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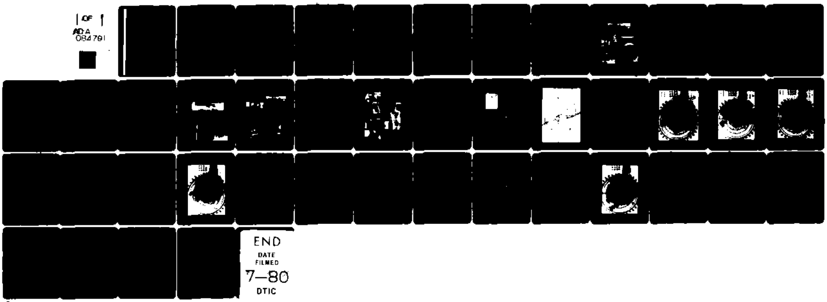

FEDERAL EVALUATION OF LIGHTNING TRACKING SYSTEMS (FELTS)

FINAL REPORT

By

R. L. Johnson

FINAL REPORT

for

N00014-79-C-0223

Prepared for

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ARCTIC AND EARTH SCIENCES DIVISION
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A side-by-side performance evaluation of two lightning tracking systems was done at Kennedy Space Center, Florida during the period 1 June-13 July 1979. The competing systems were manufactured by Lightning Location and Protection Inc. (LLP) and by Atlantic Scientific Corp. (ASC). Although the ASC system satisfied a preliminary performance test, it was observed that the device required continuing modification by the manufacturer. The LLP system experienced two hardware failures
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during this period, but otherwise operated 24 hours daily in an automatic unattended data acquisition mode.

Because of the continuing developmental effort required on the ASC device, it was determined that the operational evaluation of this system was premature.

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A

ILLUSTRATIONS

I. INTRODUCTION AND OBJECTIVE

This study was undertaken to evaluate the comparative performance of two lightning tracking systems. The design concept of both systems is based upon radio direction finding (RDF) at separated sites and triangulating lines of bearing to determine the location of the signal source. The direction finders are crossed loop sensors, originally proposed by Watson-Watt and Herd.(1)* The crossed loop direction finder is well known for its large bearing errors in the presence of a horizontally polarized electromagnetic field.(2)(3) To overcome this difficulty, both systems employ a waveform analysis algorithm which is designed to discriminate between cloud-to-ground and cloud-to-cloud lightning events. Thus, by recognizing the initial portion of a stroke to ground, which is generally oriented vertically, horizontal polarization errors can be reduced.

The objective of the evaluation is to assess system performance in terms of four criteria: (1) location accuracy, (2) misidentified lightning events, (3) false alarm probability and (4) failure to alarm probability.

Tests were performed at Kennedy Space Center. Location accuracy was taken from two sources of ground truth: (1) a network of three all-sky cameras deployed by SwRI and (2) sightings of lightning events made by an observer. The evaluation of misidentified lightning events is determined by the incidence of cloud-to-cloud flashes classified as cloud-to-ground strikes. The false alarm probability is derived from the observer input and weather radar data. This is given by the ratio of invalid location reports (for which there is no meteorological basis), to the total number of reports by each system. The failure-to-alarm probability is the ratio of missed cloud-to-ground strikes, identified by the camera network or observer, to the total number of positively identified cloud-to-ground strikes.

*See References.

II. EXPERIMENTAL DESIGN

The experimental design of this study was dictated in part by the evaluation of six lightning warning systems for the U. S. Bureau of Mines under Contract J0387207. The evaluation reported herein was undertaken as a supplementary effort to the work funded by the Bureau of Mines.

A. System Operation

The direction finding sensors for both systems are crossed loop antennas whose principle of operation has been exploited since the 1920's. The crossed loop method of direction finding has a 180° ambiguity in determining the azimuthal angle of arrival. This problem is resolved differently in the two systems. The Lightning Location and Protection (LLP) system uses a flat plate electric field sensor at each crossed loop site to determine whether the lightning discharge lowered positive or negative charge to earth. A positive electric field excursion implies that negative charge was lowered, and thus the direction of the magnetic field can be determined. This resolves the 180° ambiguity.

The bearing ambiguity is resolved somewhat differently in the Atlantic Scientific Corporation (ASC) system. In this system, three crossed loop sensors are deployed and the two lines of bearing from each site are projected to compute location predictions. The location which best satisfies a "consistency" criterion is determined to be the correctly resolved positional fix, the optimally consistent fix being a single point where all three lines of bearing intersect.

As pointed out by Taylor[2] and Uman, et al,[3] crossed loop direction finding errors due to horizontal polarization can be extremely large for signal sources in close proximity to the antenna site. To overcome errors due to horizontal components, both the LLP and ASC systems employ a signal recognition algorithm which discriminates cloud-to-ground versus inter-cloud lightning events. The cloud-to-ground test is based on two criteria: (1) time to initial peak, typically 5 to 10 microseconds, and (2) decay time, approximately 40-50 microseconds. If these conditions are satisfied, the initial peak value is used to determine the angle of arrival. A detailed description of this technique is given by Krider, et al[4] and Herrman, et al.[5] Only the initial portion of the received waveform is used for direction finding analysis (typically the first 100 meters of the lightning channel). Thus, it is assumed that this portion of the return stroke is predominately oriented vertically.

Although the concept of operation is the same in both systems, there are significant differences in the implementation. In the LLP system the line of bearing to a lightning strike is determined at each of the two remote sites. The bearing is computed to each return stroke (maximum of 8) in the lightning flash. These are tested for consistency and averaged. The results of this analysis is then transmitted to a position analyzer at the central facility. Given that the reports from the two remote sites are time coincident, the position analyzer computes a location fix at the point where the lines of bearing intersect. Communication between the two remote sites and the central facility is half duplex over single pair land line wires at 300 baud to each site. A transmitting modem is required at each remote site and two receiving modems are required at the central facility.

The ASC system uses three crossed loop sensors as compared to the two antenna deployment of the LLP system. In the ASC implementation, the received signals from the lightning strikes are digitized at each of the three sites and the digital data are transmitted to the central facility. The central processor performs the waveform analysis, computes lines of bearing from the three sites and calculates the location of the lightning strike. The ASC system does not compute a bearing on the initial return stroke in the flash, since the manufacturer believes that the branching which frequently occurs in this stroke (and not in subsequent strokes) produces sufficient horizontally polarized components to vitiate a bearing measurement. It is observed that this algorithm does not permit location estimates of single stroke lightning flashes. Communication from the three remote sites to the central facility is full duplex over two pairs of land line wires at 1200 baud.

An additional difference in the analysis technique used in the two systems is the signal passband of the remote sites. The LLP passband spans approximately 1 kHz to 400 kHz while the ASC system passband is 1 kHz to 50 MHz. Thus, both systems employ wideband receivers and signal processing. The bandwidths reported here are those expressed verbally by each manufacturer and are assumed to be approximate.

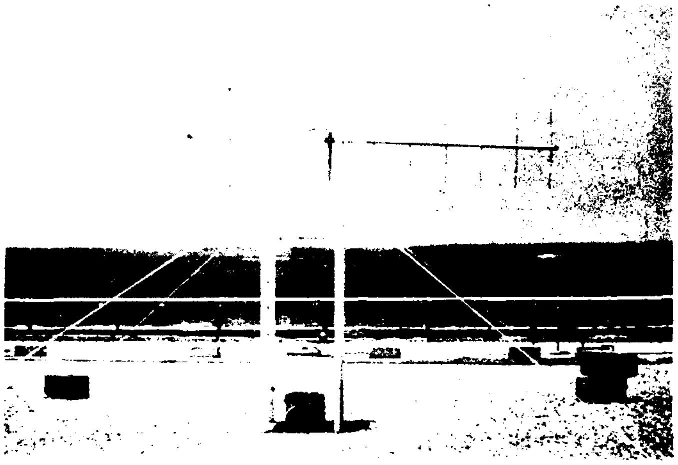
The concept of gating a receiver on the initial portion of a received atmospheric to reduce bearing errors due to horizontal polarization is not a new technique but has been employed for a number of years.[6] The new technology being exploited in these systems is the discrimination of cloud-to-ground lightning events versus inter-cloud discharges.

B. Optical Location System

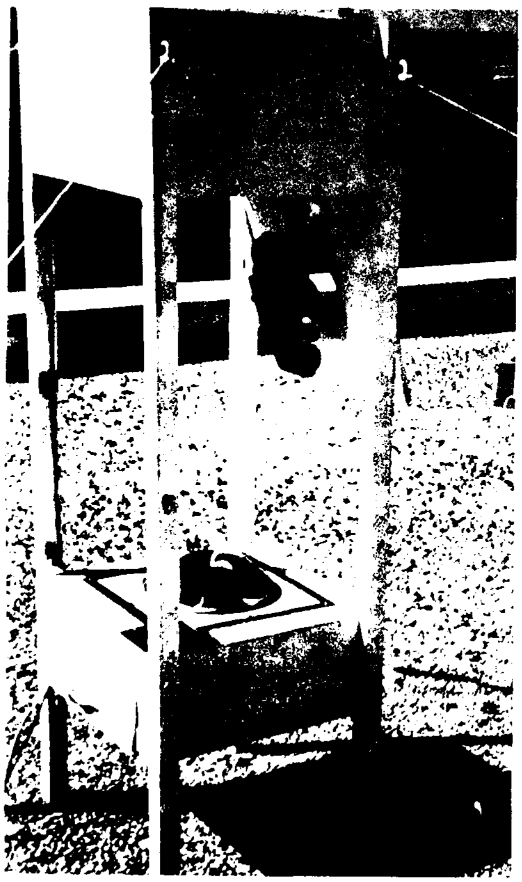
To provide precise lightning location data for the assessment of positional accuracy of the two systems, a network of three all-sky cameras was constructed.* One of the all-sky cameras is shown in Figure 1. The antenna system, stand, and battery power are shown in Figure 1(a). Cloud-to-ground lightning events were detected at the SwRI mobile laboratory. The ground flash detector was a modified version of a flash counter described by Prentice, et al.[7] When a ground strike was detected, the circuit keyed a 235 MHz transmitter. This signal was received at the camera sites and was used to actuate the camera shutter. The VHF radio receivers at each of the three sites, transmitting monopoles, and 11-element directional receiving antennas were acquired as stock commercial equipments.

As shown in Figure 1(a) the camera and associated electronics are powered by the 12-volt storage battery located beneath the stand. The

*Funded under another contract in this laboratory.



(a) Receiving Antenna and Housing



(b) Electronics Access

(c) Lightning Strike

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camera views a parabolic reflector which images the visible sky to the horizon. The camera shutters are activated by the initial lightning stroke with an inherent delay time of 95 milliseconds.

The close-up view in Figure 1(b) illustrates the access to the camera and receiver electronics located in the upper portion of the stand. When the hinged door is closed, the camera looks down upon the convex parabolic reflector and a clock as shown in Figure 1(c). A lightning strike is shown in Figure 1(c) illustrating the triangulation algorithm. Each camera was surveyed so that 0 degree on the template is aligned with true north. In the case shown, lightning struck ground at an azimuth of 345.5 degrees from the site. This procedure was originally employed by Kidder.[8]

Also shown in Figure 1(c) are the LEDs used for nighttime photography situated at 0, 90, 180 and 270 degrees with two at 0 degree. The LEDs are used to align an azimuth template for night photographs since the azimuthal grid does not photograph in the dark.

C. Visual Observations

During the period of evaluation, an observer was provided by the Cape Canaveral Air Force Station. The observer reported lightning events which were visible from the cupola atop the O&C Building at Kennedy Space Center. This vantage point provided a clear view of the NASA complex, although there was some degree of visual obstruction toward the east southeast.

Shown in Figure 2 is the format of the visual lightning events reported by the observer. The report provides time resolved to the nearest second, nominal direction to the lightning event, whether the strike was to ground or inter-cloud and space for remarks concerning unusual phenomena. The time standard used by the observer and those used in both location systems were synchronized to WWV. Thus, worst case error in time synchronization was of the order of one second. A compass had been mounted in the cupola so that nominal direction to the strike could be determined within ± 10 degrees.

Additional support furnished by the Air Weather Service at Cape Canaveral included storm alert notices. SwRI was notified when thunderstorm activity was indicated within a 25 nautical mile radius of the central facility. Also a direct telephone line was connected between the Air Weather Service radar facility and the SwRI mobile laboratory to provide storm tracking information while data acquisition was in progress.

D. Location System Deployment

The deployment of system antennas is shown in Figure 3. The LLP antennas were located at DF site No. 1 (block house 43) and DF site No. 2 (slide wire site near pad 39A). Two of the ASC antennas were co-located with the LLP sensors and the third antenna was located at DF site No. 3 (Tico Airport). Also shown in Figure 3 is the placement of the SwRI mobile laboratory at camera site FCA1 and the deployment of the all-sky cameras at camera site 1-3.

