area with a velocity of about 18 knots compared to the tornado echo which moved at about 33 knots.

Sferic records employed independently of other storm locating equipment are limited in application because it is difficult to accurately determine the distance to the point of origin. It is when sferic data is correlated with radar presentations that an accurate appraisal of a storm complex is readily obtained. When using radar and sferic data on a practical operating basis, both elements must necessarily provide information which can be quickly evaluated as to storm severity and area of concern. Radar provides a continuous picture of echo positions relative to the radar station; towns or areas of concern may be readily determined by reference to a map. Sferics, on the other hand, must be evaluated with regard to azimuth and number per unit time. This aspect of counting of impulses per unit time requires some form of integration if the various azimuth intensities are to be determined. The counting of sferics from film records, as set forth in the foregoing analysis, is rather cumbersome when used on a practical operating basis. The solution to the problem of quickly and efficiently obtaining the necessary integration, was realized by the installation of an electronic counter which automatically performed the integration of the impulses.

A Sferics Incidence Azimuth Integrator was designed and built by personnel on the Tornado Research staff to meet this need. This integrator is similar to the one previously described in Chapter II except that the cathode ray tube is scanned through a specially designed optical system rather than the direct transmission of light to the photo tube as was the case for the earlier model. The complete 360° range of azimuth is sampled every six minutes to provide a curve of sferic intensity versus azimuth as shown in Figure 25. This record shown was made made on June 17, 1955. It was the first of its kind because it was actually obtained during a test run on the new device. Since the instrument was not calibrated at that time, the recordings of the number of strokes per second are, from a quantitative view point, only relative. The azimuth of peak sferic activity was indicated as approximately 300°. This azimuth is coincident with the recorded radar echo obtained at the same time. The radar recording is shown in Figure 26. It is significant that a tornado was reported at the location and time of the recorded data. This tornado was not officially confirmed. Figure 27 is a photograph of the sferic record that demonstrates the predominance of directional pips in the vicinity of the 300° azimuth.

Several improved techniques in instrumentation have been planned, and are now being developed for the approaching tornado season of 1956.

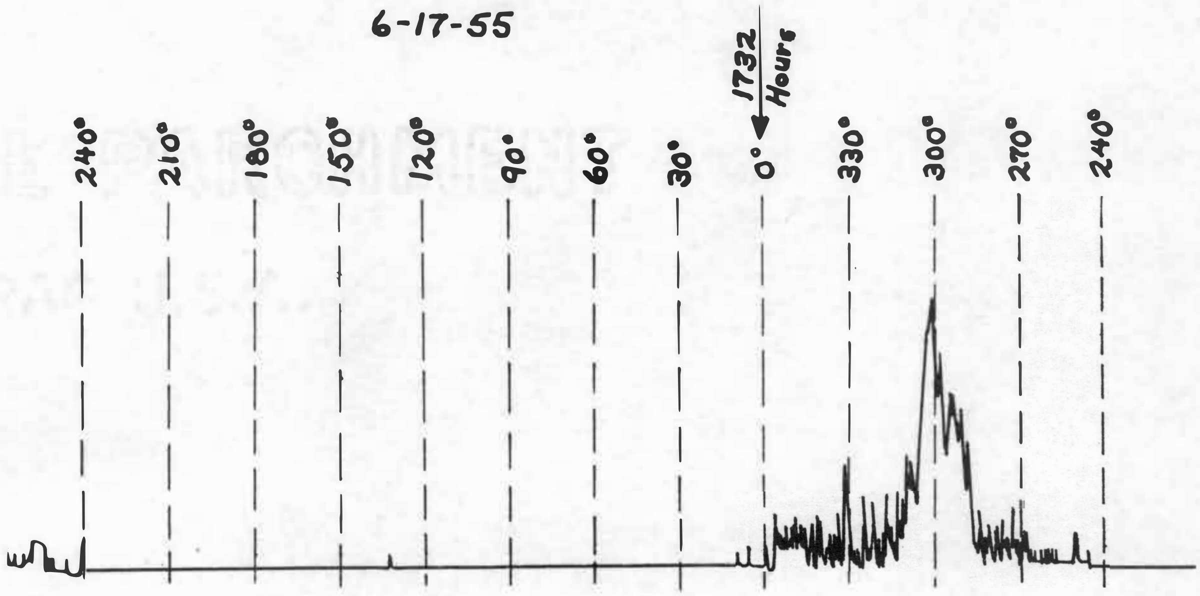


Figure 25. Record from Sferic Incidence Azimuth Integrator, Time, 1732 CST, 6-17-55

