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ILLINOIS STATE WATER SURVEY

METEOROLOGY LABORATORY

at the

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CLOUD ELECTRIFICATION STUDIES IN ILLINOIS

by

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ABSTRACT

The purpose of this research was:

1. To introduce low density space charge into the atmosphere.

2. To observe the effects of low density space charge on the fair-weather electric field.

3. To observe the effects of low density space charge on small cumulus clouds which develop or advect over the space charge source.

A description is given of the field installation used for introducing low-density space charge into the atmosphere and of the instrumentation used for detecting its distribution. The operational period for the space charge source during the summers of 1961 and 1962 totaled five months.

Two aircraft were instrumented to measure space charge and potential gradient. An atmospheric electricity observatory was installed 30 kilometers east of the experimental site to record the background values for comparative purposes. Space charge, potential gradient, both polar conductivities, and standard meteorological data were recorded continuously at this observatory.

This report discusses three selected cases of measurements made with the two aircraft near the space charge source and in the vicinity" of clouds. Further detailed analyses of the remaining data on file depends on the availability of additional funds.

The findings, although tentative and based on the analysis of three flights and a preliminary examination of data from 160 flights, are:

1. The electrical characteristics of some small cumuli can be altered by a ground space charge source.

2. The ratio of charged clouds to uncharged clouds over the wire network was extremely small.

3. On occasion small cumuli exhibit a natural charge accumulation equal to that acquired from the artificial ground source.

4. The space charge concentrations observed aloft over the seven-wire complex did not appear to be much different than the concentrations from the single wire operation of 1960.

CLOUD ELECTRIFICATION STUDIES IN ILLINOIS

1.0 INTRODUCTION

During the summer of 1960, a meteorological research project was initiated in central Illinois under the direction of Dr. B. Vonnegut and Mr. C. B. Moore of Arthur D. Little, Inc., Cambridge, Massachusetts. The purpose of this project was to examine the influence of space charge from a ground-based source on growing convective clouds. The current investigation under the direction of the authors of this report constituted a continuation of this work in the summer seasons of 1961 and" 1962 to obtain additional detailed studies of the charging of cumulus clouds.

According to Grenet(1) and Vonnegut(2) , the fair-weather space charge, residing on nuclei in the lower atmosphere, is swept into clouds by convective motions. Vonnegut hypothesized that the convective motions associated with a developing cloud act as a generator for electrification processes. An important requirement of the Vonnegut hypothesis involves the attraction of free ions from the atmosphere to the top and side surfaces of a cloud mass. These charges are then assumed to be transported to the base of the cloud, inducing additional positive space charge to arise in the convective motions associated with the cloud. By releasing space charge from a ground source in concentrations exceeding the normal fair-weather value, it is possible to study the dynamics of convection by tracing the movement of the charge.

To evaluate the effects of the artificially-produced space charge on the atmosphere and on the clouds contained therein, it is necessary to study the natural variability of the fair-weather space charge as it exists near the experimental test site. Many observations of the fair-weather space charge and potential gradient were obtained to enable measurement of the differences between the fair-weather conditions and those conditions produced by the artificial charge source.

Observations of the distribution of space charge were obtained on the ground and from two aircraft. On all days of possible data collection the synoptic weather situation was monitored closely so that flights could be initiated Immediately upon the formation of convective clouds. Some attempts were made to fly one aircraft below and one aircraft above developing clouds to determine the rate of electrification.

2.0 FIELD INSTALLATIONS

The source of space charge for the experiment consisted of a total of 45 kilometers of stainless steel wire 0.38 millimeters in diameter installed 10 meters above the surface and operated at voltages sufficiently high to allow corona discharge to occur. The operation of such a wire as a space charge source has been discussed in detail by Vonnegut, et al.(3).

The installations consisted of seven separate sections of varying length totaling 45 kilometers. The wire locations are shown in Figure 1. While it would have been desirable to have the wires located in a more symmetric, uniform pattern; for safety and because of the location of existing power and telephone lines this was impossible.

The high voltage power supplies used were capable of three milliamperes output at 50 kilovolts. One power supply was located in a small house rented for a field laboratory and the other six were installed in instrument shelters erected along county roads. If any individual wire drew an excessive amount of current, an automatic cutoff was provided to turn off the power supply.

A standard instrument shelter with a hygrothermograph and barograph was located at the field lab (Fig. 1) along with instrumentation to record the wind speed and direction. Photographs from an "all-sky" time-lapse camera provided a record of the cloud types and the direction of cloud movement. Pilot balloons (PIBAL) were released on many of the operational days to determine the vertical profile of wind speed and direction. An observer in the test area made cloud observations three times daily at approximately 0800 CST, 1200 CST, and 1600 CST.

Radar surveillance of the experimental area was accomplished with a CPS-9 and a TPS-10, each equipped with a 35-mm camera. These are located at the radar station shown on Figure 1. The CPS-9 radar with PPI presentation was programmed to scan automatically 360 degrees in azimuth for each 1-degree antenna tilt from 0 to 11 degrees of elevation. During some situations, relative intensity measurements were also made. The TPS-10 radar with an RHI presentation generally scanned a 140-degree sector centered on the experimental area.

3.0 INSTRUMENTATION

3.1 General

At the outset of the program, it was realized that to satisfy the primary conditions of the proposed research, the instruments

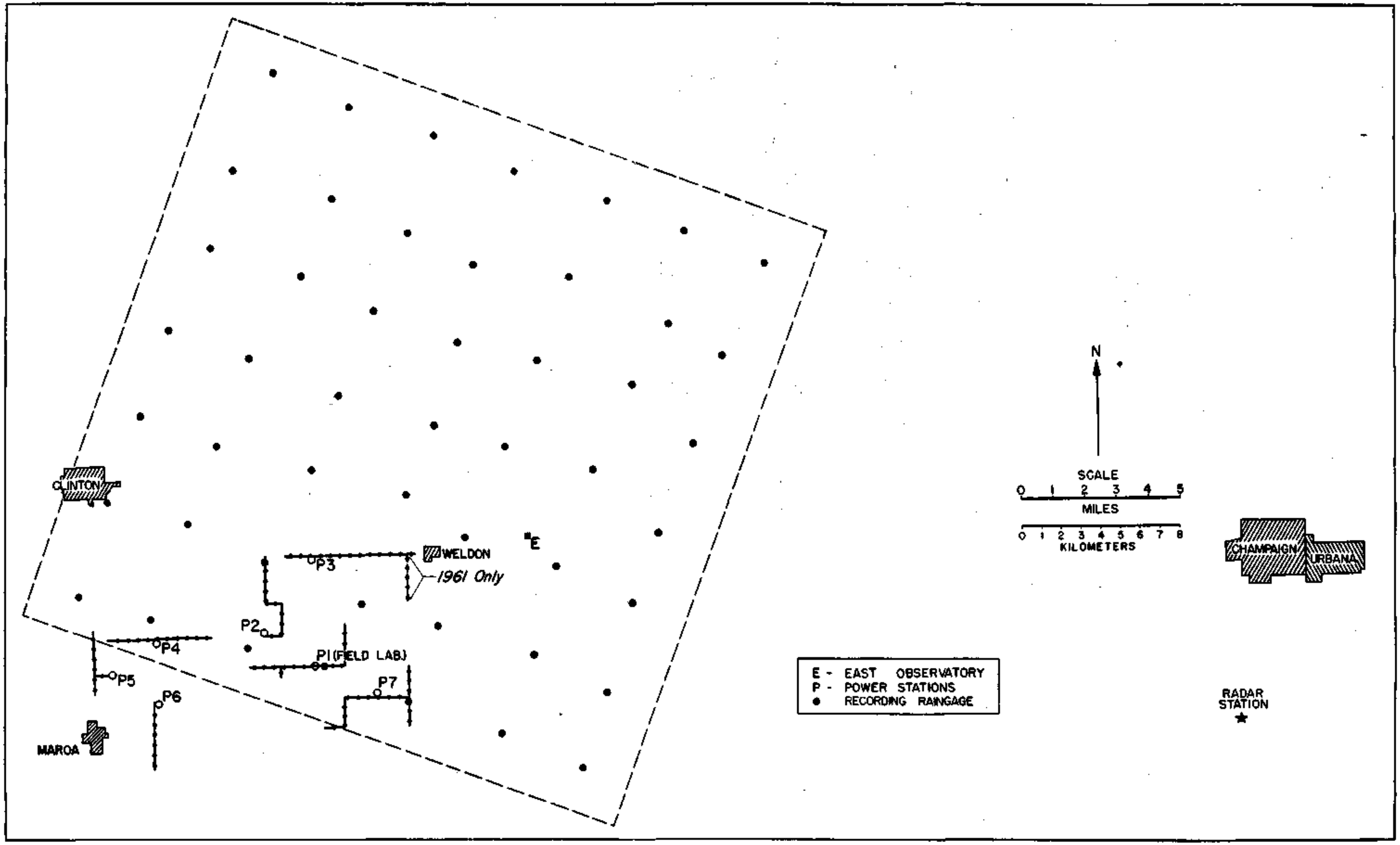


FIG.1 LOCATION OF ENERGIZED WIRE. RADAR, RAINGAGES AND OTHER INSTALLATIONS, 1961 - 1962

would be required to measure only non-thunderstorm magnitudes of space charge and electric field. Space charge and potential gradient were the primary measurements to be made aloft and on the ground. Certain additional instruments were deemed desirable for the aircraft to determine the thermodynamic environment of the atmosphere and the aircraft performance.

The aircraft instruments used in the C-45 and Piper Tri-Pacer and those used on the ground are described in the following sections. Since some of these instruments evolved during the course of the project, some could not be used to any great extent. However, this discussion describes the instruments presently available on the aircraft, and on the ground for use in future atmospheric electricity research.

3.2 C-45 aircraft instruments

Recorder - All airborne measurements in the C-45. shown in Figure 2, are recorded on a 24 channel oscillograph. This recorder, a Minneapolis-Honeywell Model 1108, uses light sensitive paper and light-beam galvonometers. Not only the variables discussed but also the scale on which the instruments are operating is recorded. A block diagram of the C-45 instrumentation is shown in Figure 3. The following is a list of the galvonometer numbers and their use:

1. Disdrometer (x 1 attenuation)
2. Disdrometer (x 4. attenuation)
3. Altitude
4. Air Speed
5. Temperature
6. Relative Humidity Factor
7. Roll
8. Pitch
9. Heading
10. Events
11. + and - conductivity
12. Conductivity scale
13. Vertical Potential Gradient Scale
14. Vertical Potential Gradient
15. Horizontal Potential Gradient Scale
16. Horizontal Potential Gradient
17. Wet Space Charge Scale
18. Net Space Charge

Potential Gradient - The horizontal and vertical components of the potential gradient in the atmosphere are sensed by the airplane instrumentation. The method used for measuring the potential gradient was reported by Vonnegut, et al.(4). The sensing probes consist of two radioactive sources mounted by means of teflon