LIGHTNING OBSERVATIONS FOR:
THE FEDERAL EVALUATION FOR LIGHTNING TRACKING SYSTEM (FELTS)

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STORM 30

DATE/TIME (GMT)	NOMINAL DIRECTION	CLOUD TO GROUND STRIKE	INCLOUD STRIKE	REMARKS
09 0650:06	095		✓	
0650:12	035		✓	
0650:49	035		✓	
0651:26	020		✓	
0651:44	095		✓	
0651:48	020	✓		
0652:26	020		✓	
0652:50	020		✓	
0653:09	070		✓	
0653:54	360-030		✓	
0654:20	010		✓	
0654:30	080		✓	
0654:36	020		✓	
	360		✓	
0654:58	025	✓		
0655:41	015		✓	
0655:59	095		✓	
0656:07	018		✓	
0656:19	095		✓	
0656:55	023		✓	
0657:00	095		✓	
0657:15	015		✓	
0657:46	010		✓	
	040		✓	
0657:52	020		✓	

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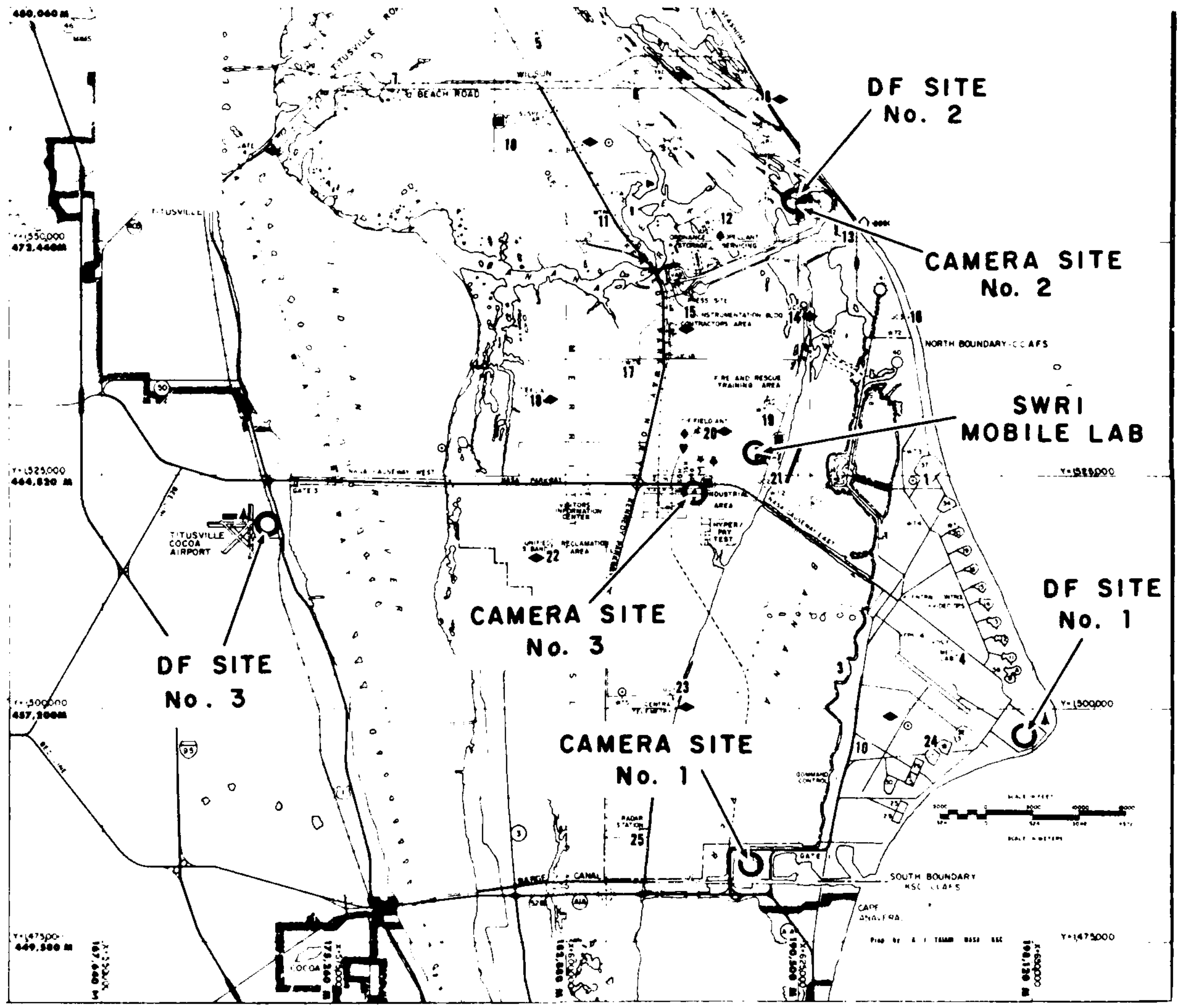
Figure 2. Lightning Observation Report



JOHN F KENNEDY SPACE CENTER,
NASA

FIGURE 3. LOCATION SENSOR DEPLOYMENT

The SwRI mobile laboratory is illustrated in Figure 4(a). The laboratory is a 23-foot aluminum trailer. Figure 4(b) shows an interior view of the mobile laboratory in which the central processor for both systems were situated.

Shown in Figure 5 is the sensor deployment for the LLP antennas. Figure 5(a) shows DF site No. 2 near pad 39A, and Figure 5(b) shows DF site No. 1 near block house 43. The deployment of the ASC antennas are shown in Figure 6. The antenna situated at Tico Airport is shown in Figure 6(a). The sensor at block house 43 is illustrated in Figure 6(b) and the antenna placed near pad 39A is shown in Figure 6(c). It is observed that at the latter two sites, the sensors were mounted atop utility poles.

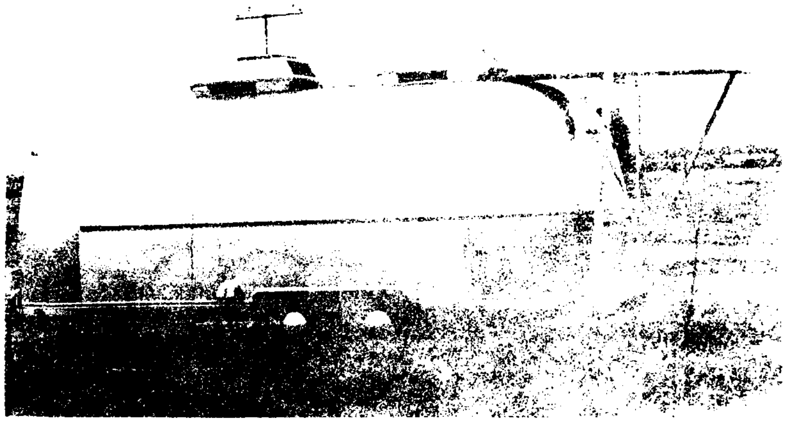
Deployment sites for the optical location system is shown in Figure 7. The camera site atop the O&C Building is illustrated in Figure 7(a). The camera site near pad 39A is shown in Figure 7(b) and the site atop the pass and ID Building is displayed in Figure 7(c). It had been planned to situate a camera system near gate three at the western entrance to Kennedy Space Center; however, this site was abandoned in favor of the O&C Building to increase the probability of detecting grounded strikes by more than one camera system.

The location of the SwRI mobile laboratory is shown in Figure 8. As can be observed from the illustration, the elevated camera site provided an unobstructed view in all directions which enabled operators to visually track thunderstorm activity in the area.

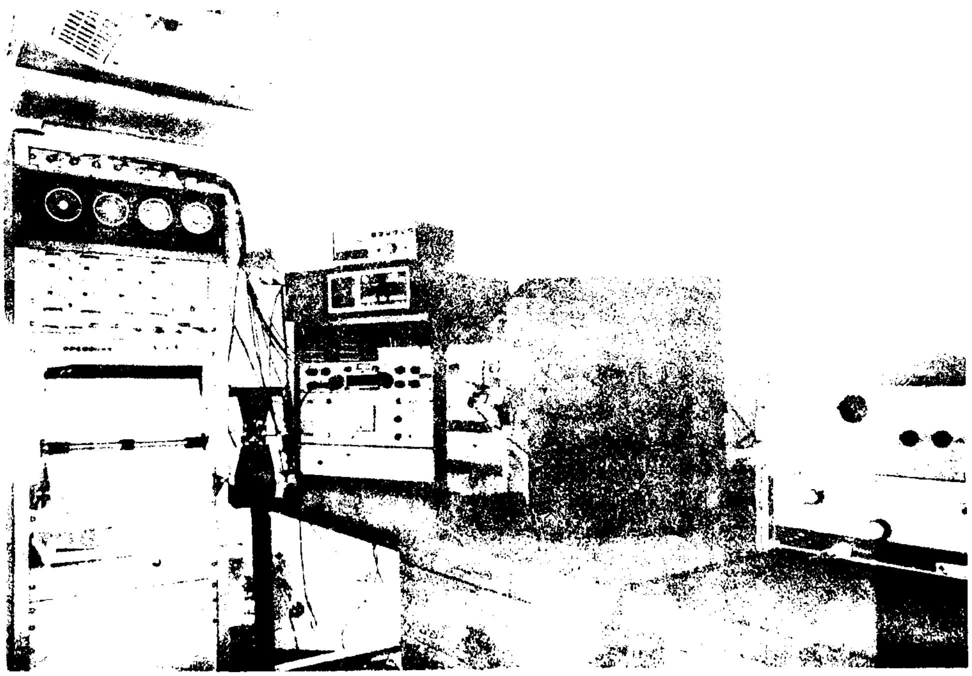
The electronics associated with each system are shown in Figure 9. The processors at the remote sites are illustrated in Figure 9(a). The large chassis situated in the left most portion of the shelf is the ASC processor and the two smaller chassis (stacked one upon the other);at the right of the shelf are the LLP processors. The devices between the two are telephone modems. The ASC electronics located at the SwRI mobile laboratory is shown in Figure 9(b). This includes a line printer, a floppy disk drive, a central processor and a display console. The LLP electronics are shown in Figure 9(c) and includes a plotter, a central processor and a TTY.

E. Installation and Data Acquisition

On 3 May 1979, Southern Bell Telephone Company was requested by SwRI to install data modems connecting the remote sites to the central processors in the SwRI mobile laboratory. This work was to be completed on or before 31 May so that tests could begin on 1 June 1979 and conclude on 13 July 1979. The SwRI mobile laboratory was placed on site 24 May 1979 and departed Kennedy Space Center on 13 July 1979. Southern Bell indicated that modem installation was scheduled to begin on 29 May 1979 and complete by 1 June 1979. Actual completion date of installation by Southern Bell was 15 June 1979. Deployment by ASC commenced on 14 June 1979 and was completed on 26 June 1979. The LLP system was installed and operational on 15 June 1979; however, a failure in the telephone modems was observed on 16 June 1979 and corrected on 21 June 1979.



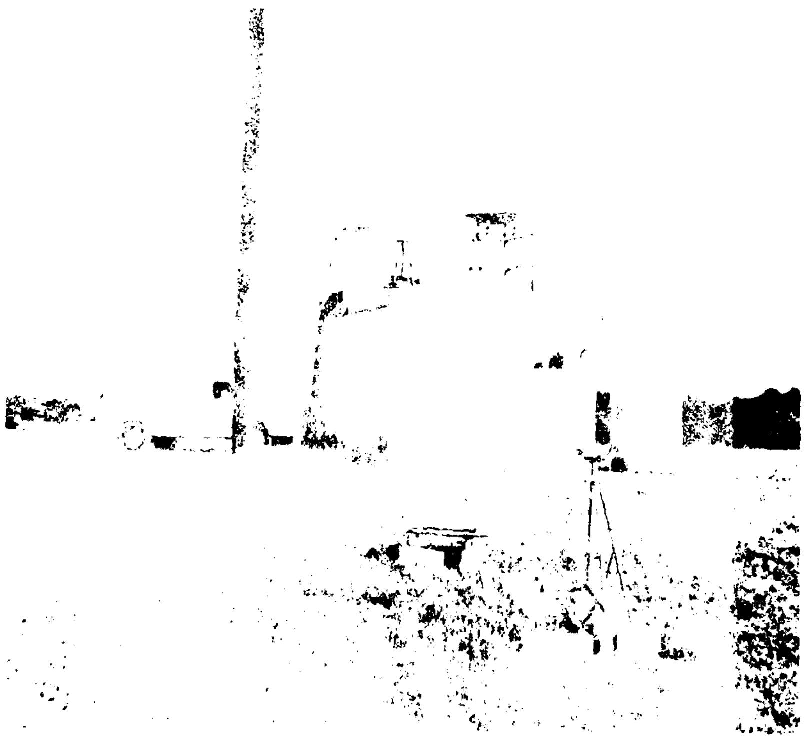
(a) SwRI Mobile Laboratory



(b) Interior View of M [illegible]

