NOAA Technical Memorandum NWS WR-153

AN AUTOMATIC LIGHTNING DETECTION SYSTEM IN NORTHERN CALIFORNIA

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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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National Weather Service Office - Fire Weather
Redding, California
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UNITED STATES DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

National Weather Service
Richard E. Hallgren, Director

This Technical Memorandum has been reviewed and is approved for publication by Scientific Services Division, Western Region.

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AN AUTOMATIC LIGHTNING DETECTION SYSTEM IN NORTHERN CALIFORNIA

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I. INTRODUCTION

Annually, lightning starts 73% of the average 1100 fires each fire season in the Redding fire-weather forecast district of northern California (Annual Fire Reports 1969-1978). While northern California has a relatively fine-mesh, fixed-surveillance lookout network and receives overlapping radar coverage from the Medford and Sacramento Weather Service Offices (WSO) radar units, sizeable observational gaps exist. Not infrequently, poor visibility in haze, smoke, and low cloud cover will significantly restrict lookout and aircraft surveillance of forest land. In addition, existing radar coverage is terrain-limited in many mountainous areas of northern California. Radar and satellite imagery can detect thunderstorm cells, but neither delineates actual lightning strikes within convective activity where the greatest potential of lightning fire ignition exists.

In 1977, Automatic Lightning Detection System Direction Finder (ALDS DF) units were installed by the USDI Bureau of Land Management (BLM) at Susanville, California, and Lakeview, Oregon, as part of the Great Basin ALDS. The ALDS is capable of detecting and locating cloud to ground lightning discharges over considerable areas. This paper describes the performance and capabilities of the ALDS in relation to radar coverage, satellite imagery, and actual lightning fire starts during the 1979 fire season in northern California.

II. DATA SOURCE AND ANALYSIS TECHNIQUE

Hourly radar overlays were examined from the Sacramento and Medford WSO radar units for the months of July and August, the most active thunderstorm months this last 1979 fire season in the Redding fire-weather forecast district. Both Sacramento and Medford radar units employ 10 cm WSR-57M radars with a maximum effective range of 250 nautical miles and report maximum echo tops out to 125 nautical miles.

Satellite coverage was provided by the San Francisco NESS office from the Geostationary Orbiting Earth Satellite (GOES-W) in position at 135 degrees west longitude. Hourly visual and enhanced infrared (HD Curve) satellite film loops, 1- and 4-mile resolution were compared with radar, ALDS output and surface observations on all days during this bimonthly period where lightning fires occurred or ground strikes were detected by the ALDS in northern California.

Actual lightning fire legal locations, estimated origin times, and discovery times were taken from USFS form 5100-29 and CDF form FC 18, and plotted on USFS 1/2 inch: 1 mile USFS National Forest maps. The longitude/latitude printouts of all ground strikes (flashes) from the Susanville DF unit were hand plotted on the same USFS maps for each month of July and August, indicating the ALDS identification number and time of each flash. Transparent overlays graduated in 1-, 5-, and 10-mile increments with cardinal directions radiating out from the fire site and depicting all flashes in proximity were traced for all lightning-caused fires. Scatter diagrams were then constructed from the overlays for fires sharing a common geographic proximity to eliminate flashes that represented noise and to locate common areas of flashes about fires along approximately the same azimuth and distance from Susanville.

III. AUTOMATIC LIGHTNING DETECTION SYSTEM (ALDS)

A typical cloud-to-ground lightning discharge is characterized by a distinctive electromagnetic waveform (Noggle, et al, 1976; Tiller, et al, 1976). A stepped leader precedes the more energetic, highly luminous return stroke which traces upward along the ionized channel formed by the stepped leader (Uman, 1969; Krider, et al, 1976; Krider and Radda, 1975). A dart leader then propagates downward, followed by another return stroke. A series of leader-return combinations complete a typical flash (Uman, 1969). A cloud-to-cloud discharge waveform differs considerably in rise time, polarity rebound magnitude and pulse width, as well as frequency of occurrence, from a cloud-to-ground discharge (Figure 1) (Noggle, et al, 1976; Krider, et al, 1980). The current ALDS circuitry is capable of identifying cloud-to-ground discharges and filtering out cloud-to-cloud discharges with an estimated 80-90% detection efficiency (Krider, et al, 1980).

The Susanville and Lakeview DF units are on the western fringe of the USDI BLM Great Basin ALDS network (Figure 2). The major functional components of the DF installations are (1) an antenna array and (2) an electronics chasis with analog and digital subsystems (Figures 3 and 4). The electronics chasis serves to screen, process, and plot flash vectors (Figure 5) from the antenna outputs. The digital subsystem computes and stores flash azimuth angles, peak magnetic field values, and strokes per flash; then transmits this data to a position analyzer (PA) in Elko, Nevada.

The Elko PA computes flash locations by triangulation for chronologically coincident flashes detected by the Susanville, Lakeview, Ely, and Elko DF units. When flashes occur near a common DF unit baseline, flash location is computed from a ratio of DF signal strength. The PA map plots each flash (Figure 6), then transmits longitude/latitude flash positions back to a line printer at the peripheral DF sites at Susanville and Lakeview (Figure 7). For wider, operational dissemination in northern California, the Susanville DF operators enter the PA computed longitude/latitude flash positions into AFFIRMS. (For a more detailed review, refer to Krider, et al, 1980; Krider and Noggle, 1975; Vance, et al, 1979; Noggle, et al, 1976, and Herman, et al, 1976.)

IV. PRELIMINARY RESULTS AND DISCUSSION

Until the advent of the ALDS, the principal large-scale method of detecting and tracking thunderstorms was through the use of the NWS radar network. Since radar coverage is blocked by terrain, this system has inherent limitations over the mountainous terrain in northern California; especially over the Shasta Trinity/Marble Mountain Wilderness and Siskiyou County. Even with both radar units operational, there are areas of northern California where the minimum detectable cell height is 20,000 feet. Should one radar become inoperable, the minimum detectable cell height balloons to 40,000 feet for some locations (Pappas, 1969).

The BLM ALDS network was found to complement and refine NWS radar coverage over northern California during the 1979 fire season. Examination of the WSO radar overlays and ALDS flash locations revealed that where radar indicated maximum cell tops and intensity levels, that the ALDS also detected corresponding areas of maximum cloud-to-ground lightning activity. While there existed a definite correlation between radar-ALDS areas of maximum thunderstorm activity, the ALDS often identified areas of heavy downstrike activity an hour or so before radar later detected rapidly building, intense thunderstorm echoes.

The ALDS further refined radar coverage by identifying cloud-to-ground activity in low reflectivity cells. An example occurred during the afternoon of August 28th. The Medford WSO radar indicated a scattered area of light rainshowers with maximum tops of 19,000 feet near Mount Shasta at 1730 PST. The ALDS was detecting downstrikes at this same time in the Mount Shasta area. The Shasta-Trinity National Forest suppressed a lightning-caused fire 7 miles southeast of Mount Shasta, in proximity to where the ALDS had plotted ground strikes less than an hour before (Figure 8).

Scatter diagram analysis and subjective examination of gross patterns of lightning fires and specific flash locations strongly indicated a consistent deviation between actual lightning fires and the ALDS longitude/latitude computed flash positions (Figure 9). The ALDS flash longitude/latitude plots exhibited a definite clockwise rotation with respect to Susanville from the actual lightning fires starts, occasionally forming a displaced, imperfect mirror image of each other. A series of lightning fires near Chester on July 20th in the Lassen National Forest formed a rough "horseshoe" pattern, while the ALDS derived downstrike pattern roughly duplicated the same pattern displaced to the northwest (Figure 10).

