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# THE RELATIONSHIP OF STORM SEVERITY TO DIRECTIONALLY RESOLVED RADIO EMISSIONS

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# I. INTRODUCTION AND OBJECTIVE

As reflected in recent policy statements of the American Meteorological Society,[1]* several types of severe storms are of primary public concern, viz., storms which produce flash floods, severe windstorms, hail, tornadoes, and hurricanes. Typically there are 700 to 1200 tornadoes in the United States each year.[2] These tornadoes have a life cycle of one to three minutes and cause relatively light damage over a path less than a mile long and 100 yards wide. Wind velocities are of the order of 100 mph.

Large-scale tornadoes (one to five percent of reported tornadoes) account for virtually all tornado injuries and the majority of total damage. Such tornadoes may exist up to three hours, resulting in damage paths more than 100 miles long and hundreds of yards wide. Maximum wind speeds have been estimated upwards of 200 mph. Atlas reports[3] an annual average of 100 deaths, 2000 injuries and 50 million dollars in property damage due to tornadoes.

Wind gusts from severe windstorms often reach 50 mph or more and occur in all parts of the United States.[4] During the year ending July 1974, nearly 5000 mobile homes were damaged or destroyed by severe windstorms.

Flash floods are considered to be the major killers and destroyers among weather-related disasters in the United States.[5] Since 1968 the average annual death toll from flash floods has risen to about 200, while property damage is averaging about a billion dollars a year.

At present development effort is concentrated in four areas:

(1) improving conventional weather radar displays and interpretive techniques,[6-7]

(2) satellite surveillance,[8]

(3) atmospheric electricity detection,[9] and

(4) Doppler radar.[10]

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*See References

This report summarizes the results of the first year of a three-year systematic effort toward (a) determining the reliability of detection and (b) predicting thunderstorm severity using directionally resolved 2 MHz atmospheric electrical emissions (sferics). The sferics data are acquired and analyzed using a crossed baseline phase interferometer. The count of sferic bursts as a function of azimuthal angle of arrival identifies the centers of intense electrical activity. Local reports of severe meteorological events are correlated with these estimates to determine their reliability as an indicator of thunderstorm severity. Systematic monitoring of thunderstorm electrical activity has been performed over the five-state area of New Mexico, Texas, Oklahoma, Arkansas, and Louisiana and has included tropical cyclones at ranges of approximately 2000 km during the six-month period from May - September 1979.

# II. DATA ACQUISITION

## A. Instrumentation

A block diagram of the crossed baseline phase interferometer used for data acquisition is shown in Figure 1. Portions of this equipment are owned by SwRI, and other portions are provided as GFE.* The interferometer consists of an L-array of 60 inch crossed loops and a nested L-array of 6-foot monopoles. The crossed loops (low band array) are used in the 2-10 MHz band, while the monopoles (high band array) are used in the 10-30 MHz region.

In each array the apex antenna is used as a phase reference. The remaining six antennas are sampled sequentially to provide phase measurement with respect to the apex. The electrical phase of the short baselines is used to resolve the 360-degree phase ambiguity of the intermediate and long baselines. The outermost antennas provide the phase measurement used for direction of arrival. The intermediate baseline resolved phase (including 360-degree rotations) is compared with resolved long baseline phase to test for linear phase propagation across the array aperture. If the phase does not satisfy the linearity criterion, the measurement is discounted. Only those data satisfying the linearity criterion are used in this study.

Unless otherwise indicated, all data reported herein were obtained at 2.001 MHz with a bandwidth of 2.7 kHz. The system computer is a Data General Nova 3/12 with 32 K memory and a 5 MB disk system. A second Nova 3/12 manages a graphics CRT for real-time display of the acquired data. The operating console is shown in Figure 2.

## B. Unattended Storm Monitoring

To maximize the time of storm observation, software was written to permit unattended data acquisition on a 24-hour basis. Data were acquired under computer control and logged to disk storage for post-processing. Data are identified by frequency, the start time of acquisition, and data block termination time (the time at which 3200 directional measurements were complete).

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*On a non-interference basis with U. S. Army under Contract DAAB07-76-C-1368.

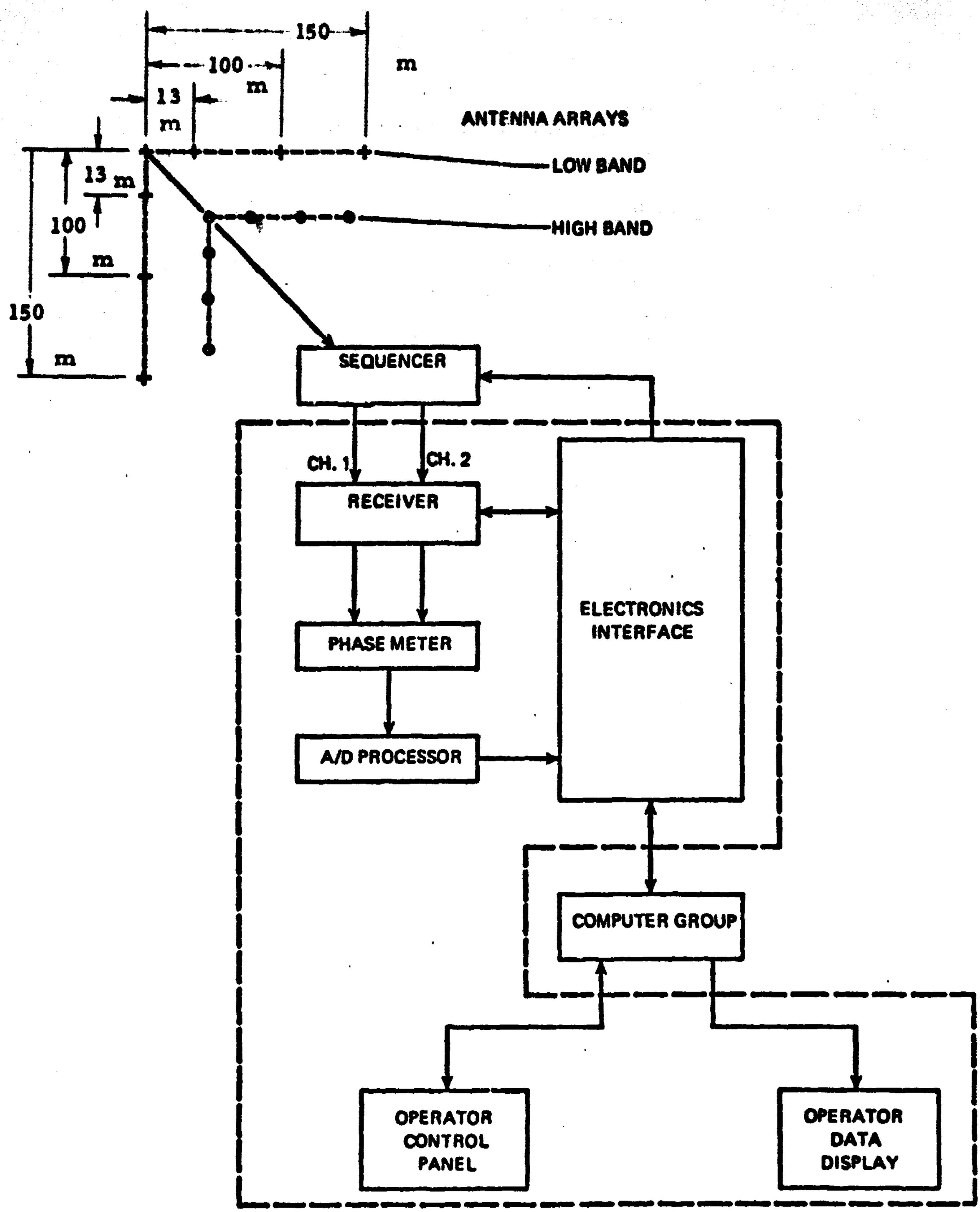



FIGURE 1. DF INTERFEROMETER

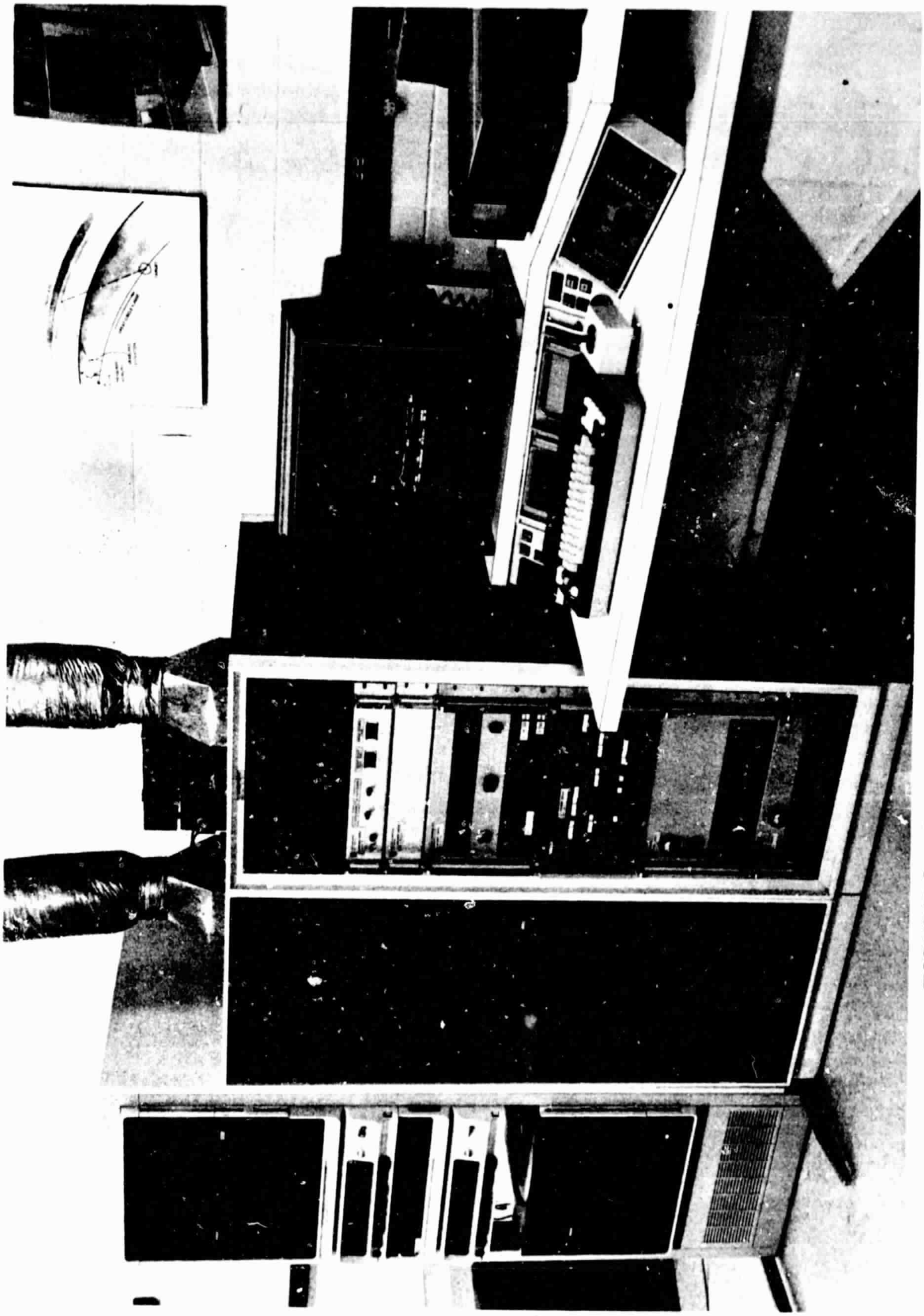


FIGURE 2. OPERATING CONSOLES

Data frames are logged in terms of measured azimuth and elevation with 0.1-degree resolution. The data buffer is stored when 3200 DF frames are completed (i.e., signal above preset threshold). Of these 3200 frames only those tagged as phase linear were used in the analysis. Post analysis includes a line printer plot of the azimuth histogram of phase linear frames.

## C. Thunderstorm Observations

During the data acquisition period May-September 1979, observations were made on 96 thunderstorm days (including hurricanes and tropical depressions), and 668 hours of sferic data were recorded. Observation ranges of 1000 km were originally expected; however, a preliminary analysis of the data revealed that sferic activity was being monitored out to ranges of 2000 km; e.g., a tropical depression was tracked off the east coast of Florida and thunderstorm activity was observed in the vicinity of the Yucatan Peninsula.