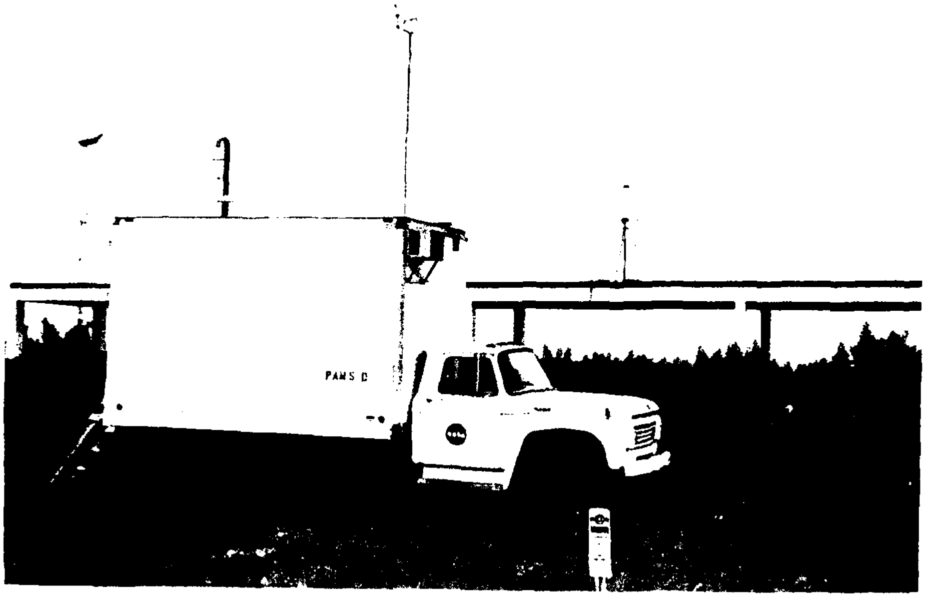
FIGURE 4. CENTRAL LABORATORY FACILITY

(a) Location Sensor Near Pad 39A



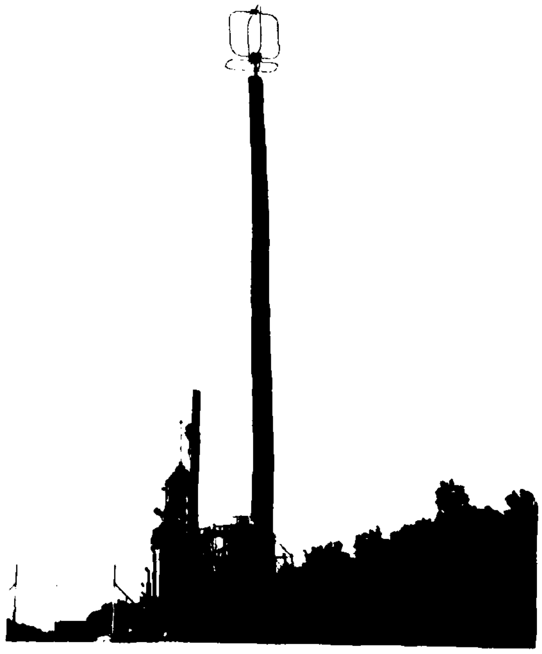
(b) Location Sensor Near Met Rocket Launcher

FIGURE 5. LLP SENSOR DEPLOYMENT AT KENNEDY SPACE CENTER



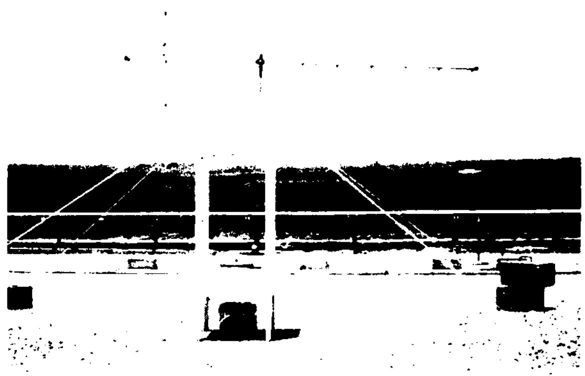
(a) Location Sensor At Tico Airport

(b) Location Sensor Near MET Rocket Launch Pad



(c) Location Sensor Near Pad 39A

Figure 6. ASC Sensor Deployment At Kennedy Space Center

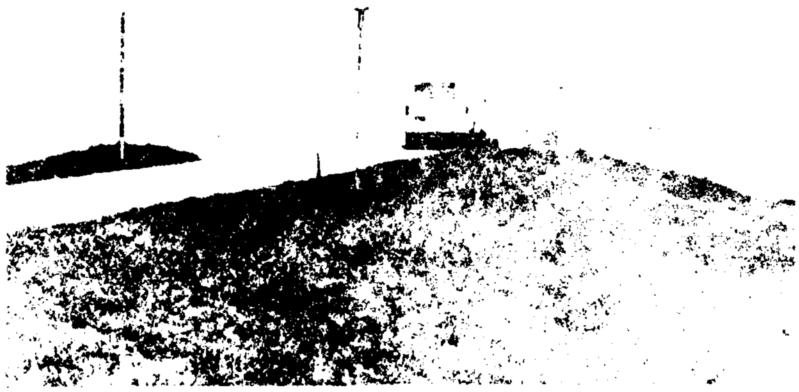


(b) Camera Site Atop the O & C Building

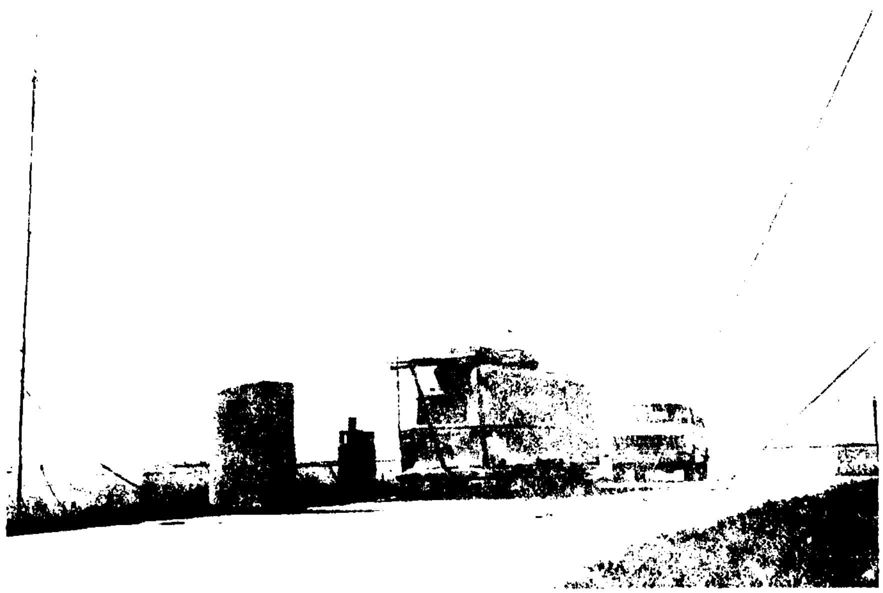
(a) Camera Site Near Pad 39A

(c) Camera Site Atop the PID Building

FIGURE 7. OPTICAL LOCATION SYSTEM DEPLOYED AT KENNEDY SPACE CENTER

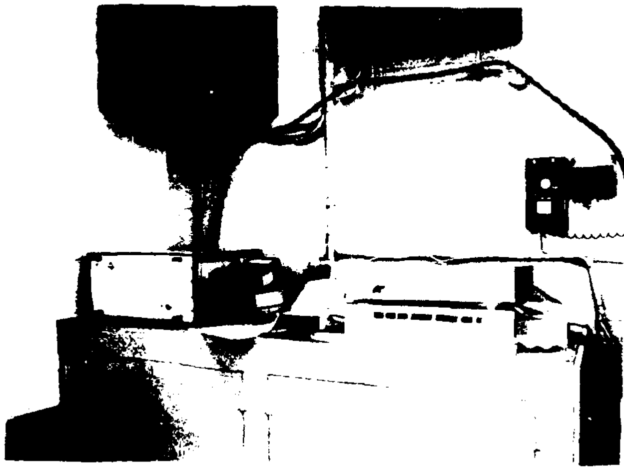


(a) KSC Site Looking North



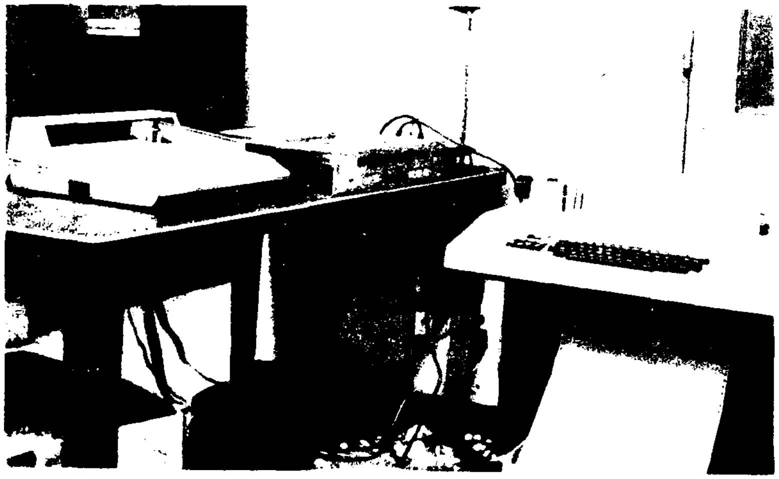
(b) KSC Site Looking S[illegible]

FIGURE 8. MOBILE LABORATORY SITE AT KENNEDY SPACE CENTER



(a) Remote Site Electronics

(b) ASC Central Facility



(c) LLP Central Facility

Figure 9. Lightning Location System Electronics

An initial task in the conduct of this evaluation was the verification of performance of the ASC location system. During the afternoon of 26 June 1979, 1700 EDT, an isolated convective cell developed within a triangular area bounded by Melbourne, St. Cloud and Cocoa Beach, Florida. This cell was located 22 to 25 miles distant from the SwRI mobile laboratory and was the only discernible echo on the Cape Canaveral Air Force Station Air Weather Service radar. The data collected during this period are shown in Figure 10. The cross-hair plot on the NWS radar map are the locations computed by the LLP system. The inset map at the upper right is the data plot photographed on the ASC display CRT. The dots indicate lightning strike locations. The cluster of lightning activity as detected by both systems was in agreement with the meteorological activity indicated by weather radar. The lightning strikes were occurring at the rate of one every ten to twenty seconds, and it was observed that both systems were reporting ground strike locations on the same flash, the LLP system computing somewhat faster. The ASC operating software at this time did not report individual flash location data to the line printer. This required a subsequent modification to provide the capability for comparison testing with the LLP system. Based upon the observations made during this single storm event, it was determined that the ASC system had the capability to detect and track lightning events.

During the period 27 June 1979 through 9 July 1979, the ASC system was undergoing software development to incorporate line printer output. Updated software implementing the line printer output was operational on 8 July. Additional enhancements provided were refinements to the CRT map display and a circle drawn about developing or active storm cells as determined from the computed lightning location data. The modified display is shown in Figure 11; however, there exists no corresponding line printer output for these data.

On 8 July 1979 a power interrupt caused the LLP processor to restart with the internal clock locked in a fixed state. This was due to weakened batteries which failed to maintain clock operation during power outage. The LLP system was operated on 8 and 9 July in this mode. The condition was not catastrophic since the remote site reported a line of bearing to the lightning strike. A computer program was written to postprocess the data for a determination of lightning strike locations. On 10 July 1979 GMT, the clock was reset at the remote site. The impact of the clock problem is that the LLP system could not locate lightning flashes which were separated by fewer than eight seconds in real time. Thus, it is possible that some lightning events were missed during operation on 8 and 9 July.

The data acquisition period over which both systems were operational was 8 July 1979 1633-1808 GMT, 9 July 1979 0647-0719 GMT, 10 July 1979 0130-0330 GMT, and 10 July 1979 1955-2045 GMT.