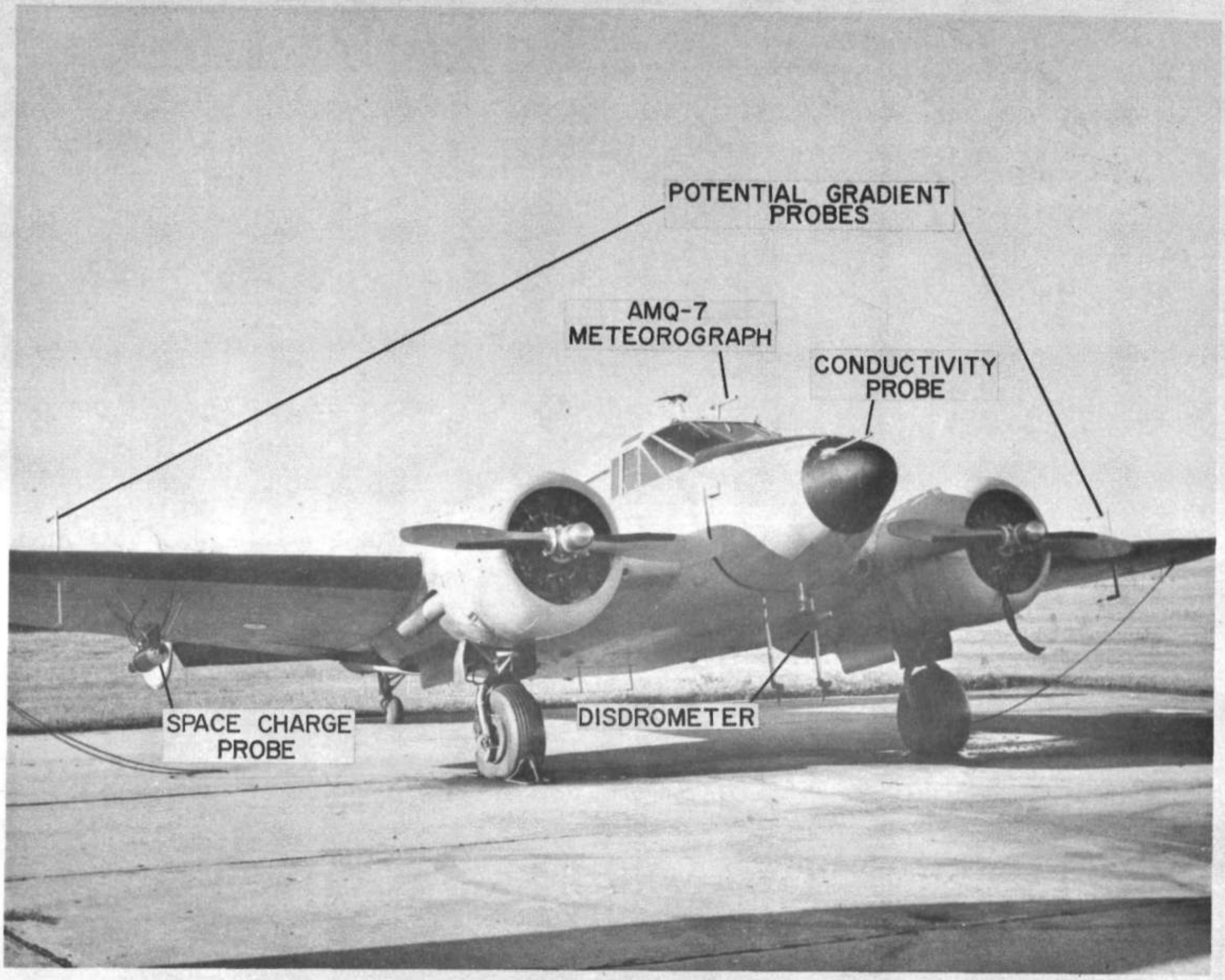


FIG. 2 C-45 AIRCRAFT USED FOR ATMOSPHERIC ELECTRICITY MEASUREMENTS

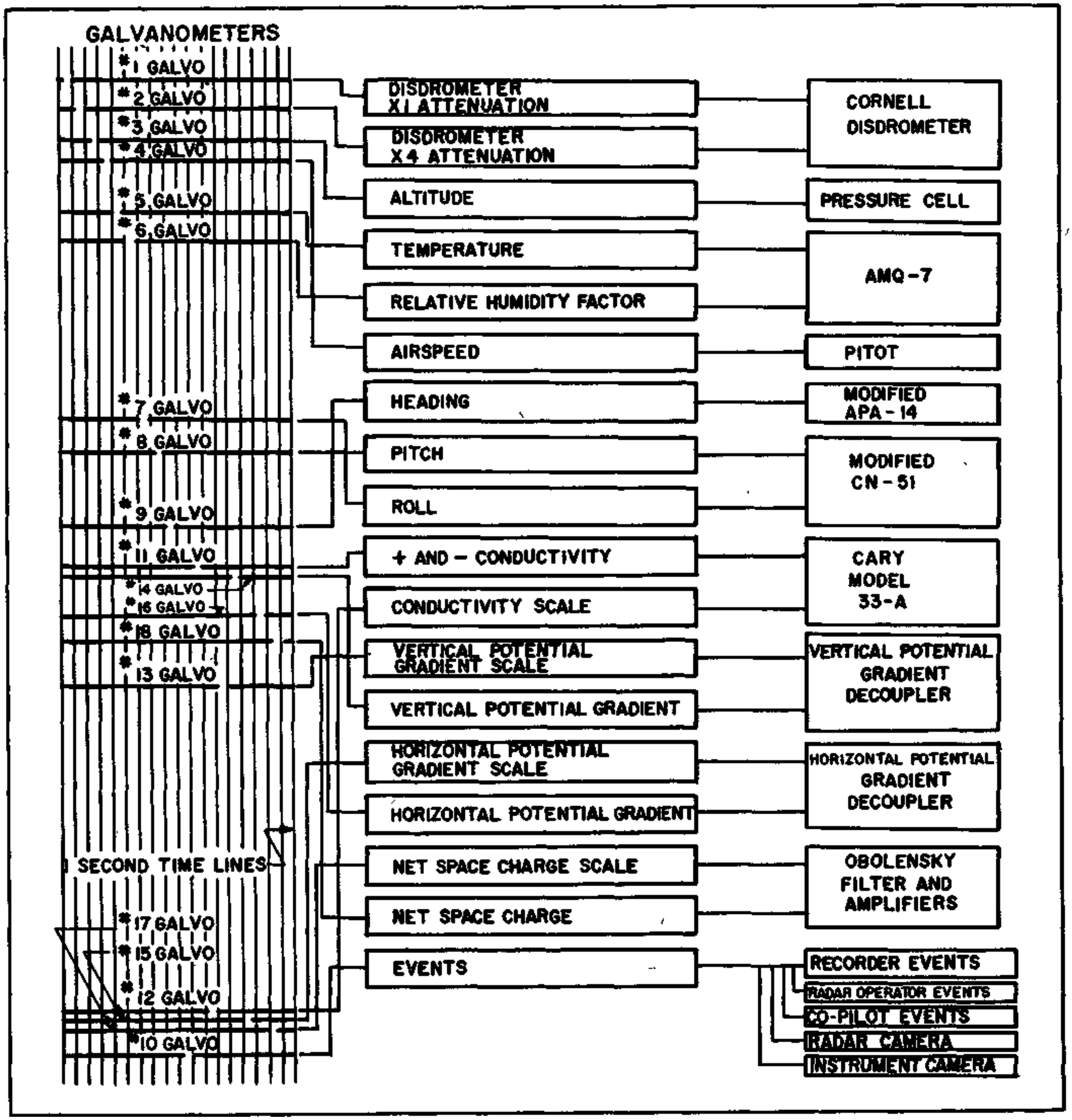


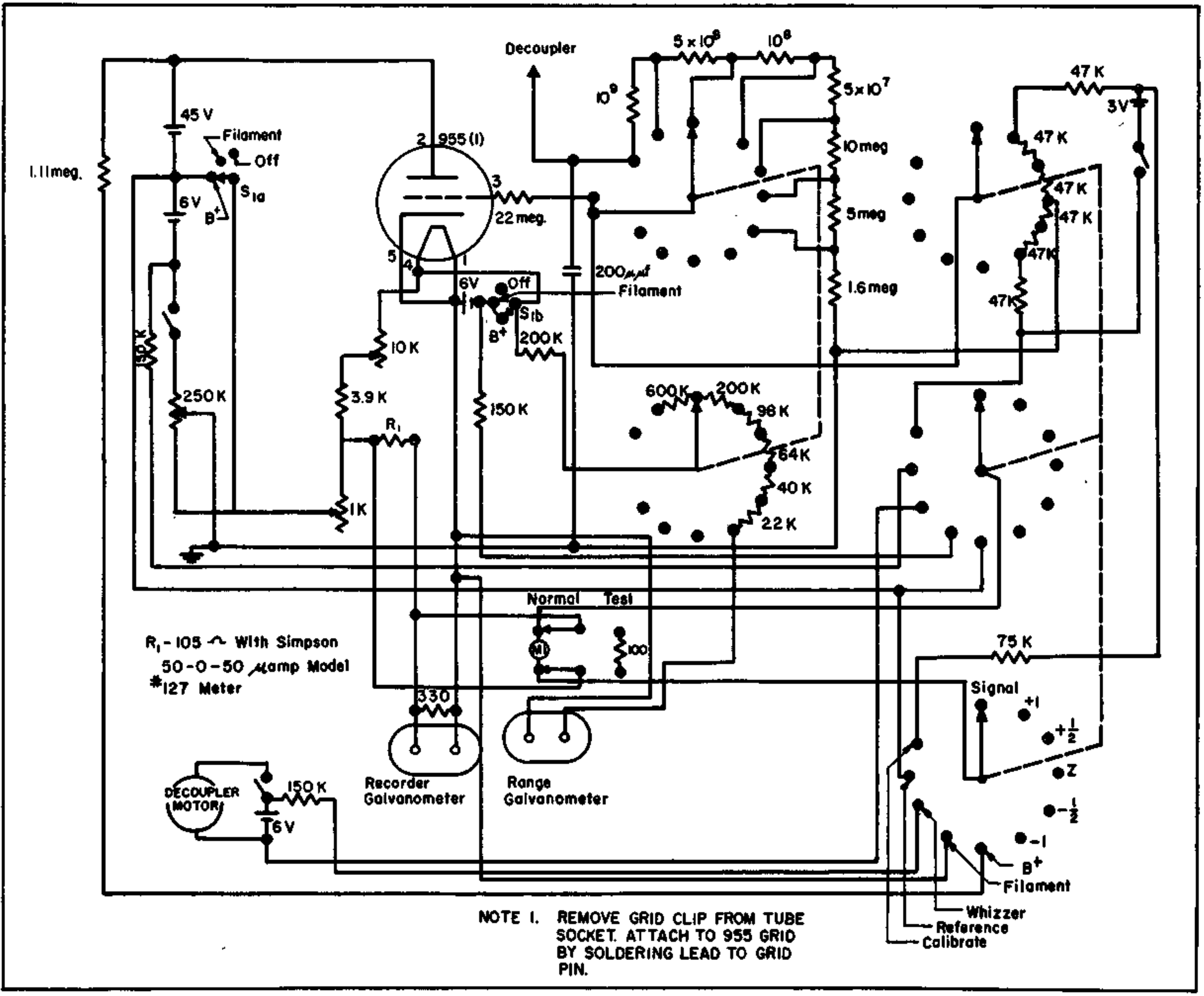
FIG.3 BLOCK DIAGRAM OF C-45 AIRCRAFT INSTRUMENTATION.

insulation from struts above and beneath the wing as shown in Figure 2. The leads from these probes are connected to a potential-to-current transducer (hereafter referred to as a "whizzer"). The current from the whizzer is then amplified by a single tube electrometer and is used to provide a signal for a visual meter and one of the recording galvonometers in a recording oscillograph. A schematic of the potential gradient electrometer is presented in Figure 4. The whizzer permits adjustment of the relative coupling of the individual probe inputs so that the current response is directly proportional to that part of the individual probe potentials which are a direct result of the potential gradient. In this way potentials on the probes which are due to aircraft charging can be effectively reduced if not completely eliminated.

The operation of the whizzer has been reported in detail by Vonnegut, et al.(4). It consists of a rotating blade which can be considered one plate of a rotating condenser. The input leads are terminated on plates which alternately serve as the second plate of the condenser and a reference plate. A brush is used to commutate the rotating plate between ground and the input to the electrometer. If it is considered that the rotating plate is grounded when under input plate 1, the charge on the rotating plate becomes proportional to the capacity between the plates and the potential difference between probe 1 and the aircraft. The commutated ground is then removed and the rotating plate is moved under input plate 2 with the output connected to the electrometer. The charge which the rotating plate now assumes is proportional to the capacity to plate 2 and to the potential difference between plate 2 and aircraft ground. The current which is sensed by the electrometer is now equal to the difference in charges and the rate at which the blade is rotating. By adjusting the spacing between plates, the individual capacities can be varied so that with proper adjustment the potential differences between the individual probes resulting from aircraft charge can be cancelled.

The procedure adopted for adjusting these capacities is to fly the airplane as high as possible so that the natural electric field is small and constant. By means of a high voltage power supply and a trailing wire, the aircraft can be charged rapidly with either sign of charge. The plates of the condensers are then adjusted so that the charging produces no signal from the whizzer. A somewhat less sensitive but convenient method consists of changing the fuel richness of the aircraft engines which alters the magnitude of the aircraft charge. The plates can then be balanced for no signal.

The calibration of the overall system is accomplished by simultaneously measuring the potential gradient at the earth's surface by conventional means and measuring the potential gradient



R1 - 105 Ω With Simpson 50-0-50 μamp Model #127 Meter

NOTE 1. REMOVE GRID CLIP FROM TUBE SOCKET. ATTACH TO 955 GRID BY SOLDERING LEAD TO GRID PIN.

FIG.4 SCHEMATIC OF THE POTENTIAL GRADIENT ELECTROMETER.

from the airplane as passes at 20 to 25 meters altitude are made over the ground station. The results of these calibrations yielded a form factor of 1.6 for the vertical potential gradient.

Routine calibrations of the electrometer and whizzer were performed before or after each flight. These were accomplished by-connecting known voltages to the inputs of the whizzer. Also, the resistance of the insulators was checked frequently.

The horizontal potential gradient was measured in the same way by means of probes extending outward from the wing tips. The horizontal gradients were assumed to be small and a large separation of the probes was deemed necessary. After testing, it soon became evident that the wing tips were an extremely poor location for the horizontal probes. The horizontal fields in the vicinity of active electrified clouds produced extreme potential differences, which in turn produced arcing and point discharge in the whizzer. These effects produced a very erratic output and destroyed the high impedance necessary for the electrometer.

The second disadvantage of the tip location was the uncertainty of the potential to which the probes attain. In the vicinity of the wing tips of the airplane the equipotential lines in a lateral electrical field become very concentrated with large curvature. There is also a good possibility that there may be space charge generated by these fields at the tips of the wings due to point discharge when flying in the vicinity of highly electrified clouds. Because of these two disadvantages, the horizontal gradient was not measured very satisfactorily in 1961-62.

To eliminate these difficulties in 1963, a second pair of probes of the same configuration as those used for the vertical component were mounted on the right wing of the aircraft. By modifying the whizzer to a 4-plate input, the two left probes can be added together and the difference between this potential and the sum of the potentials from the two right-hand probes determines the horizontal gradient. The horizontal whizzer is balanced for aircraft charging in the same manner as the vertical. The form factor is obtained by flying in a steady non-perturbed field and banking the aircraft to 45° and comparing the vertical and horizontal measurements.

Eight sensitivity ranges were available in the electrometer. Of these ranges only the middle five were found useful. The two lowest sensitivity ranges could not be used because the potentials required as input was so large that arcing occurred in the whizzers. This has been noted on several occasions in the vicinity of thunderstorms. Full-scale sensitivities of the useful ranges were about 0.5, 1.5, 4.5, 40 and 80 volts per centimeter.

Space Charge - The aircraft was instrumented to measure net space charge by means of an absolute filter enclosed within a shielded Faraday cage. This arrangement was reported by Moore, et al.(5). The entire assembly including the electronics was mounted beneath the right wing of the C-45 (Fig. 2).

The absolute filter removes nearly all of the particulates in the air greater than one micron in radius. If it is assumed that fast ions of smaller size are rapidly attached to large relatively immobile particulates, they will be captured in the filter as the air passes through and thus nearly all of the charged particles are caught. The filter was enclosed within a Faraday cage which in turn was shielded from electric field variations by an outer grounded cage consisting" of a solid aluminum tube. The current flow from the inner cage to the ground is equal to the rate of charge capture by the filter providing the potential of the cage is maintained at a small level.

During 196l the space charge electrometer was located inside the aircraft fuselage. This required an entrance cable which had to have a very small leakage current. This arrangement proved unsatisfactory as the cable was noisy and also was affected by temperature. Therefore, an electrometer was designed, built, and placed within the outer shell of the filter assembly for the 1962 operations. This electrometer was similar to one reported by Vanderschmidt(6). It consisted of balanced 5886 electrometer tubes feeding the differential input of a Burr-Brown Type 1303 operational amplifier. All of the voltage output of the operational amplifier was fed back to the input resistor of the electrometer tube. This not only insured relatively drift free operation but also reduced the time of response of the instrument. Using feedback in this manner maintains the potential of the inner Faraday cage very close to ground potential. The electrometer used an input resistor of 10^{11} ohms. The time response of the instrument is estimated to be on the order of 0.2 seconds. A schematic of the circuitry is shown in Figure 5.

In order to deduce the space charge concentration, the rate of airflow through the filter must be known. One of the filter assemblies was mounted in a wind tunnel' and pressure taps were installed in the instrument opening. The airflow was then deduced from the pressure measurements and the diameter of the assembly at the pressure point. The wind tunnel is only capable of air velocities to 50 meters per second at which a flow of 27 liters per second was obtained. Most flights were made in this range of velocities.

The smallest useful measurement increment for space charge amounts to a current of about 10-14 amperes and at 50 meters per

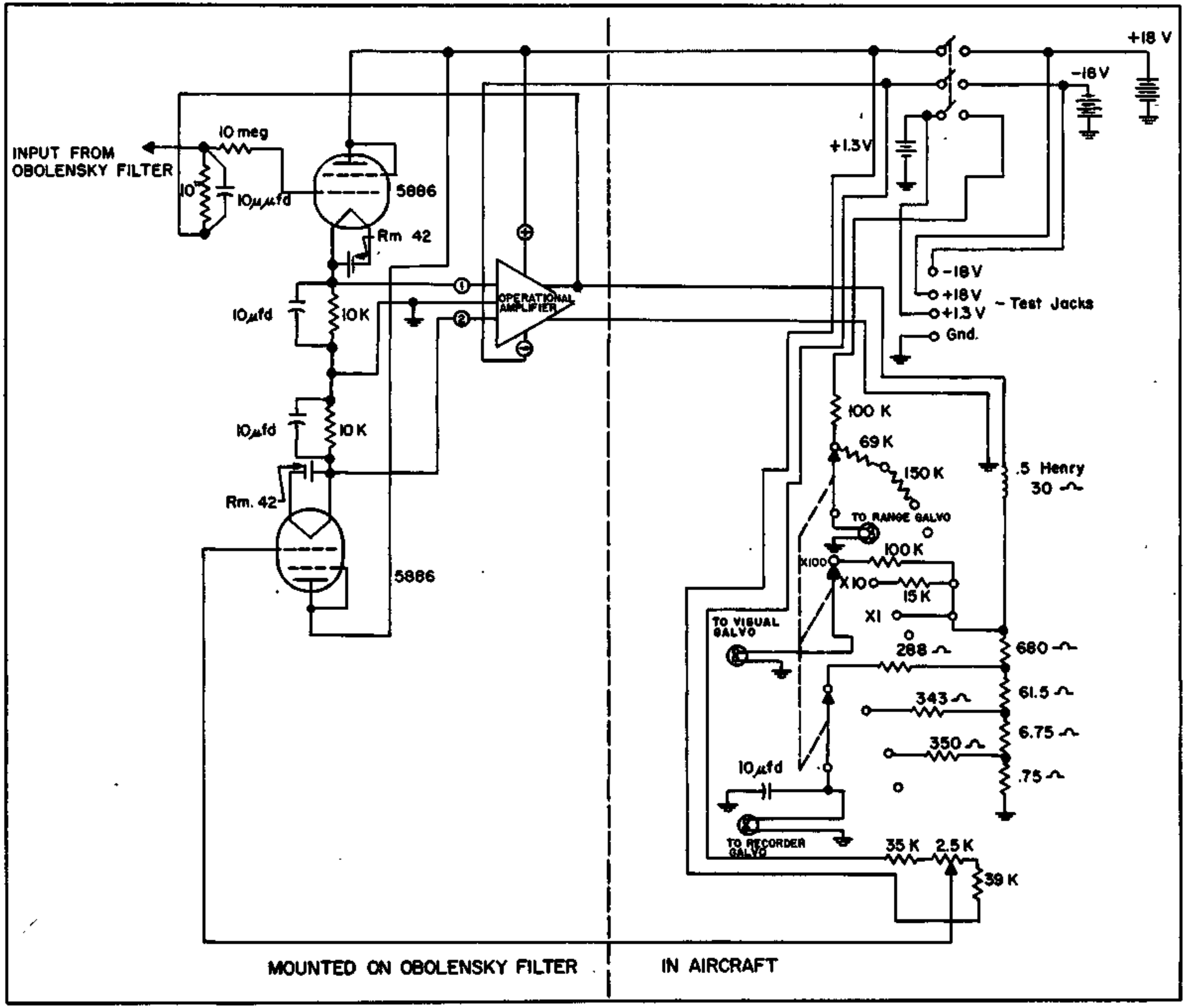


FIG.5 SCHEMATIC OF NET SPACE CHARGE INSTRUMENTATION

second this is equal to a space charge of 2.3 electrons/cm3. Three sensitivity scales were available. The most sensitive scale was not used because of aircraft noise (mechanical and probably electrical), but operated properly in the laboratory. The middle scale was used for nearly all measurements and had a sensitivity of 30 electrons/cm3/cm on the recorder chart.

Forward Scattering Optical Disdrometer - This instrument uses the magnitude of forward scattering at 28° from the direction of illumination as a measure of the size of individual water droplets passing through its sampling field. The sampling field is optically delineated and does not suffer from extreme edge effects that are present in mechanical collectors. It was located beneath the nose of the C-45 fuselage as seen in Figure 2.

To satisfy the requirement of mechanical rigidity and minimum aerodynamic influences on the sample, the sensing unit was mounted in a cone-capped cylinder. A portion of the cloud being studied passes through a cylindrical tube and is sampled along the axis of the tube. Because of its central location and small size, in relation to the passage diameter, the sampling region is free of artificial changes in cloud concentration due to aerodynamic effects.