## III. DATA ANALYSIS

### A. Inland Thunderstorms

#### 1. Near Storms

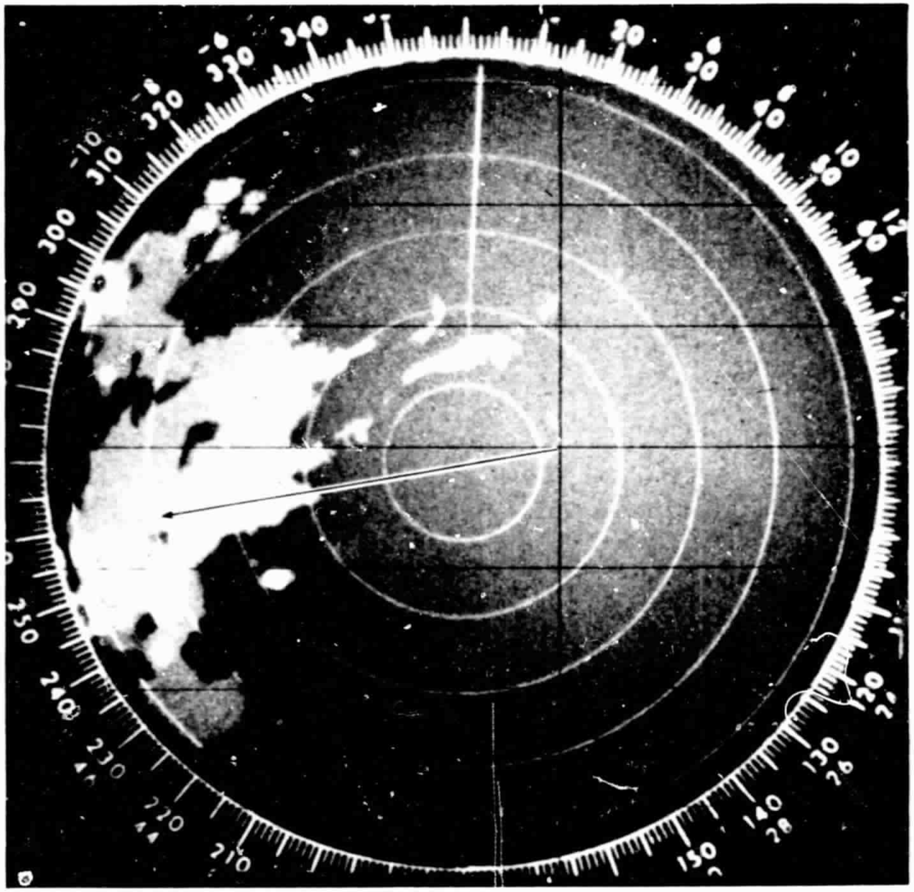
Figure 3 shows a squall line of thunderstorm cells approximately 100 miles distant from San Antonio observed at 0032 GMT, 28 May 1979. The radar picture was taken from the NWS 10-cm radar in Hondo, Texas, 30 miles west of San Antonio. The shaded echoes correspond to VIP levels 1, 2 and 3.*

The corresponding sferic data collected during this storm period are shown in histogram form in the plot on the right of Figure 3. The ordinate is the number of phase linear sferic bursts measured during approximately a 30-minute time period. The abscissa is the azimuthal angle of arrival. The mode of the histogram shows a center of relatively intense electrical activity as indicated by the vector superimposed on the radar trace.

A contour map obtained from the NWS station log shows the more intense portions of the storm (Figure 4). As indicated, three extremely intense cells were developing along the indicated bearing in the midst of general thunderstorm activity. One cell indicates a hail shaft. The directionally resolved sferic data clearly detect the center of storm severity. Electrical activity and meteorological severity are highly correlated.

A stationary mass of cold air coupled with a continual flow of warm moist Gulf air provided prolonged instability and consequent thunderstorm activity. The same storm system is shown in the radar trace of Figure 5, approximately 20 hours later. The center of electrical activity is situated approximately 50 Nmi north/northeast of San Antonio. The histograms of sferic bursts are more tightly clustered than those of Figure 3. These data were collected over a period of six minutes compared with the thirty-minute period indicated in Figure 3. Approximately the same number of phase linear sferics are observed in each case. However,

*These are the only VIP levels utilized since the presentation is black and white and higher VIP levels would repeat the color pattern.