On July 21, an early evening thunderstorm over the Mt. Eddy area near Mount Shasta started 8 fires. The Medford radar unit indicated an isolated, heavy thundershower with a 42,000 foot maximum top in this area. While the ALDS detected numerous downstrikes, apparently associated with that thunderstorm, the longitude/latitude PA computed positions were all in the Shasta Valley, several miles to the northeast of the actual thunderstorm activity and resultant fires (Figure 11). The surface weather observations from the Montague Airport, 5 miles east of Yreka, showed only broken midlevel cloudiness, though the ALDS placed several strikes within 1 mile of Montague. Enhanced infrared satellite imagery also indicated an intense thunderstorm west of Mount Shasta over the Mt. Eddy area during this same time period (Figure 12).

A more dramatic illustration of the clockwise deviation in the longitude/latitude flash plots occurred on August 16th along the extreme limit of the Susanville-Lakeview ALDS sector. The Sacramento WSO radar indicated a north-south line of thundershowers positioned slightly east of Lake Tahoe from 1430 PST to 2030 PST. Several ALDS longitude/latitude flash positions were plotted well to the west in the Frenchman Lake area of the Plumas National Forest during this time span (Figure 13). No fires near Frenchman Lake were reported during the entire month of August. Visual GOES-W satellite pictures corroborate Sacramento WSO radar coverage by placing the thunderstorm line in Nevada through the entire period well east of the Frenchman Lake area (Figure 14).

August 28-29 were relatively active thunderstorm days in the Shasta Lake-Burney area of the Shasta-Trinity National Forest and on the adjacent CDF Shasta Ranger Unit. Lightning started 6 fires on the 28th and 7 fires on the 29th in this area. The Sacramento and Medford WSO radars depicted broken areas of rainshowers or thundershowers in northeastern Shasta-Trinity National Forest both days. A plot of the lightning-caused fires and ALDS longitude/latitude flash positions illustrated a northeast deviation of about 7 miles relative to actual lightning ignition and ALDS flash positions (Figure 15). The fire near the southwest end of Shasta Lake is bounded by a southwest-northeast flash pattern, reflecting the movement and development of thunderstorm cells in that area on the 29th.

The actual distance of displacement was found to vary with distance from Susanville, but was generally consistent with a clockwise rotation of an average 9 degrees. When the clockwise deviation is allowed for, the ALDS placed flashes within 1 mile of approximately 80% of all lightning-caused fires reported in the Redding fire-weather district for the period investigated.

Two general types of locating errors can exist in the ALDS; systematic and siting. The two are not mutually exclusive. Siting errors are localized anomalies due to interference from high-tension lines or large metal structures in close proximity to the DF antenna array. Systematic errors could arise from the longitude/latitude algorithm software in the PA computations generating the longitude/latitude flash positions. LLP is currently rewriting the longitude/latitude algorithm to be used next fire season (Krider, personal communication).

While ALDS DF range is optimally 260 miles, the system is calibrated to detect 80% of ground strikes with channel currents of 20 KA at 120 miles (Duane Herman, personal communication). The ALDS failed to detect any flashes for several lightning-caused fires in the more remote Shasta-Trinity/Marble Mountain Wilderness Area, roughly 160 miles from both Susanville and Lakeview DF units. Through examination of the Susanville flash vectors, the authors could not discriminate vectors along that azimuth from other flashes slightly farther to the east on those days. The Lakeview flash vectors were not available for examination. Both stations would have to detect flashes for the Elko PA to compute longitude/latitude positions.

The lightning activity over the Shasta-Trinity/Marble Mountain Wilderness Area could have been below the detection threshold of the Lakeview-Susanville DF at that extreme range. Other possibilities are that the ground strikes producing ignition were of positive polarity or long continuing current (LCC) ground strikes of relatively lower channel current and longer duration (Fuquay, 1979). D. J. Latham of the Intermountain Northern Forest Fire Laboratory at Missoula has postulated that while positive flash-to-negative flash frequency is about 1:100, the positive flashes persist slightly longer and occur along the periphery of thunderstorms subjected to significant wind shear (D. J. Latham, personal communication). The current ALDS circuitry only detects and plots negative polarity flashes.

The thunderstorms over the Shasta-Trinity/Marble Mountain Wilderness Area were associated with an upper-level, cold-core low, which did exhibit some cyclonic wind shear. However, thunderstorms further east were subjected to the same shear and flashes were detected by the ALDS those same days. Lightning Location and Protection Incorporated, the manufacturer of the ALDS, is designing a PROM breadboard to detect the positive flashes and the BIFC communication division plans to install two in a test mode at Boise, Idaho, and Vail, Oregon, this coming 1980 fire season (Duane Herman, personal communication).

V. CONCLUSIONS

The ALDS represents a potentially powerful tool toward achieving an improvement in lightning-caused fire detection, more efficient use of surveillance resources, time and suppression cost reduction. The performance of the ALDS during the most active period of the 1979 fire season in the Redding fire-weather forecast district establishes the local system's detection capability, as well as, identifies the ALDS complementary utility in detecting lightning activity in low reflectivity thunderstorm cells. The ALDS can offer a significant refinement to existing radar network by locating actual ground-lightning activity in areas of poor radar coverage, an addition to isolating lightning centers with radar detected storm cells. This has meaningful applications not only to the fire-weather program, but potential NWS public service significance as well.

The clockwise deviation in PA-derived longitude/latitude positions are amenable to solution by a more refined longitude/latitude algorithm, resiting the DF antenna array, electronic antenna rotation, or programming the site anomalies into the PA software. Further extention of the detection range in northern California, and associated increase in triangulation accuracy, could be achieved by siting a DF unit near Weaverville to cover the west sides of the Shasta-Trinity and Klamath National Forests.

The ALDS not only offers a promising method in creating precise, localized ground strike-fire probability maps, but also fills a critical input function toward the eventual development of probabilistic lightning ignition models similar to those proposed by the Missoula Fire Laboratory (Fuquay, et al, 1979; Latham, 1979). Also, additional refinement of the current NFDRS Lightning Activity Level (LAL) guides deserves further attention through examination of ALDS lightning data in conjunction with IR satellite-derived cloudtops superimposed on radar indicated intensities (Ellrod, 1979). This would be especially useful for application over data-sparse forests or extension to areas lacking adequate radar coverage.

VI. ACKNOWLEDGMENTS

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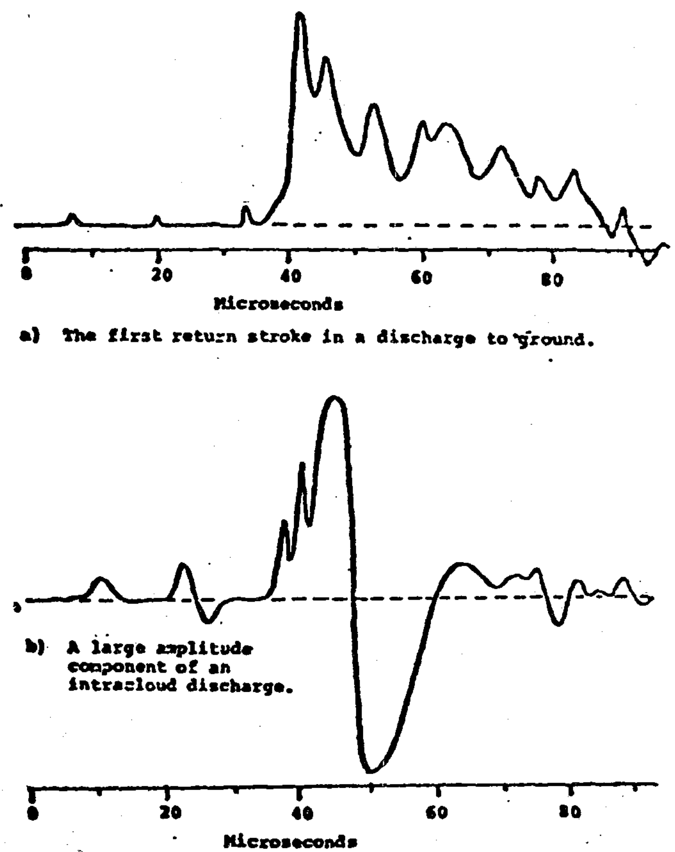

Figure 1. Typical Lightning Magnetic Waveforms.
(Courtesy of E. P. Krider.)