The optical system that collects the light scattered from the droplet projects the light through a variable-density attenuator disc onto the photocathode of a photomultiplier tube. Rotation of the variable-density disc produces an attenuation that varies cyclically from maximum to minimum during the two-second scan cycle of the system. Thus, during the cycle the size of a droplet which will produce a given amplitude light (or electrical) pulse varies in a similar cyclical fashion. A discriminator passes those photomultiplier output pulses which exceed a predetermined threshold, and a counting-rate meter produces a d-c output proportional to the rate of arrival of pulses which exceed the threshold. Because the scattered light amplitude needed to produce a super-threshold pulse is altered by the variable attenuator disc, the size of those droplets which produce super-threshold signals will vary with the scan cycle. Using a simple single-level discriminator, at any given moment the instrument will count droplets larger than a particular threshold size and, thus, with the scan produce a cumulative distribution. The signal from the counting-rate meter is then amplified and recorded on the oscillograph.

Because the brightness of the arc lamp that furnishes illumination may drift (even though current regulation is provided), an internal," standard calibration signal was included. The method involves taking light from the direct beam of illumination and chopping it to produce a standard signal equivalent to that from a droplet eight microns in radius. The instrument may be standardized in flight to check its sensitivity immediately before taking a spectrum.

A cycle of the attenuator disc requires 2 seconds to complete); therefore, the assumption must be made that the cloud droplet distribution is homogeneous over this distance (about 120 meters). The disdrometer is capable of measurement of droplet sizes from approximately 3 microns to 90 microns in radius. However, no absolute calibration was made during this research and the distributions obtained are presented as relative numbers. A sample of data obtained in stratocumulus with this instrument is shown in Figure 6.

Temperature and Humidity - The temperature and humidity were measured with an AMQ-7 mounted on top of the C-45 cockpit (Fig. 2). This equipment is a two-channel, remote-indicating measuring set which includes a probe, three amplifiers that can be used interchangeably - two in use and one spare, one temperature indicator, and one humidity indicator. The probe is mounted to the outside of the aircraft and is interconnected electrically to the amplifiers and indicators located within the aircraft. The probe contains elements that continuously sense the temperature and humidity conditions of the atmosphere. The temperature indicator presents a continuous dial reading of temperature in degrees centigrade while the humidity indicator presents a continuous dial reading of humidity conditions in terms of a relative humidity factor. A potentiometer was mounted on the humidity and temperature dial to allow recording of the information on the oscillograph.

Altitude - The altitude of the' aircraft was recorded by means of a pressure activated rheostat which was connected directly to the oscillograph.

Air Speed - The air speed was measured by means of a pressure sensitive differential transformer connected between the pitot pressure tube and the static pressure tube. The output of the transformer was recorded on the oscillograph.

Aircraft Heading - The aircraft heading was obtained by a flux gate magnetic compass. The output of the flux gate magnesyn was fed to an azimuth stabilization amplifier from an APS-15, radar system and then recorded on the oscillograph.

Aircraft Roll and Pitch - A tilt stabilization gyro from an APS-33 airborne radar system was modified slightly to allow signals for aircraft pitch and roll to be recorded.

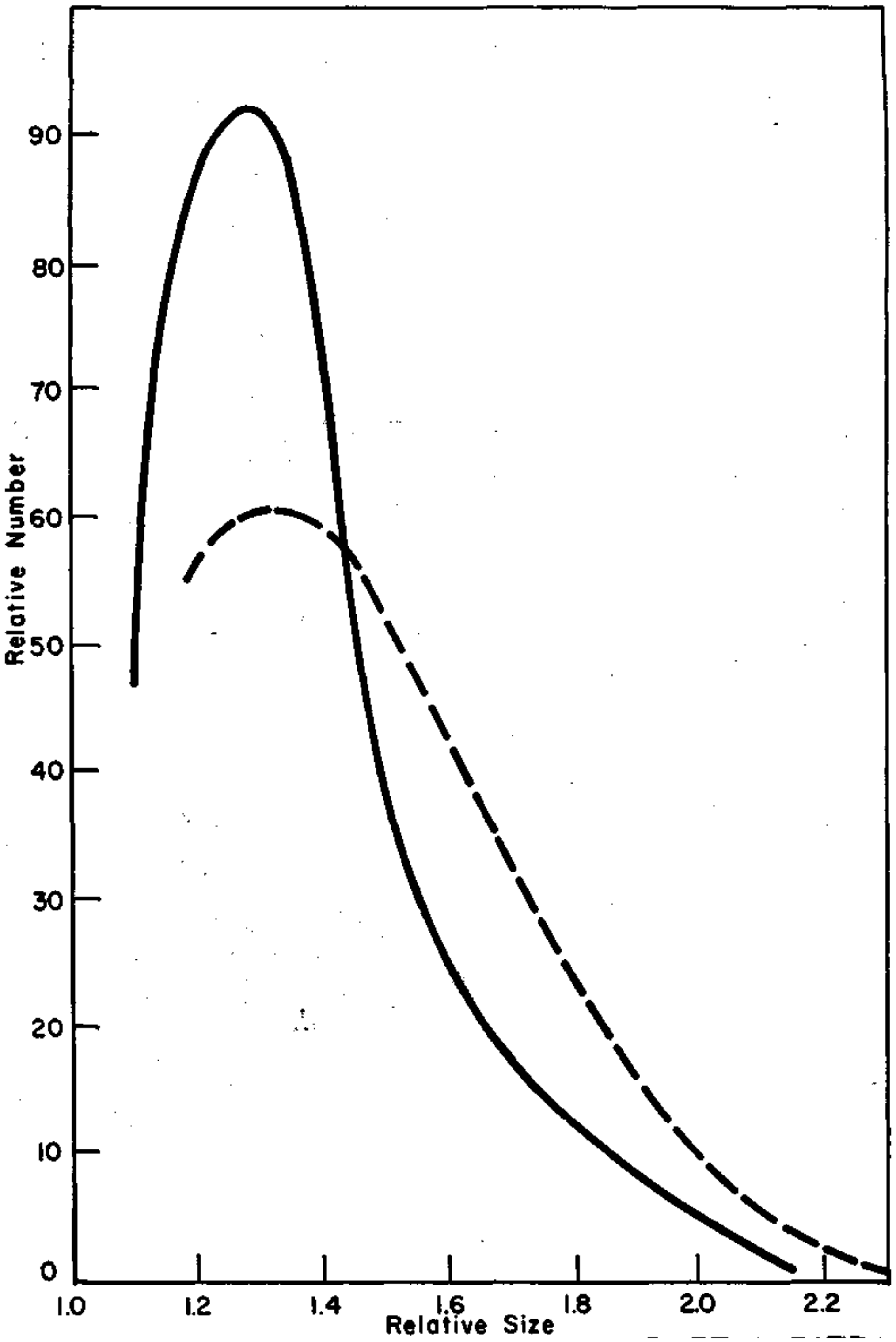


FIG. 6 TWO ADJACENT CLOUD DROPLET SPECTRA OBTAINED ON 9-27-62 WITH DISDROMETER IN STRATOCUMULUS CLOUDS.

3.3 Tri-Pacer aircraft instruments

In addition to the relatively high performance C-45, a Piper Tri-Pacer was used to measure space charge, potential gradient, temperature, pressure altitude, and relative humidity for altitudes up to three kilometers. The temperature, pressure altitude, and relative humidity were measured with a recording meteorograph. The temperature was sensed by a bi-metallic strip while the humidity measurements were obtained by a hair hygrometer. The pressure altitude was obtained from a single aneroid unit.

The potential gradient and space charge instruments were essentially the same as those used on the C-45 aircraft as described in Section 3.2. The electrical data acquired with the Tri-Pacer were recorded on a dual-channel Esterline-Angus, one milliampere recorder. This method of recording required minor changes in the circuit diagrams shown in Figures 4 and 5.

3.4 Ground instruments

<u>Potential Gradient</u> - The potential gradient was measured continually on the ground at two permanent locations, part-time at a third permanent site, and intermittently with one mobile device. The three permanent locations are shown in Figure 1 as the Field Lab, E (East "Observatory- part time), and Radar Station. The measuring instrument consisted of a stretched stainless steel wire suspending a polonium source approximately four meters above the ground surface.

The potential of the wire was determined with an electrometer voltmeter and recorded on a one-milliampere recorder. The potential gradient was computed by dividing the potential of the wire by its height above the ground. This method of determining the gradient assumes that the potential increases linearly with height from the surface to the wire.

<u>Space Charge</u> - The space charge was measured continuously at the Meteorology Laboratory using a 2-meter cube of copper screen wire as a Faraday cage and supported by cables on a framework to obtain vertical soundings from the surface to 15 meters. The installation is shown in Figure 7 This measurement is obtained by sensing the potential at the center of the cube using a polonium ionization source. The voltage at the center of the cage, according to Vonnegut and Moore(7), is given as:

$$V_c = \frac{x^2 N}{780}$$

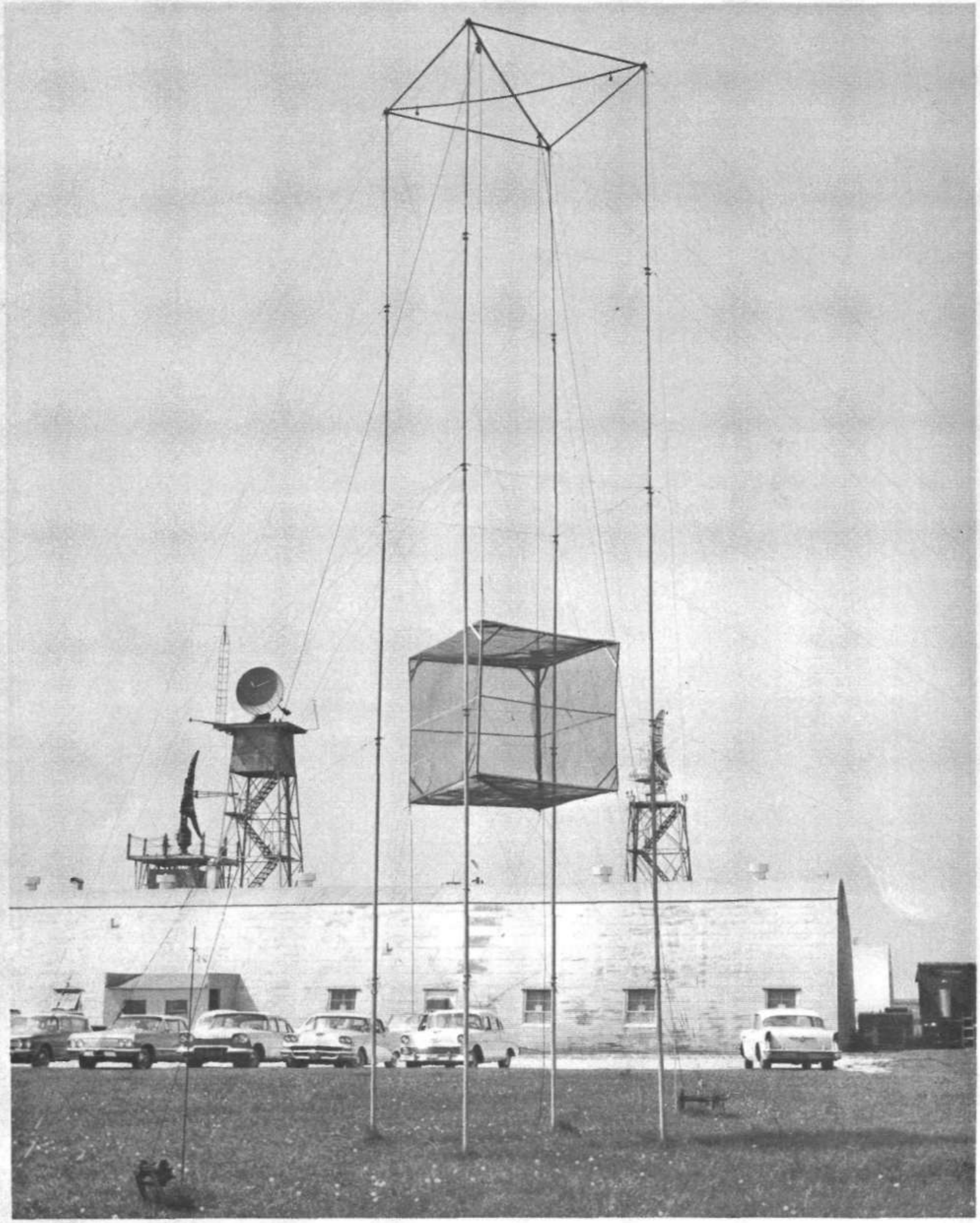


FIG.7 SPACE CHARGE CAGE AT THE METEOROLOGY LABORATORY

where x is length of one edge of the cube in meters and N is the number of elementary charges per cubic centimeter. A fair-weather space charge concentration of 10 electrons/cm3 would thus produce a signal of about 50 millivolts to an electrometer voltmeter supplied with suitable feedback for stability and amplification. A schematic of the circuit is shown in Figure 8.

An additional Faraday cage was constructed and installed at the Field Laboratory near Wire No. 1. However, because of the close proximity of the wire (15 meters), the signal strength exceeded the capability of the electronics at this site and few charge data were obtained. This second cage was also capable of being raised and lowered approximately 15 meters, but this cage was destroyed by high winds.

Conductivity - The polar conductivity was measured with a Gerdien tube as described by Moore, et al.(8). The installation was located at the Meteorology Laboratory and is shown in Figure 9. With a single instrument both polar conductivities were obtained by providing a suitable timing mechanism which automatically reversed the polarity of the G-erdien tube. In addition, a zero check was achieved by an open circuit in the voltage source. This zero permitted the measurement of triboelectric charging due to dust striking the central probe. While this may normally be a small effect, it can become serious during severe dust conditions.

4.0 CASE STUDIES OF AIRCRAFT MEASUREMENTS

4.1 Introduction

The introduction of space charge into a growing cumulus cloud may possibly affect the collision efficiency as well as the coalescence efficiency of cloud droplets. Rayleigh(9) discussed the effects of the presence of a charged body in reducing the bouncing apart of water drops in a vertically pointed jet of water. Since the completion of the research described in this report Lindblad and Semonin(10) have shown significant increases in collision efficiencies for pairs of drops in a uniform externally-applied electric field. However, subsequent calculations by Plumlee, Hassler, Lindblad, and Semonin (private communication) show that the collision efficiency between charged droplets of like sign and typical magnitude may be reduced by as much as 50 percent. However, the decrease in collision efficiency is proportional to the charge and is insignificant until the quantity of charge approaches 10,000 electrons per drop. The observations reported by Vonnegut and others(11) of space charge beneath the bases of small, growing cumuli show typical values of space charge in the range of 100-200 electrons/cm^3. Assuming these charges were distributed uniformly among the droplet concentration, the change in collision efficiency would not be significant.