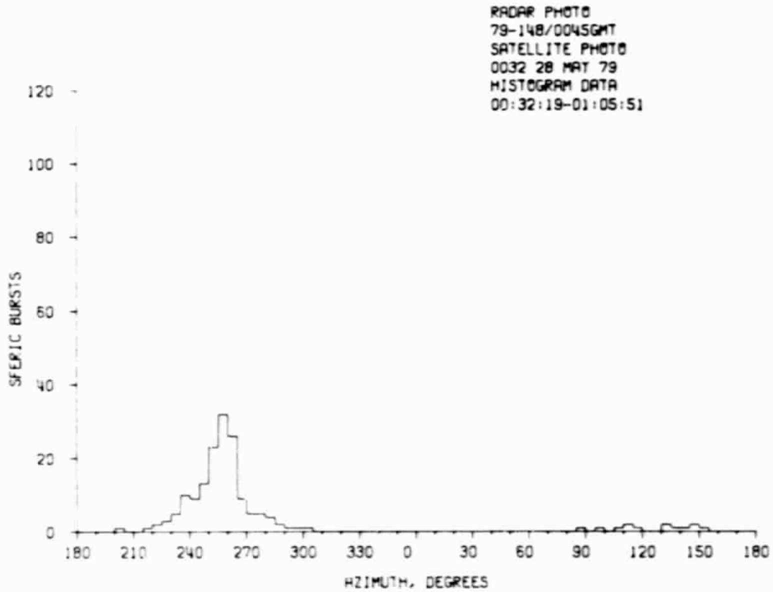



FIGURE 3. NEAR THUNDERSTORM ON 28 MAY 1979, 0032-0105 GMT
NWS RADAR 125 NMI SWEEP, 25 NMI RANGE CIRCLES

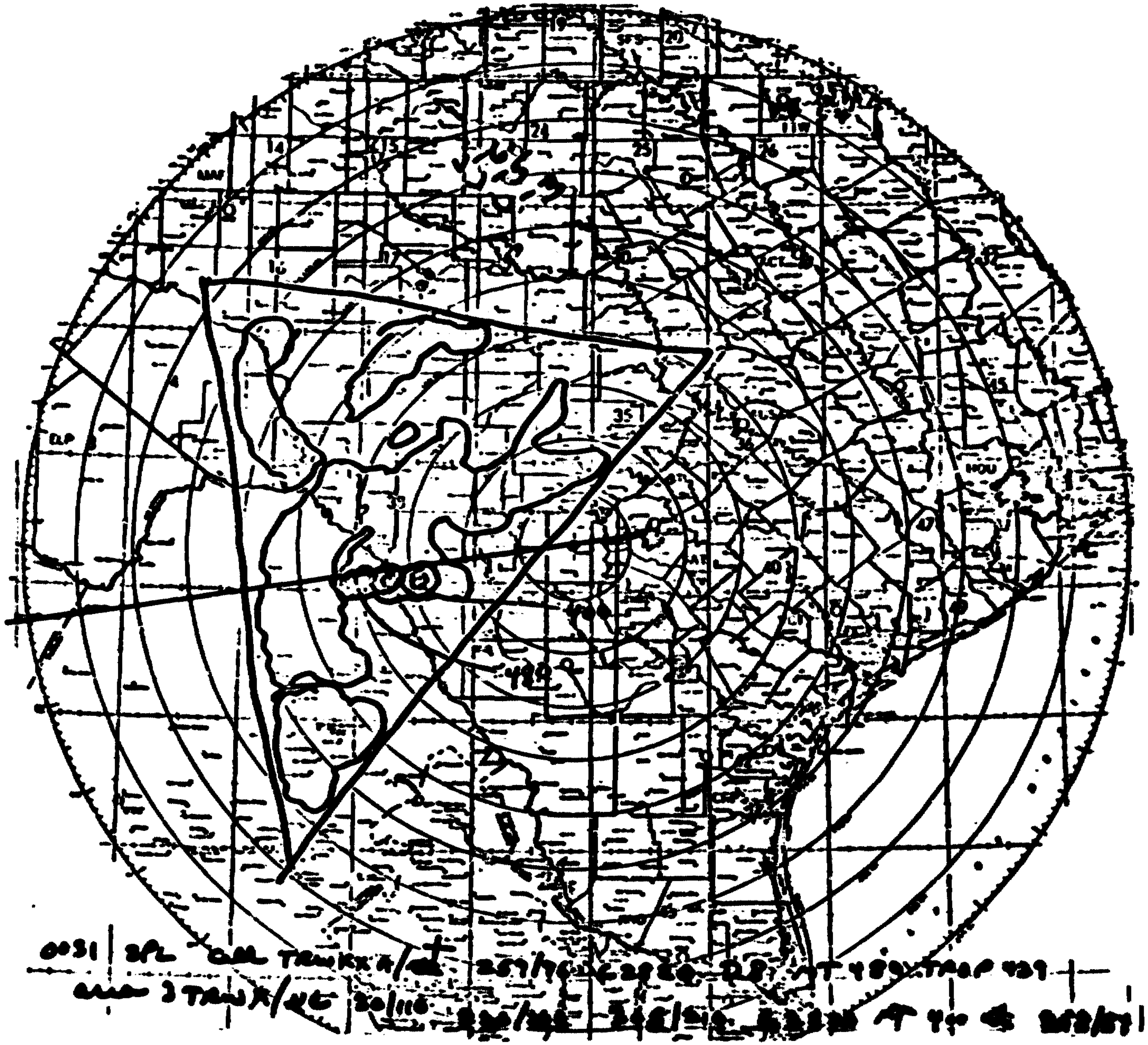


FIGURE 4. STORM CONTOUR MAP FOR 28 MAY 1979, 0031 GMT

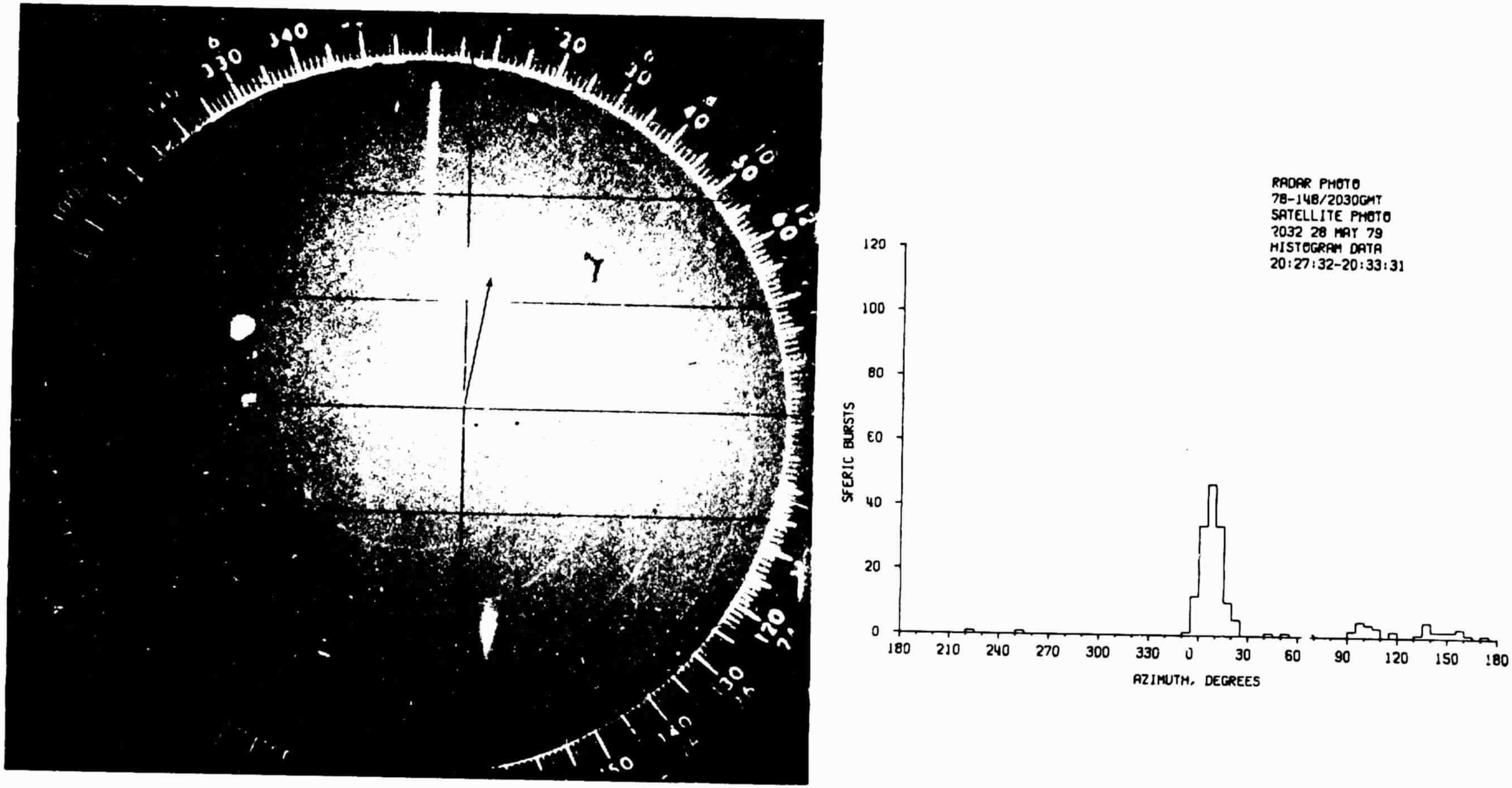



FIGURE 5. NEAR THUNDERSTORM ON 28 MAY 1979, 2027-2033 GMT
RADAR SWEEP 250 NMI, 50 NMI RANGE CIRCLES

the ambient noise background level was significantly different. Specifically, the greater background exists in the six-minute data since the 3200 sample buffer was filled in significantly less time with data which failed to satisfy the phase linear criteria. This could be attributed to a higher incidence of sferic bursts lasting less than 14 milliseconds or a greater frequency of simultaneous sferic emissions. The storm contour map shown in Figure 6 shows the center of maximum meteorological activity is in line with the directionally resolved sferic data. The phase linear sferics resolve points of maximum meteorological severity in a broad area of multicellular thunderstorm activity. It is also noted that the storm systems west of San Antonio were neither electrically active nor meteorologically intense.

## 2. Long-Range Inland Storms

The data presented in the previous section are typical of thunderstorm observations at ranges of 250 km or less. In this section typical results are given for system performance at ranges of 250 to 2000 km from San Antonio.

Shown in Figure 7 are the satellite data for 11 April 1979. The image is an MB enhancement of the GOES infrared data.[11] At the upper right is a tracking chart showing lines of bearing from San Antonio as straight lines. The histogram shows the phase linear sferic burst rate in bursts per minute. As shown by the satellite data, a large frontal system extended across the west Texas plains and into the midsection of Oklahoma. These data were acquired approximately 4 hours after the devastating Wichita Falls tornado of 10 April 1979. The time of acquisition was 11 April, 0430 GMT, or 10 April, 2130 CST. Meteorological reports at this time indicate tornadic activity near San Angelo, Texas, and severe windstorms near Oklahoma City. Excerpts from the NWS publication STORM DATA are given in Table 1 of Appendix A. Both the reports of meteorological severity and histogram of sferic activity are in good agreement regarding the intensity of the storm and its widespread nature.

Figure 8 is a display of the satellite data for 26 May 1979 at 0832 GMT (0232 MDT local New Mexico time). As indicated by the infrared data, a large storm system was in progress in the El Paso-Carlsbad, New Mexico, area. The NWS storm data for this period indicate flash flooding was occurring in the Carlsbad area (Table 2 of Appendix A). As noted in Figure 8, the peak sferic intensity is directed somewhat south of El Paso in northern Mexico. Although a significant portion of the storm was active in northern Mexico, no ground truth data are available for that region.

