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LIVES-88 - VERIFICATION OF DETECTION EFFICIENCY AND ACCURACY OF THE NEVADA TEST SITE AUTOMATIC LIGHTNING DETECTION SYSTEM

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INTRODUCTION

Real-time lightning products from the Automatic Lightning Detection Systems (ALDS) have been available via the AFOS communications loop (Rasch and Mathewson, 1984) for several years. However, many meteorologists utilizing the lightning products are unsure of the ALDS capabilities or limitations.

The National Weather Service Nuclear Support Office (NWSNSO) Lightning Identification Verification Evaluation Studies 1988 (LIVES-88) attempted to verify the accuracy and the detection efficiency of the ALDS for both negative and positive cloud-to-ground (CG) flashes (Scott, 1988a). It was hoped that results from the study would give the Nevada Test Site (NTS) forecaster more confidence in the system, and thus improve lightning safety procedures on the NTS.

An additional sidelight to the lightning verification study was the field testing of a prototype optical lightning detector. Results of the proof-of-concept study will also be presented.

PREVIOUS STUDIES OF ALDS

Several studies have been conducted over the past few years to evaluate ALDS effectiveness in detecting CG flashes. The ALDS consist of two or more gated wideband magnetic direction finding (DF) stations (Krider, et al., 1976) that are separated by tens to hundreds of kilometers, and that transmit lightning direction and signal amplitude data to a central position analyzing (PA) computer (Krider, et al., 1980). Falconer (1984) described a study of the East Coast Network performance in central New York State. Orville (1987) also investigated the detection efficiency of the East Coast Network in the vicinity of the Kennedy Space Center. Scientists at the National Severe Storms Laboratory (NSSL) have performed the most thorough lightning detection field evaluations to date (Mach, 1984, Mach, et al., 1986, and MacGorman and Rust, 1988).

Results from the various studies of ALDS show a wide disparity in both flash location accuracy and detection efficiency. The Falconer study indicated a low CG detection efficiency (49 percent) with CG location errors of 10 to 60 km. It must be stressed, however, this study was restricted to a very small area. More importantly, the East Coast Network, operated by the State University of New York - Albany (SUNYA) has been upgraded since the experiment.

Orville of SUNYA undertook a ground-truth analysis in the vicinity of the Albany campus. The study estimated the detection efficiency of the East Coast Network in that area to be about 70 percent within the nominal range. Nominal range is loosely defined as the range from the center of the network where the detection efficiency begins to drop off significantly. It depends on many factors, including the configuration of the DFs in the network.

NSSL studies, using a network covering portions of Oklahoma and Texas, show detection efficiencies ranging from 65 to 90 percent, within the nominal range of the network (70-80 percent is a typical detection efficiency claimed by most ALDS). Estimates of flash location errors were also tabulated in the 1988 study. The majority of errors fell in the range of 0-10 km difference between the ground-truth and ALDS flash position.

ERROR SOURCES IN THE ALDS

Following is a brief explanation of how errors may creep into the processing of the potential CG flash. The bibliography provides an excellent source for those readers desiring more detail.

Location Errors

In a previous study, Scott (1988a) described the NTS ALDS and the theoretical error patterns associated with the system as configured in 1987 (Figure 1). The average theoretical error in CG flash location in the vicinity of the NTS was approximately 1 km. Theoretical errors assume systematic errors (such as site errors or misalignment of the loop antennas) have been eliminated. "Differences", then, between the actual flash location and the position calculated by the PA are due largely to the random error (caused by nonvertical channels, background noise, and fluctuations in the DF's electronics) inherent in the azimuths measured by the DFs.

The clover-leaf appearance of Figure 1 suggests another source of error in flash locations. As the input azimuths from 2 DFs become more parallel, the flash location accuracy of the ALDS decreases (Mach, 1984). The so-called "baseline effect" errors in flash triangulations increase as the distance to the flash lengthens.