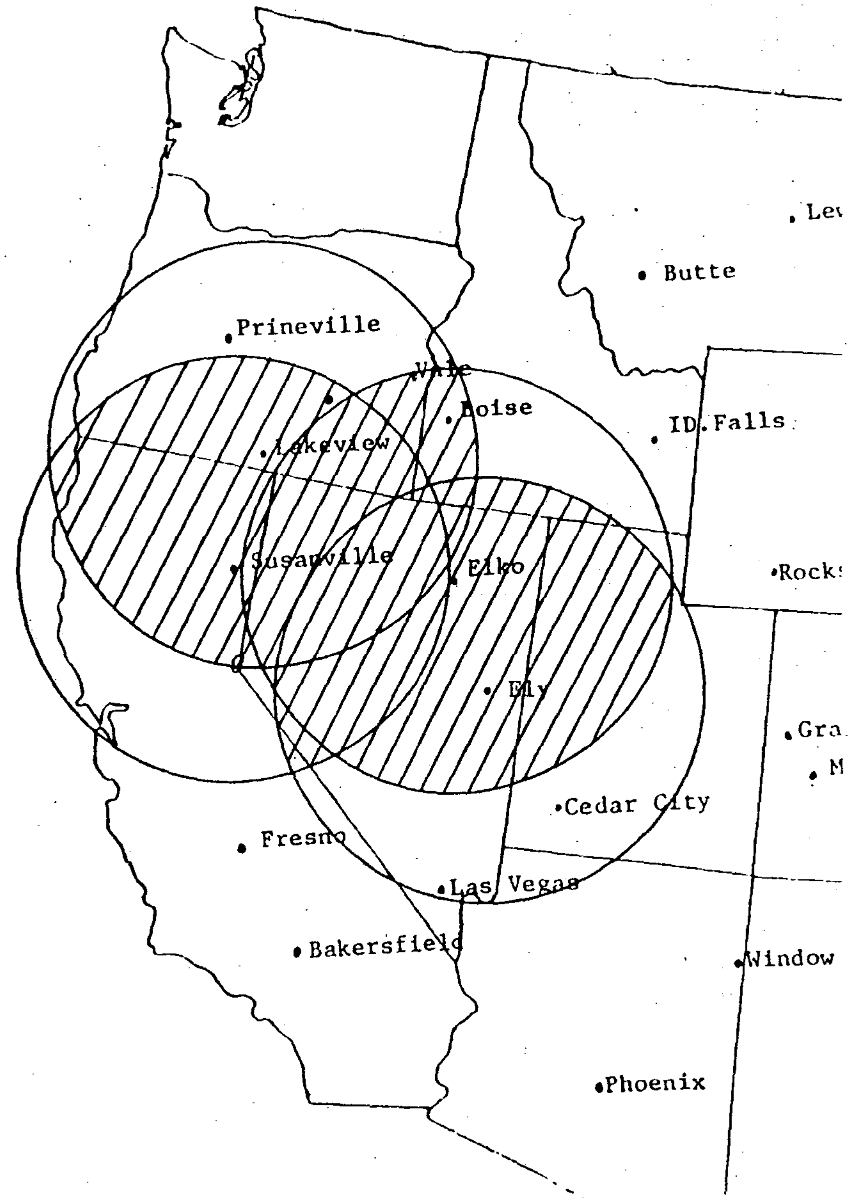

Figure 2. Northern California-Elko ALDS.

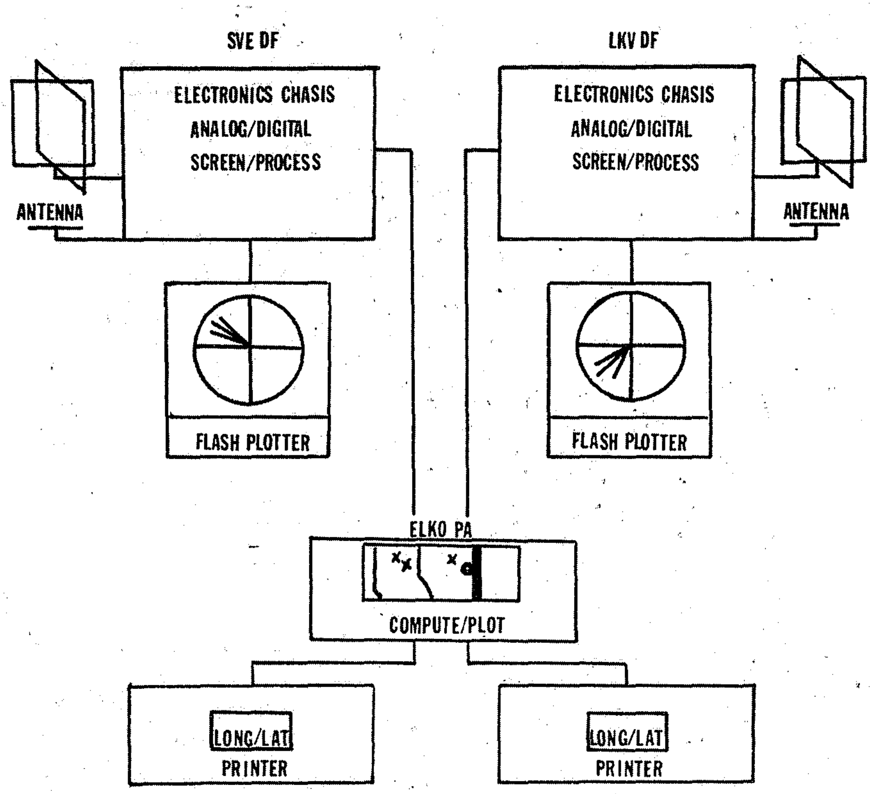

Figure 3. Schematic of Northern California ALDS.