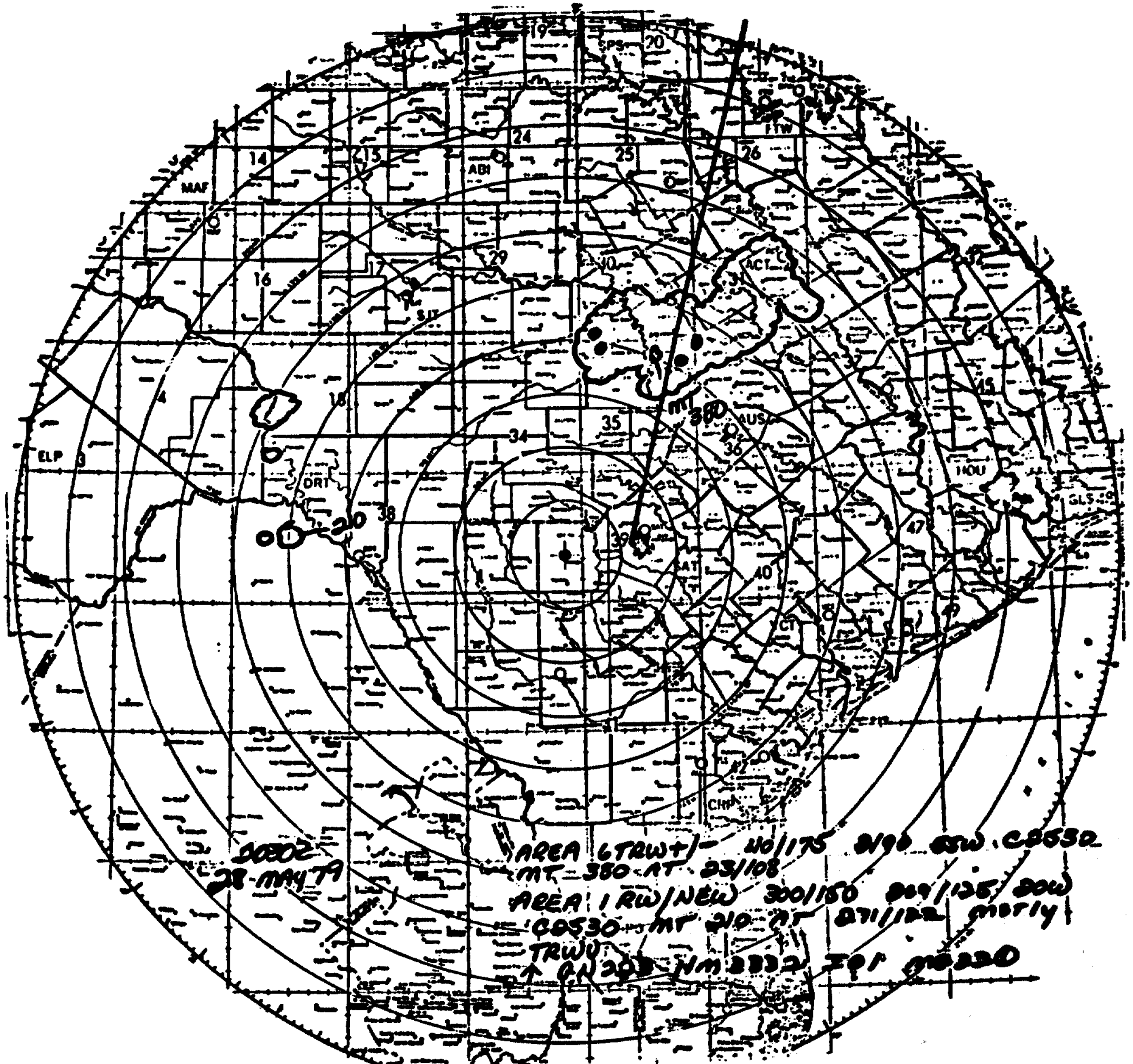



FIGURE 6. STORM CONTOUR MAP FOR 28 MAY 1979, 2030 GMT

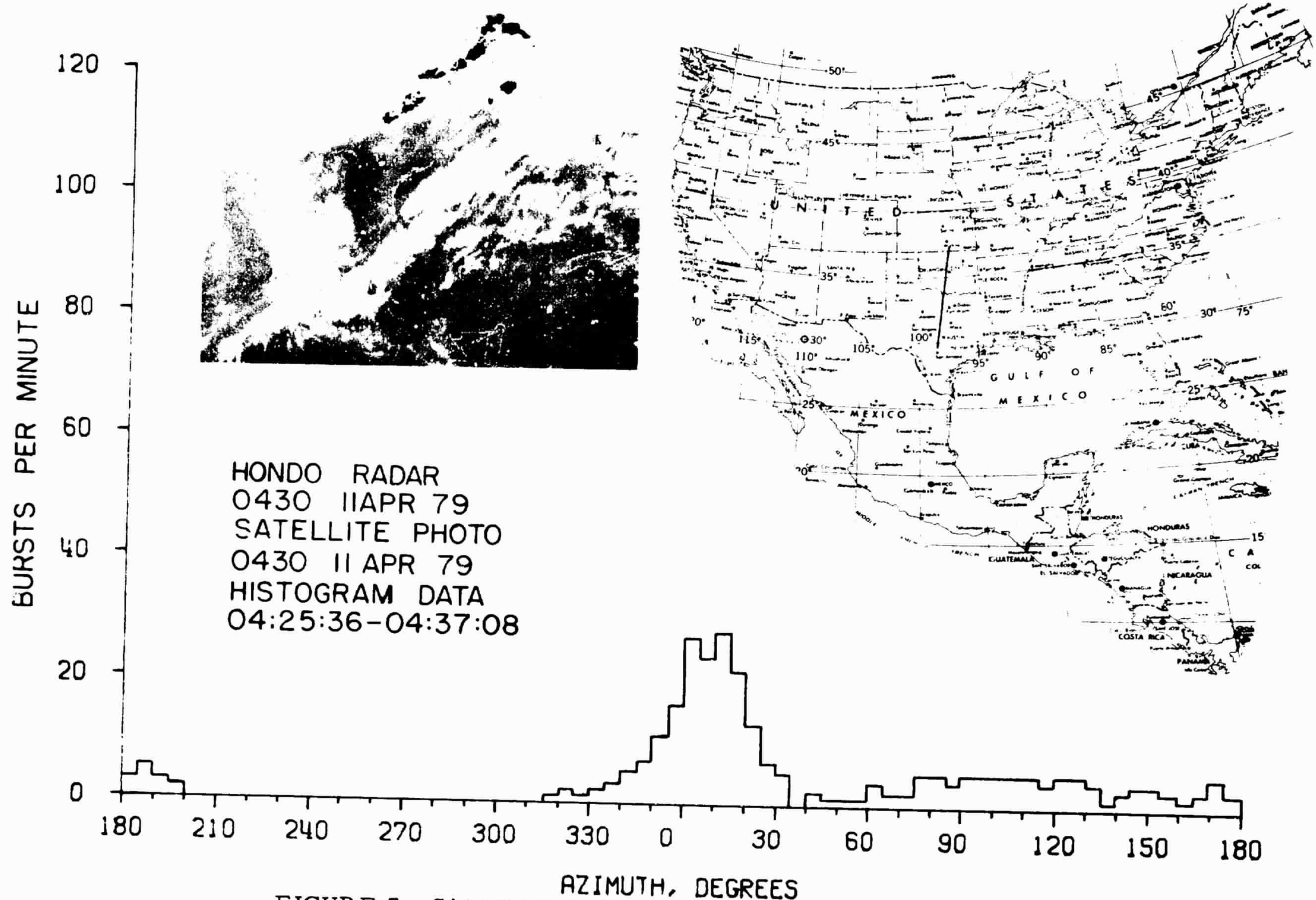



FIGURE 7. SATELLITE DATA FOR 11 APRIL 1979, 0430 GMT

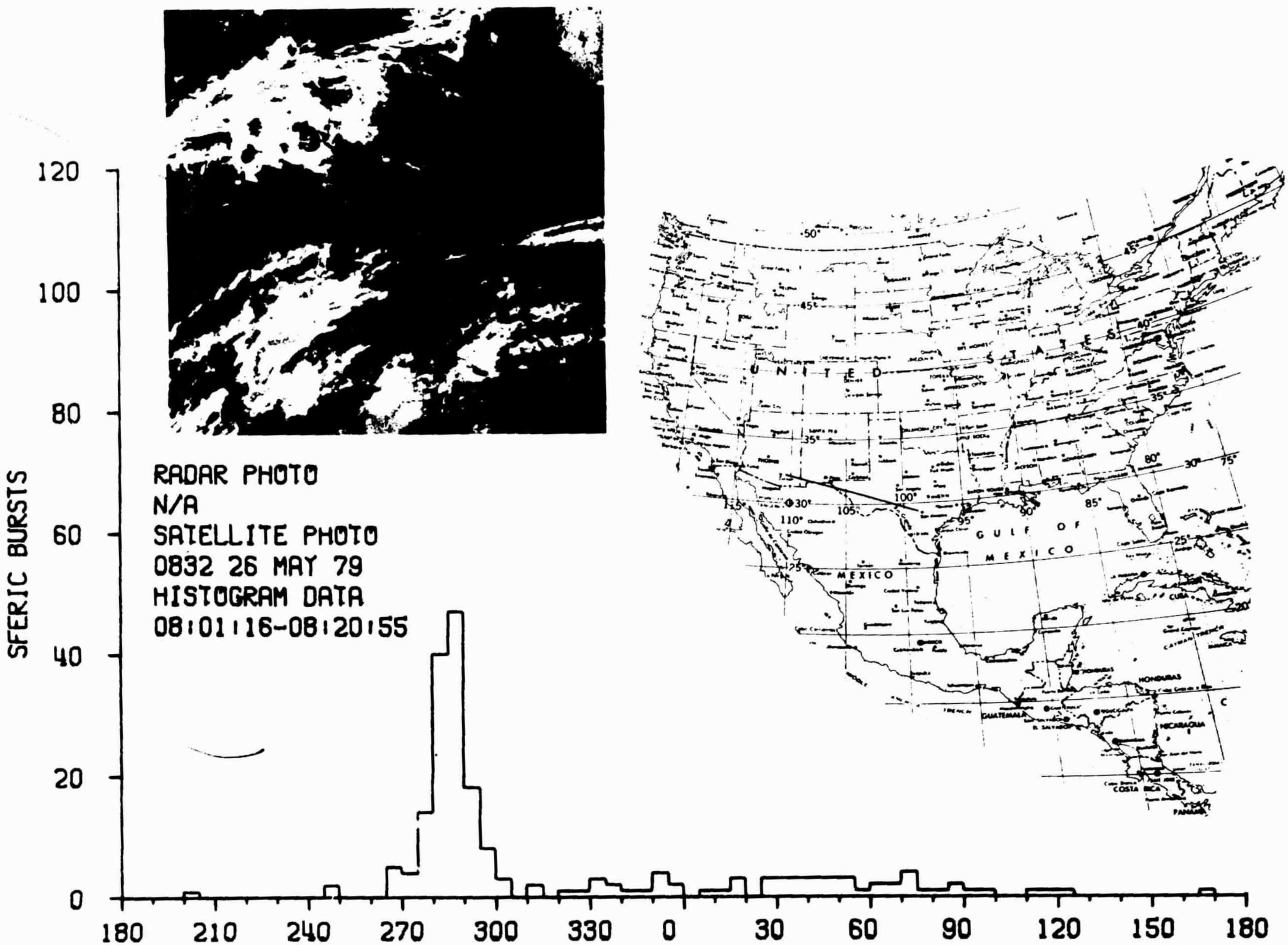



FIGURE 8. SATELLITE DATA FOR 26 MAY 1979, 0832 GMT

A massive storm system is shown in the satellite display of Figure 9. This storm covered virtually the eastern half of Kansas. A distinct center of phase linear sferic activity is indicated slightly east of Salina, Kansas. Meteorological reports for this period from the hail-loss clearing house indicate hail was especially severe in Dickinson and Morris counties, east and southeast of Salina (Figure 10). Distance to the storm from San Antonio is 1400 km.

Figure 11 is the satellite data for a large storm system occurring in the northwestern portion of Kansas near the Nebraska border on 17 June 1979 at 0332 GMT. The phase linear sferic histogram indicates a well-defined peak directed toward the western portion of Kansas. During the time period of data acquisition, 2230-2350 CDT, a tornado touched down three miles north of St. Peter in Graham County, causing extensive damage to farm houses and buildings. Also in other parts of Graham County severe windstorms with velocities up to 80 mph were recorded, and hail up to three inches in diameter caused damage to homes, farm buildings and utility lines (Figure 12). A detailed report is given in Table 3, Appendix A.

### 3. Inland Severe Storm Detection

The data reported in the previous section indicate the ability of the system to detect severe thunderstorm activity at long ranges under the condition that a single large storm system is in progress. The data in this section demonstrate the capability of the system to discriminate severe storm systems from nonsevere storm systems.

Illustrated in Figure 13 are the satellite data for 10 July 1979 at 0232 GMT. At 2130 CDT during data acquisition, two large storm systems were in progress: one on the north central Texas plains and a second in the western half of Arkansas. Some moderate activity was in progress west of San Antonio. The satellite data do not suggest that one storm system is more severe than the other; however, the phase linear sferic burst count indicates that the storm system on the north central plains of Texas is significantly more electrically intense. A review of the meteorological data indicates four tornadoes had been sighted, and widespread damage due to severe wind and hail storms had occurred in the west Texas storm system during this time. Tornadoes had been reported in the Arkansas storm three hours prior to this time; however, no severe activity was currently in progress and the storm was dissipating. Thus, the electrical data are highly correlated with the ground observations of meteorological activity. (Table 4 in Appendix A details the ground truth data.)