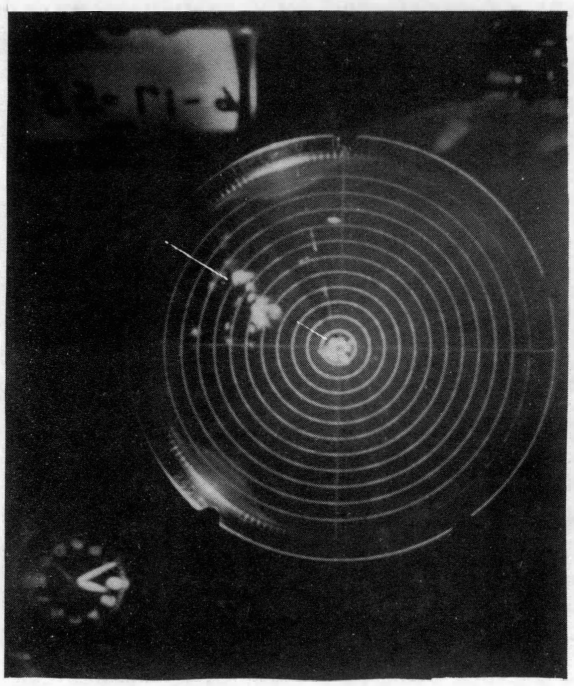


Figure 26. Radar Record 1735 CST, 6-17-55

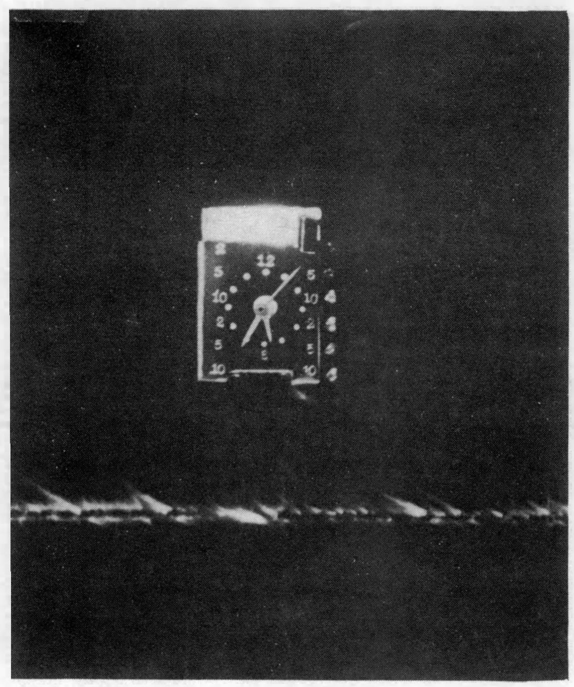


Figure 27. Sferic Record 1735 CST, 6-17-55

In addition to continued testing of the new electronic stroke counter previously described, several improvements in the photographic technique for directional pips are being accomplished. Of primary importance are the installation of a variable-speed film-transport mechanism designed for higher available speeds, together with a circuit designed to rotate the axis of the cathode ray tube in order to permit resolution of directional pips from the east-west directions comparable to that for the north-south directions. These new equipments will materially increase both the quantity and operation application of useable data for the tornado season of 1956.

BIBLIOGRAPHY

Adcock, F., and C. Clarke, "The Location of Thunderstorms by Radio Direction Finding", Institute of Electrical Engineers, Journal, Vol. 94, Pt. III, March 1947, pp. 118-125.

Appleton, E.N., and F. W. Chapman, "On the Nature of Atmospherics IV", Royal Society of London, Proceedings, Vol. 158, January 1937, pp. 1-22.

Fawbush, Major E. J., Captain R. C. Miller, and Captain L. G. Starrett, "An Empirical Method of Forecasting Tornado Development", Bulletin of the American Meteorological Society, January, 1951, pp. 1-9.

Hess, Phillip N., "Installation and Operation of Electronic Sferic Detection Equipment", unpub. Master's Thesis, Oklahoma A&M College, 1950, p. 50-52.

Jones, Herbert L., "A Sferic Method of Tornado Tracking and Identification," Oklahoma Engineering Experiment Station Publication, No. 82, January, 1952, p. 3.

"Panel Discussion of Tornado Problems", Stenographic Report, U. S. Department of Commerce, Weather Bureau, (Washington, D. C.) February, 1955, p.5.

Penn, S.,C, Pierce, and J. K. McGuire, "The Squall Line and Massachusetts Tornadoes of June 9, 1953", Bulletin of the American Meteorological Society, March, 1955, pp. 116-122.

"Research on Tornado Identification", First Quarterly Progress Report, Signal Corps Research Project No. 172B-0, 1952, pp. 6-8.

"Research on Tornado Identification", Eighth Quarterly Progress Report, Signal Corps Research Project No. 172B-0, 1953, pp. 26-31.

"Research on Tornado Identification", Eleventh Quarterly Progress Report, Signal Corps Research Project No. 172B-0, 1954, pp. 4-14.

"Research on Tornado Identification",Second Quarterly Progress Report, Signal Corps Research Project No. 172B, 1955

"Research on Tornado Identification", Third Quarterly Progress Report, Signal Corps Research Project No. 172B, 1955.

Schonland, B. F. J., "Thunderstorms and Their Electrical Effects," Physical Society of London, Proceedings, Vol. 55, Pt. 6, 1943, pp. 445-458.

Staats, Wayne F., and Charles M. Turrentine, "Some Observations and Radar Pictures of the Blackwell and Udall Tornadoes of May 25, 1955", Bulletin of the American Meteorological Society, 1956, Scheduled for Publication.

Stout, G. E., and F. A. Huff, "Radar Records Illinois Tornadogenesis", Bulletin of the American Meteorological Society, June, 1953, pp. 281-284.

Wormel, T. W., "Lightning", Royal Meteorological Society, Quarterly Journal, Vol. 79, 1953.

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TYPIST PAGE

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