Another potential source of error in flash location are non-vertical components in the CG waveform. To understand this problem, one has to visualize the electromagnetic signal emitted by the tip of the return stroke flowing up the ionized channel much "like a rock thrown onto a still pond." As the lightning path becomes more tortuous and branched with height, radiation emitted from this portion of the CG flash will have a large horizontal component. Normally, contamination of this sort is generated in two ways: when a CG flash has a large non-vertical component near the ground; or when the signal from the flash is reflected off the ionosphere. However, the DF analyzes only the initial portion of the electromagnetic waveshape when the return stroke channel is near vertical (within 100 meters of the ground). This ensures that horizontal polarization errors are minimized.

Azimuthal errors from a DF may also enter the calculations in another way. Site errors (caused when the electromagnetic wavefront from the flash is absorbed and reradiated by a structure or terrain feature near the DF) can lead to incorrect flash placement.

Optimization routines in the Advanced Position Analyzer (APA) recently installed at the NTS attempt to reduce most of the above described errors. The optimization algorithm is utilized when more than the required two DFs identify, or process the same flash. The technique employs input from multiple DFs to identify a "best fit" flash position (LLP, 1988). In most cases, results utilizing the optimization technique are more accurate than triangulation solutions where only input from the two DFs receiving the largest signal are used. Improvement in system performance is especially noticeable at ranges where triangulation solutions begin to become unreliable. The optimization technique thus increases the NTS ALDS network area of effective coverage. This is especially obvious in a comparison between Figure 1 and Figure 2 in the vicinity of Las Vegas, Nevada (near the bottom, right-hand corner). The system error decreases from 16 km to 8 km.

Both the Bureau of Land Management (BLM) network in the western United States, and the East Coast Network operated by the State University of New York - Albany utilize optimization techniques.

Detection Efficiency

Detection efficiency is defined as an estimate of how well an ALDS network will detect flashes at a given location. All of the above mentioned factors that affect the systems ability to accurately locate a CG flash also affect the system's ability to detect a flash.

A DF will reject any electromagnetic signal that does not fit the parameters of a model waveform of a lightning return stroke. Factors such as electrical activity preliminary to the CG flash, site errors, and distance to flash will all modify the CG waveshape processed by the DF. Thunderstorms may also produce CG flashes that do not fit the model waveform. All of these factors act to decrease the system's capability to detect CG lightning flashes.

A potential flash will also be rejected by a DF if the measured signal strength exceeds a certain threshold level. Signal saturation occurs, ordinarily, when lightning activity is within about 8 km of a DF. Thus, at times, the "closest" DF will be excluded from the calculations.

Obviously, the further CG lightning occurs outside of a network, the higher the probability the flash will go undetected. Flashes that are detected outside the network will likely suffer larger location errors. The probability of error is also higher in regions where DFs are further apart, or where network geometry is irregular. An extreme example of irregular geometry would be a multiple DF system with more than two adjacent DFs on, or near a line. Lightning information located in these areas should be viewed with a little more discerning eye by the forecaster.

Under ideal conditions, the detection efficiency of an ideal (an equilateral triangle), 3 DF system should approach 90 percent (Figure 3) within the network's area of effective coverage (LLP, 1988). The ideal multiple DF system would be a checkerboard of DFs, with comparable detection efficiencies. However, the studies cited previously show that the efficiency may vary from 50 to 90 percent depending on the factors mentioned above.

LIVES-88

The 1988 summer thunderstorm season provided an opportunity for a rigorous field evaluation study and operational meteorological research project of the NTS ALDS. This study, cited in a previous Western Region Technical Attachment (Scott, 1988b) was conducted during August and September of 1988.

Meteorological Technicians were deployed with pilot balloon (pibal) rigs at selected locations around Yucca Flat on the NTS. The field study was conducted during the afternoons of potential thunderstorm days from late July through early September of 1988.

To observe and locate the CG lightning, the technicians utilized double-theodolites that are designed to track pibals. The observer determined approximate azimuths to the ground location of the flash and logged the information, along with the time, in a journal. Communication among the various positions was maintained through the NTS radio network.