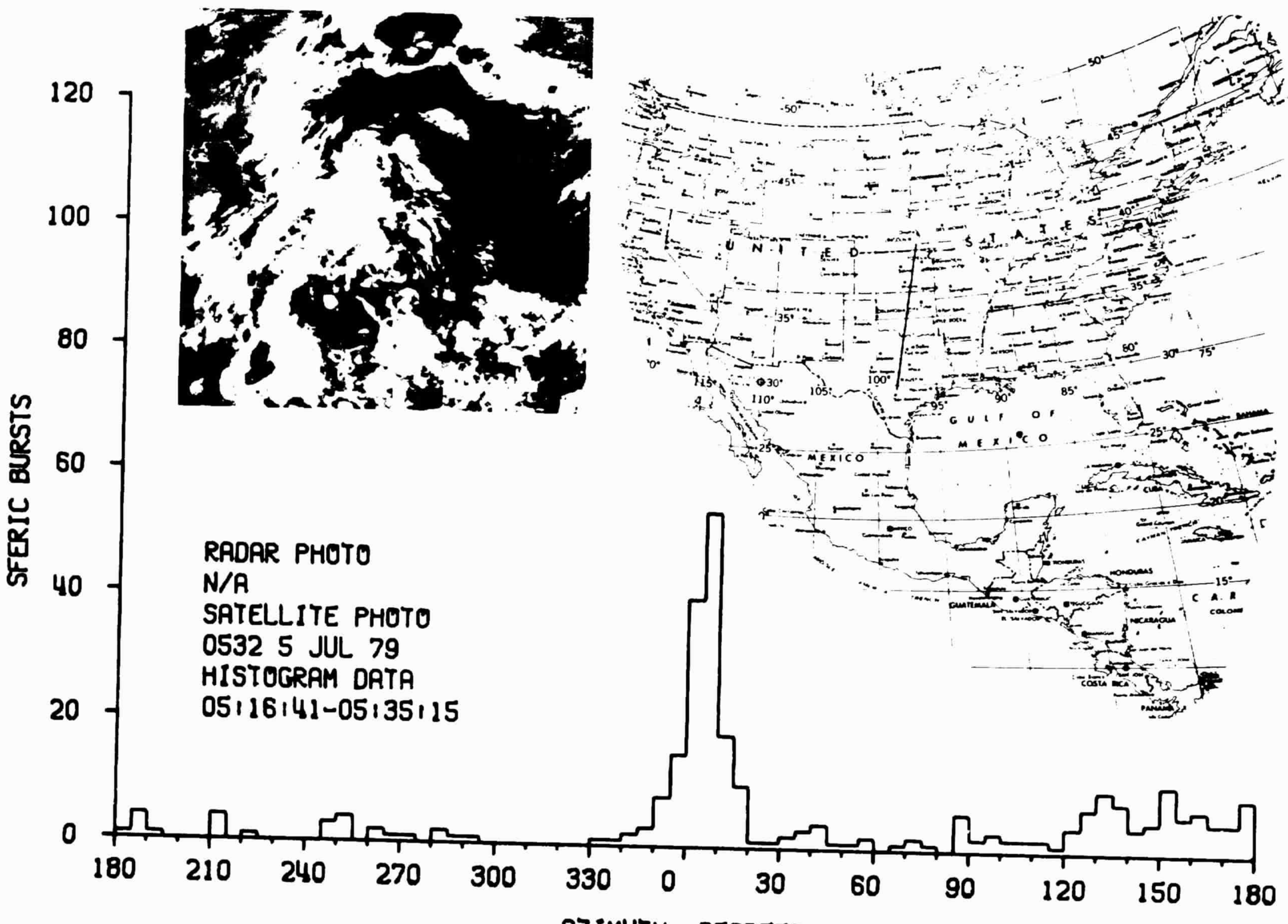



FIGURE 9. SATELLITE DATA FOR 5 JULY 1979, 0532 GMT

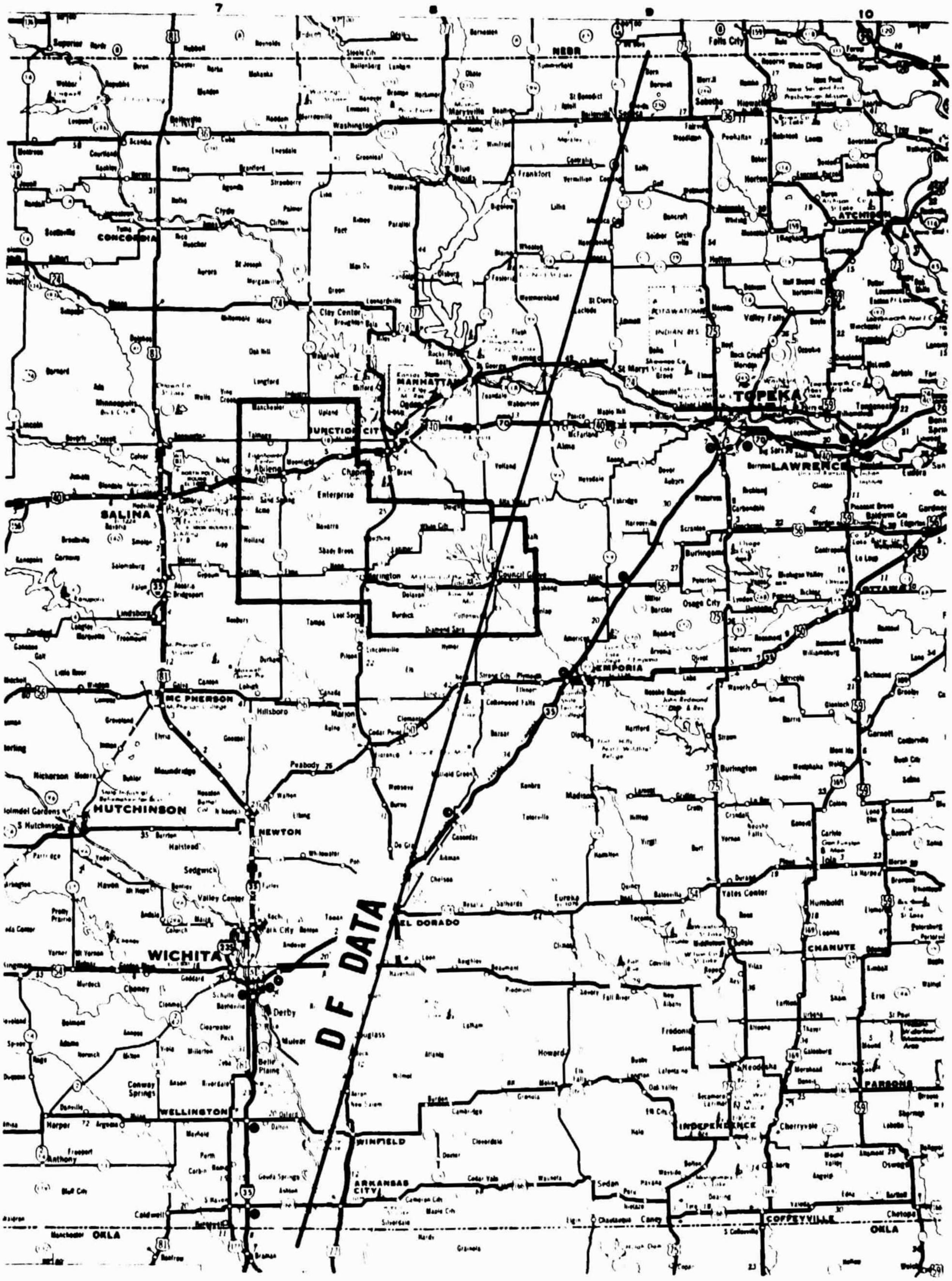



FIGURE 10. MAP OF EASTERN KANSAS HAIL DAMAGE AREA

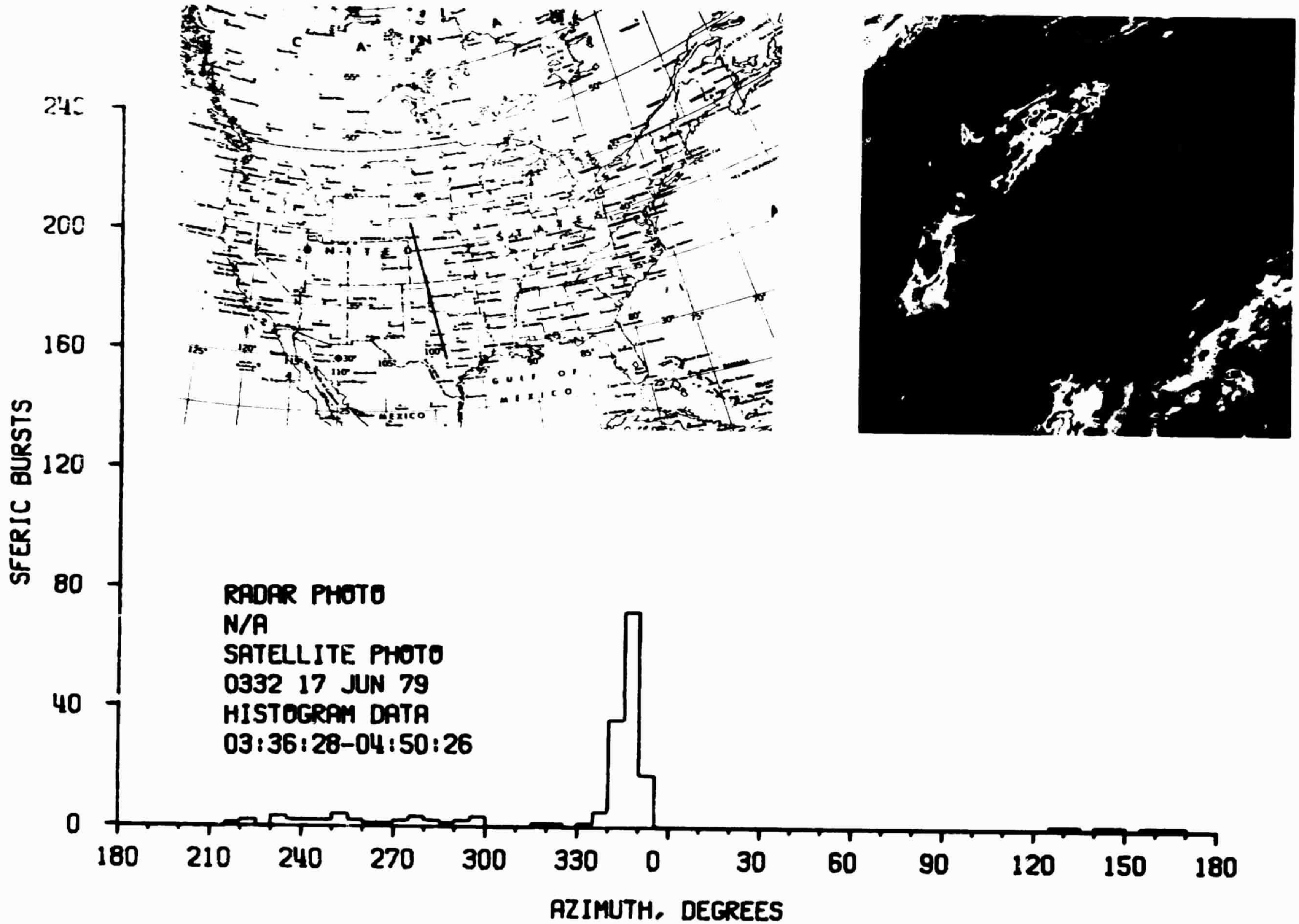



FIGURE 11. SATELLITE DATA FOR 17 JUNE 1979, 0332 GMT

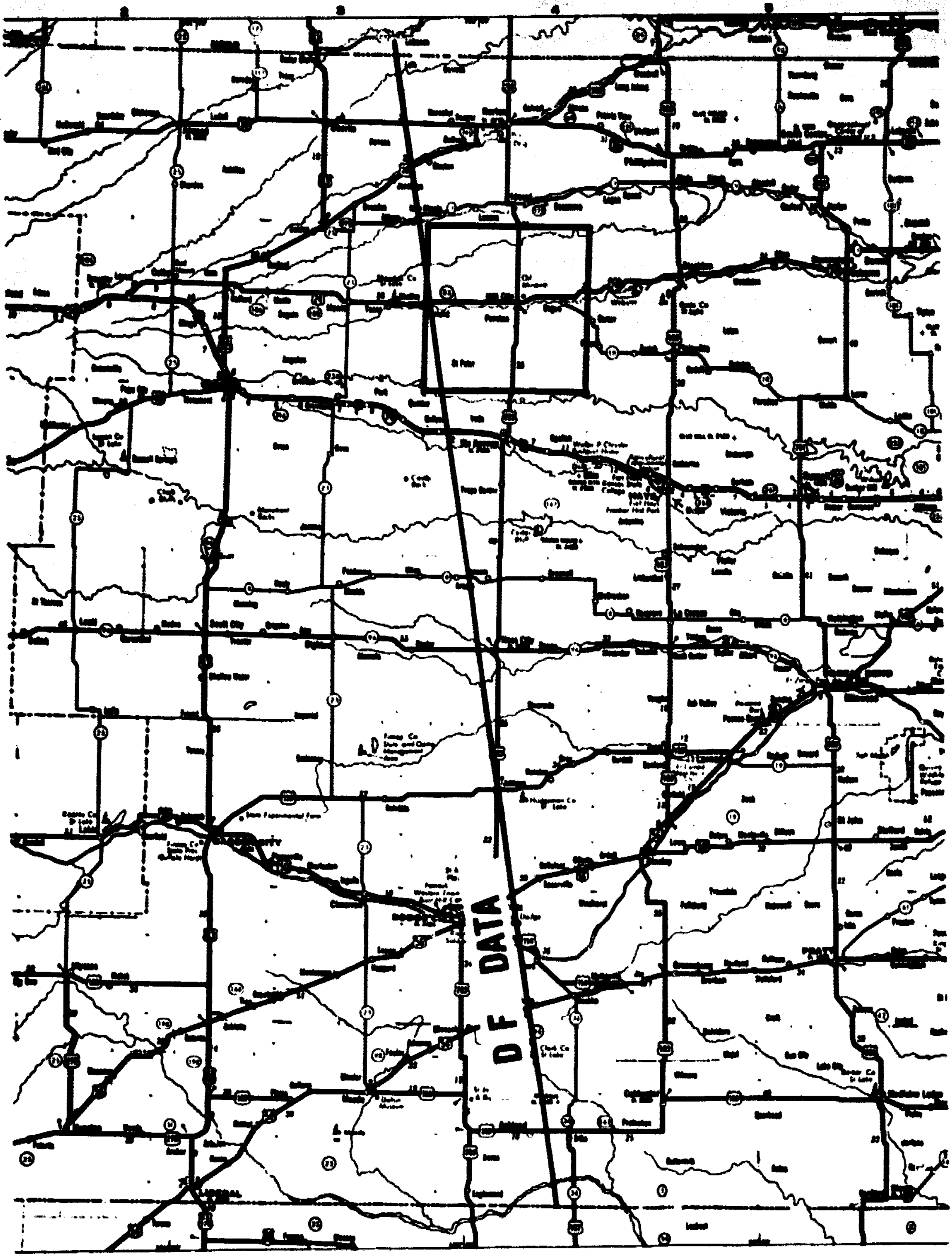



FIGURE 12. MAP OF WESTERN KANSAS WIND DAMAGE AREA

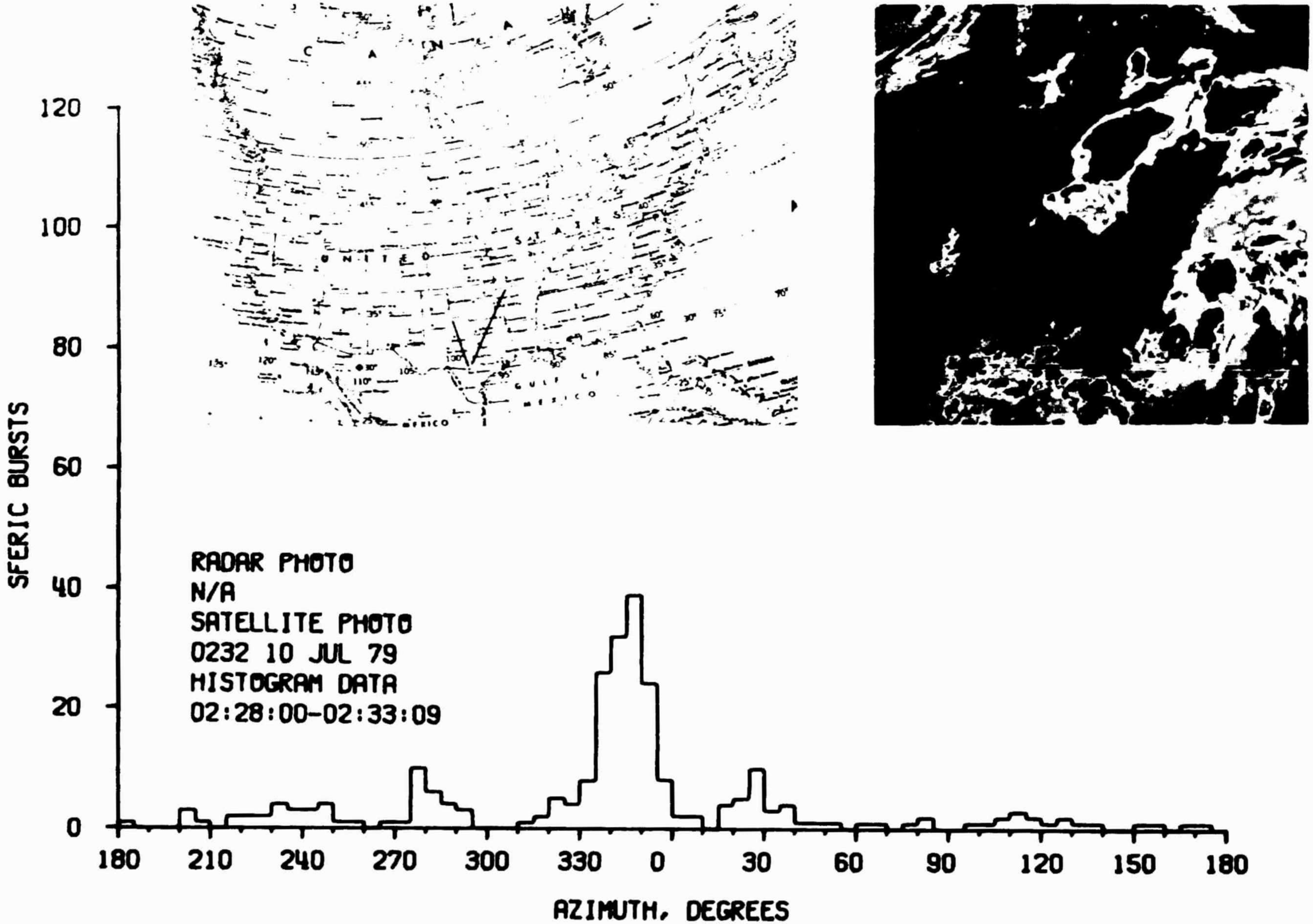



FIGURE 13. SATELLITE DATA FOR 10 JULY 1979, 0232 GMT

The satellite data shown in Figure 14 indicate two large storm systems in progress, one in the eastern portion of Texas and western Louisiana and a second storm system occurring in the north Texas-Oklahoma panhandle. The storm situated in east Texas was significantly electrically more active, as shown by the phase linear sferic peak, than was the system located in northern Texas. During the period of data acquisition, 30 May 1979 at 0530 CDT, flash flooding was occurring in east Texas and windstorm damage was reported in Louisiana. Details of the meteorological reports are given in Table 5, Appendix A. There were no reports of severe storm activity in the Texas-Oklahoma panhandle area during this period.