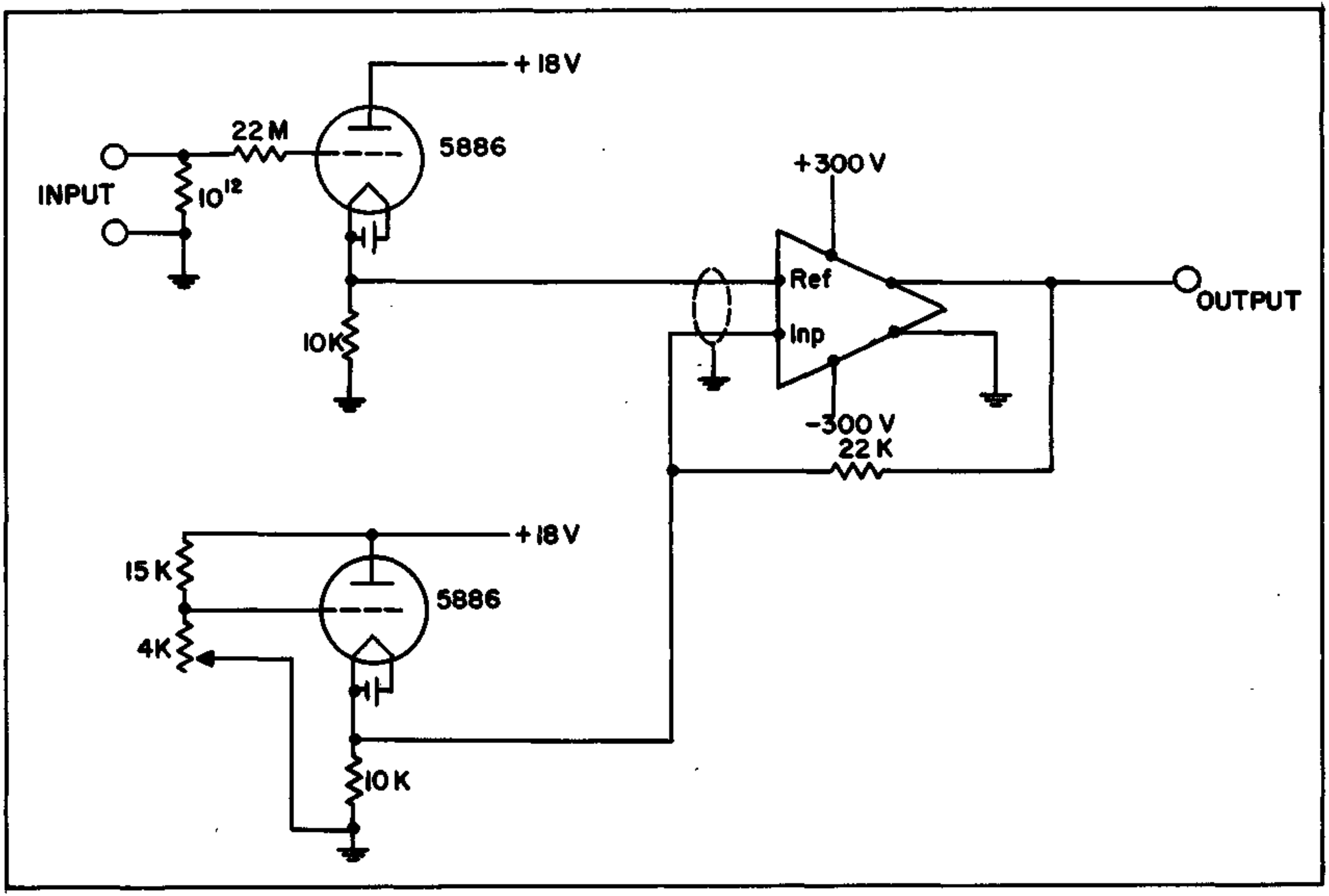


FIG.8 SCHEMATIC OF ELECTROMETER VOLTMETER AND FEEDBACK SYSTEM FOR FARADAY CAGE SPACE CHARGE MEASUREMENTS.

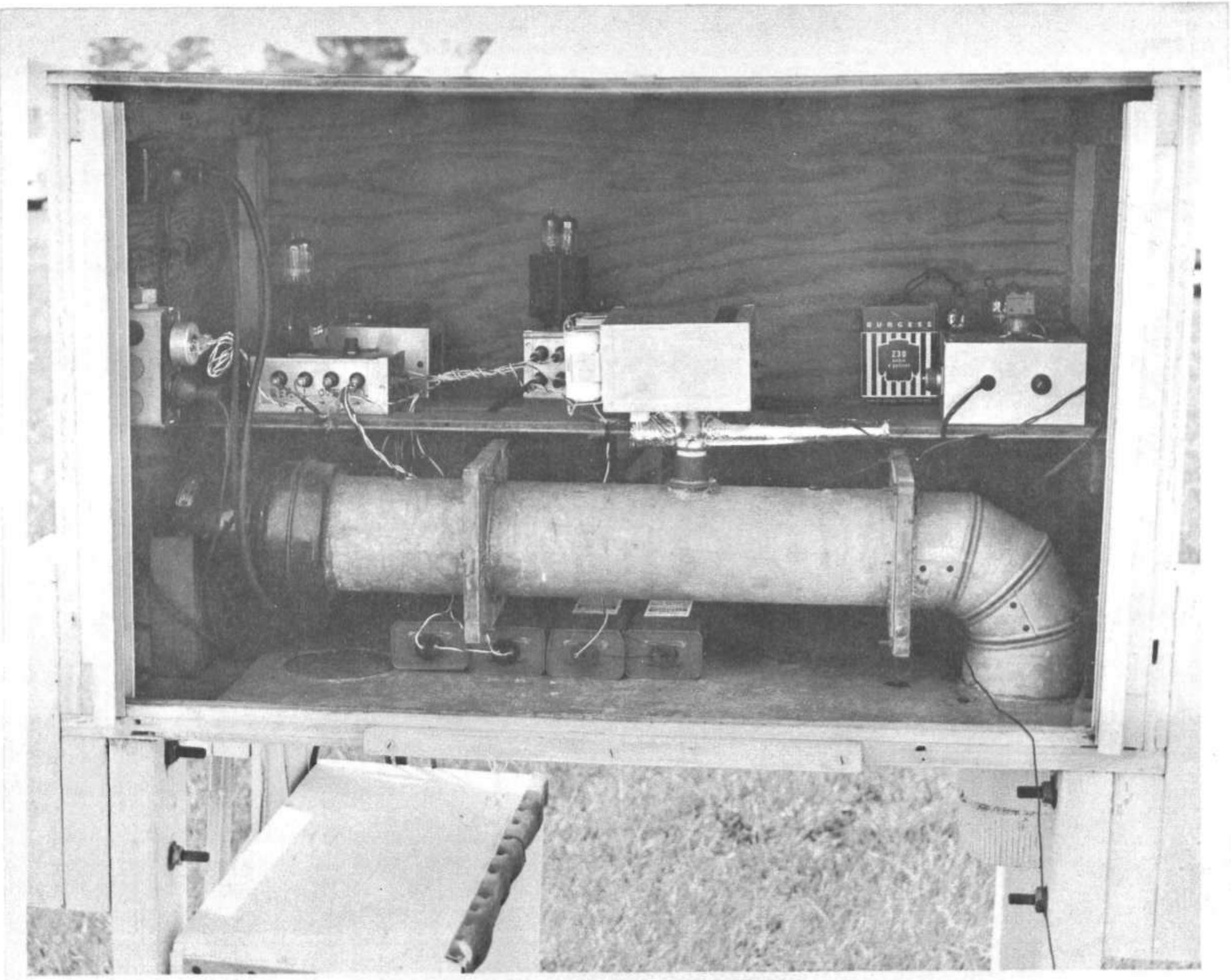


FIG.9 CONDUCTIVITY INSTRUMENTATION AT THE METEOROLOGY LABORATORY

However, quantitative measurements of the effects of charge on the coalescence efficiency were not available at the time of this writing. The unpublished results of experiments performed in the Charged Particle Research Laboratory at the University of Illinois suggest that the charges absorbed by these small clouds from the ground source may be sufficient to ensure a 100 percent coalescence efficiency.

In order to examine the effect of the space charge introduced into these small clouds, a complete life history of the clouds must be obtained. Although the initial effect on a cloud would be expected to be small, it may be sufficient to upset an established colloidal equilibrium so that at a later time significant changes in droplet distribution and electrification may occur. Of course, this presumes that an individual cloud survives and develops to the cumulus congestus stage. Unfortunately, it is a commonly recognized fact that the chances that an individual cloud will develop into a congestus is small. The ideal research case would consist of an individual cloud located in a favorable position to accept charge from the ground source, and with subsequent growth to the congestus stage. However, no such desirable case occurred during the two year program. However, much data were gathered on the charging of small cumuli which are indicative of the dynamics of these clouds in their early stages.

Clouds were examined in various stages of growth both over the source and in a natural environment of space charge. These cases need to be examined in greater detail and perhaps a complete model of the effect of the wire on clouds can be developed by examination of the data acquired on individual cumuli.

Certain data of general interest were obtained during the research period. Many flights were made in the vicinity of a 300-meter television transmitter tower. The data obtained from these flights confirmed the observations of Moore and others(12) with a few exceptions. There are obse'rvations which seem to show a dipole distribution of space charge downwind of the tower, implying that a screening layer is present. These data are not shown in this report since the flight records have not been reduced due to a lack of funds.

Interesting and unique observations of the space charge and potential gradient associated with whirlwinds were obtained with the Tri-Pacer aircraft. These observations, reported by Bradley and Semohin(13), have raised some questions concerning the origin of the observed charge. Experiments have been initiated to explain the reported charge distributions, but since they can only be carried out under extremely mild weather conditions, the final answers must await additional data.

During the summers of 1961 and 1962, missions were flown during a variety of weather situations. Most of the flights were made during periods of small to moderate sized cumuli (approximately 200 to 1000 meters in diameter). On some clear days flights were flown in a grid type pattern over and downwind from the wire at a constant altitude to determine the size and structure of the space charge plume and the resulting potential gradient perturbation. On one occasion continuous vertical soundings were made every hour from 0400 CST to 1500 CST to an altitude of 2.3 kilometers. Plights were also made around moderate sized cumulus congestus but unambiguous measurements could not be made when the natural electric fields exceeded those resulting from space charge released from the wire. Many data were taken furing the hours of flying but this report will describe only those pertaining to a few case studies. Funds" are being requested from the National Science Foundation to complete the analyses.

4.2 June 13, 1962 case

On June 13, 1962, measurements were made in the vicinity of clouds located near and away from the wire network. The air was very clear after a cold front passage and the cumulus clouds were broad and flat from inversional capping. At the time of the first measurement the cloud bases were at 1830 meters MSL, but by the end of the flight, approximately three hours later, they were 2200 meters MSL.

All of the wires in the network were emitting positive charge except No. 3 (Fig. 10) which was charged negatively. For a distance of several kilometers downwind of the positive wires the gradient at cloud top level was considerably decreased, sometimes to zero, and occasionally reversed because of the excess positive charge below. Passes made immediately over the tops of clouds in this region indicated a still greater excess of positive charge below by a further decrease of the gradient directly over the cloud. Passes made over clouds that were not downwind of the wire often indicated negative charge below the aircraft by an enhancement of the potential gradient. Although this phenomenon occurred many times on June 13 and 14 it was not observed on any other flights and its cause has not yet been determined. In no case was an excess of space charge encountered while flying above the clouds.

Figure 10 shows the location of cloud "A" at the time of the first of eight passes. Because of northeasterly winds shown by a pibal run at 1027 CST (Fig, 11), it is apparent that the cloud was downwind 5 kilometers from wire No. 4 which was emitting positive charge. The cloud was about 1.5 kilometers in diameter and 200 to 300 meters in vertical extent.

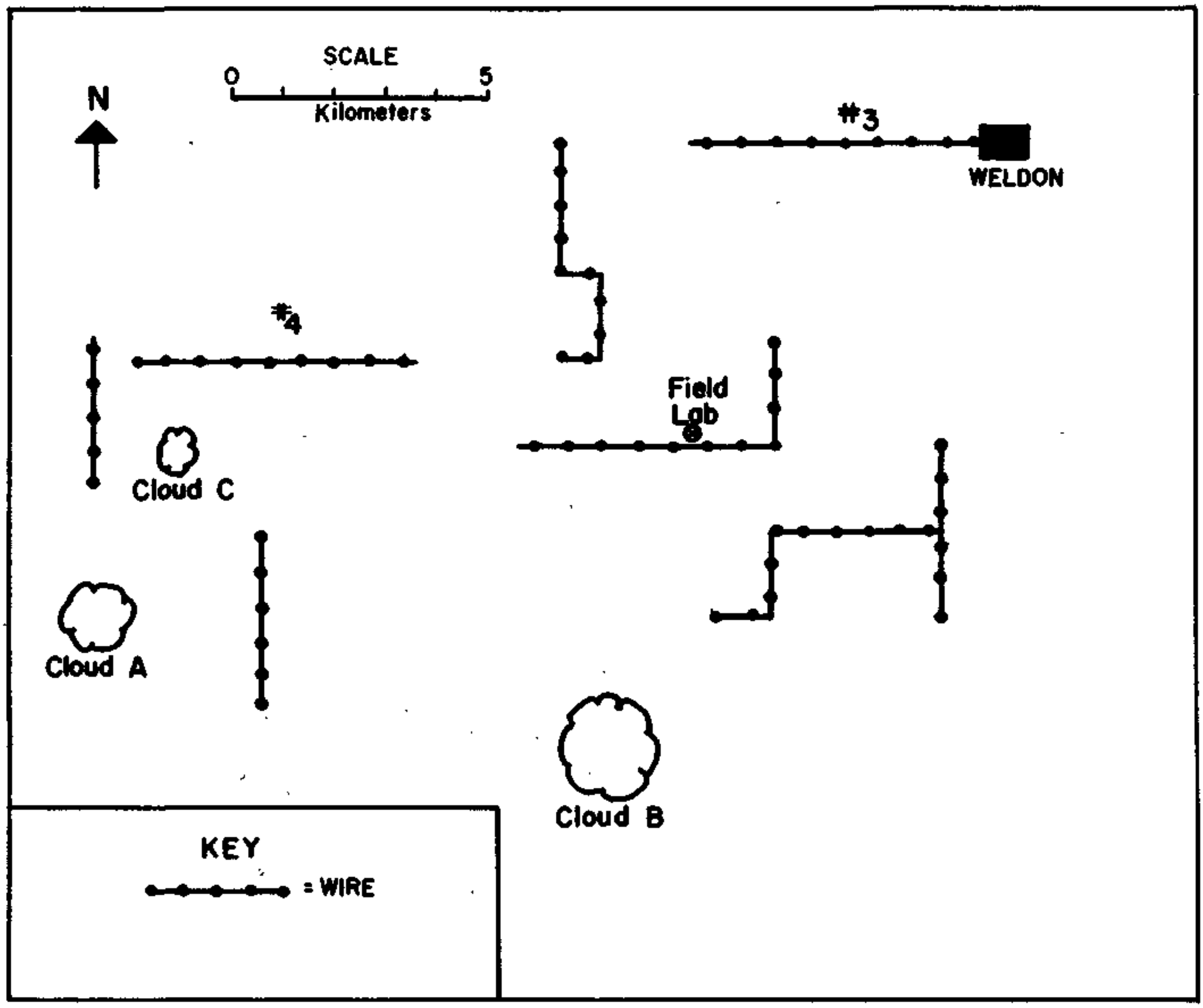


FIG. 10 INITIAL LOCATION OF SELECTED CLOUDS STUDIED ON JUNE 13, 1962.

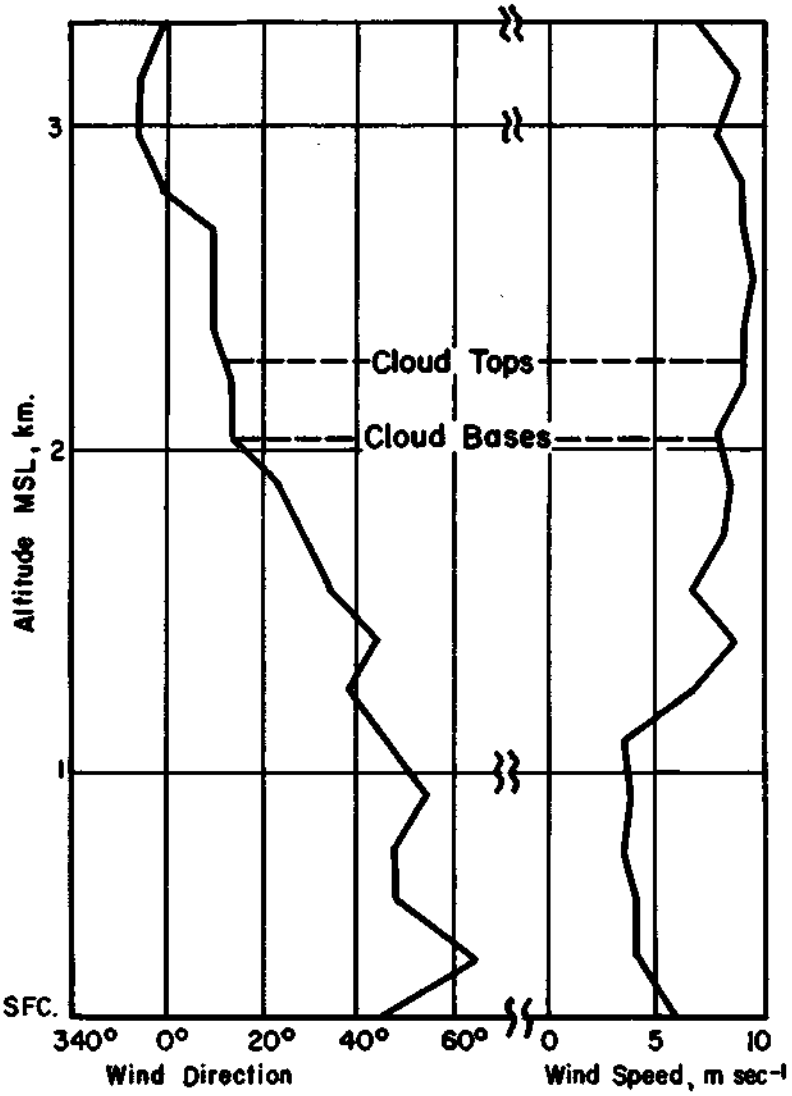


FIG.11 WIND SPEED AND DIRECTION FROM A PIBAL RELEASED AT THE FIELD LAB AT 1027 CST, JUNE 13, 1962.