Input from at least three of the observers was required for flash validation. This routine was established to minimize the possibility of incorrectly reporting a cloud-to-cloud or extra-cloud lightning flash as a CG flash. Field data was then correlated in time, and location with output from the ALDS to estimate the detection efficiency. Location accuracy was more difficult to verify. Without the multiple videocamera dataset, ambiguity in bearings to flashes from observers made a large portion of the field data unusable.

RESULTS

The CG Lightning Verification

During the field experiment, 350 flashes were observed in and around Yucca Flat. Of those flashes, 98 were reported simultaneously by the three observers. Approximately 85 percent (83 of the 98 flashes) were recorded coincidently by field observers and the NTS ALDS. Conversely, 15 of the 98 flashes were rejected by the ALDS as invalid. All of the flashes resolved possessed negative polarity.

As stated previously, ambiguity in the field data made determination of location accuracy nearly impossible for most of the flashes. Locations of only ten flashes were known with sufficient confidence to be included in the study. Of the ten flashes, errors in flash location ranged from a minimum of 0.5 km to about 4 km. The average error in flash location was 1.3 km.

The NTS ALDS detection efficiency and accuracy compares very well with similarly configured systems. The field study also shows that the NTS ALDS performance approaches the theoretical expectation on the NTS.

There are considerable differences between the configuration of the BLM ALDS and the NTS system. The distance between DFs on the NTS ranges from 40 km to 75 km, while the distances on the BLM system approach 400 km. The sensitivity (gain settings) of the DFs differ, also. NTS DF signal thresholds are adjusted so that the nominal range is approximately 90 km versus 370 km for the BLM DF's.

The BLM ALDS detection efficiency has recently been estimated at 50 to 70 percent within the nominal range (location accuracy has not been evaluated). This, of course, does not compare favorably with the LIVES-88 results. The comparison is unfair, as the NTS system was "tuned" for high resolution over the NTS (3200 km^2), while the BLM network was designed for lightning detection over the western states. An informal comparison of location accuracy between the systems also indicates absolute errors of the BLM ALDS exceed 40 km at times across the NTS. Results of the NTS study represent, most likely, system performance beyond the capability of the current BLM configuration.

The Optical Lightning Detector

Results from tests of the optical lightning detector were exciting. The hand-held system (Scott, 1988b) provided unparalleled lightning (thunderstorm) detection capability for the meteorological observer at the Desert Rock Observatory and at Nellis Air Force Base. Lightning of all types were as easily observed during both daylight and nighttime hours. This allowed the observer to assess lightning frequency and distinguish a thunderstorm from a non-thunderstorm. Both of these tasks are difficult at night, let alone during the day. There is little doubt, for those involved in the field test, that the detector would be an invaluable aid for the meteorological observer.

The optical sensing system works by responding to the rapid changes in the photoelectric emission generated by a lightning flash. A bandpass filter, tailored to the optical signature of lightning, discriminates against most other light variations which are slower and longer in duration. A lens provides a field of view of 20 degrees, or by removing the lens the field of view is 140 degrees.

Lightning was detected at ranges of up to 150 km during the daytime, and since the device operates along a line-of-sight, that would mean it was detecting intra-cloud lightning. The system also provided up to a 15 minute lead-time from the first intra-cloud flash to the first CG flash. Detection of intra-cloud lightning frequency is important for monitoring thunderstorm development and intensity due to its close relationship to other aspects of thunderstorms such as microbursts and hail (Williams, 1988 and Beuchler, et al., 1989).

LIVES-89

The summer of 1989 will hopefully provide even more valuable information on lightning and the ALDS. NTS ALDS lightning data will be directly compared to data from the BLM system. NWSNSO will also have the opportunity to utilize developing lightning identification technology such as an improved optical detector and possibly a new lightning ranging system. It is hoped data collection will continue to increase our operational understanding of the lightning phenomena.