Figure 15 shows satellite data on 9 June 1979, 0132 GMT. Two major storm systems were evident. One was in progress in the northeast portion of Oklahoma/northwest corner of Arkansas, while a second storm system was in progress in north central Texas. The area of maximum phase linear electrical activity was directed toward the storm in north central Texas. Meteorological data for this period of time (1900 CDT) indicate tornadic activity in north central Texas and flash flooding in central and northeastern Oklahoma (Table 6, Appendix A). During this period of time (approximately one hour) the storm system indicating tornadic activity appears in the phase linear data to be electrically more active than the system which produced excessive rainfall. It is noted that sferic bursts were received from the extended frontal system through the west Texas plains area and a storm cell located in Mexico, west of Brownsville, Texas.

Illustrated in Figure 16 are two large storm systems in Oklahoma, one in the southwestern part of the state and a second in the northeastern portion of the state. The dominant phase linear sferic activity (2330 CDT on 22 June 1979) was apparently emitted by the system in northeastern Oklahoma. Meteorological reports for this time (Table 7, Appendix A) indicate severe winds, a sighted funnel and subsequent flash flooding are reported from the northeastern storm system. No severe weather was reported in the southwestern storm system.

These four instances show the peak of phase linear sferic activity consistently associated with the most meteorologically intense storms. No apparent discrimination is available from the MB images alone. The severe storm detections were made at ranges from 1000 km to 1500 km from San Antonio.

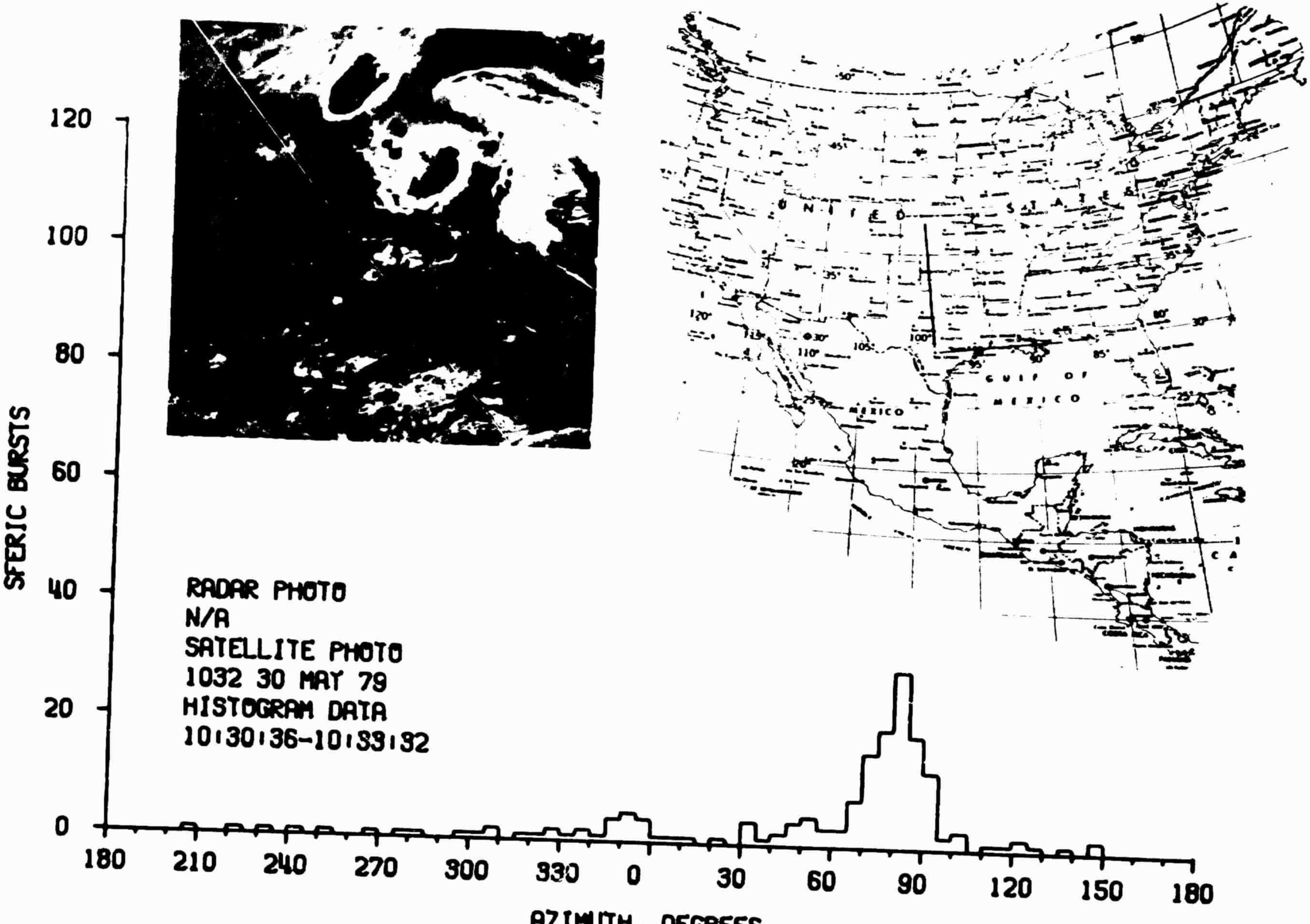



FIGURE 14. SATELLITE DATA FOR 30 MAY 1979, 1032 GMT

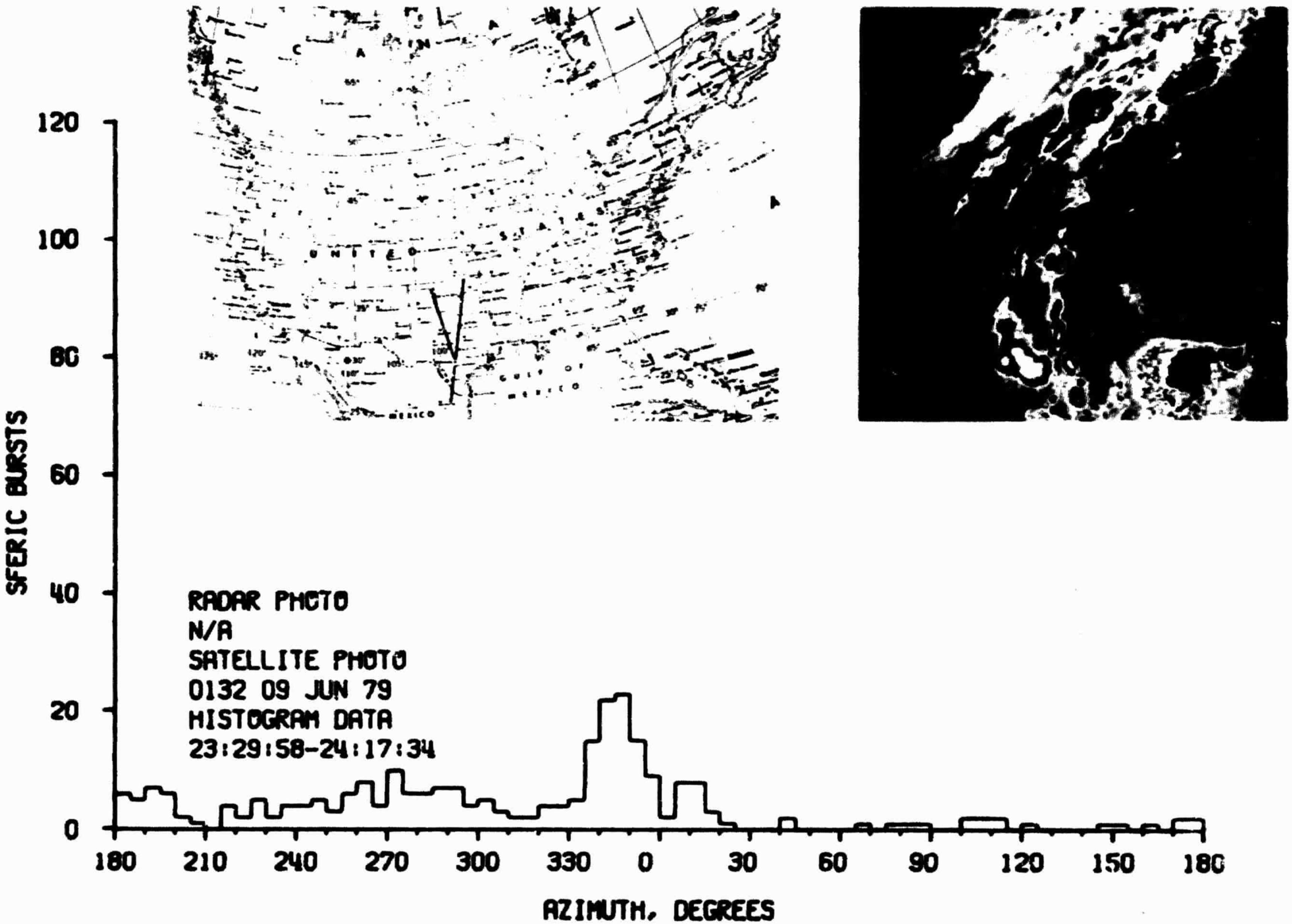



FIGURE 15. SATELLITE DATA FOR 9 JUNE 1979, 0132 GMT

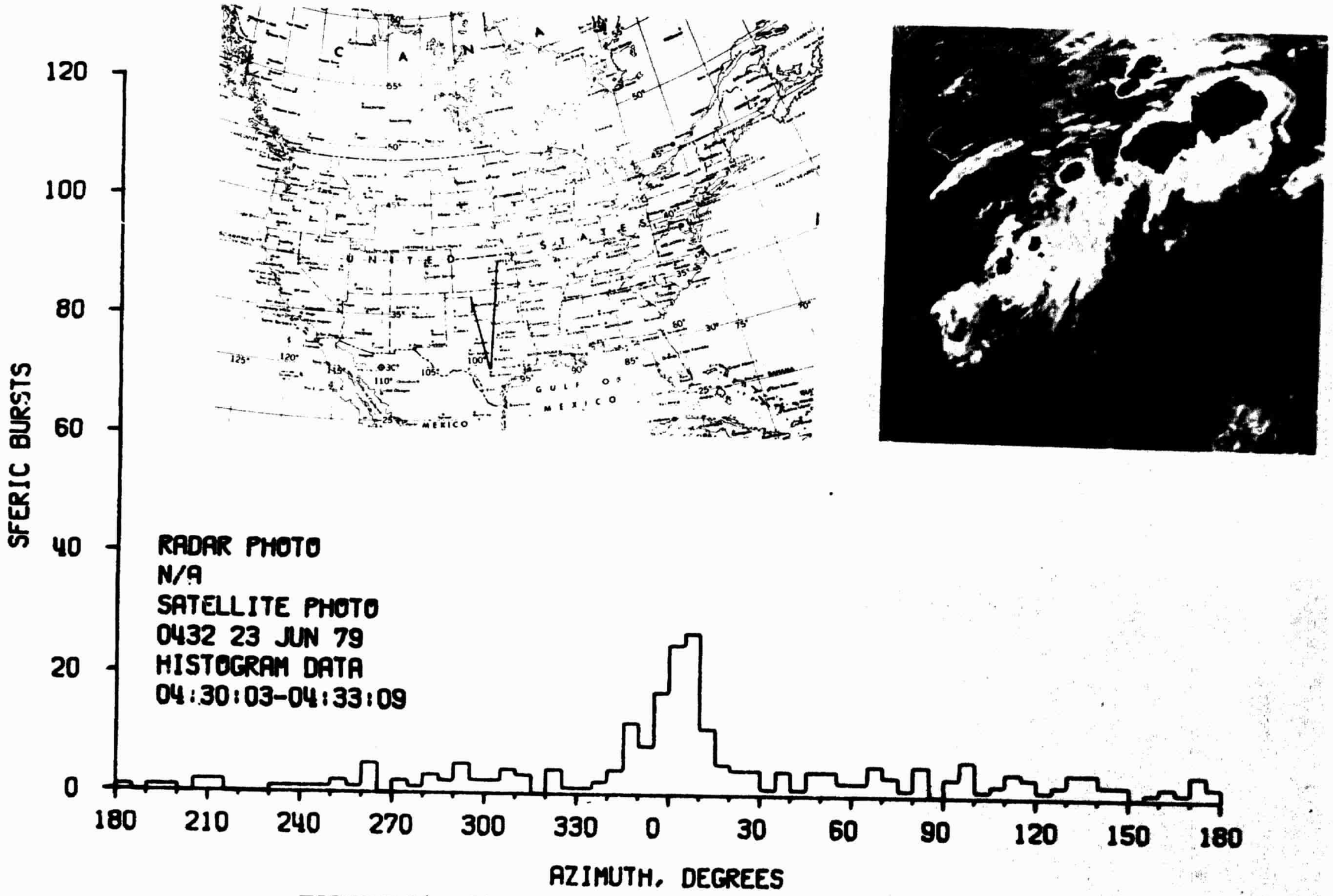



FIGURE 16. SATELLITE DATA FOR 23 JUNE 1979, 0432 GMT

## B. Oceanic Storms

### 1. Tropical Depressions

The satellite data shown in Figure 17 is a relatively large oceanic storm which occurred in the Gulf of Mexico, slightly northwest of the Yucatan peninsula. The tracking data are of interest since no inland storms were active in the direction of the oceanic storm; thus, the data are readily correlated with the tropical storm system. N meteorological data are available from the National Hurricane C nt r to ascertain the intensity of this storm. Since these particular sferic data were acquired over a relatively lengthy time period (one hour and twenty minutes), it is speculated that the storm may have been of light to moderate intensity.