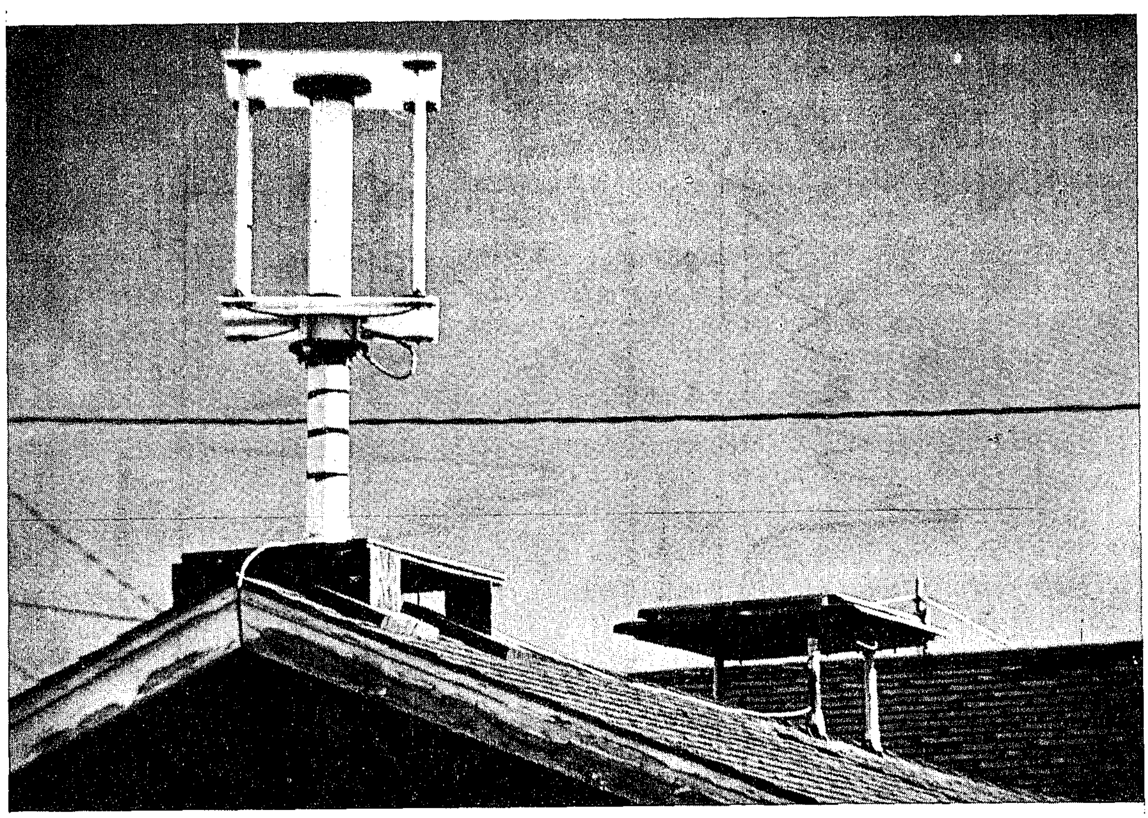

Figure 4. ALDS Antenna Array At Susanville, California.

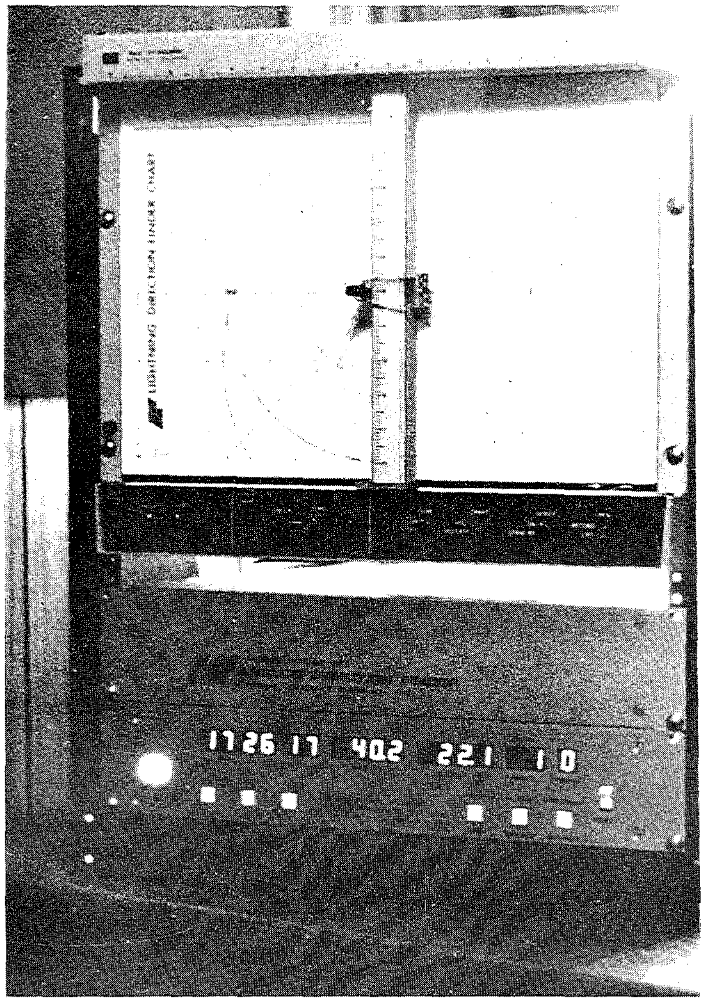

Figure 5. ALDS Flash Plotter.

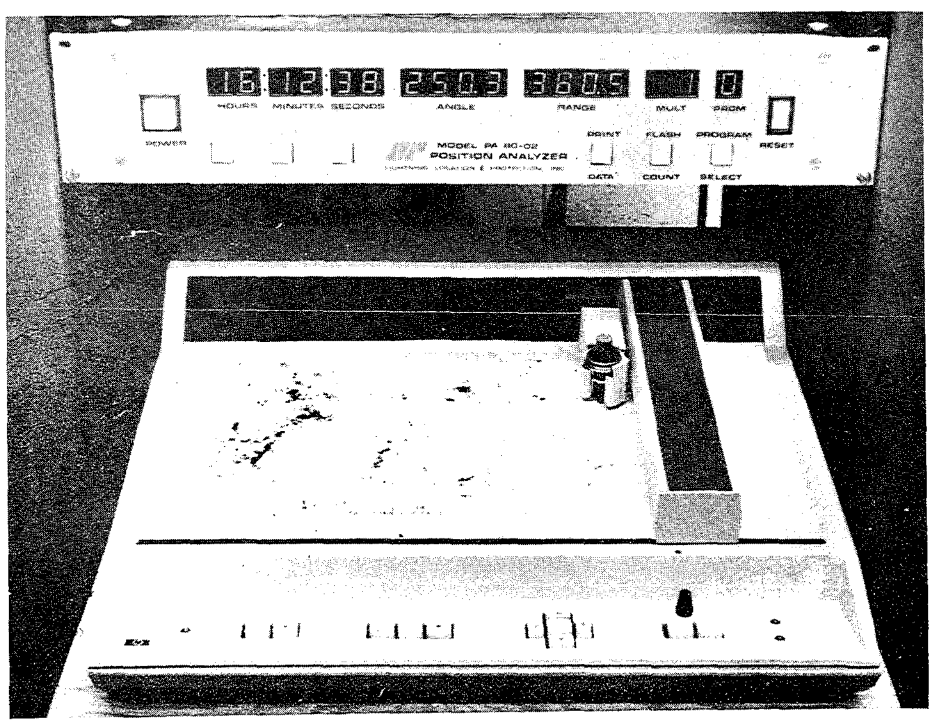

Figure 6. Position Analyzer.

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22:07:23 10/13/79
            ---FLASH TOTALS---
            GOOD    OUT    BAD    REGION
D.F. #1      16      8     15      8
D.F. #2      82     74     11      8
D.F. #3       6      5      1      8
FLASHES       8      0      0      8


LIGHTNING LOCATION & PROTECTION, INC.