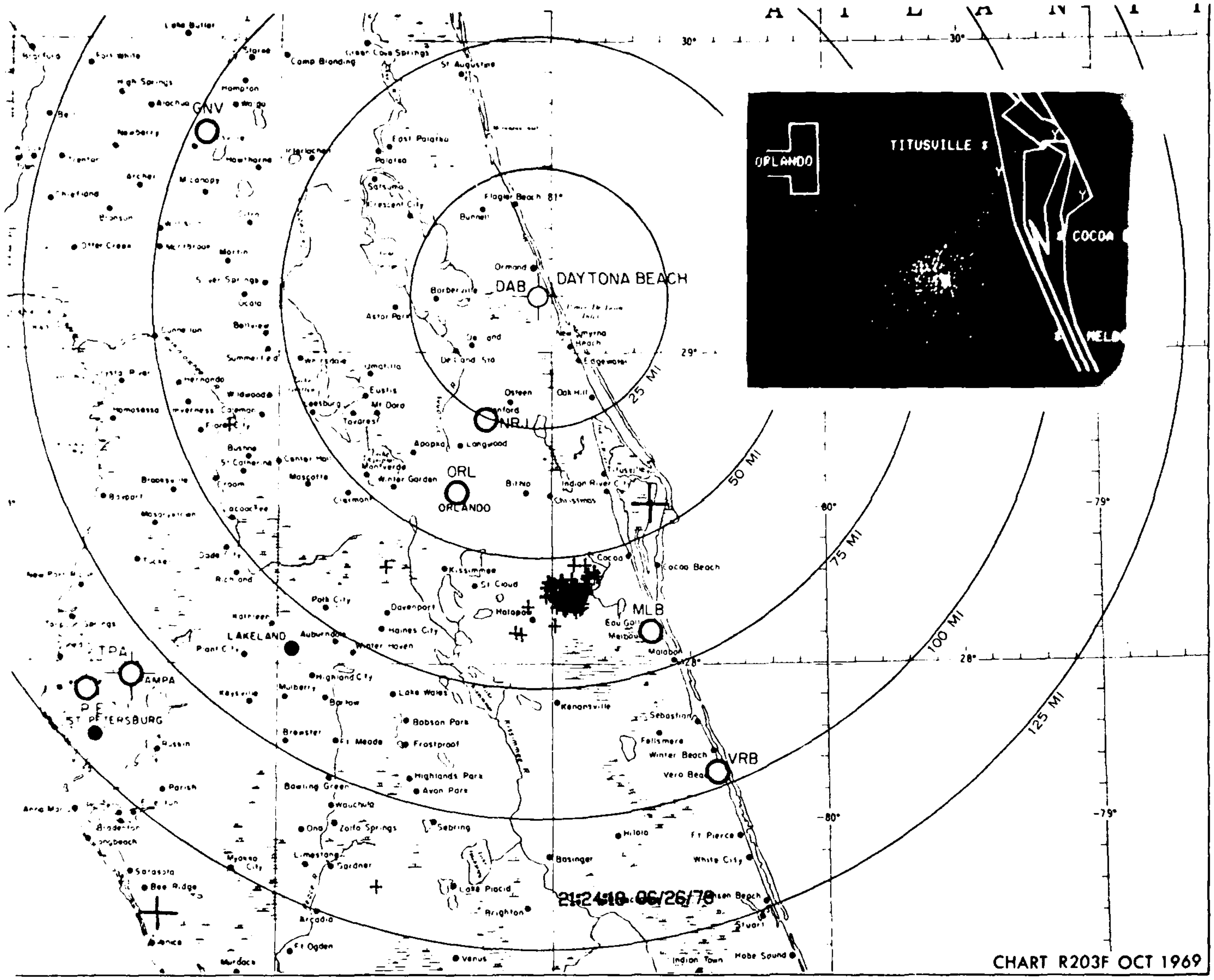


Figure 10. Performance Verification Data

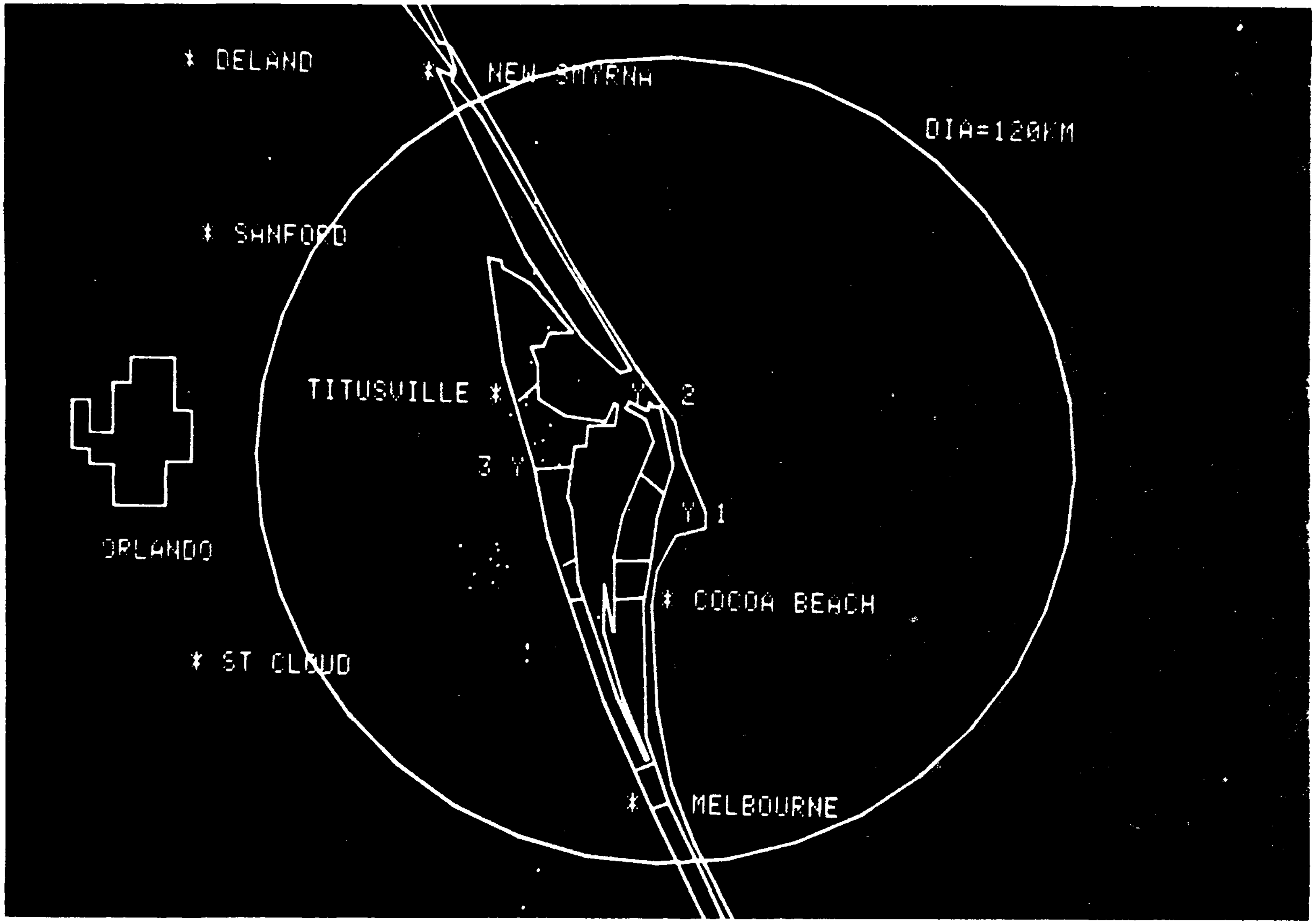


Figure 11. ASC Lightning Location Display

III. DATA ANALYSIS

A. Optical Locator Performance

The three all-sky locator cameras did not provide the consistent lightning location data anticipated for the tests. After the initial development and success with one camera at the SwRI site, it was expected that the system would produce useful location results routinely whenever electrical storms were within viewing range of at least two cameras.

Based on primarily mid to late afternoon storm activity at KSC, neutral density filters were acquired to overcome problems of daytime/nighttime exposures. In addition, separate development mixtures for daytime and for nighttime exposures provided twenty four-hour capability. Daytime and nighttime photographs taken at KSC demonstrated this approach was viable.

During testing at KSC, however, the inexpensive, relatively broadband camera trigger receivers were found to be vulnerable to the high density interfering signal environment at KSC. Consequently, the camera system continually false triggered. As a result of variable and persistent interference, only four two-camera correlated lightning photographs were obtained during the six week test period at KSC. Moreover, none of these data coincided in time with the period of time in which both location systems were operational.

Although use of an optical lightning location system is a good approach, experience in these tests shows improved camera trigger receivers with significantly less vulnerability to radio frequency interference are required. In addition, at least two more cameras should be deployed in the network to enhance the probability of lightning strike location for baselines of the order of seven to ten miles in the presence of overcast and obscurity due to rain encountered under field conditions.

B. Storm of 8 July 1979 (1633-1808 GMT)

At midday local time, a storm system developed over the KSC complex and extended approximately 100 nmi southward. The storm is shown in Figure 12 as observed on the NWS radar at Daytona Beach at approximately 1638 GMT. Figure 13 displays the system an hour later at 1732 GMT and Figure 14 was taken at 1808 GMT. As is indicated in the sequence of radar pictures, the storm was stationary over its lifetime.

During the storm, the ASC system reported 95 lightning events. These are plotted in Figure 15. A comparison of the data with the meteorological reports indicate a reasonable degree of correlation. One feature of concern is noted. The scatter of points to the northwest and to the southwest extremes lie on a straight line. It would appear that in many cases the east-west value remained fixed while only the north-south location estimate varied. It seems to be a highly unlikely distribution of lightning strikes; however, the median scatter about the west is quite reasonable.