Passes were made immediately over the top of the cloud. No excess in space charge was found, but the potential gradient records shown in Figure 12 indicate that the first pass gave the maximum reversal. On succeeding passes the gradient decreased and finally passed through zero to become positive. It is apparent from Figure 12 that the maximum gradient occurs past the center of the cloud on each pass even though the passes were made in opposite directions. For this particular cloud the maximum perturbations fall, on the average, about 20 seconds beyond the middle of the cloud because of the response time of the polonium probes in adjusting to the ambient gradient. Figure 13 illustrates how the maximum gradient perturbation on each pass varied with time.

On cloud "B" (Fig. 10), three passes were made above the cloud and three below, and all six were at different altitudes as shown in Figure 14. The potential gradient was negative both above and beneath the cloud indicating that the "center of gravity" of the charge was somewhere beneath the cloud in the updraft associated with it.

Further passes were made through cloud "C", 1.6 kilometers downwind of wire Wo. 4 as shown in Figure 10. On a pass through the center of the cloud (Fig. l5a), negative charge was found on both edges of the cloud and also in the clear air of a large depression in the cloud's center. A portion of the cloud's interior was positively charged. The potential gradient indicated an excess of either positive charge below, or negative charge above, or both. On a second pass through the base (Fig. 15b) a large amount of negative charge was found in clear air in the somewhat" diffuse portion of the cloud on the side of approach. The rest of the base indicated positive charge as shown in Figure 15b. The potential gradient and space charge distribution found in this cloud is in agreement with the Vonnegut hypothesis in that it appeared as if positive charge was convected into the cloud from the wire below and negative charge was attracted to the periphery of the cloud. Although measurements were not normally made inside clouds because of possible triboelectrification of the collectors and insulator wetting, experience has shown that measurements taken in uncharged small cumulus do not usually produce electrical signals, and the above mentioned in-cloud measurements appear reasonable in terms of charge sign although the magnitude may be questionable.

4.3 June 29, 1962 case

Between 1020 CST and 1200 CST on June 29, 1962, electrical measurements were made immediately beneath the bases of several cumulus clouds of moderate vertical extent in the vicinity of the wire network. Although most of the cloud tops did not exceed an estimated 2.5 to 3 kilometers MSL, at least four of them developed

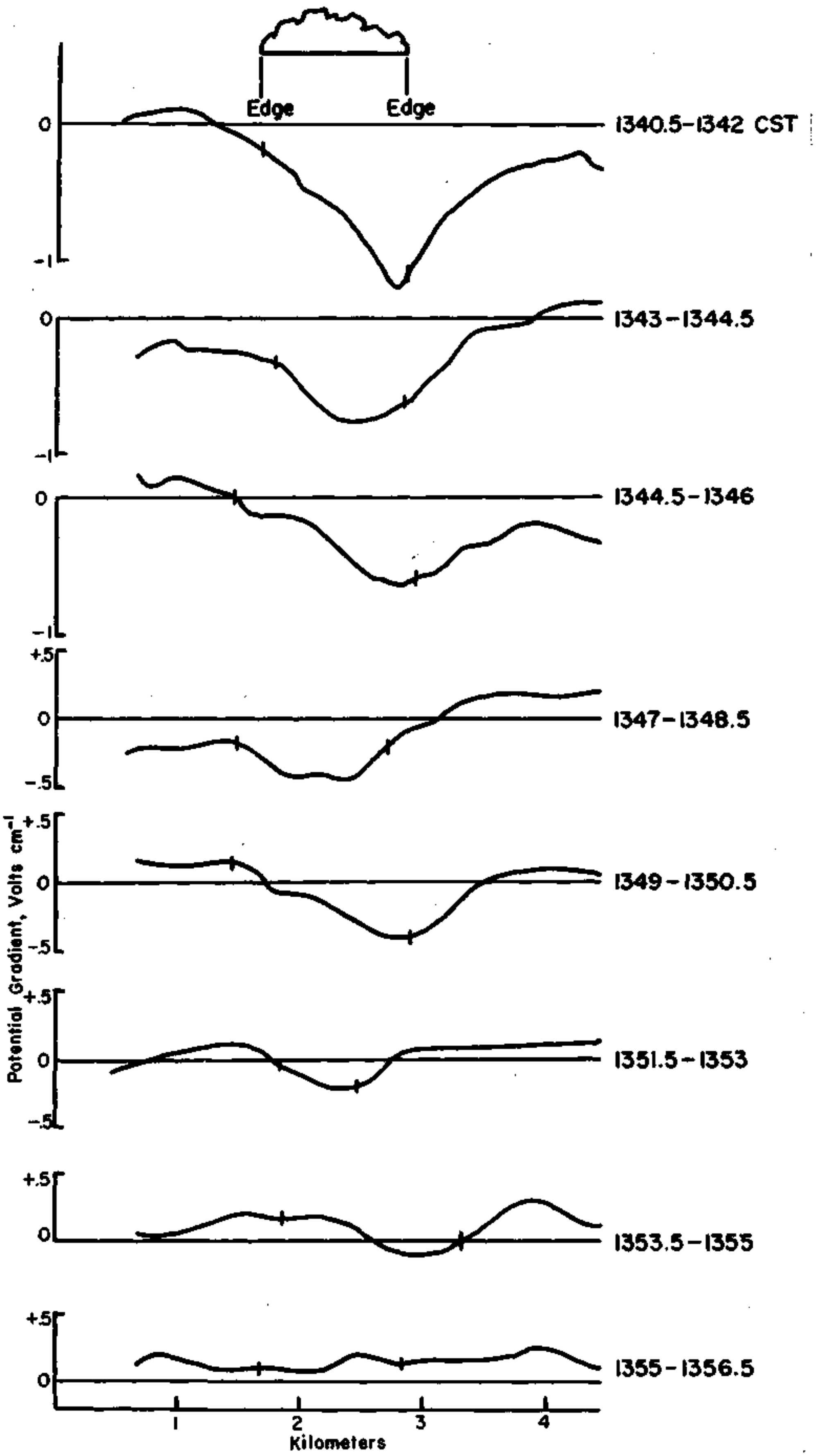


FIG. 12 REPEATED FLIGHTS AT 2180m(MSL) ALTITUDE OVER POSITIVELY CHARGED CLOUD "A" ON JUNE 13, 1962.

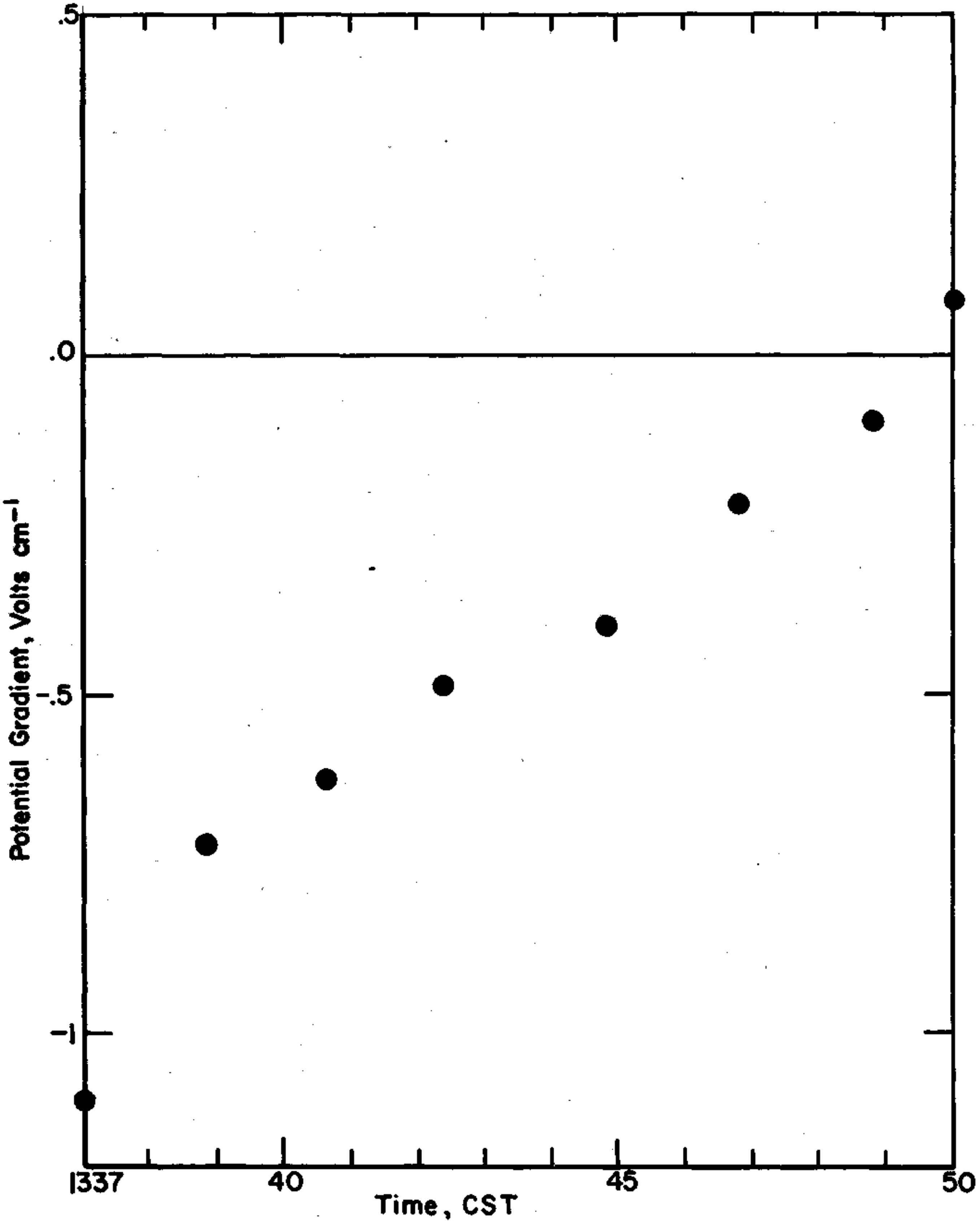


FIG.I3 MAXIMUM POTENTIAL GRADIENT VS. TIME FOR CLOUD "A", JUNE 13, 1962.

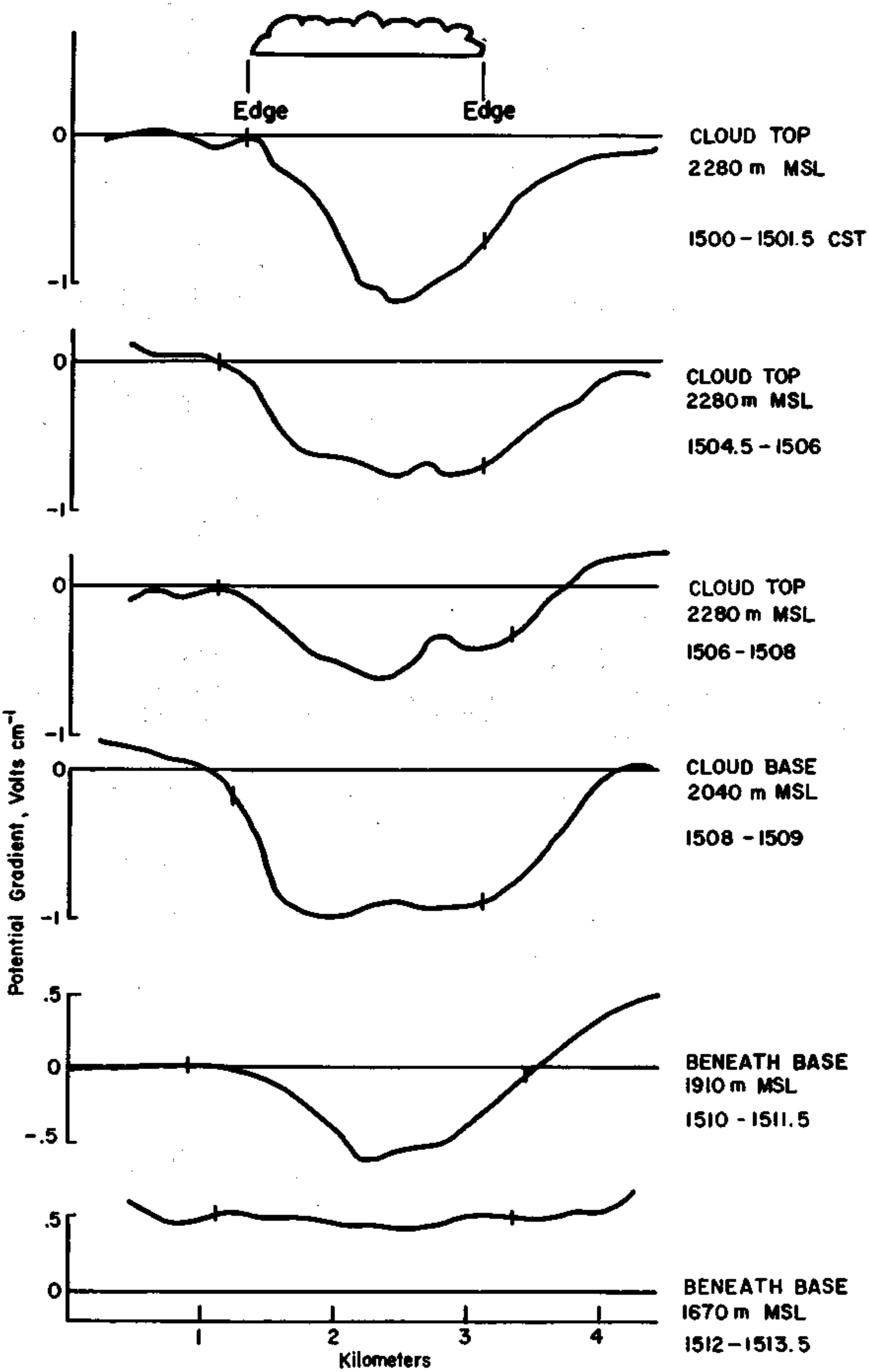
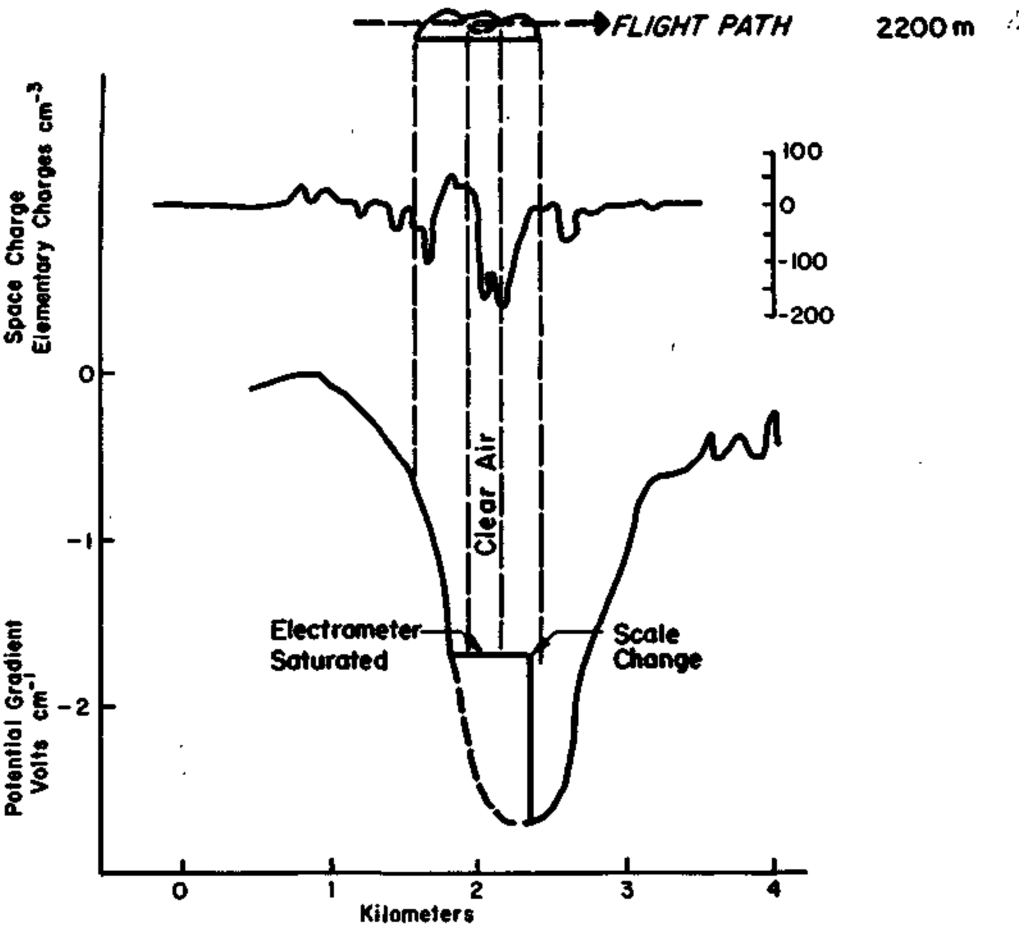
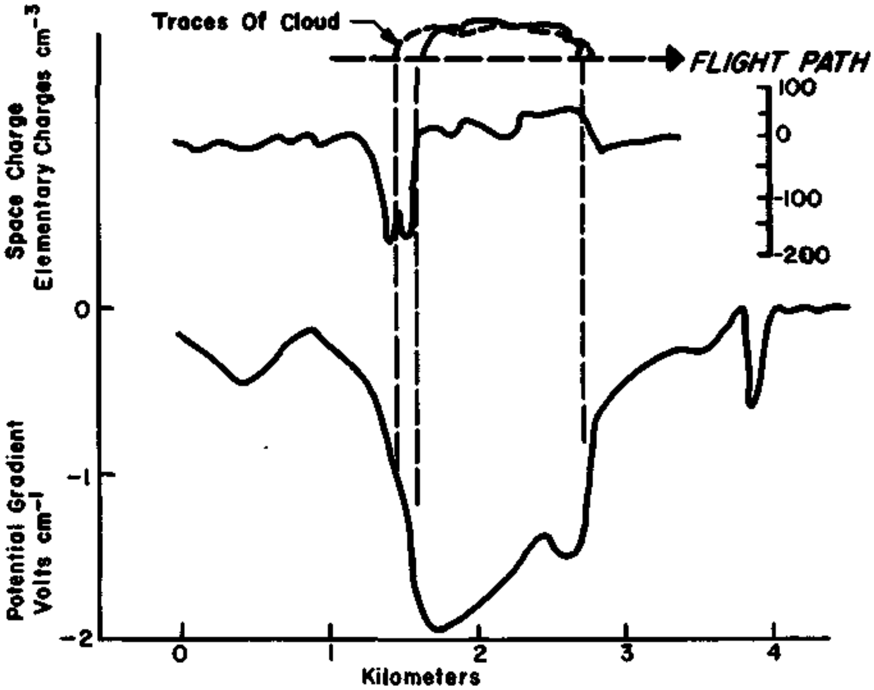