FLASH    TIME          LAT       LONG    DF'S
   1 22:11:53 1    40:00:24   -123:09:57 21      21
   2 22:19:54 1    40:11:36   -122:52:58 21      21
   3 22:28:52 2    40:03:48   -123:04:06 21      21
   4 22:30:40 1    40:00:31   -122:40:04 21      21
   5 22:31:40 1    40:16:31   -122:55:25 21      21
   6 22:34:20 1    39:51:23   -122:52:08 21      21
   7 22:39:12 1    40:31:41   -122:58:00 12      12
   8 22:41:13 1    39:45:52   -120:16:59 12     123
   9 22:48:21 1    39:52:33   -120:04:48 21      21
  10 22:48:42 1    40:30:38   -122:53:47 21      21


  11 23:05:17 1    40:04:58   -122:57:18 21      21
  12 23:16:03 1    39:49:27   -123:03:16 21      21
  13 23:18:27 1    35:41:07   -122:56:50 21 B    21
  14 23:20:23 1    36:46:34   -122:25:46 21 B    21
  15 23:33:07 1    34:33:23   -121:30:21 21 B    21
  16 23:41:54 1    40:48:59   -122:58:14 12      12
  17 23:58:58 1    40:06:33   -122:56:29 21      21

00:02:01   *****DF 1 STATUS U U U U *****
00:02:01   *****DF 2 STATUS U U U U *****
00:02:01   *****DF 3 STATUS U U U U *****
CO
```

Figure 7. Longitude/Latitude Printout.