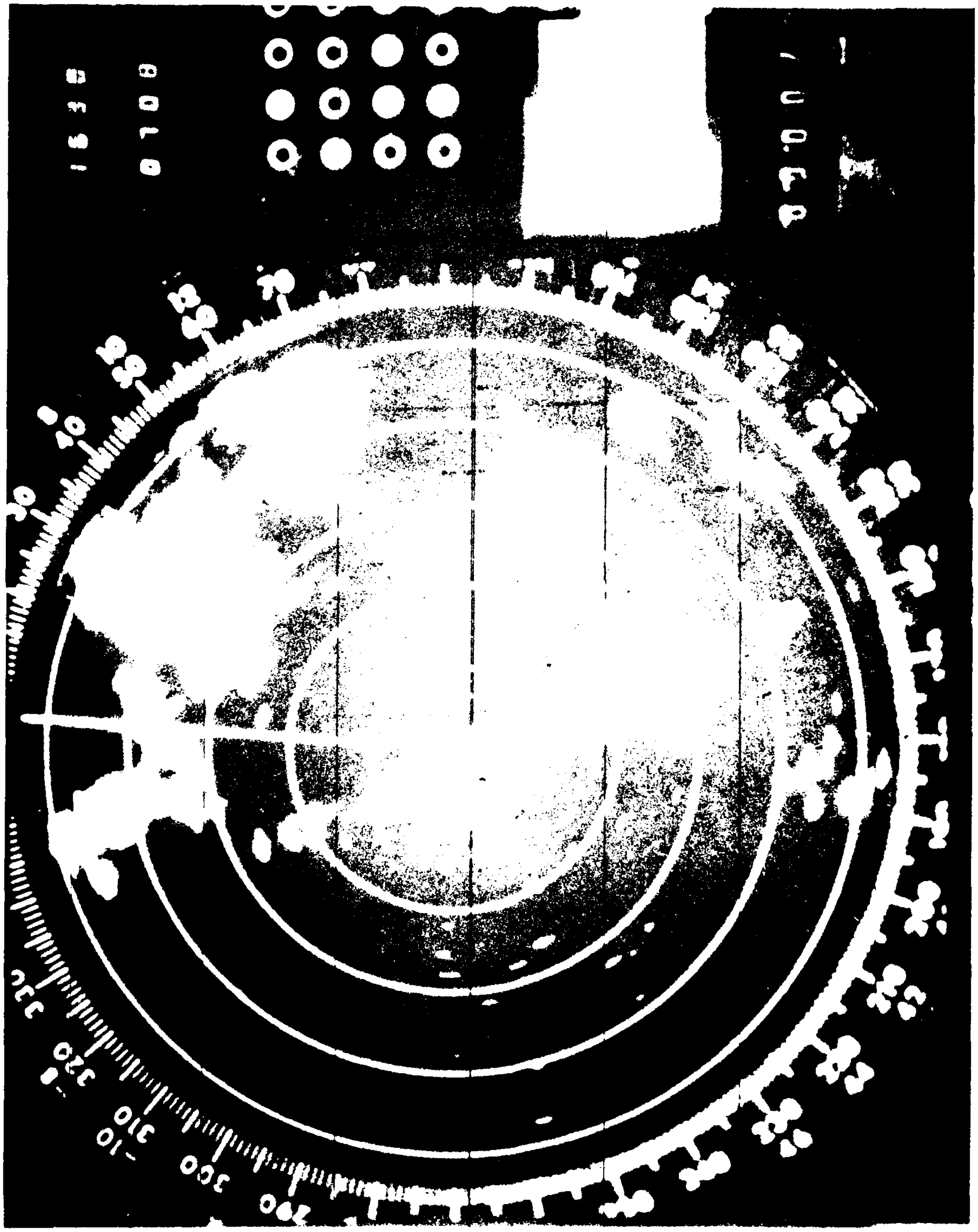


Figure 12 Daytona Beach Radar 8 July 70 1635 GMT

Figure 13. Daytona Beach Radar, 8 July 79, 1732 GMT

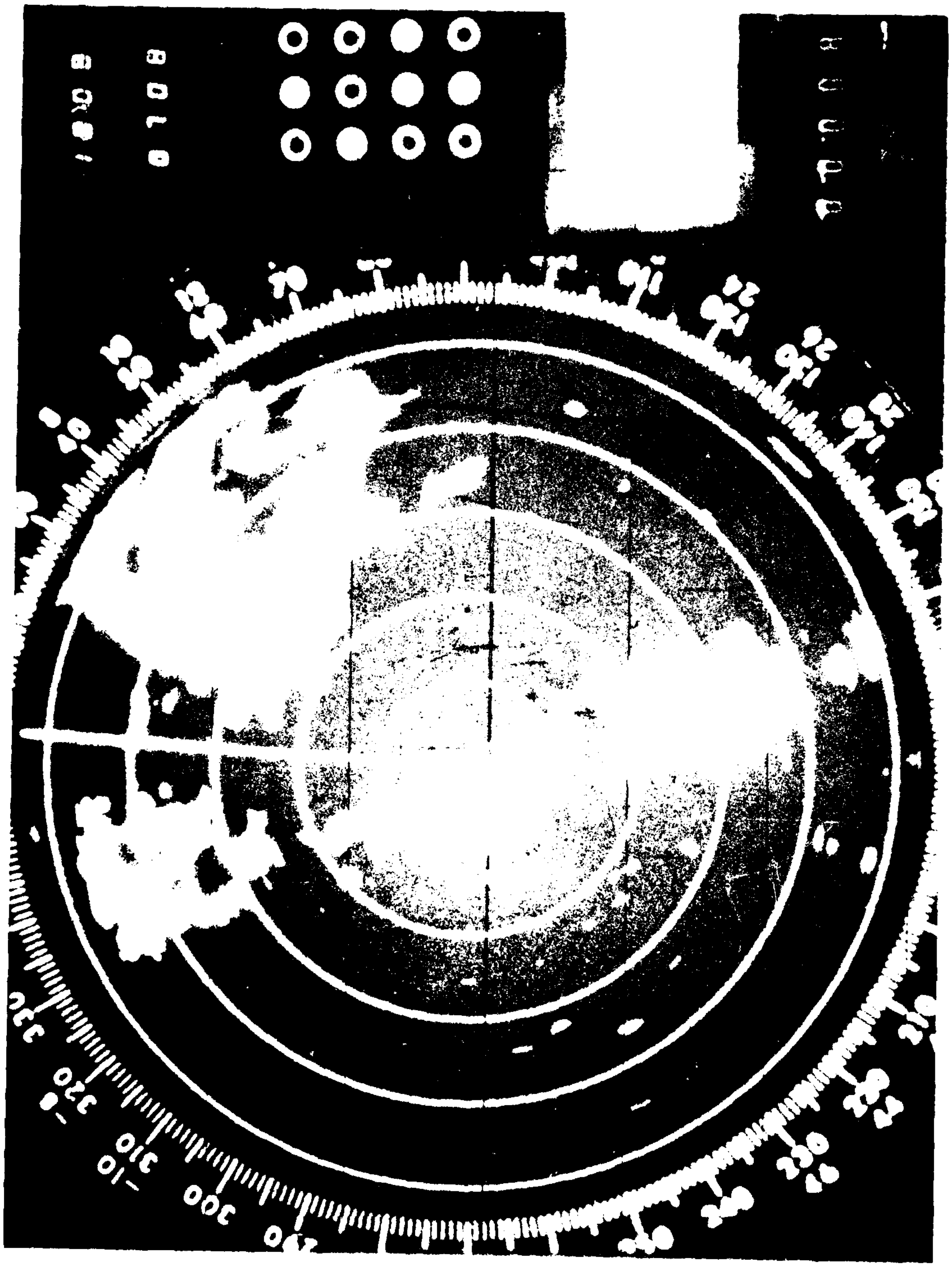


Figure 14. Daytona Beach Radar, 8 July 79, 1808 GMT

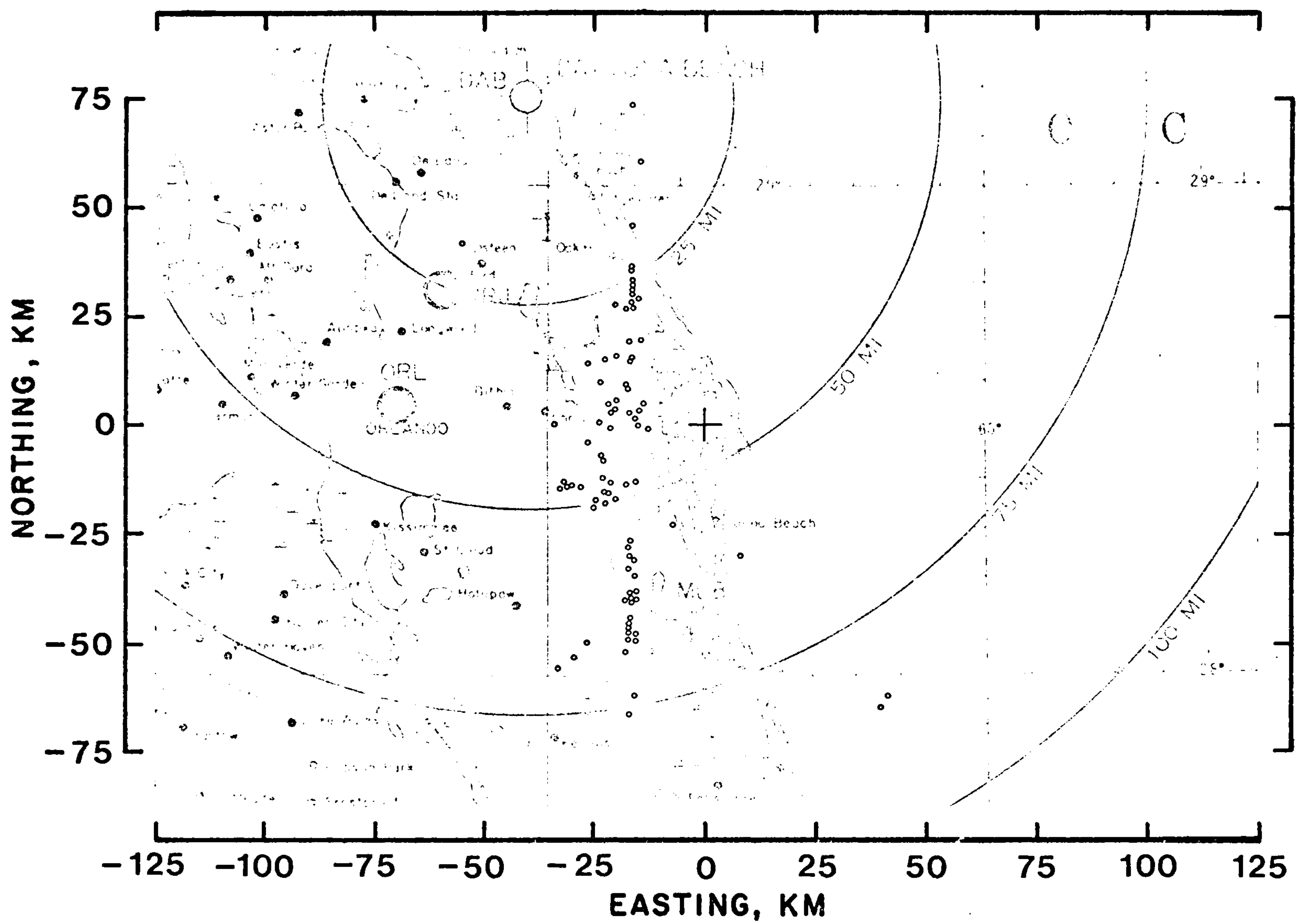


FIGURE 15. ASC LIGHTNING LOCATIONS, 8 JULY 1979 1633-1840 GMT

Figure 16 shows the corresponding scatter plot for the LLP system. During this same time period 64 lightning events were reported by the LLP device. The primary reason for the difference in lightning event counts resides in the fact that the LLP could report lightning events no closer in time than eight seconds. In this operating mode, a review of the data output indicates that the buffer capacity was sufficient to facilitate four observations from each remote site. These data were then output pairwise to the line printer. Time was assigned on output so that multiple return strokes were separated by eight seconds. Thus, in a strict sense, time of the lightning strike had several seconds of variability. Presumably, data were lost while multiple stroke reports were being made and worst case would have been 32 seconds. Again, the data seem to be scattered in reasonable agreement with the meteorological data.

During this period of time, 12 cloud-to-ground strikes were reported by the observer in the O&C Building. These were located to the west and northwest. The visual sightings would tend to correlate most favorably with the ASC scatter shown in Figure 15; however, not one visually reported ground strike can be credibly correlated with a location report made by either the ASC or LLP system. Correlations were attempted taking into account the differences in reporting time, computational time, systematic time offsets, etc., and nothing yielded credible results.

Correlation of lightning events reported by the two systems was also attempted and again no degree of correlation was evident. This was not a surprising result in view of the obvious differences in the scatter patterns of Figures 15 and 16.

C. Storm of 9 July 1979 (0647-0719 GMT)

Shown in Figure 17 is the NWS radar trace of a large storm system at 0658 GMT. Although widespread, this proved to be a relatively short duration storm of moderate electrical activity.

The scatter plot of lightning events reported by the ASC system is shown in Figure 18. There were 24 reported locations. The row structure of location data which were observed in the storm of 8 July is evidenced here in the east-west direction. In this case a number of points appear fixed in the north-south direction and vary only in the east-west direction.

A corresponding scatter plot for the LLP system is shown in Figure 19. This plot consists of 30 points which would suggest that the interval between strikes was longer than for the storm of 8 July, and thus, the number of events reported by the two systems are in closer agreement. A review of the times of the reported strikes reveals that this was in fact the case.

Nine visual observations of cloud-to-ground strikes were made during this storm. They were directed toward the northeast which would suggest a high degree of correlation with the LLP data shown in Figure 19. Of the nine visual reports only one appeared to be in agreement with the LLP data and none were found to correlate with the ASC data.