FIG.14 POTENTIAL GRADIENT MEASUREMENTS ABOVE AND BENEATH CLOUD V ON JUNE 13, 1962.



a. Pass Through Center Of Cloud



b. Pass Through Base Of Cloud

FIG.I5 SPACE CHARGE AND POTENTIAL GRADIENT ASSOCIATED WITH CLOUD "C" ON JUNE 13, 1962.

very light precipitation that was observed on the aircraft windshield and detected by the ground-based radar. Of the four precipitating clouds under which electrical measurements were made, only one cloud exhibited electrification from the ground source. The electrified cloud was found 3 kilometers north and downwind of wire No. 1.

At the beginning of a series of six passes beneath this cloud it was estimated to be about 3 kilometers wide at the base' and 750 meters in vertical extent. Before the fifth pass (14 minutes later) it was estimated to be 1200 meters in vertical extent.

On the first pass at 1280 meters MSL positive space charge from the wire beneath was encountered over a distance of 1700 meters (or about 60% of cloud width). The maximum concentration was 75 electrons/cc. The potential gradient reversed polarity to -0.5 volts per centimeter indicating an excess of positive charge below (Fig. 16). On the two succeeding passes, beginning at 1110 CST and 1113 CST, space charge was not encountered and the gradient became enhanced positively, indicating an excess of positive charge above the plane, that is, in the cloud. On the fourth pass a small area of extremely light precipitation was encountered and this area was larger in areal extent by the sixth pass.

It will be noted in Figure 16 that during the fourth pass the space charge filter indicated positive space charge concurrent with the interception of precipitation. Normally the filter measurements are considered unreliable during precipitation because of the possible wetting of the insulation within and because of frictional electrification of drops splitting on the intake. However, no space charge was measured in the precipitation from the three other precipitating clouds so it may be justifiable to assume that the precipitation in this cloud was charged. On the last pass no precipitation was found and the potential gradient had almost returned to its undisturbed state.

4.4 June 11, 1962 case

On June 11, 1962, the C-45 was flown so as to encircle a growing cumulus congestus at 4.4 kilometers. Continuous measurements of space charge and potential gradient were made. These measurements were obtained to provide data on the natural electrification of clouds away from the ground space charge source. At the time of the initial approach to the cloud it was imbedded in a small line of developing cumulus oriented WSW-ENE and moving SSE.

The cloud under observation was separated from two smaller cells on each side by approximately 8 kilometers. The cloud originally did not exhibit an anvil formation but just prior to termination

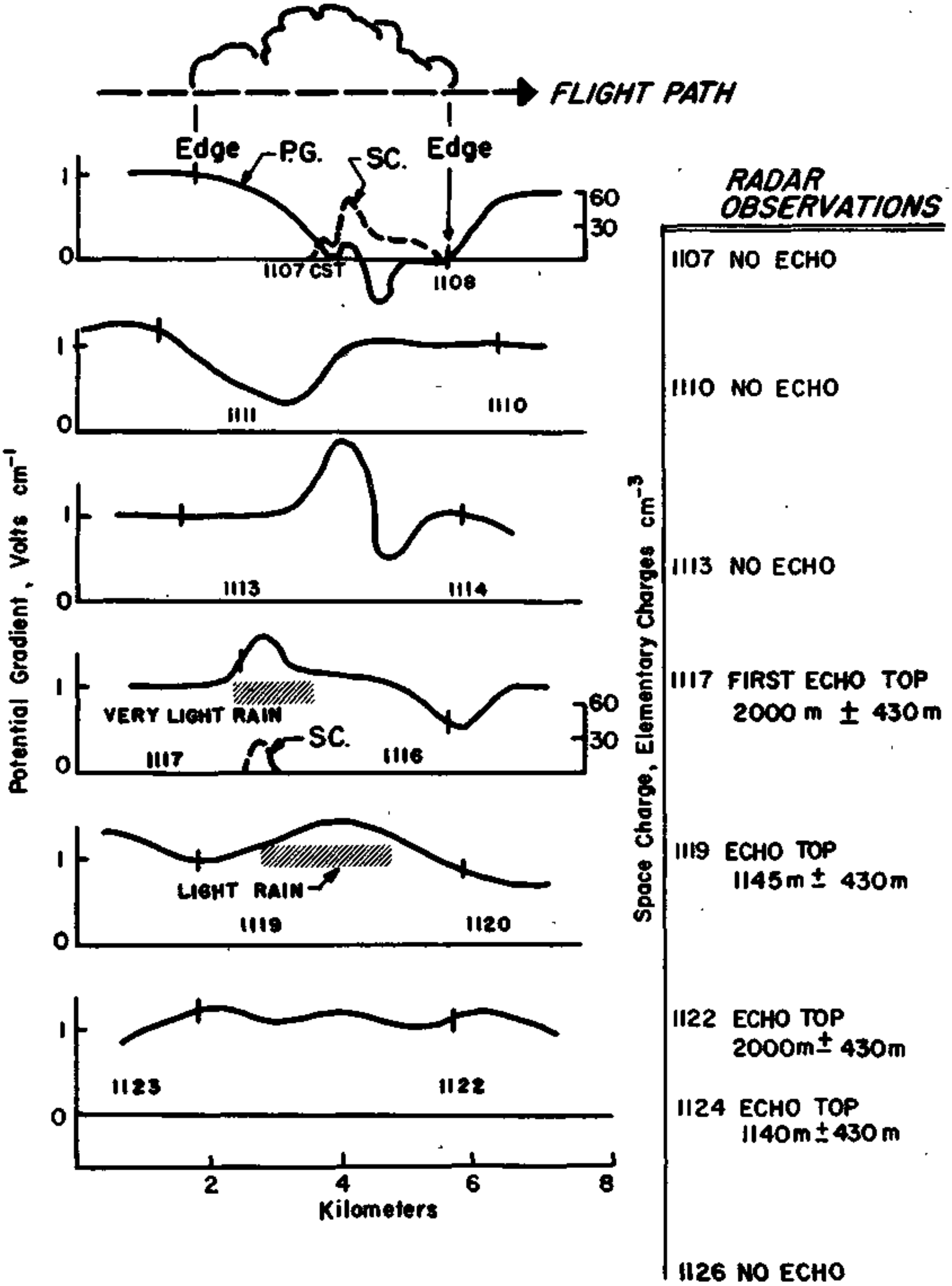


FIG.16 SPACE CHARGE AND POTENTIAL GRADIENT MEASURED BENEATH A CLOUD AT 1280 m (MSL) ON JUNE 29, 1962.

of the flight, the anvil was observed to be forming in a southerly direction at an estimated altitude of 4.8 kilometers.

The peculiar space charge distribution associated with this cloud is depicted in Figure 17. The southwest quadrant appeared to contain negative space charge while the northeast quadrant showed positive space charge of a' larger magnitude. These measurements were made completely outside of the visual cloud, and could not be directly associated with the anivl which formed during the period of observation.

The horizontal potential gradient saturated indicating a charge distribution to the right of the line of flight shown in Figure 17. This particular measurement is sensitive to the aircraft attitude so that absolute numbers were impossible to achieve.

This charge distribution is not in agreement with any existing thunderstorm-charging theory. However, since the line of clouds dissipated prior to passing over any routine weather observing station, it is not possible to verify the existence of a thunderstorm. Perhaps this charge distribution is associated with dissipating systems.

5.0 DIFFUSION STUDIES

In order that the location and concentration of the plume of space charge from the wire might be compared with theoretical calculations, Sutton's diffusion equation for a continuous, infinite, crosswind, line source was solved to show the vertical cross section isograms of equal space charge concentration. For this equation the emitting source is located at the surface of the ground and is of infinite length. The actual wire source used was 10 meters above the ground, but the height of the wire can be ignored since it is small in relation to the distances and altitudes at which most of the concentrations are determined. Whereas the wire source used was of finite, rather than infinite length, a fringe effect occurs near the edge of the plume at the longer distances from the wire, causing the theoretical calculation to be larger than it should be in principle. Sutton's equation for a finite line source could have been used in place of the infinite line source equation, but the latter was used for the sake of simplicity.

Sutton's diffusion equation for a continuous, infinite crosswind line source(14) is:

$$\chi_{(x,\ z)} = \frac{2Q}{\pi^{1/2}\, C_z \bar{u}\, x^{1 - 1/2n}} \exp \frac{-z^2}{C_z^2\, x^{2-n}}$$

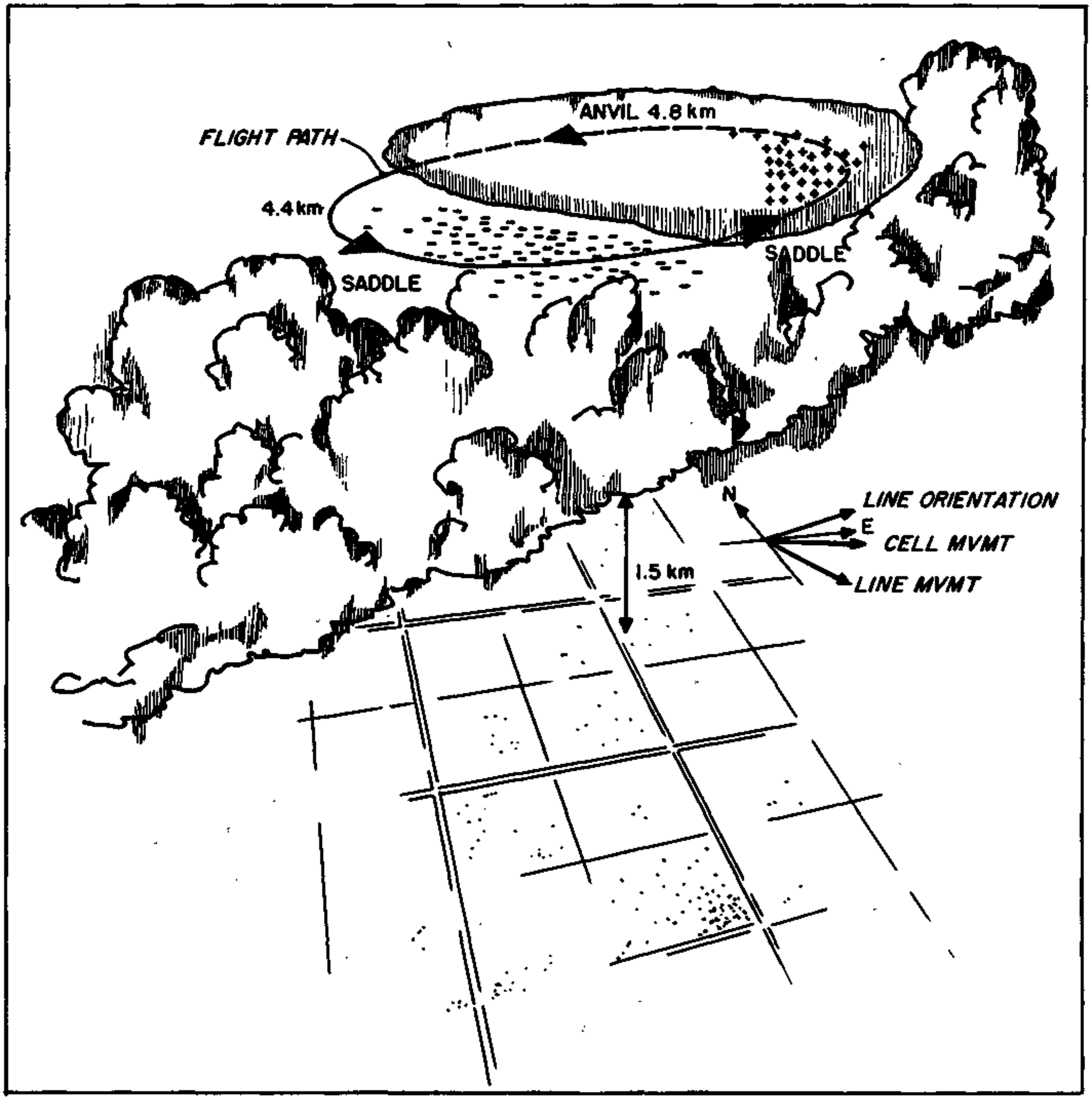


FIG.17 CHARGE DISTRIBUTION, FLIGHT PATH, AND APPROXIMATE CLOUD STRUCTURE ON JUNE 11, 1962.

the equation gives the average concentration χ of an emission at a point downwind a distance x from the source and at a height z, where Q = emission at the source, C_z = vertical diffusivity, $\bar{u}$ = average wind speed, and n = stability factor. If the equation is solved for z, the height versus distance contour of a given concentration can be determined for different wind speeds and stability factors. Solving for z

$$z = C_z x^{1 - 1/2n} \left[-\log_e \left(\frac{\chi \pi^{1/2} C_z \bar{u} x^{1 - 1/2n}}{2Q} \right) \right]^{1/2}$$

A charge Q decays with time according to the relationship $Q = Q_o e^{-\frac{\lambda t}{\epsilon}}$ where $t = \frac{x}{\bar{u}}$ and ϵ = permittivity of free space. Assuming that the electrical forces between the charged particles are neglectable and substituting this in the equation we have

$$z = C_z x^{1 - 1/2n} \left[\log_e \left(\frac{2Q_o}{\chi \pi^{1/2} C_z \bar{u} x^{1 - 1/2n}} \right) - \frac{\lambda x}{\epsilon \bar{u}} \right]^{1/2}$$

Assuming all the fast ions formed by the wire are converted to slow ions and carried downwind, the charge output for three different wind speeds derived from Vonnegut and others$^{(15)}$ are shown in Table 1.

Table 1

CHARGE OUTPUT AS A FUNCTION OP WIND SPEED

	Wind Speed, ($m\ sec^{-1}$)		
	1	3	5
Charge output, Q ($e\ sec^{-1} \times 10^{-11}$)	1.83	6.40	10.5

Values of C_z taken from Holland$^{(16)}$ are shown in Table 2.

Table 2

VALUES OP C_z FOR WIND SPEEDS

	Wind Speed ($m\ sec^{-1}$)			
Stability	1	3	5	n
Lapse	.43	.20	.18	.20
Neutral	.24	.14	.13	.25
Moderate Inversion	.12	.09	M	.35

M - Data not available

Substituting these values in Sutton's equations we obtain space charge distribution cross-sections shown in Figures 18-20. It is hoped that in the near future these data can be compared with the aircraft measurements.

6.0 FIRST ECHO OBSERVATIONS

During the warm seasons of 1960-1962 the CPS-9 radar set was operated in such a manner as to observe the first development of echoes in convective clouds. The first echoes were studied to determine if the space charge from the ground source affected the rate of growth of the droplet spectrum within clouds. The majority of the data to be discussed were obtained during 1960 and 1962 since the radar was used primarily in a study of hail detection in 1961. The hail operation was not compatible with first echo detection since the sensitivity was deliberately attenuated to obtain high Z (reflectivity) values.