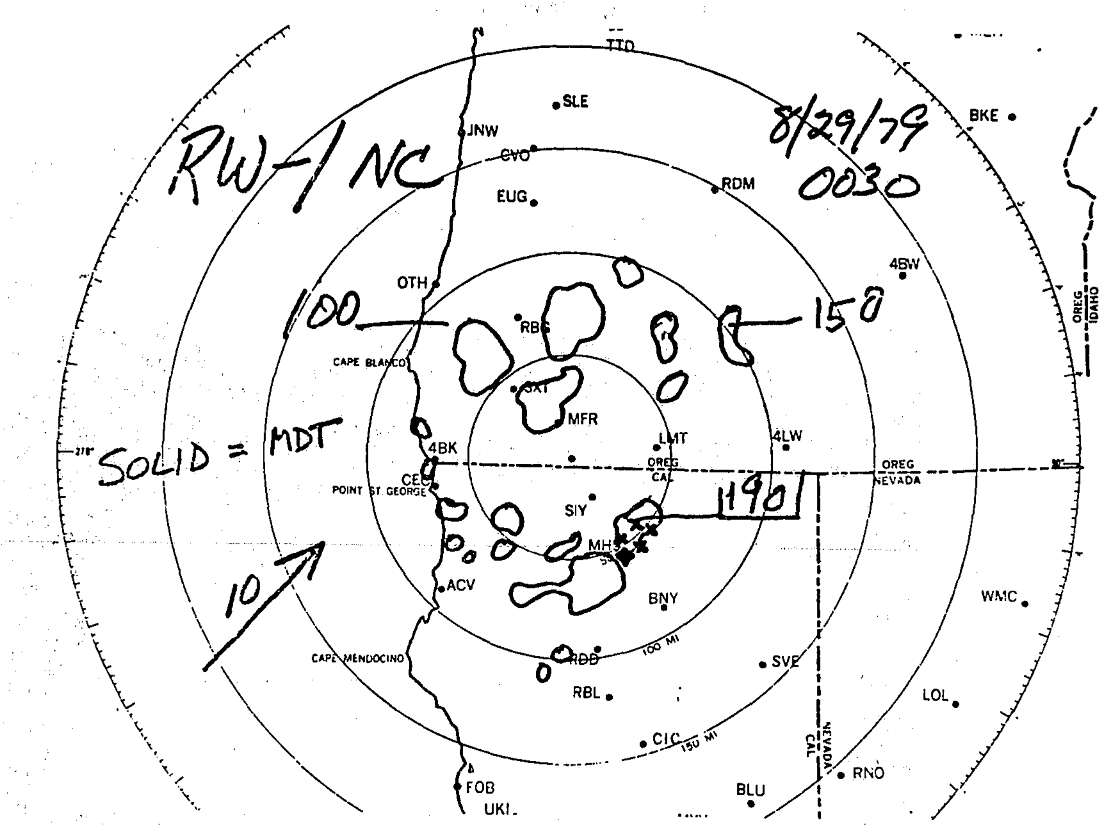

Figure 8. Medford Radar Overlay, 0030Z 8/29/79. ♦Lightning Fires. X Ground Strikes.

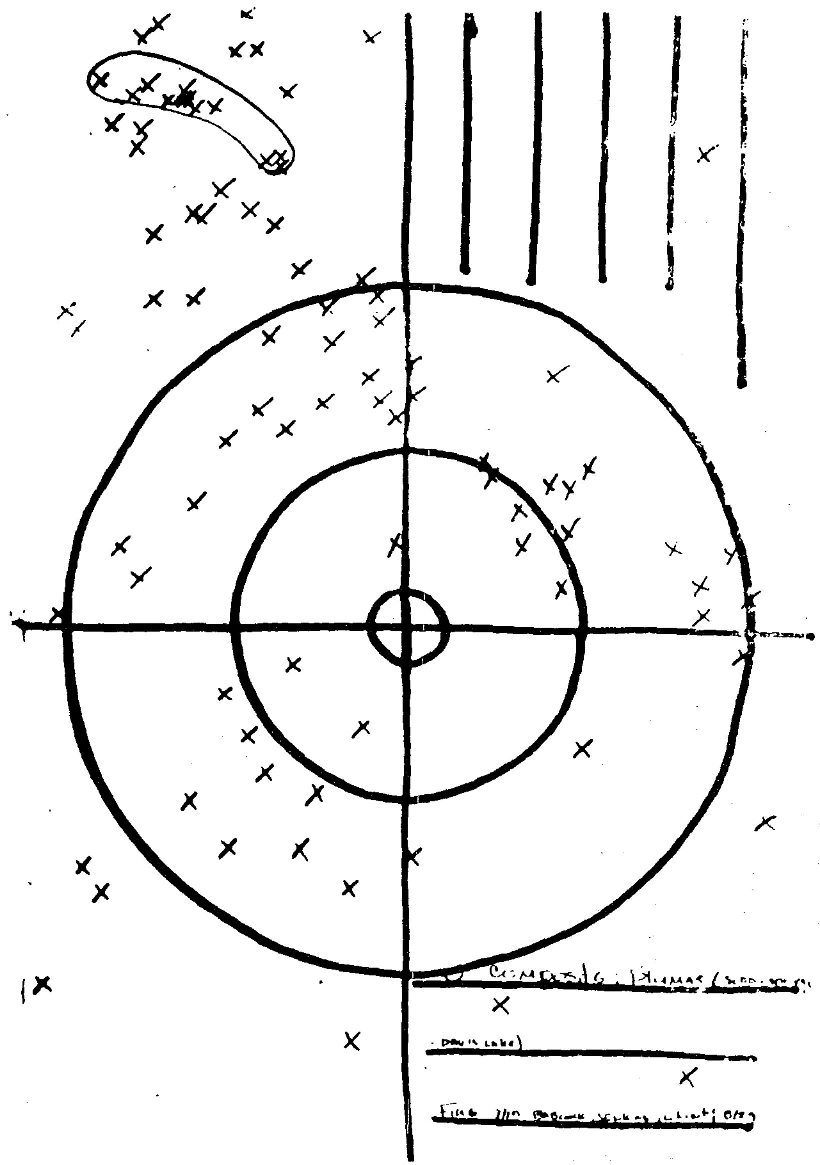

Figure 9A

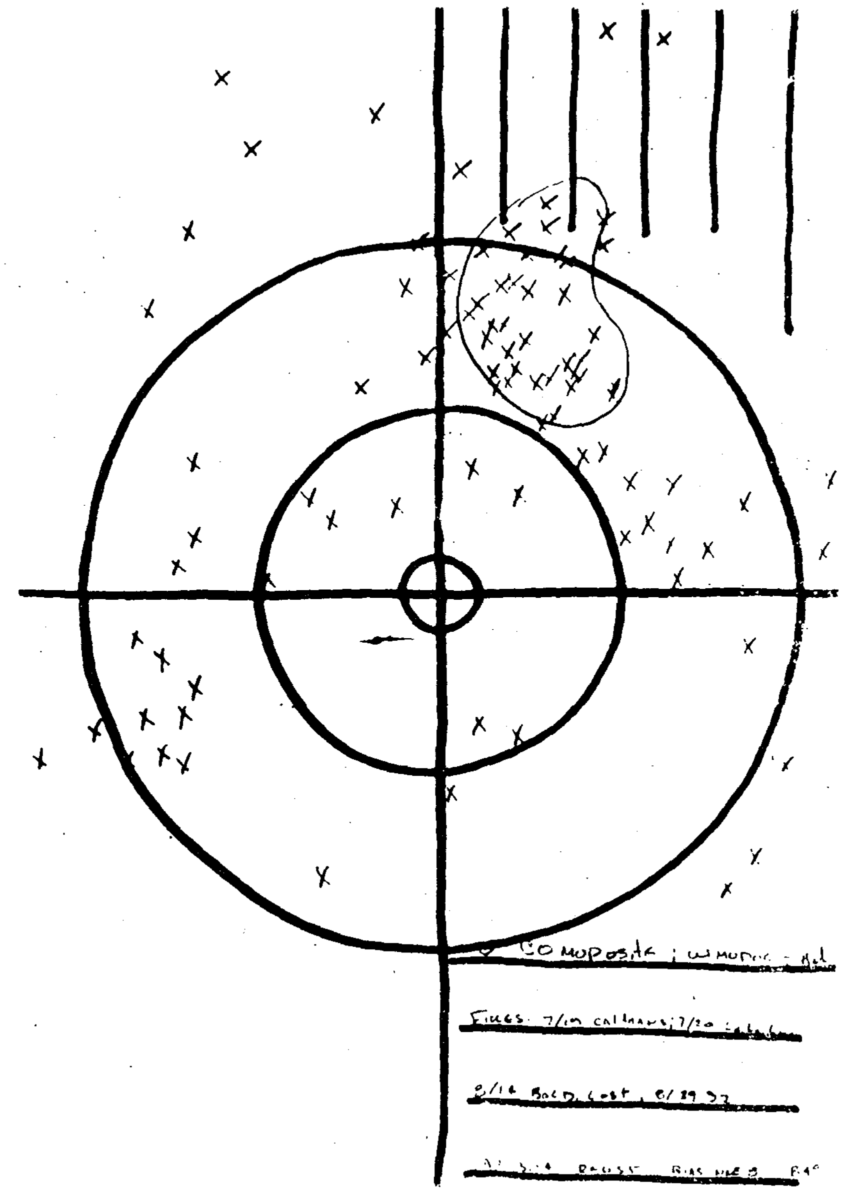

Figure 9B

Composite Lightning Scatter Diagram

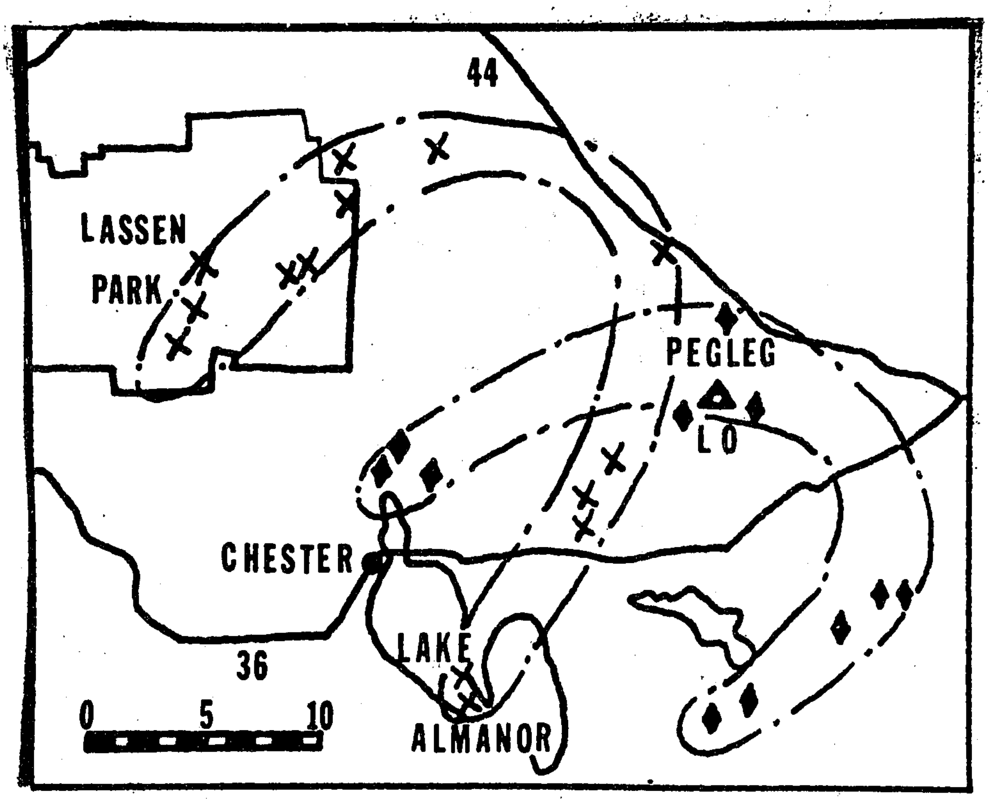

Figure 10. Lightning Fires-Ground Lightning Lassen NF, July 20, 1979.
♦ Lightning Fires. X Ground Strikes.

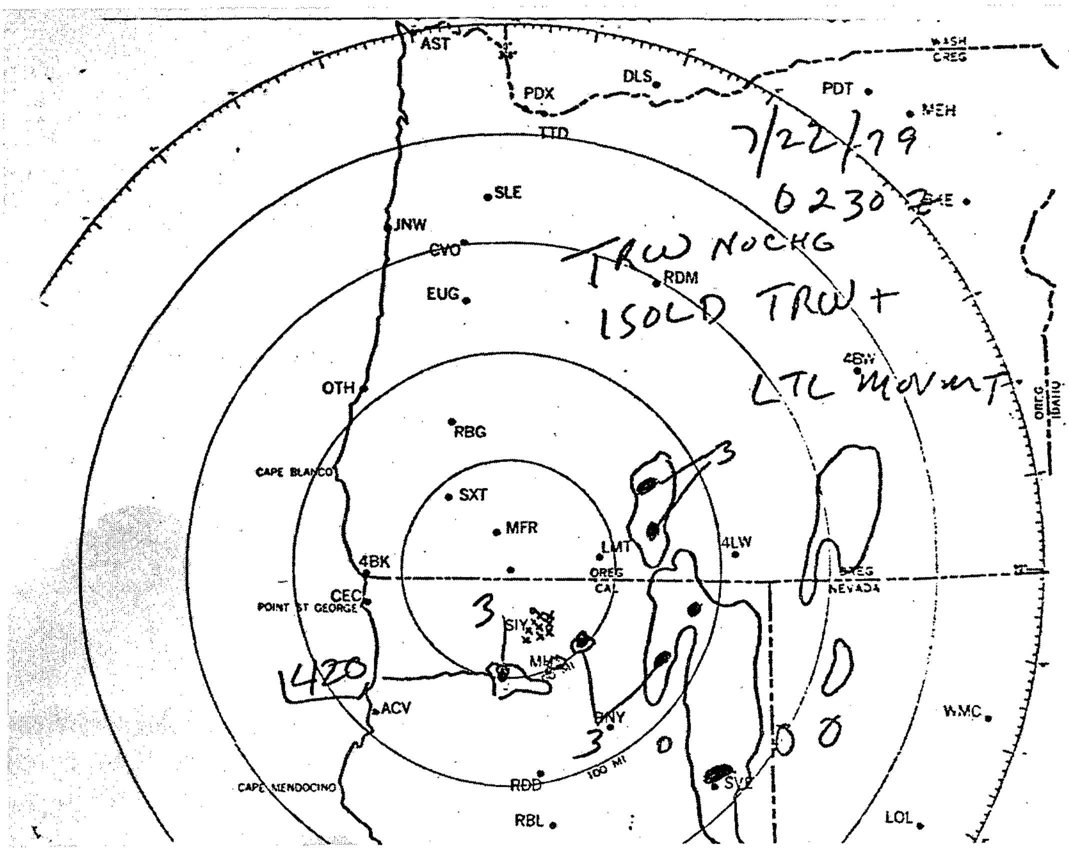

Figure 11. Medford Radar Overlay, 0230Z July 22, 1979. X Ground Strikes.