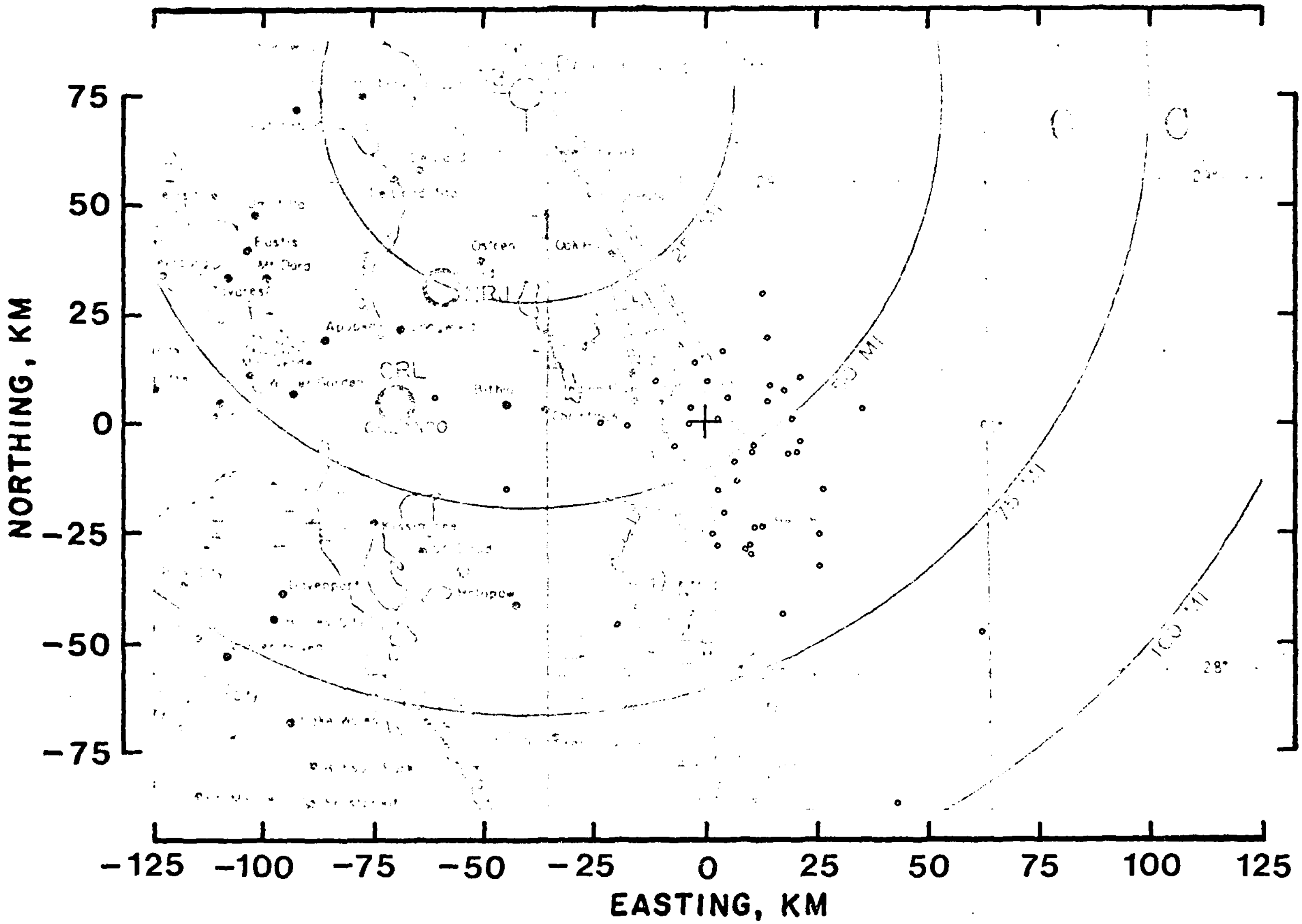


FIGURE 16. LLP LIGHTNING LOCATIONS, 8 JULY 1979 1633-1840 GMT

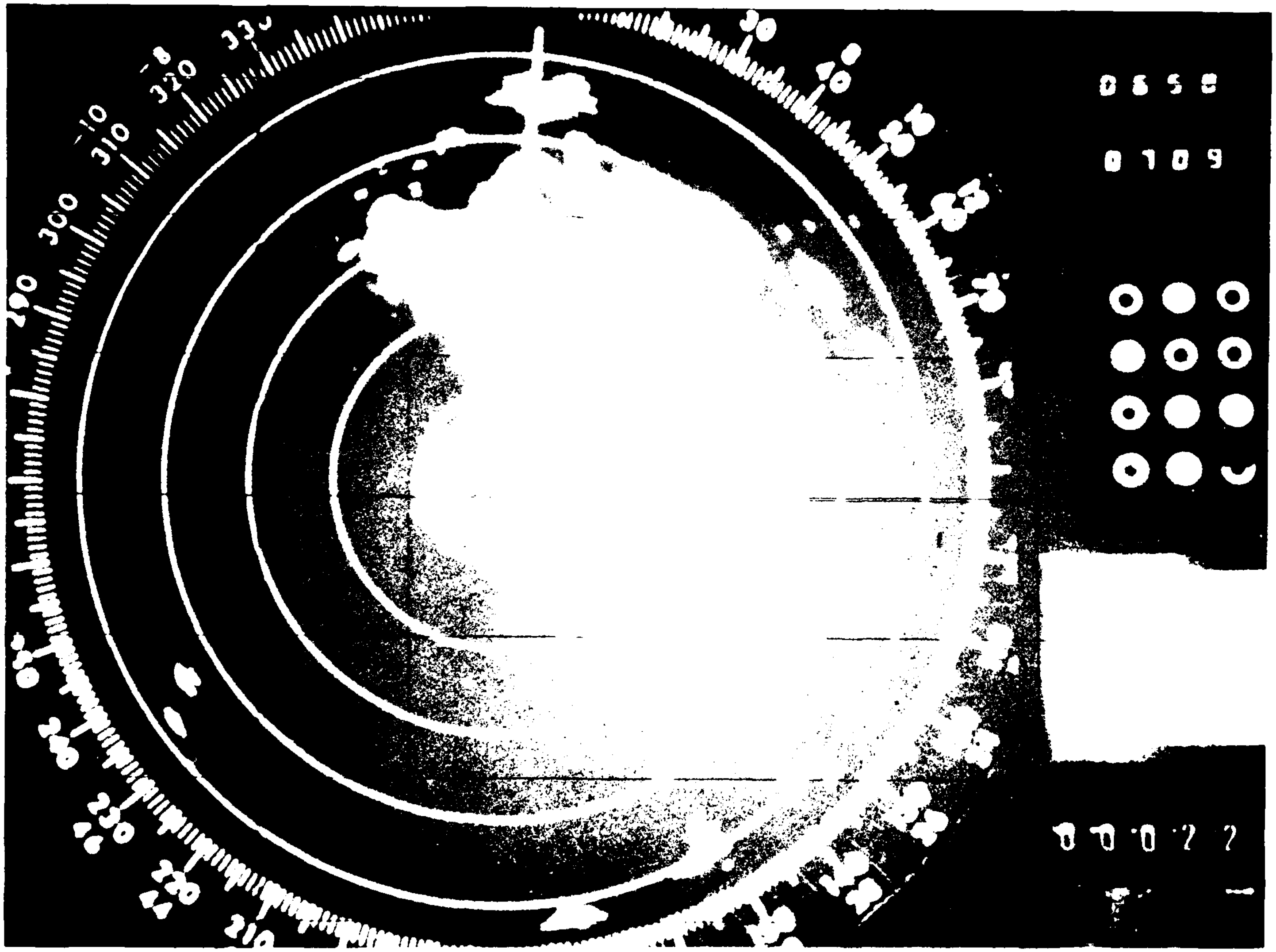


Figure 17. Daytona Beach Radar, 9 July 79, 0658 GMT

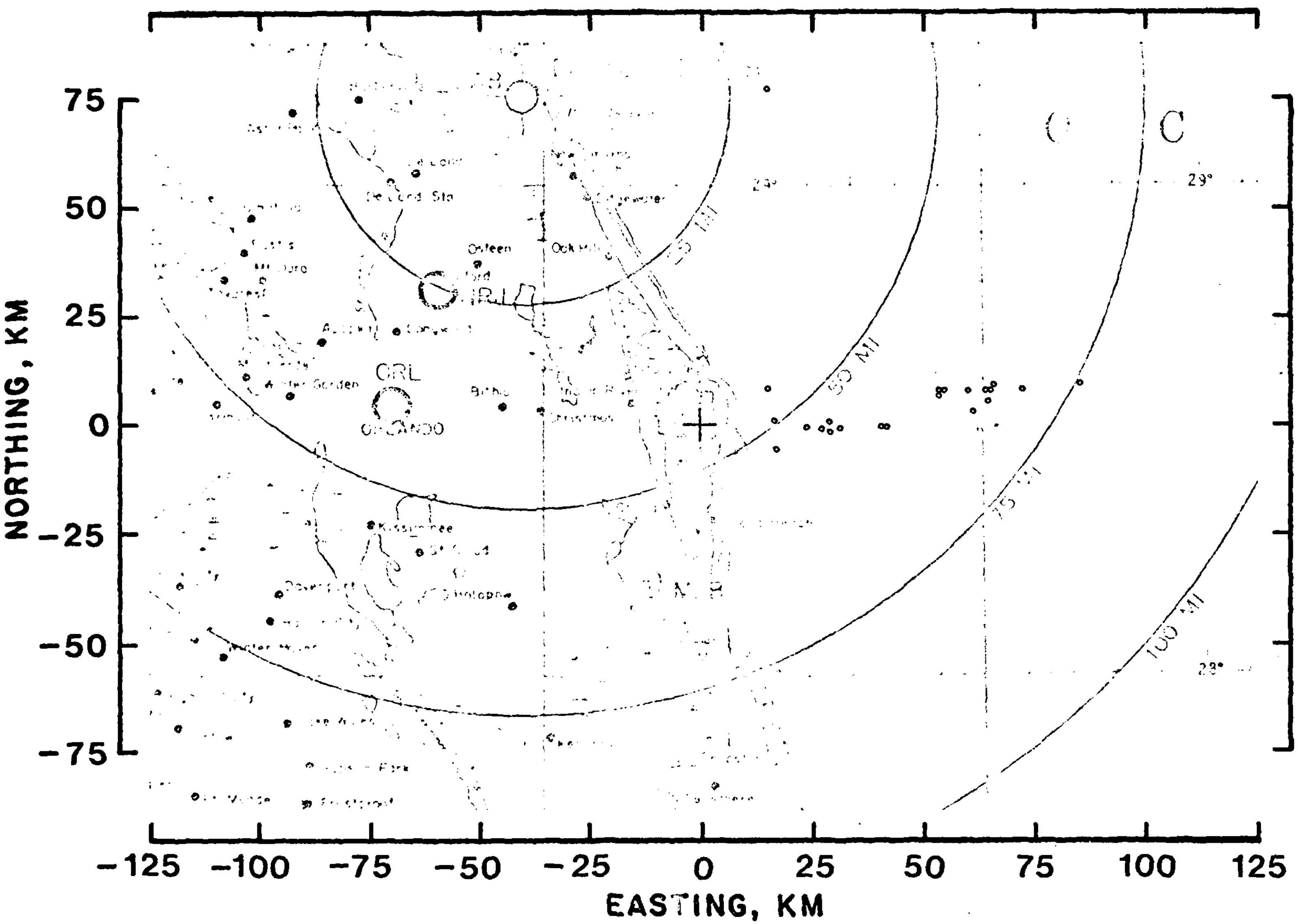


FIGURE 18. ASC LIGHTNING LOCATIONS, 9 JULY 1979 0647-0719 GMT

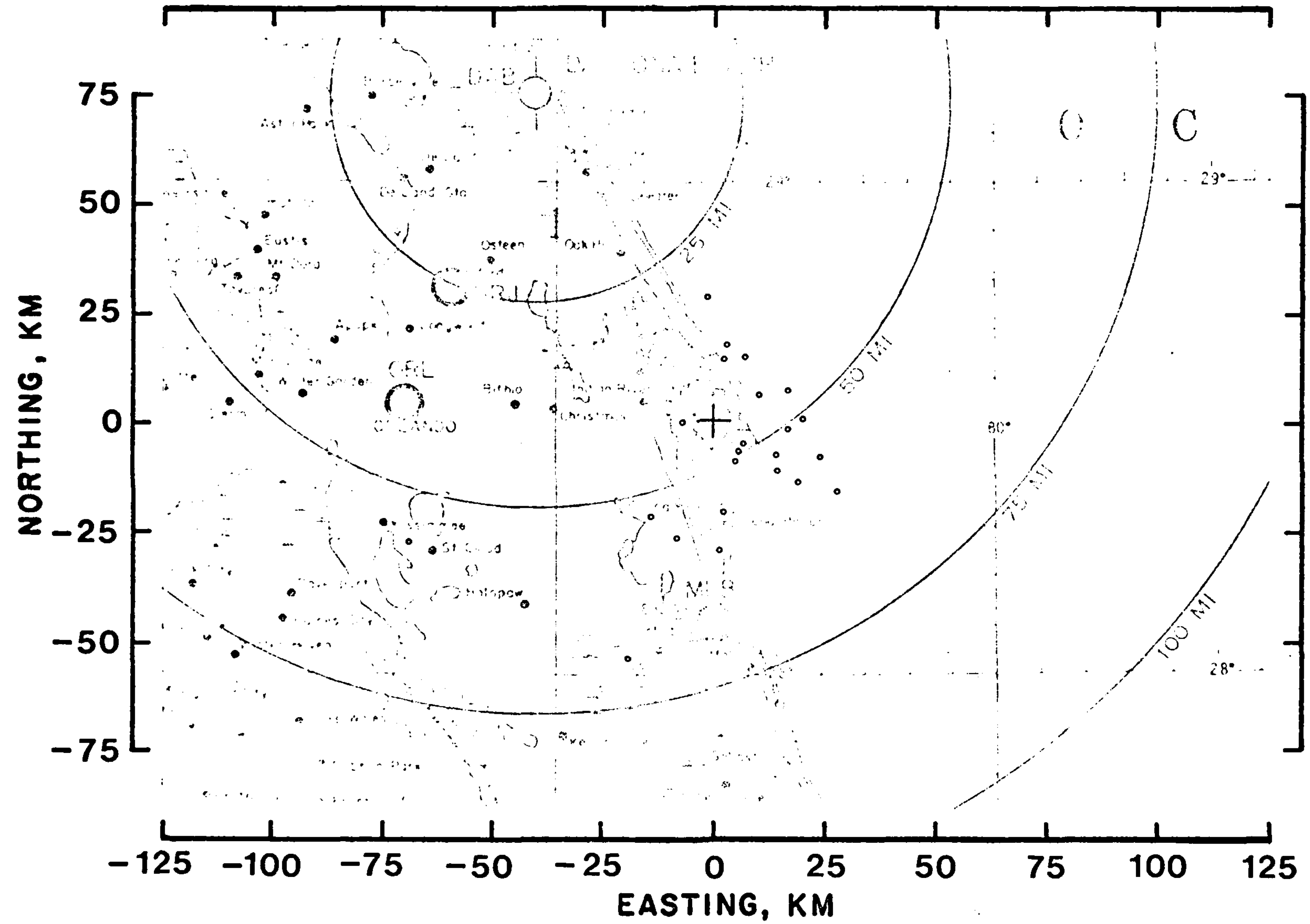


FIGURE 19. LLP LIGHTNING LOCATIONS, 9 JULY 1979 0647-0719 GMT

Again an attempt was made to correlate the location reports made by the two systems and no credible correlation was evident. As was pointed out previously, a visual comparison of the two scatter plots would suggest that no correlation existed.

D. Storm of 10 July 1979 (0130-0330 GMT)

During the late evening at 9:30 p.m., 9 July local time a severe thunderstorm moved inland from the Atlantic ocean and produced a tornado which caused considerable property damage in the Cocoa Beach area. The storm was extremely active electrically.

Figure 20 is a scatter plot of the ASC data reported during this storm. Ninety location computations were indicated. As is shown in the plot, the data show a heavy concentration in the Cocoa Beach area in association with the most intense meteorological activity.

Figure 21 is a plot produced by the LLP system during this time. The LLP clock at the remote site had been reset so that the system was fully operational. The LLP system reported 689 lightning events within this time span.

During this period there were 25 visually observed cloud-to-ground strikes. Correlating the LLP data with the visual data it was determined that the LLP clock was two seconds fast with respect to the observer's clock. Using time and azimuth as reported by the observer, 21 lightning location events were found to be highly correlated which would suggest that the LLP system has a detection probability of the order of 84 percent. In the case of the ASC data it was found the clock was five seconds slow with respect to the observer's clock. Of the lightning events reported by the ASC system, 14 locations could be reasonably correlated with the visual data which implies a detection probability of 56 percent.