To obtain the first echo information the antenna was tilted one degree per revolution on full gain sensitivity. The method of antenna control permitted azimuth scanning in one degree steps of elevation from 0° - 11° in a total elapsed time of 2½ minutes. "First" echoes were defined as those echoes which first appeared between ranges of 15 and 40 miles and excluding those which moved into this region. It is possible that a few echoes were missed between approximately fifteen to twenty miles due to ground clutter; but, without reservation, the echoes presented here are first echoes produced by hydrometeors.

The data obtained during 1960 were examined for first echoes between 180° and 360° azimuth, since this information formed the basis of assessing the development of precipitation in the vicinity of the artificial space charge source. The entire 360^0 sweep was used to obtain the first echo sample during 1962.

It would be instructive to examine seasonal and diurnal variations in echo formation, but because of dual purpose operations it was impossible to collect sufficient radar data to permit this type of analysis. However, there were numerous days when the radar was operated on full gain sensitivity throughout.

The geographical location of each first echo and the wire network for 1960 and 1962 is shown in Figure 21. The 1962 first echo locations for the 360° sweep are shown in Figure 22. Without sophisticated statistical tests it can be seen that the distribution is quite random.

The height of the tops versus frequency of first echoes is shown in Figure 23. These data compare very well with those

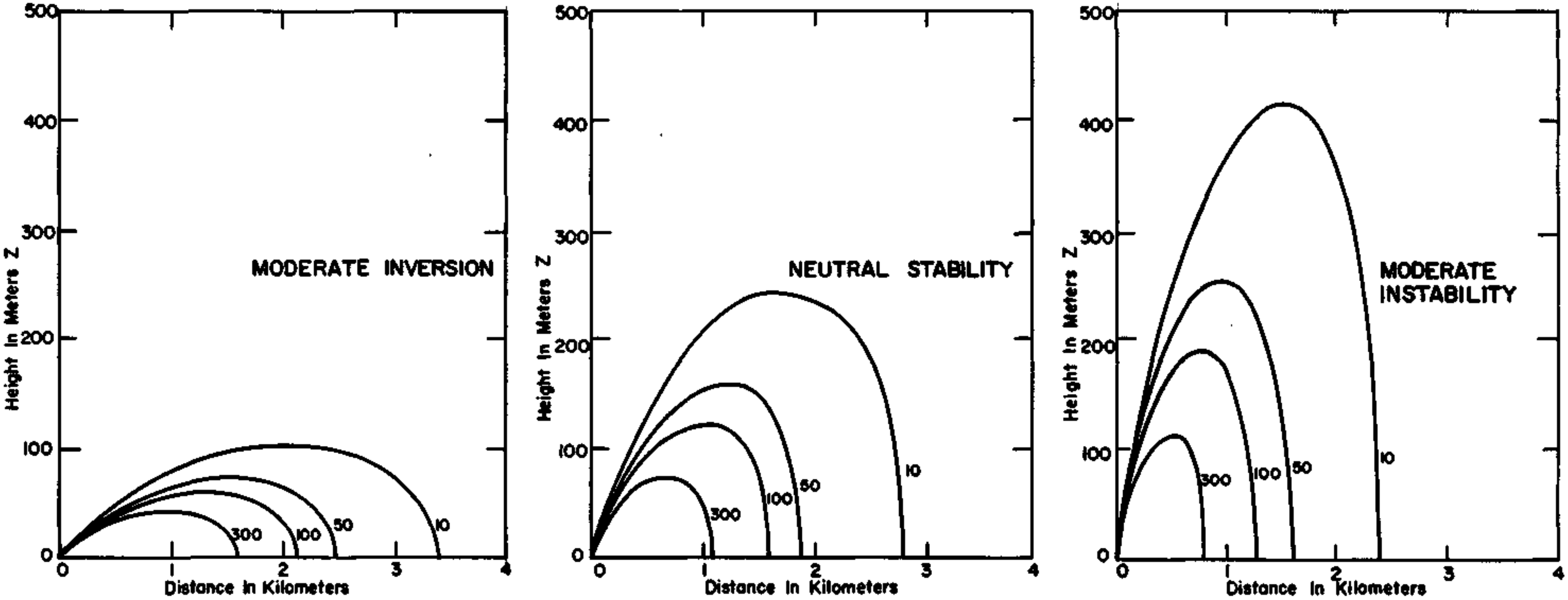


FIG.18 CROSS SECTIONS OF CHARGE DISTRIBUTIONS IN ELEMENTARY CHARGES PER cm^3 FROM AN INFINITE LINE SOURCE WITH AN AIR SPEED OF 1 m sec^{-1} AND VARIED STABILITY CONDITIONS.

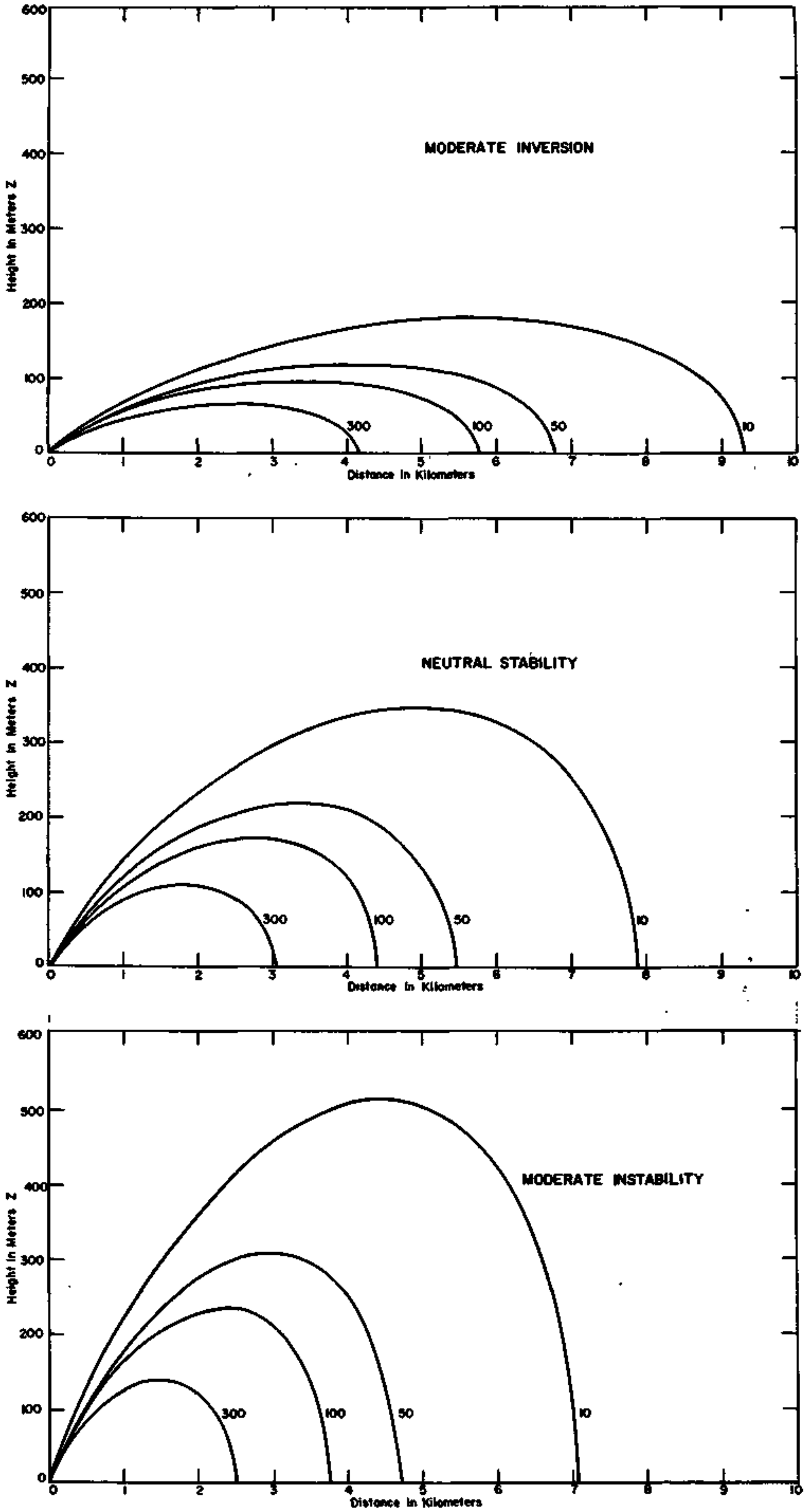


FIG.19 CROSS SECTIONS OF CHARGE DISTRIBUTIONS IN ELEMENTARY CHARGES PER cm^3 FROM AN INFINITE LINE SOURCE WITH AN AIR SPEED OF 3m sec^{-1} AND VARIED STABILITY CONDITIONS.

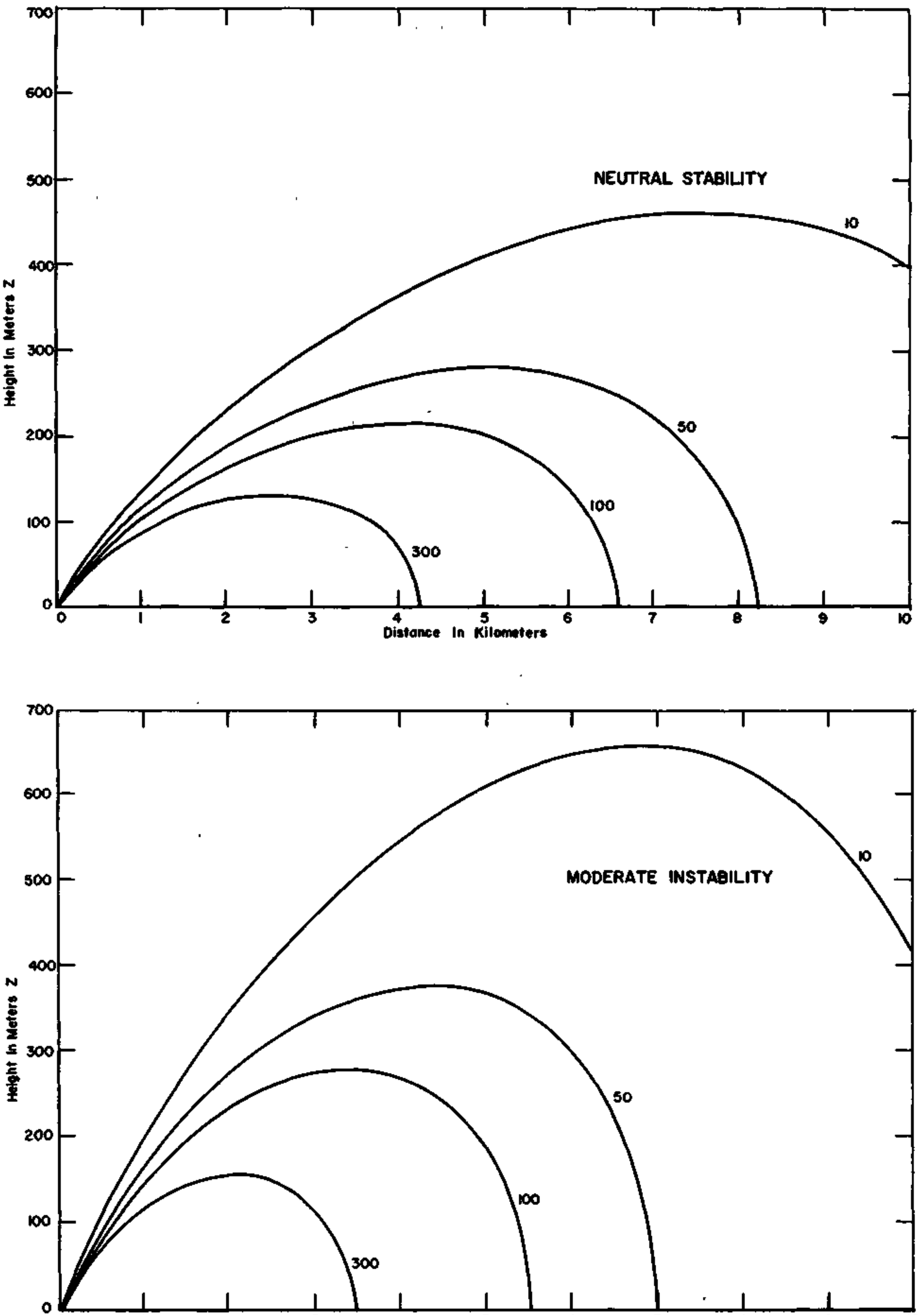


FIG.20 CROSS SECTIONS OF CHARGE DISTRIBUTIONS IN ELEMENTARY CHARGES PER cm^3 FROM AN INFINITE LINE SOURCE WITH AN AIR SPEED OF 5 m sec^{-1} AND VARIED STABILITY CONDITIONS.

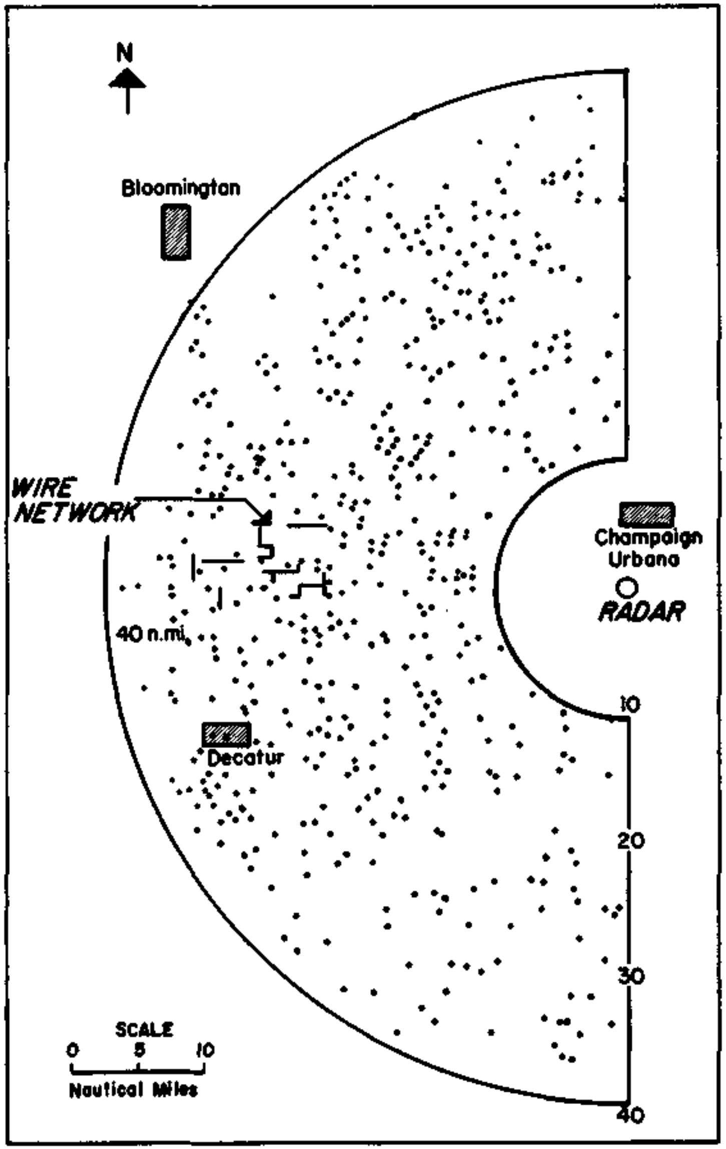


FIG.2I LOCATION OF FIRST ECHOES FROM JUNE 10-AUGUST 30, 1960 AND FROM MAY 1 - AUGUST 6, 1962 DURING OPERATIONAL PERIODS.