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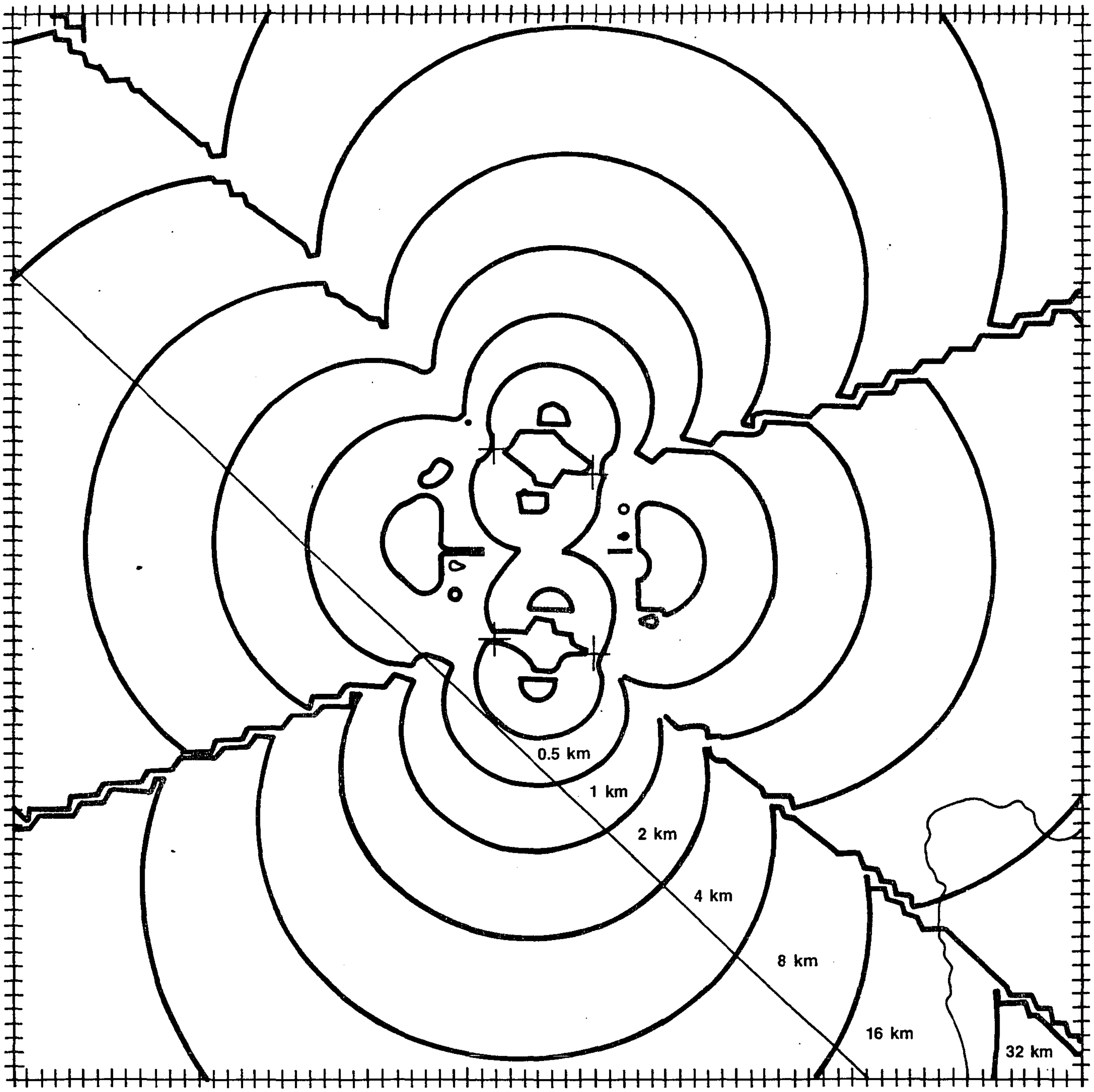

FIGURE 1
NTS/ALD SYSTEM ACCURACY
(CONTOUR PLOT SHOWING LINES OF EQUAL ACCURACY. VALUES ARE THE LENGTH OF THE SEMI-MAJOR AXIS OF A 50% PROBABILITY ELLIPSE.)