Figure 18 shows the tracking data for a tropical depression which progressed northward in the Atlantic Ocean off the east coast of Florida. Additionally, a large storm system was being monitored as it occurred inland on the Yucatan peninsula. Based upon the relative peaks in the sferic histogram, the inland storm showed phase linear data more active than was the tropical depression. These tracking data, like those of Figure 17, are interesting since there are no nearby inland storms which might mask the effects of the long-range sferics from the tropical depression. The high degree of correlation is readily apparent. These data represent the longest range severe storm tracking done during the May-September 1979 data acquisition period. Storm range exceeded 2000 km for these data. As in the case of the data reported in Figure 17, no meteorological data are available.

### 2. Hurricanes

During the May-September data acquisition period, sferic tracking data were obtained for hurricanes "Bob," "Claudette," "David," "Elena," "Frederic," and "Henri." The data are somewhat limited regarding "Claudette" since equipment failures prevented continual observation.

Figure 19 presents the satellite data for 11 July 1979 at 0132 GMT. At 0000 hours on 11 July, "Bob" was designated a hurricane by the National Hurricane Center. The satellite data show a storm system also in progress along the Texas Gulf coast. This may have enhanced the sferic intensity observed in the direction of the hurricane.

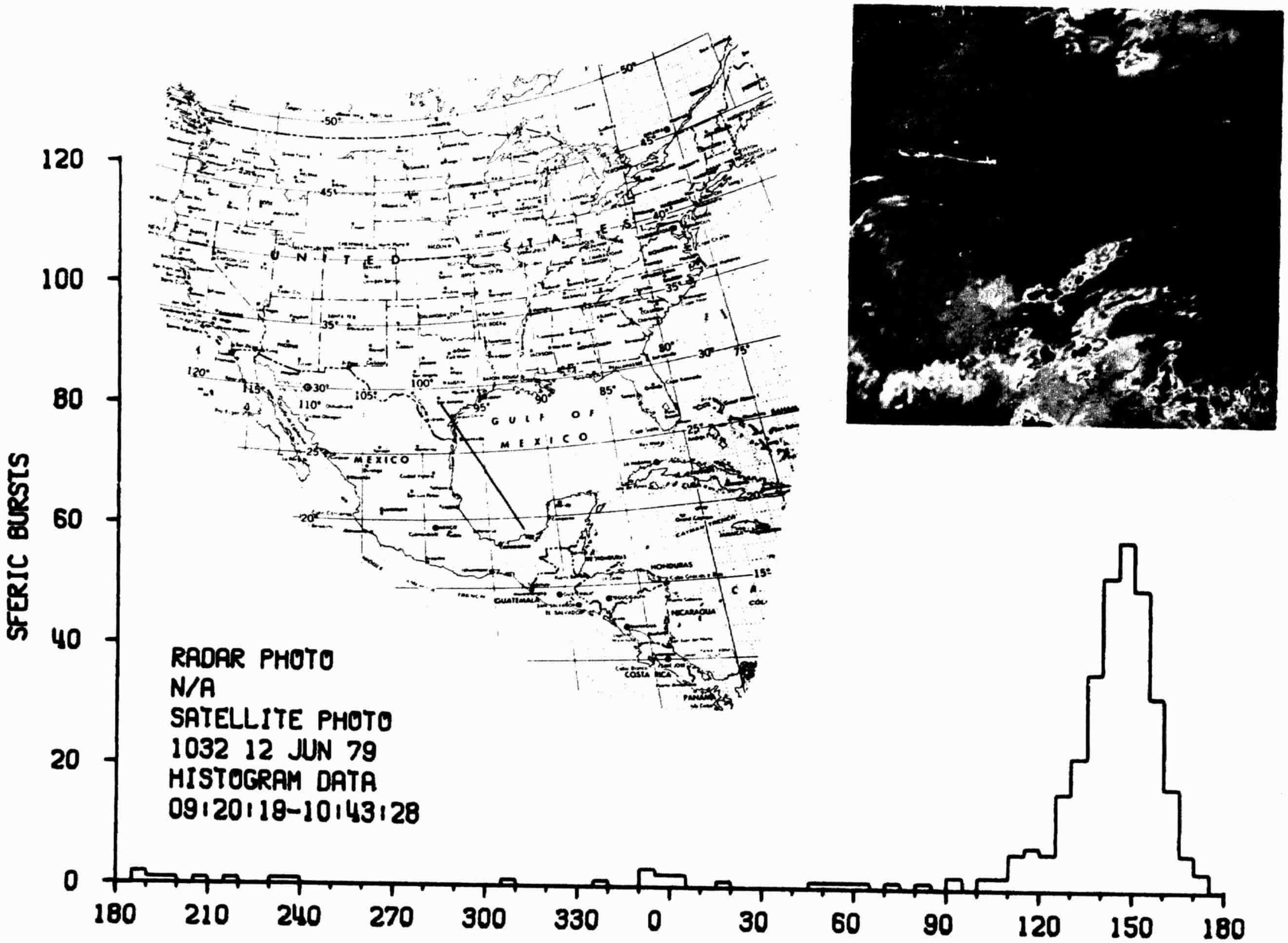



FIGURE 17. SATELLITE DATA FOR 12 JUNE 1979, 1032 GMT

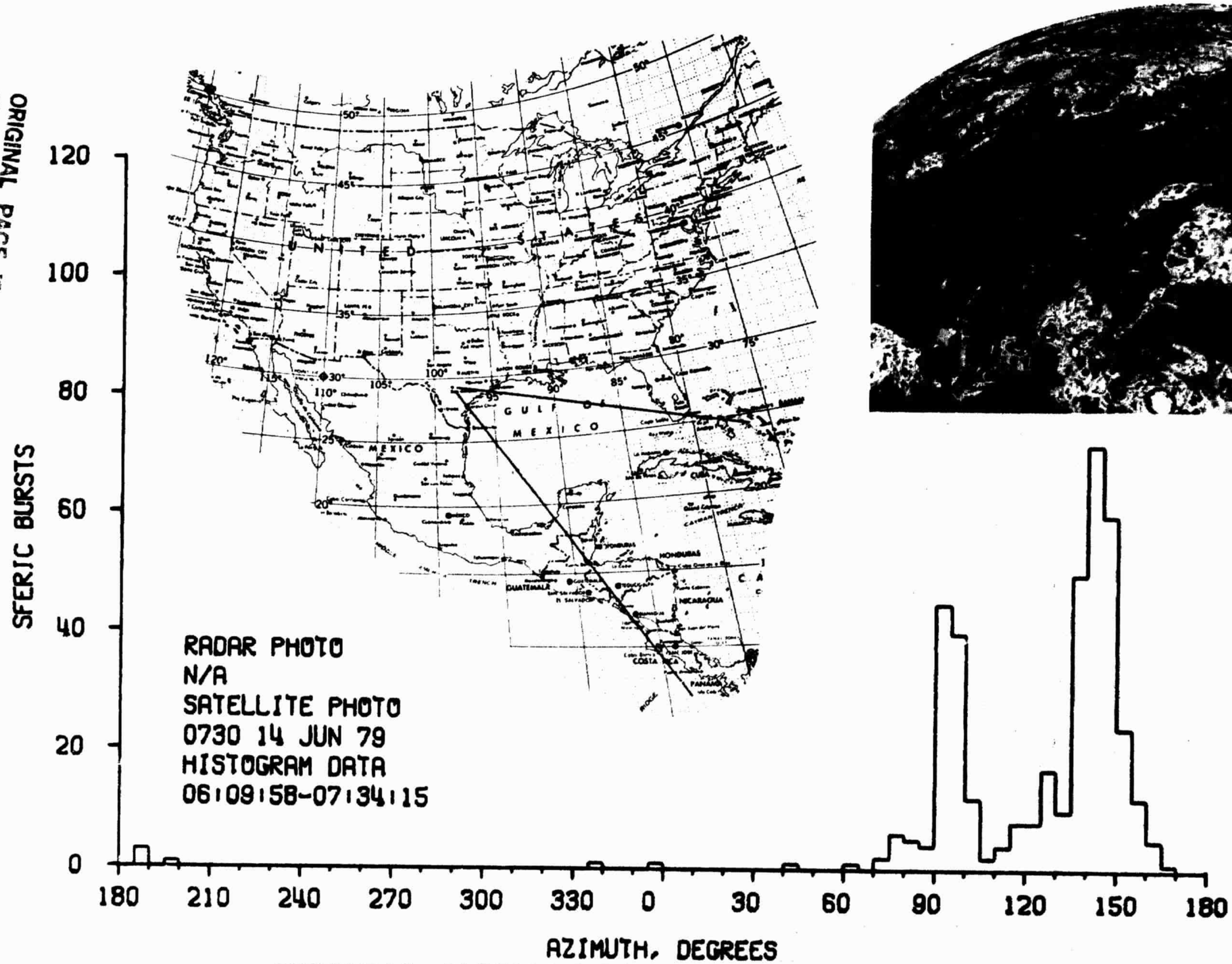



FIGURE 18. SATELLITE DATA FOR 14 JUNE 1979, 0730 GMT

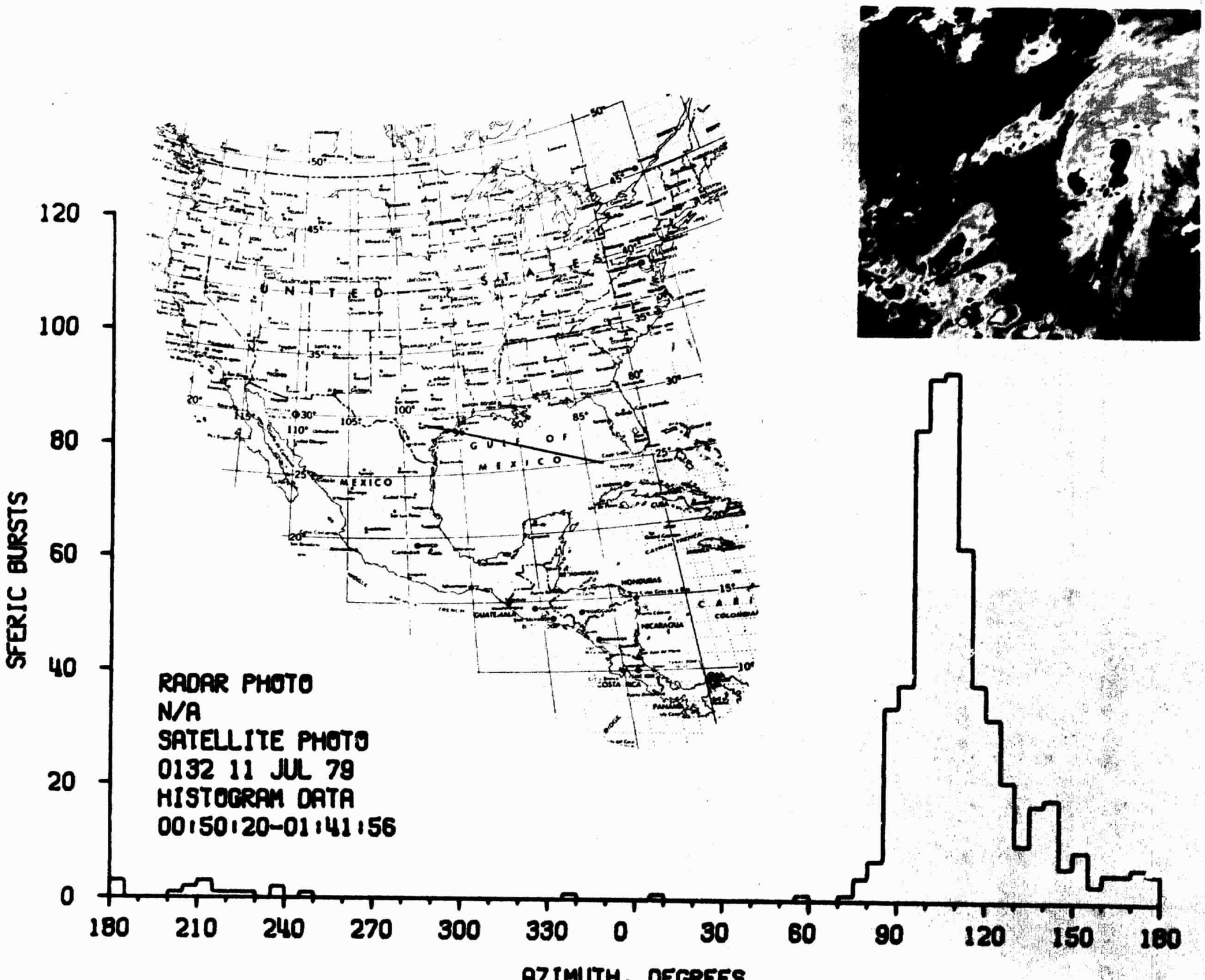



FIGURE 19. SATELLITE DATA FOR 11 JULY 1979, 0132 GMT

Figure 20 shows the satellite and phase linear sferic data at 0932 GMT, or eight hours later. The storm along the Texas coast had dissipated and the phase linear sferic intensity was predominantly acquired as a result of the electrical activity associated with the hurricane. During this time sferic activity was also received from a storm system located in southern Mexico.