It was also found that the mean time to report a location following a visual sighting was 1.76 seconds for the LLP system and 6.86 seconds for the ASC system. This no doubt contributed significantly to the large differential in reported locations between the two systems.

A correlation was made between the time and location reports output by both systems. In this correlation it was found that the ASC clock was seven seconds slow compared to the LLP clock. This is in agreement with the earlier time slip found between each system individually and the observer's clock. Forty five points were determined to be reasonably correlated. A plot of these data are shown in Figure 22. Both systems appear to be in agreement that the most intense activity is in the vicinity of Cocoa Beach.

E. Storm of 10 July 1979 (1955-2045 GMT)

A system of storms developed during the late afternoon, 4:00 p.m. local time, on 10 July. These are shown in the radar trace of Figure 23. These storms were of moderate to light in electrical intensity.

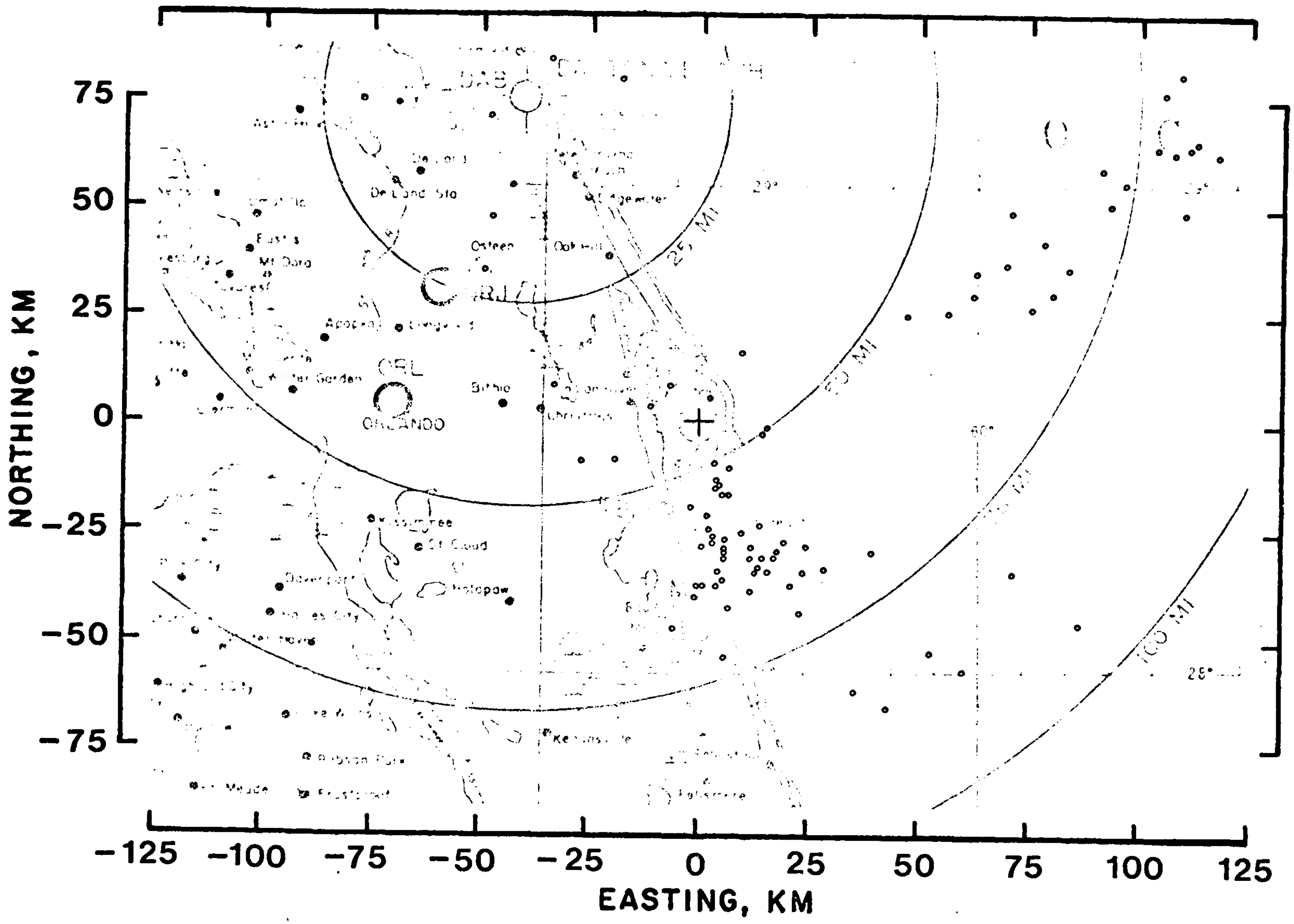


FIGURE 20. ASC LIGHTNING LOCATIONS, 10 JULY 1979 0130-0330 GMT

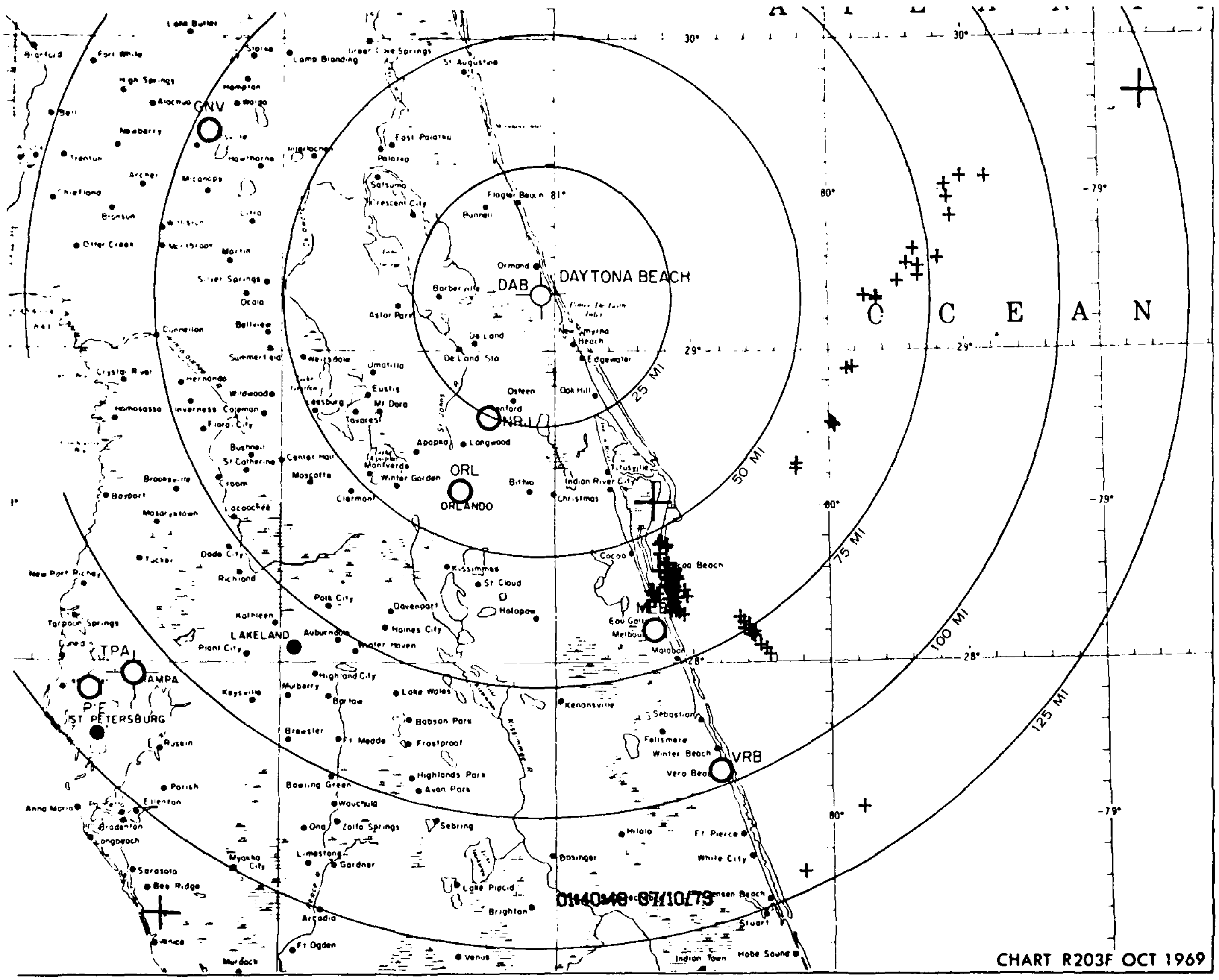


Figure 21. LLP Lightning Locations, 10 July 79, 1408 GMT

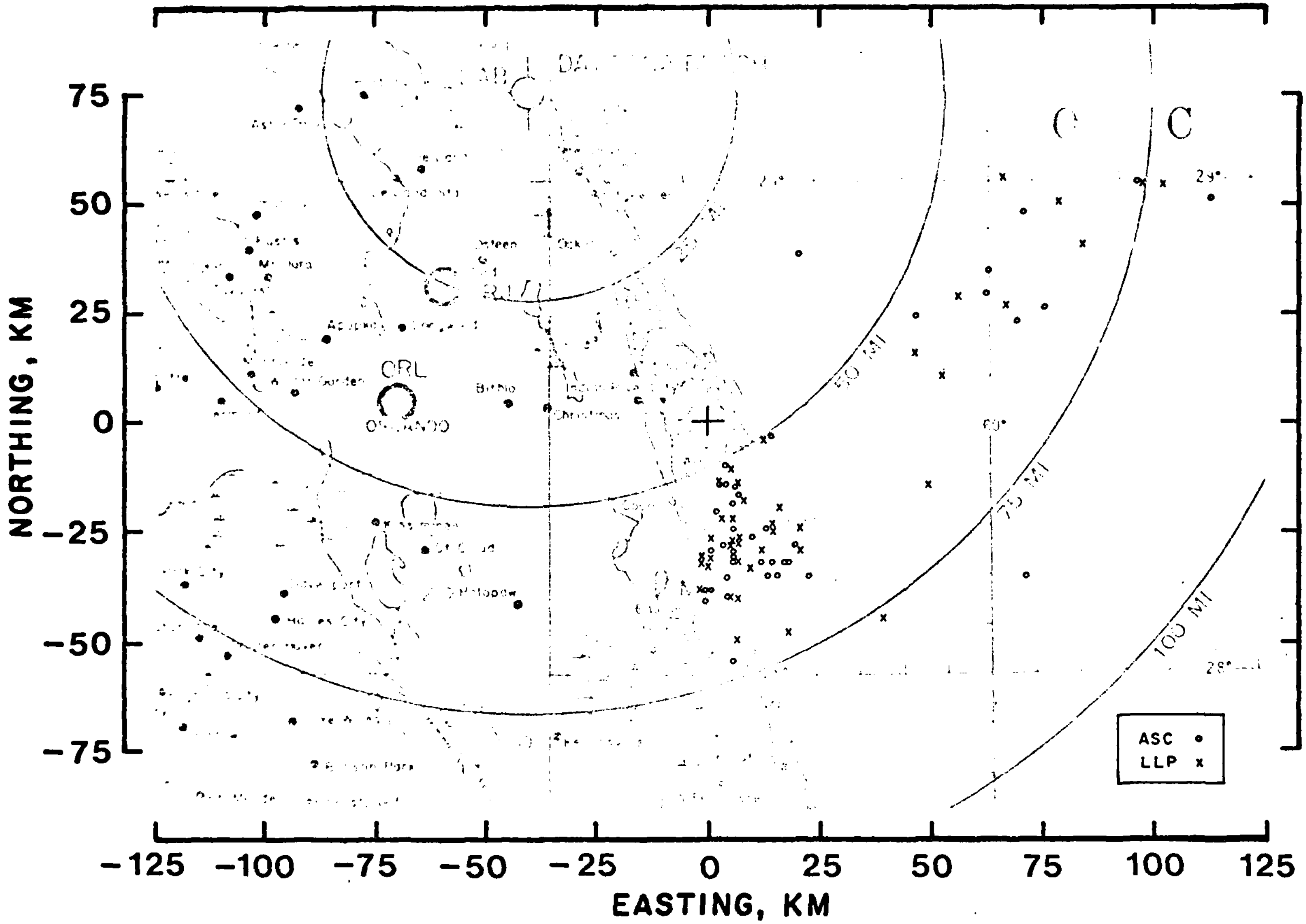


FIGURE 22. ASC and LLP CORRELATED LIGHTNING LOCATIONS, 10 JULY 1979 0130-0330 GMT

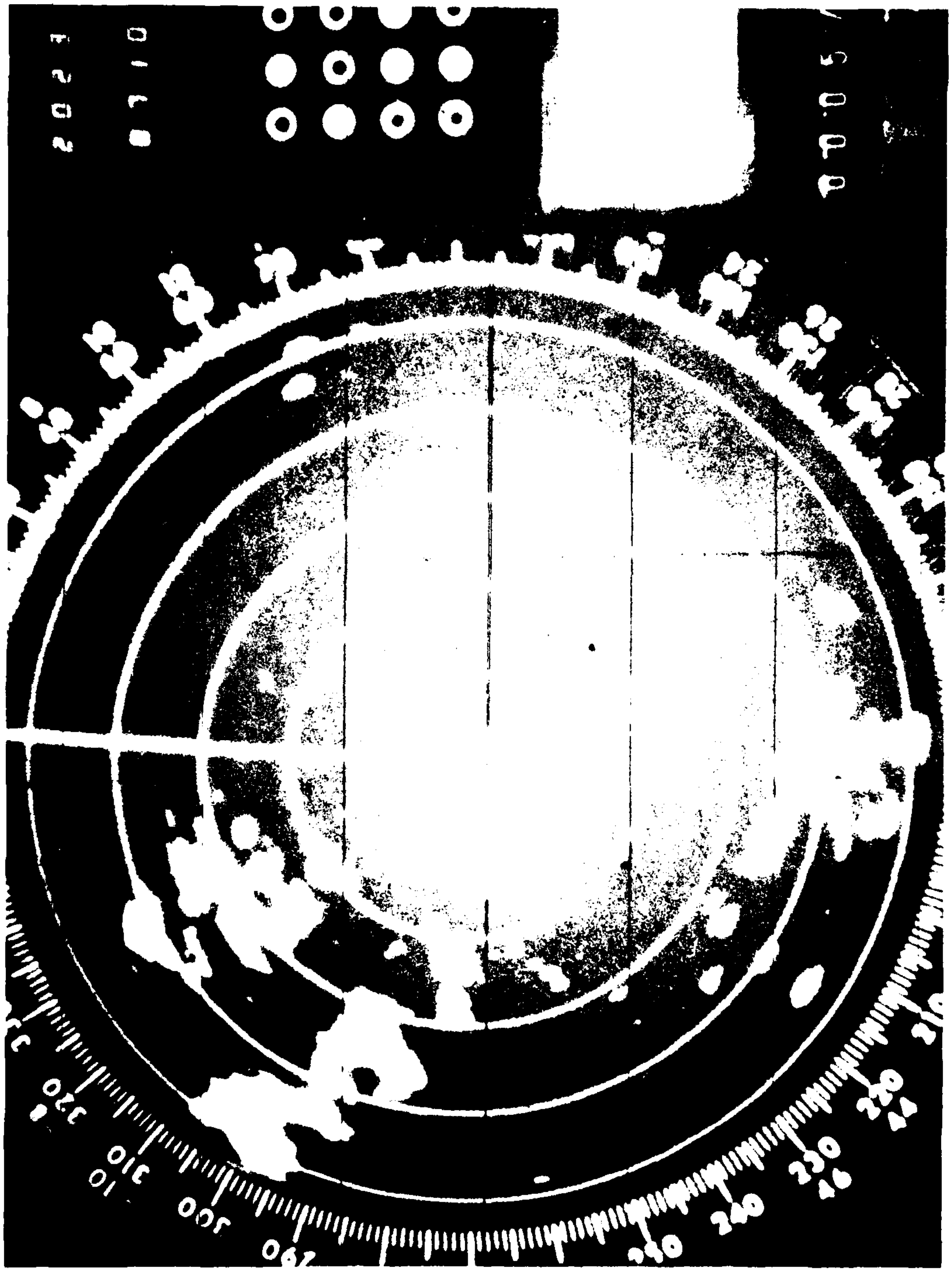


Figure 23. Daytona Beach Radar, 10 July 79, 2023 GMT

A composite plot showing the ASC and LLP data are given in Figure 24. The ASC reported 15 locations some 75 km north-northwest of the test site. The LLP data show scatter to the southwest and to the northwest with only one point of agreement with the ASC data. The LLP system reported 36 locations.

It is believed that both systems were fully operational during this storm so that the effects of impaired operation evidenced on 8 and 9 July are not contributing to the differences observed here. It is believed that the ASC system reported no location results in agreement with the LLP system because of system implementation. At no time during the test did the ASC system report locations beyond a range of 150 km. It is not known whether this is a software or hardware design decision. It is a matter of speculation why the LLP system did not report locations in agreement with the ASC system (with the exception of one point). A number of possible reasons exist, however, in the absence of ground truth data no determination can be made.

No visual data were obtained for cloud-to-ground strikes during this final test period.

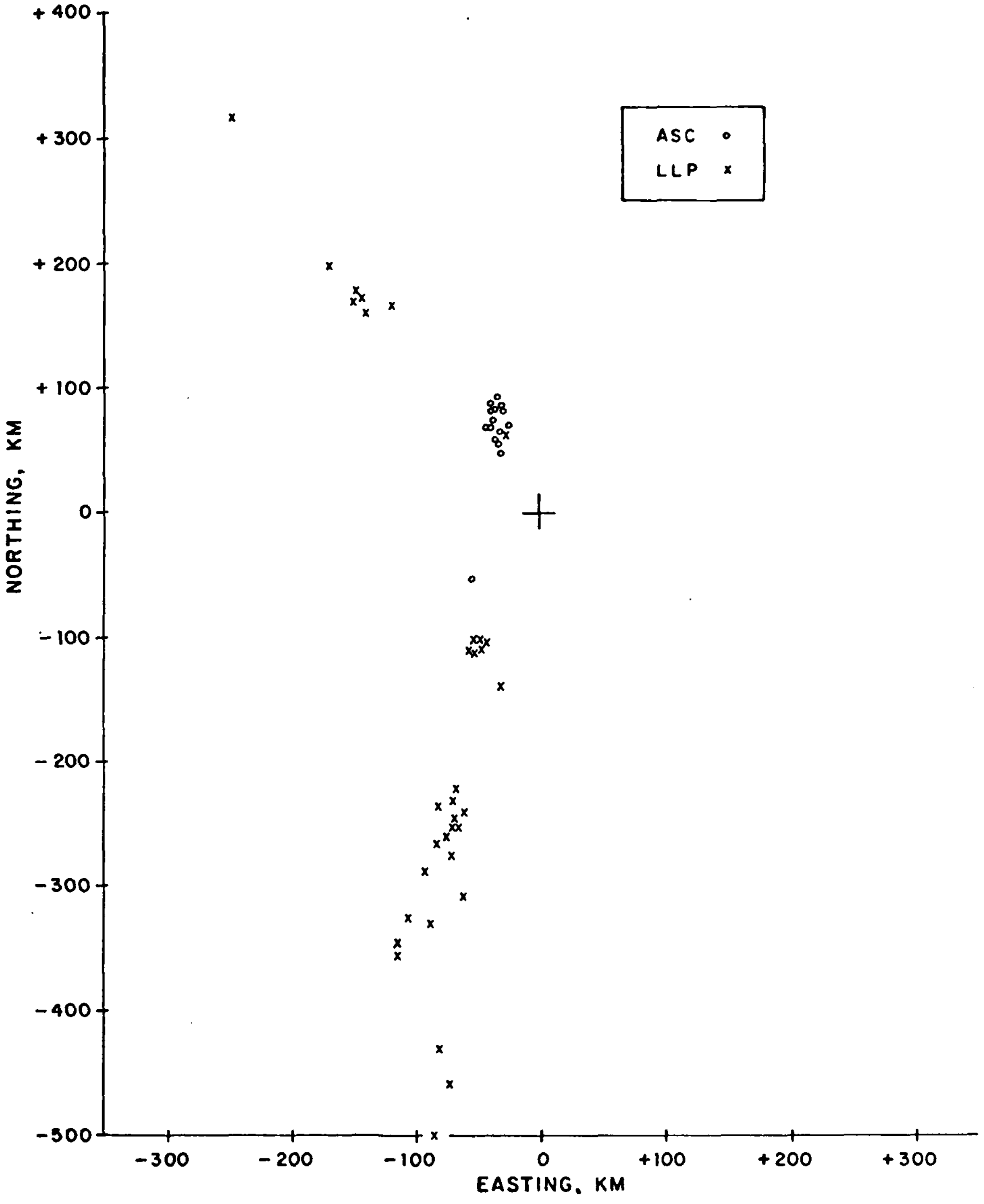


FIGURE 24. COMPOSITE OF ASC AND LLP LIGHTNING LOCATIONS, 10 JULY 1979 1955-2045 GMT

IV. DISCUSSION

One major feature of this test is the small quantity of comparative performance data obtained during the six week test period. One contributing factor was the two week delay by the Southern Bell Telephone Company in completing installation of the communication modems.*

The LLP system was installed in parallel with the modem installation. The system was operational for one day, 15 June; however, a telephone modem failure prevented data acquisition until the problem was corrected by Southern Bell on 21 June 1979. This proved not to be a significant factor since only four thunderstorms occurred during the first three weeks of test. Somewhat more inhibiting was the failure of the LLP remote site to restart after a power interrupt. During power outage, the batteries were too weak to maintain operation of the clock, and a backup mode of data acquisition was initiated on 8 and 9 July. As was pointed out earlier, system performance appears to have been somewhat impaired during this period.

Installation of the ASC system was begun on 14 June and completed on 26 June 1979, the delay being due primarily to the difficulty in obtaining "cherry pickers" for the mounting of antennas atop telephone poles. Although a performance checkout of the ASC system was accomplished on 26 June, the system software did not provide hard copy output to line printer as had been requested. ASC system software modification and hardware adjustment was not completed until the evening of 9 July local time (10 July GMT). The ASC system was never operated in an automatic unattended data acquisition mode. During the course of the evaluation, a representative from ASC was required to be in attendance to operate the system. Diskettes were left for SwRI personnel to load and initiate data acquisition; however, in every case the system failed to operate when loaded from these diskettes.