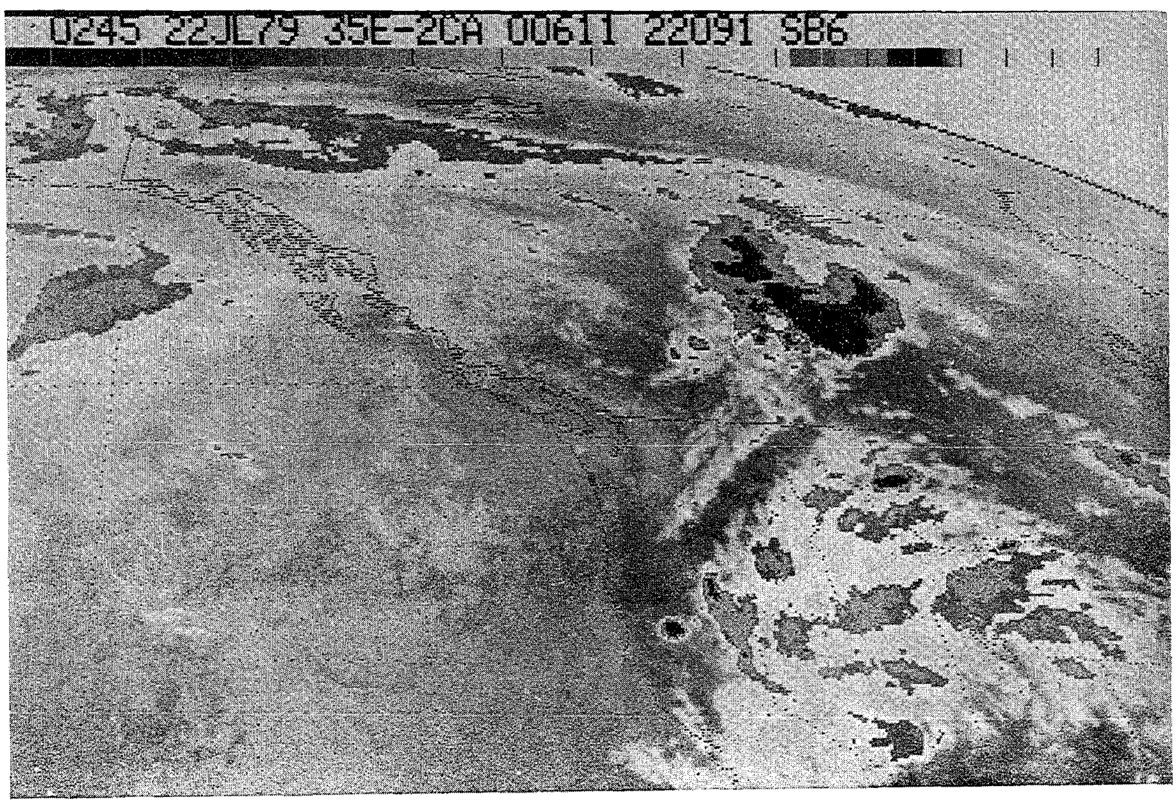

Figure 12. Enhanced GOES IR, 0245Z July 22, 1979.

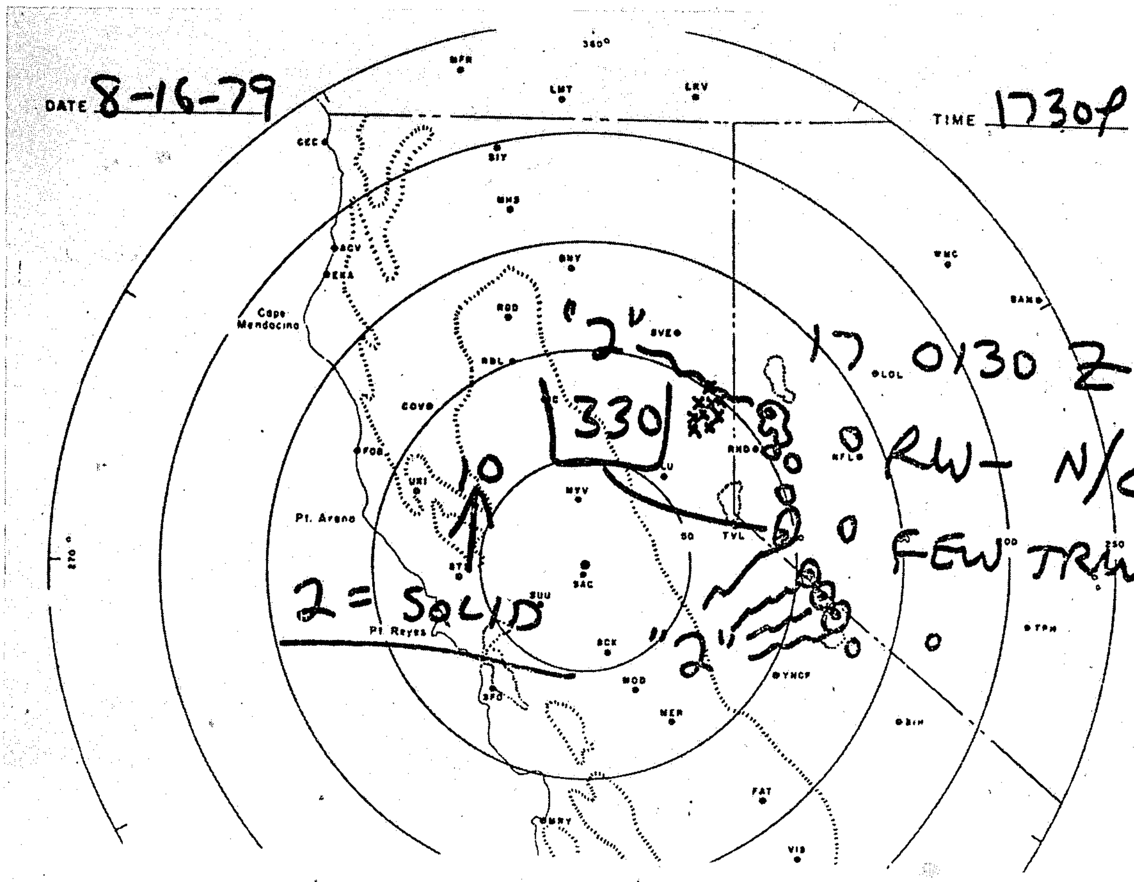

Figure 13. Sacramento Radar Overlay, 0130Z August 17, 1979.

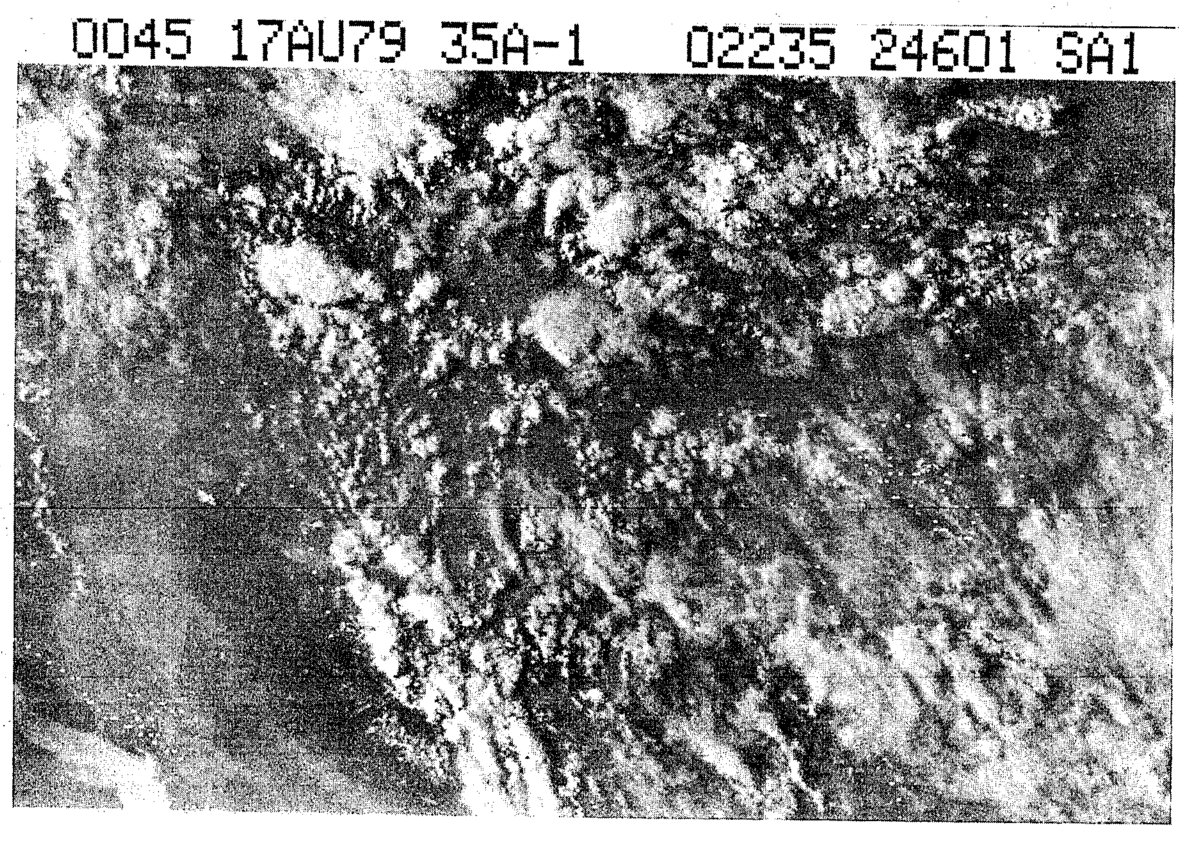

Figure 14. VIS GOES, 0045Z August 17, 1979.

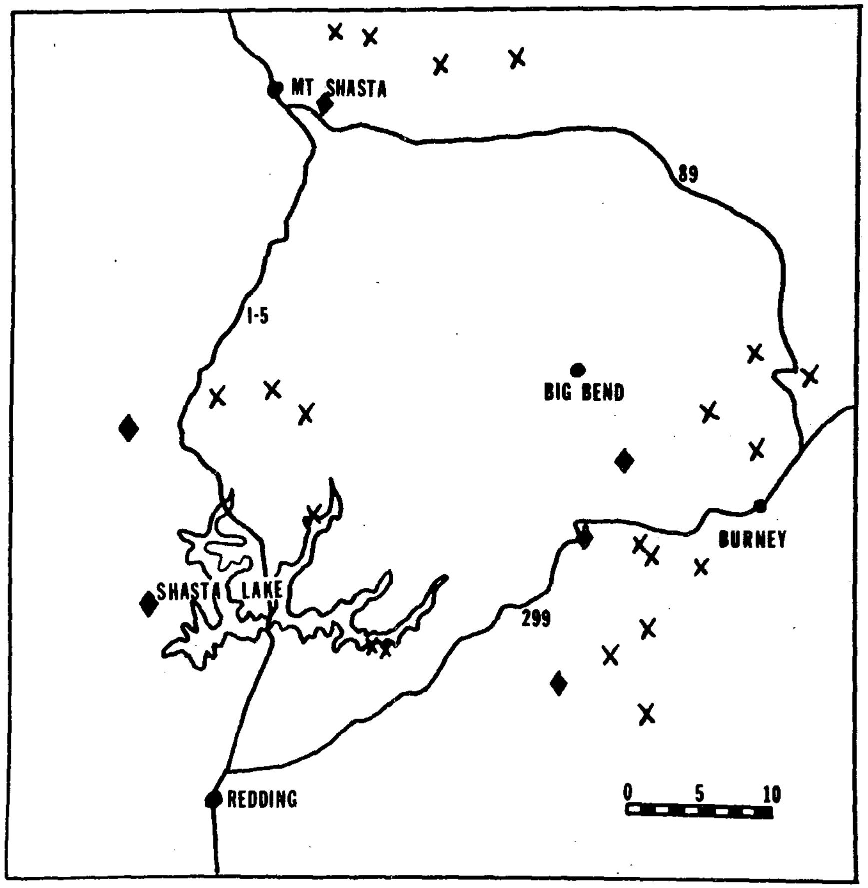

Figure 15A

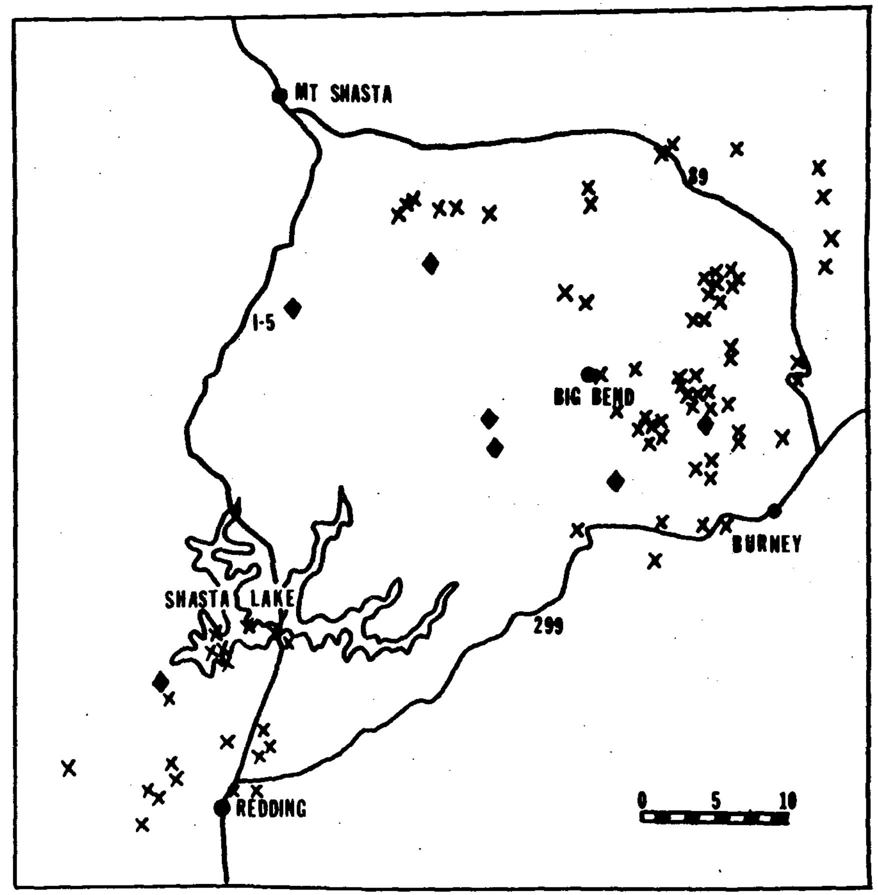

Figure 15B

Lightning Fires-Ground Lightning Shasta-Trinity, August 28-29, 1979.
◆ Lightning Fires. X Ground Strikes.

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