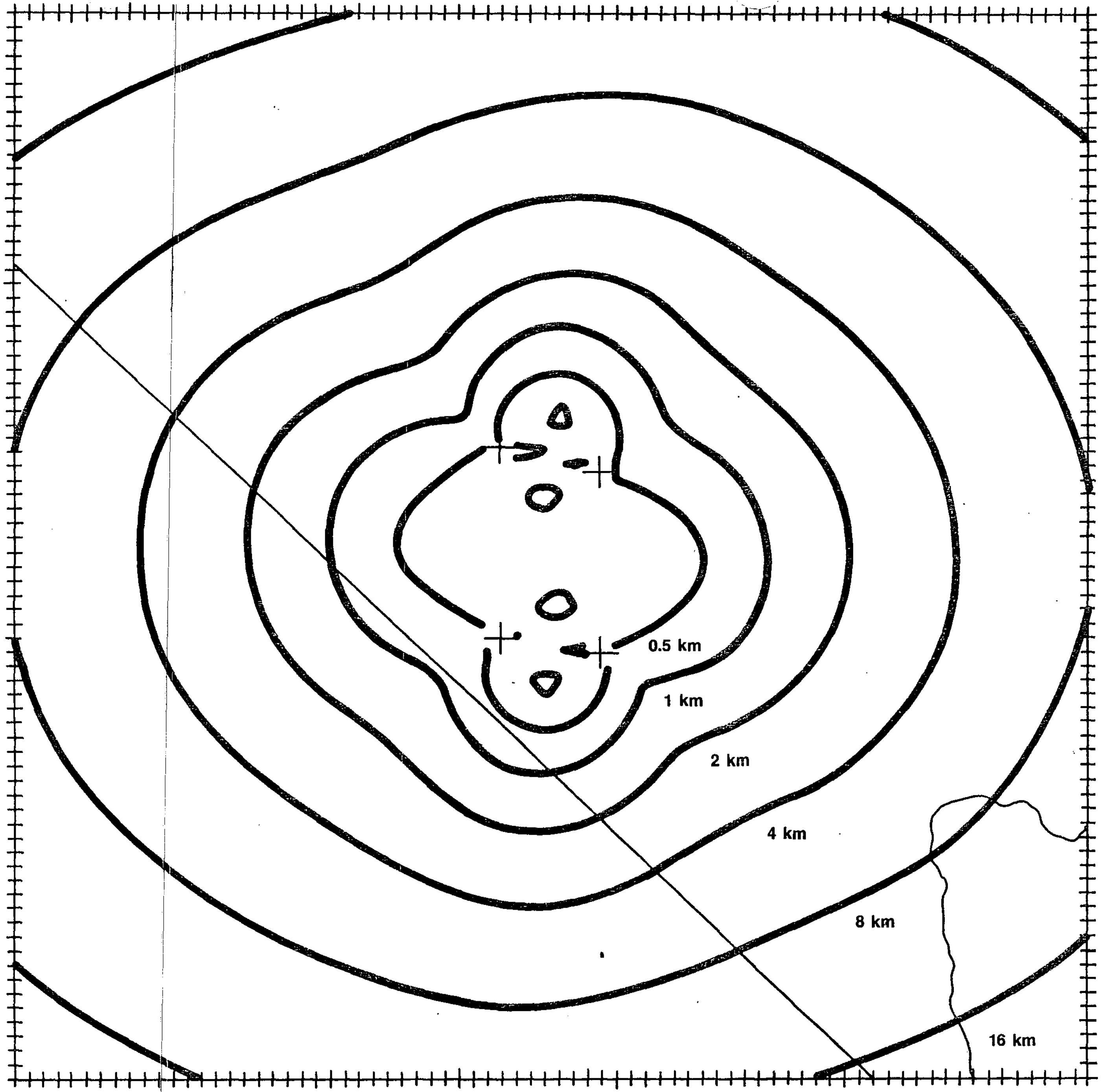

FIGURE 2
NTS/ALDS SYSTEM
ACCURACY WITH
"FLASH FITTING
ALGORITHM"