One of the parameters which was to be used in the assessment of system performance was the incidence of misidentification of inter-cloud lightning as cloud-to-ground strikes. It was determined that this task was not feasible using single point observations. The problem which frequently arises is that a glow in the cloud is visually identified as inter-cloud lightning when in fact a ground strike is obscured by precipitation and the observer can only see the streamer processes associated with the ground strike. A network of observers should be deployed to overcome these problems and obtain a credible assessment of misidentified lightning events.

Another parameter which was to be used in evaluating system performance was location accuracy. These data were to be provided by the network of all-sky cameras whose performance has already been discussed. One interesting aspect of location results is in the comparison of data between the two

*Similar experience in San Antonio had indicated that the modems could be installed in three to four weeks after the order had been placed, however, twice that time was required at KSC.

systems from the tornadic storm of 10 July. It is recalled that there appeared to be 45 lightning events which could be correlated in time. Of these simultaneous events only seven locations agree within five percent or less as a function of range. This can be observed from the scatter plot of Figure 22 where few points are directly superposed. A factor which contributed to the differences between corresponding location estimates was a 500 meter error in fixing the position of DF site No. 1. This error was corrected in the ASC system; however, in the LLP system the correction was considered to be inconsequential for the Bureau of Mines evaluation. Had sufficient ground truth locations been obtained, the LLP locations could have been postprocessed to make this correction.

A third parameter which was examined in this evaluation was the false alarm rate, that is, those cases of reported lightning for which there was no credible meteorological activity. Neither system appeared to estimate lightning events where there existed no possibility of electrical activity.

In summary, while the initial objectives of the evaluation were incompletely achieved, the test did produce sufficient data to support a partial assessment of the comparative performance of the two systems.

The three site (ASC) antenna system deployment offers a potentially higher degree of location accuracy than the two site (LLP) deployment. The theory of triangulation nets clearly indicates the superiority in fix reliability of a three station net compared to a two station net. One tradeoff is the additional cost of the third land line for communication; however, the improvement in location accuracy may be cost effective.

Both systems require a laboratory environment for the electronics at the remote sites. Since both systems can tolerate only 100 feet of lead length to the antennas, this means that the crossed loop direction finders may be subjected to significant site errors due to reradiation from nearby structures, power and telephone lines, etc. The antennas could be placed in more desirable sites by installing two broadband preamplifiers at the base of the crossed loops thus permitting the use of longer lead lengths. This would overcome some of the coupling errors caused by placing the antennas in close proximity to electronics shelters.

V. CONCLUSIONS

This section summarizes the evaluation of the comparative performance of the two systems.

1. The field evaluation of the ASC system at the time of this test was premature since the device was still under development. The system satisfied a preliminary performance test but required a continuing effort by the vendor to maintain operation.

2. With the exception of the telephone modem failure and the clock restart problem, the LLP system operated on a 24 hour day, unattended basis. The LLP system appeared to be fully developed and operationally ready for field evaluation.

3. Based upon visual observations of cloud-to-ground lightning events, the LLP system demonstrated a superior detection rate than was observed on the ASC system, viz. 84 percent versus 56 percent.

4. Since virtually all processing in the ASC system is done at the central facility, the system appears to be limited by computational speed. On the average, location estimates are produced approximately five seconds slower than with the LLP device. Some lightning events may be missed by the ASC system since DF data acquisition is interrupted while computer processing is in progress.

VI. RECOMMENDATION

An objective evaluation of system performance cannot be accomplished while system modifications are being incorporated which impact device performance. At such time that the ASC system can be operated in an automatic unattended data acquisition mode, a side-by-side performance comparison can be made. If this condition is satisfied and sufficient interest exists, it is recommended that a comparative evaluation be reinitiated.

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