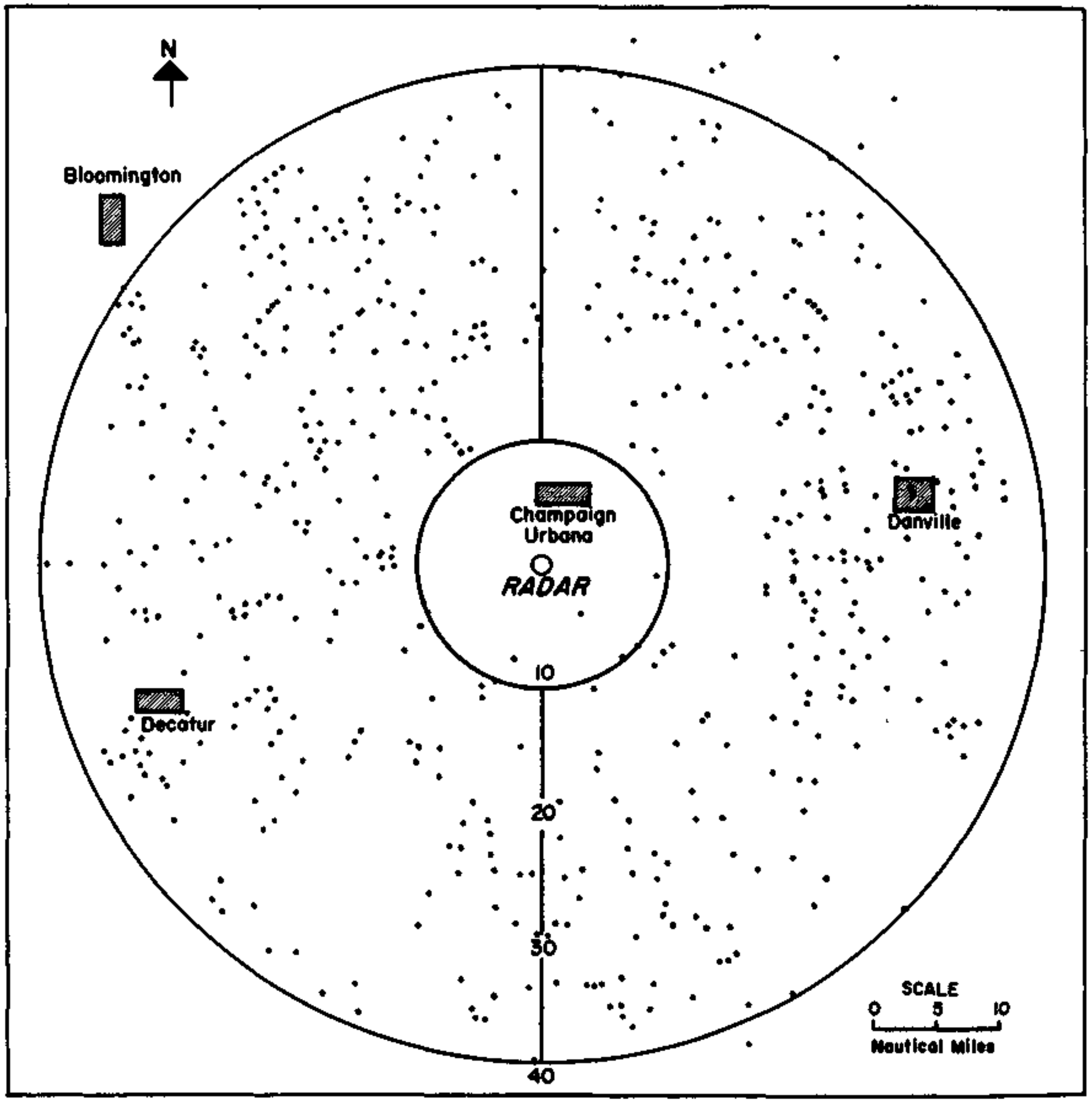


FIG.22 LOCATION OF FIRST ECHOES FROM MAY 1-AUG 6, 1962 DURING OPERATIONAL PERIODS.

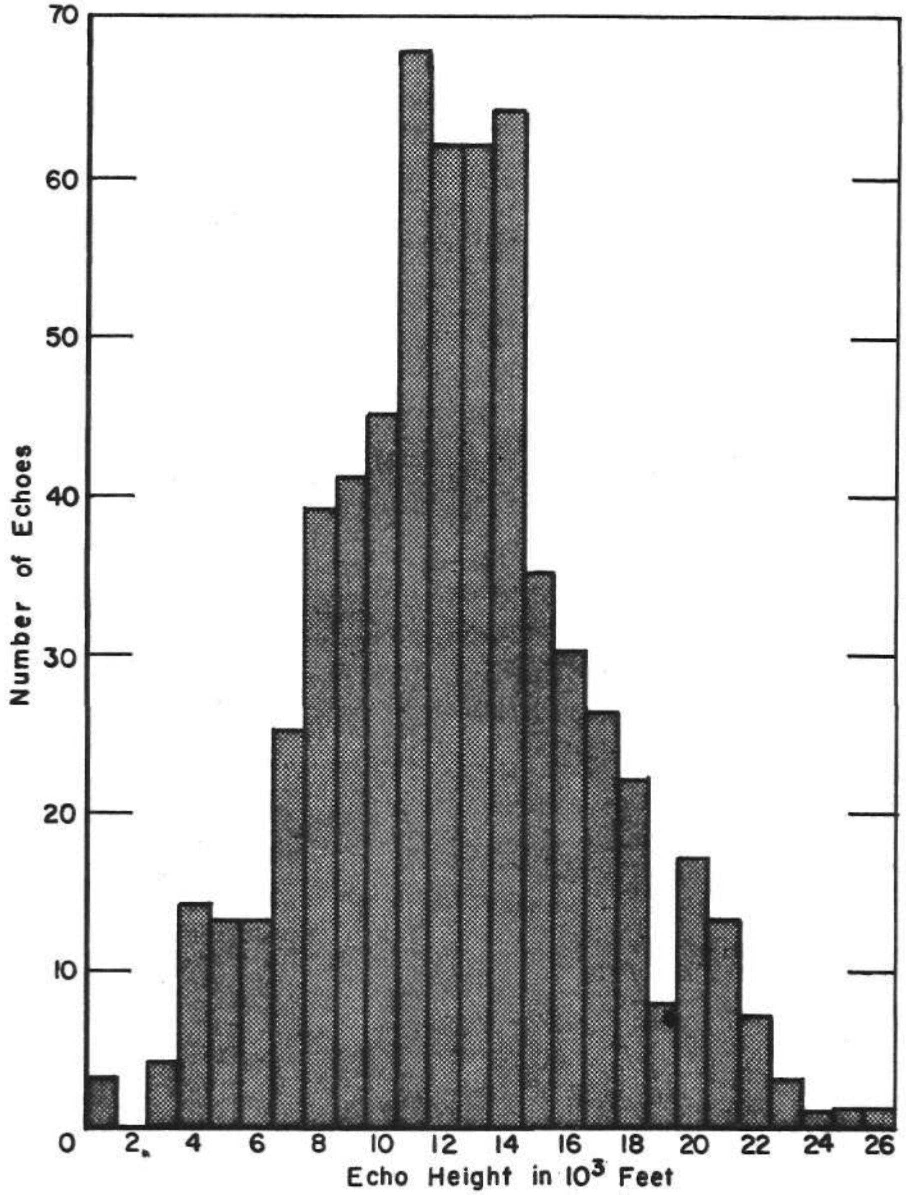


FIG. 23 FREQUENCY DISTRIBUTION OF THE TOPS OF FIRST ECHOES FOR THE YEARS I960 AND 1962.

discussed by Braham(17) for south central Missouri first echoes. When the initial echo top is determined in reference to the freezing level, it is noted that 56 percent form as all-water echoes. This clearly points to the importance of the coalescence mechanism in summer season rainfall in Illinois.

7.0 CONCLUSION

The task of this research project was to make electrical measurements of small clouds that became electrified and continued to grow. Unfortunately, this happened only rarely during the 1961-1962 seasons. Normally, very few small cumulus grow to an appreciable size, and fewer still began their development over the wire when an aircraft happened to be measuring it. The situation necessary to substantiate Vonnegut's hypothesis never occurred over the wire network. On many occasions small clouds accumulated opposite charge at their periphery, which is necessary for the bootstrap process, but they failed to continue their growth.

It has been demonstrated that on occasion the space charge from the wire was convected into fair-weather cumulus. Once the charged cumulus moves away from the source, the charge soon decays with a lifetime similar to that of the cloud. This is to be expected if the cloud does not initiate a charging mechanism of its own which has not been noted to happen in a small cumulus.

Aside from the efforts for the central purpose of the research, much experience has been gained through the instrumentation of an aircraft for fair-weather atmospheric electrical measurements. In particular, the space charge filter and potential gradient system operated very satisfactorily during the two-year program. Although the instruments were not designed to be operated in the vicinity of thunderstorms, some meaningful data can be obtained near less intense storms as evidenced by the case of June 11, 1962.

Much of the exhaustive data have not been scrutinized to the fullest and much information concerning the convective process could be gained by analysis of grid patterns over the wires. These observations will be compared with the theoretical concentrations deduced in the above section on diffusion.

The orientation and proximity of the various wires apparently were not a detriment to their operation when the output current is compared to the 1960 wire(15). The average hourly current to the wire has been punched into cards for correlation with wind direction and speed, proximity of other wires, humidity, and other meteorological variables. The final analysis of these data must await further funding.

The limited cases which have been examined do not permit any generalization. Thus, the primary conclusion from the study at present is that all of the data on clouds must be examined quite closely in relation to the likelihood of charge acceptance, the quantity of. charge absorbed, and their subsequent development. Unfortunately, the present grant period and funds were insufficient to accomplish these analyses.

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APPENDIX A

Research Plights in Tri-Pacer

1961

Flight No.	Date	Take Off	Duration	Observer
1	Jul 5	0920	0.9	RS
2	Jul 5	1525	1.1	RS
3	Jul 7	1545	0.6	RS
4	Jul 11	1355	1.7	RS-DW
5	Aug 14	1520	0.9	RS
6	Aug 15	1445	1.4	RS-WB
7	Aug 16	1335	1.9	MMcC-WB
8	Aug 17	1350	2.0	WB
9	Aug 18	1350	1.6	WB-MMcC
10	Aug 21	1250	2.2	WB-MMcC
11	Aug 22	0840	2.5	RS
12	Aug 22	1315	2.0	DW-WB
13	Aug 23	0920	2.6	WB
14	Aug 23	1500	1.7	MMcC
15	Aug 24	1315	2.2	WB
16	Aug 28	1111	1.0	RS
17	Aug 28	1340	2.2	MMcC
18	Aug 29	0915	1.5	MMcC
19	Aug 29	1430	2.3	MMcC
20	Aug 30	0940	1.5	MMcC
21	Aug 30	1325	2.3	RS-GS
22	Aug 31	0900	2.7	WB
23	Aug 31	1345	1.7	MMcC
24	Aug 31	1930	2.3	RS
25	Sep 1	1200	1.7	RS
26	Sep 5	1025	1.8	WB
27	Sep 5	1328	2.0	RS-DW
28	Sep 6	1315	2.4	DW
29	Sep 7	1630	0.9	WB
30	Sep 8	0943	1.9	DW
31	Sep 8	1355	1.4	RS-DW
32	Sep 11	1310	3.2	WB
33	Sep 12	1120	2.7	DW
34	Sep 18	1600	0.5	WB
35	Sep 20	1200	0.5	WB
36	Sep 22	1215	1.9	DW
37	Sep 28	1200	1.3	WB-GS
38	Oct 9	1215	2.0	WB
39	Oct 12	0815	3.1	WB
40	Oct 17	1000	2.7	WB

APPENDIX' A (cont'd)

Research Plights in Tri-Pacer

1962

Flight No.	Date	Take Off	Duration	Observer
1	May 3	M	1.00	DS
2	May 5	1230	2.50	WB
3	May 7	1510	1.50	WB-RS
4	May 8	0905	1.10	WB
5	May 11	1030	2.25	RS
6	May 14	1220	0.15	WB
7	May 15	1245	2.55	WB
8	May 15	1615	2.15	RS
9	May 16	1250	2.35	RS-WB
10	May 17	1230	3.00	WB
11	May 18	1145	1.15	WB
12	May 21	1225	2.50	RS
13	May 26	1310	0.55	RS
14	May 28	1220	2.15	RS
15	May 29	1255	2.15	RS-WB
16	Jun 4	1305	2.15	RS-WB
17	Jun 7	1300	1.55	RS-WB
18	Jun 8	1330	2.40	WB
19	Jun 11	1030	1.45	RS
20	Jun 11	1410	1.40	WB-GS
21	Jun 13	1225	3.05	CH-WB
22	Jun 14	1100	1.45	WB
23	Jun 18	1030	3.00	WB-GS
24	Jun 21	1300	2.00	WB-CH
25	Jun 22	1100	1.45	WB-CH
26	Jun 23	1325	2.12	WB
27	Jun 25	0720	0.15	DS
28	Jun 29	1015	1.55	WB
29	Jul 3	1250	1.40	WB-CH
30	Jul 6	1445	0.45	GS
31	Jul 11	1420	0.30	WB-CH
32	Jul 12	1415	1.35	WB-CH
33	Jul 18	1225	2.40	GS
34	Jul 19	1320	1.25	RS
35	Jul 20	1325	2.20	CH
36	Jul 23	1300	2.30	WB
37	Jul 24	1240	2.05	CH
38	Jul 25	0810	1.10	CH
39	Jul 25	1025	0.30	CH
40	Jul 25	1210	1.25	CH

M = missing

APPENDIX A (cont'd)

Research Plights in Tri-Pacer

1962

Flight No.	Date	Take Off	Duration	Observer
41	Jul 26	1250	1.45	WB
42	Jul 27	1305	2.40	CH
43	Jul 28	1310	1.00	WB
44	Jul 30	0930	0.20	DS
45	Jul 30	1320	1.55	CH
46	Jul 31	1230	3.00	WB
47	Aug 1	0405	0.35	WB
48	Aug 1	0500	0.30	RS
49	Aug 1	0600	0.30	RS
50	Aug 1	0700	0.30	RS
51	Aug 1	0805	0.35	RS
52	Aug 1	0905	0.40	RS
53	Aug 1	1000	0.45	WB
54	Aug 1	1105	0.40	WB
55	Aug 1	1215	1.20	WB
56	Aug 1	1425	0.30	WB
51	Aug 1	1530	0.35	WB
58	Aug 2	0945	2.45	RS
59	Aug 3	0745	2.30	WB
60	Aug 6	0640	0.25	RS
61	Aug 7	1240	2.00	WB
62	Aug 8	1245	2.30	WB-CH
63	Aug 9	1315	2.00	CH
64	Aug 10	0940	2.10	RS
65	Aug 13	1145	1.50	RS
66	Aug 13	1440	0.45	RS
67	Aug 14	0740	1.25	WB
68	Aug 15	0855	1.20	EM
69	Aug 16	0935	2.15	WB-RS

APPENDIX B

Research Plights in C-45

1961

Flight No.	Date	Take Off	Duration	Observer
1	Aug 14	1630	.5	DW
2	Aug 15	1400	2.0	D¥
3	Aug 18	1340	1.9	DW
4	Aug 21	1340	1.1	DW
5	Aug 23	1500	1.9	DW-WB
6	Aug 25	1430	2.0	WB
7	Aug 28	1335	2.3	WB
8	Aug 29	1330	2.5	WB
9	Aug 30	1330	3.0	WB
10	Sep 1	1200	2.9	WB
11	Sep 5	1315	2.4	WB
12	Sep 6	1330	2.7	WB
13	Sep 8	1330	2.1	WB
14	Sep 12	1115	3.0	WB
15	Sep 13	1230	2.2	WB
16	Sep 14	1030	2.6	WB
17	Sep 15	1420	1.9	WB
18	Sep 20	1400	.9	WB
19	Sep 22	1200	2.5	WB
20	Oct 4	1220	2.5	WB
21	Oct 19	1130	.8	WB-CBM
22	Oct 26	0630	4.6	WB-DS

Research Plights in C-45

1962

Plight No.	Date	Take Off	Duration	Observer
1	May 11	1035	2.25	WB-DS
2	May 17	1225	2.20	GS-EM-DS
3	May 22	1305	1.25	RS-WB-EM
4	Jun 5	1310	1.00	RS-WB-DS
5	Jun 11	1110	1.40	WB-GS-EM
6	Jun 11	1420	1.50	RS-EM
7	Jun 14	1100	2.15	RS-EM
8	Jun 18	1210	2.40	RS
9	Jun 22	1110	2.00	RS-DS-EM
10	Jun 23	1110	1.45	RS-EM-CBM

APPENDIX B (cont'd)

Research Plights in C-45

1962

Flight No.	Date	Take Off	Duration	Observer
11	Jun 28	1230	0.45	RS-EM
12	Jun 29	1310	2.20	RS-EM-DS
13	Jul 3	1315	1.15	RS-DS
14	Jul 6	0840	1.00	RS-EM-BV
15	Jul 6	1110	0.55	RS-EM
16	Jul 6	1410	1.40	WB-EM-JK
17	Jul 11	1230	2.20	RS-EM-DS
18	Jul 25	0910	2.00	RS-WB
19	Jul 25	1320	1.50	WB-DS
20	Aug 8	1300	2.25	EM-DS
21	Aug 9	1320	2.10	WB-DS
22	Aug 15	0850	1.30	RS-DS-WB
23	Aug 15	1235	0.30	RS-DS-CH
24	Aug 21	0825	1.00	BS-GS-EM
25	Aug 29	0725	2.15	WB-EM-GS
26	Aug 29	1415	0.40	WB-EM-GS
27	Aug 30	1025	2.20	WB-EM-GS
28	Sep 13	0915	1.10	WB
29	Sep 25	1250	1.20	RS-DS-PS

Observer Listing

DS - D. Staggs
WB - W. Bradley
RS - R. Semonin
GS - G. Stout
CH - C. Hayes
EM - E. Mueller

CBM - C. B. Moore
BV - B. Vonnegut
JK - J. Kraakevik
PS - P. Squires
DW - D. Watson
MMcC - M. McGord