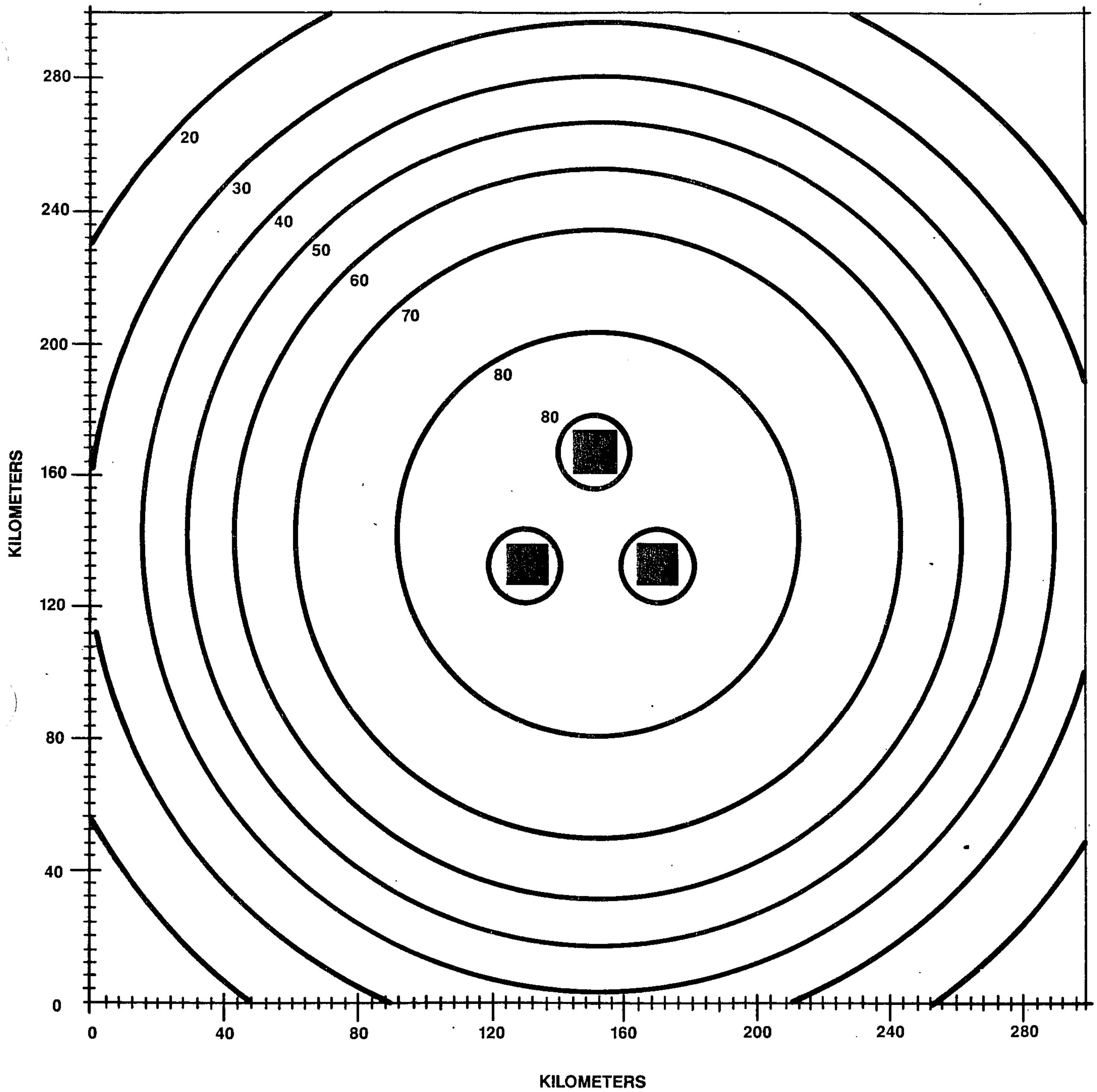

FIGURE 3
LIGHTNING NETWORK LOCATION
EFFICIENCY CONTOUR PLOT