Figures 19 and 20 represent the period of peak electrical activity associated with hurricane "Bob." Although the earlier sferic data cannot be resolved into that associated with the Texas coastal storm and the hurricane, maximum phase linear electrical activity occurred in conjunction with minimum barometric pressure and highest wind velocities of the hurricane (Table 8, Appendix A).

A preliminary analysis of hurricane "Frederic" data indicates that this storm system had significantly less phase linear activity than hurricane "Bob." The Best Track data, on the other hand, indicate that hurricane "Frederic" was considered to be significantly more intense meteorologically. This apparent paradox requires a more detailed analysis of the data to determine the degree of correlation of different types of meteorological intensity with phase linear electrical activity in oceanic storms.

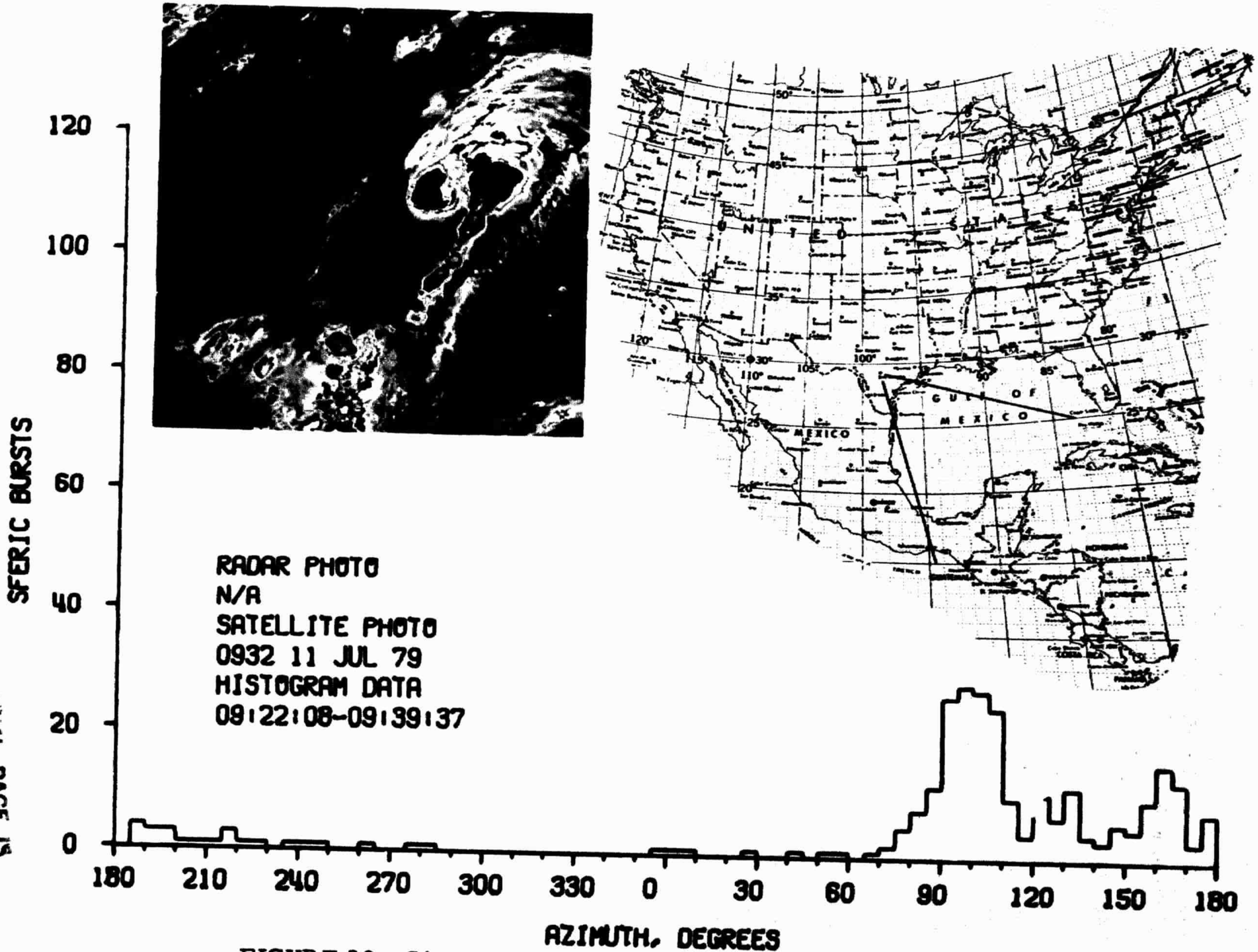



FIGURE 20. SATELLITE DATA FOR 11 JULY 1979, 0932 GMT

## IV. DISCUSSION

### A. Review

One major branch of lightning radio frequency emission research emphasizes short-range, mesoscale phenomena. Measurements at VHF and above are constrained to line-of-sight (or nearly so) propagation paths, thus limiting observation range to 50 km or less. These studies at present emphasize extremely fast measurement of DF fine structure emitted in single lightning events.(16-17)

Sferic direction finding at LF and HF has hitherto provided local to long-range detection and storm tracking data. However, these measurements have been limited instrumentally by:

(1) Polarization DF error in loop DF systems,

(2) Wave interference DF error in all conventional DF systems,

(3) Instrumental confusion introduced by the superposition of multiple sferic bursts from short- and/or long-range.

The phase linear DF interferometer effectively eliminates all the above instrumental limitations. In addition, this technique provides the following additional instrumental capability:

(1) Accumulation of (phase linear) burst counts as a function of time and angle of arrival in azimuth and elevation,

(2) Synoptic 24-hour per day data acquisition,

(3) Range capability from 5 km (or less) to 2000 km or more,

(4) Phase linear DF measurement not only at HF but equally valid at VHF.

The following summarizes results obtained during the May-September 1979 period:

## B. Results

The analysis of short-range data at 2.001 MHz performed under the subject contract demonstrates the capability of phase linear direction finding to detect intense thunderstorm cells in large frontal systems comprised of numerous severe and nonsevere storm cells. This capability has been consistently evident in large storm systems occurring within the 250-km range.[14-15] Within 10-20 km range, the dimensions of the thunderstorm cell and the consequent widespread angular sectors of electrical activity result in sferic burst histograms of 60-90 degrees. It appears that the higher frequencies in the HF band (15-30 MHz, for example) may produce directional resolution appropriate to very close range storm systems.

At longer range (250-2000 km), data analysis indicates phase linear direction finding can: (1) detect severe storm activity and (2) discriminate severe from nonsevere storm systems based on the bearings of phase linear sferic burst counts. The phase linear DF technique has discriminated intense from nonintense systems which are otherwise indistinguishable meteorologically in MB-enhanced satellite IR imagery.

The long-range capability of the technique to selectively monitor severe storms has been applied to oceanic storms, including tropical depressions and hurricanes in the Gulf of Mexico and Caribbean. This represents a potentially new capability for oceanic storm meteorology to the extent the phase linear technique proves successful as determined by ground truth studies.

The data base acquired during the May-September 1979 time period has been partially analyzed. Data analysis will continue during the proposed 1980 period in addition to continued synoptic data acquisition. When complete, the data analysis will provide quantitative statistics of the reliability of phase linear DF to detect severe storms in terms of (a) failure to detect and (b) false detection of severe storm events.

## C. Elevation Angle Data Reduction

Each DF frame recorded by the phase linear interferometer includes azimuth and elevation data. Only azimuth data have been analyzed thus far. Elevation angle data may provide additional information related to the range of the sferic. For example, one-hop sferics occurring within 500 km are expected at elevation angles of 40 degrees or greater, while at 1000 km range the expected one-hop elevation is less than 30 degrees.

## D. Severe Storm Location

The phase linear direction finder operating in San Antonio has shown severe storms can be uniquely discriminated to ranges exceeding 2000 km. A single DF station, however, does not uniquely locate the storm since it can provide only a line of bearing toward the active cell. Another such phase linear DF station operating at Marshall Space Flight Center (or elsewhere on the east coast) could provide excellent data for uniquely locating the storm regions. A two-station net consisting of stations at San Antonio and Hunstville would provide excellent location coverage from Oklahoma/Kansas eastward and southward to include the Gulf of Mexico and Caribbean regions. This would permit analysis of inland tornadoes as well as hurricanes in ocean areas.

## E. Phenomenology

The capability of phase linear DF to uniquely recognize severe storm events is treated as a hypothesis to be tested both in this report and in the proposed analysis for the 1980 effort. Should the hypothesis prove true, the origin of the radio emission phenomenon is within the storm cloud, rather than in the direction finder. Thus, a conclusion in favor of phase linear DF indicating severe storm occurrence would point to phenomena within the cloud (which can be recognized by phase linear DF) that can potentially be recognized by other than HF sferic emission.

## V. CONCLUSIONS

The following conclusions are reached based on the 1979 study:

1. This study reports the first known capability for multistate regional severe storm discrimination using directionally resolved sferic burst counts. Simultaneous observation of two or more storm systems on a multistate regional basis has yielded real-time detection and discrimination of severe meteorological activity.

2. The phase linear interferometer is capable of severe storm discrimination and tracking to ranges of 2000 km, a factor of 2:1 greater than had been observed in earlier work.[13]

3. The extended range capability permits observation of phase linear sferics from oceanic storm systems. This area of investigation has not previously been undertaken at this laboratory.

4. Automatic, unattended data acquisition developed under the 1979 effort provides capability to systematically monitor thunderstorm activity on a 24-hour basis under the contract, obviating the need for a laboratory operator and NWS advance storm warning.

## VI. RECOMMENDATIONS

Based upon the results and conclusions of the 1979 program, the following are recommended initiatives for 1980:

1. Analyze the data acquired in 1979 and extend data acquisition in 1980 to assess probability of failure to alarm, false alarm, and alarm reliability of severe storm detection based on phase linear, directionally resolved sferic burst counts.

2. Analyze the data acquired in 1979 and extend data acquisition in 1980 to determine the capability of phase linear electrical activity to provide a short-term forecast of impending severe meteorological intensity.

3. Develop a geodetic mapping algorithm to display satellite and directional sferic count data on a tracking chart, (instead of the existing oblique spheroid view) for automatic real-time data analysis.

4. Review existing sferic data for elevation angle capability for gross range estimation.

5. Incorporate a second phase linear sferic sensor at the Marshall Space Flight Center to permit triangulation and storm scale location based on phase linear electrical phenomena associated with severe meteorological activity.

6. Continue effort to study oceanic electrical storm data. This area of research, in particular, could exploit two station triangulation of synoptic sferic data.

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# APPENDIX A

## TABLE 1. 10 APRIL 1979 STORM DATA

| PLACE | DATE | TIME - LOCAL STANDARD | LENGTH OF PATH (MILES) | WIDTH OF PATH (YARDS) | NO. OF PERSONS KILLED | NO. OF PERSONS INJURED | ESTIMATED DAMAGE PROPERTY | ESTIMATED DAMAGE CROPS | CHARACTER OF STORM |
|---|---|---|---|---|---|---|---|---|---|
| **TEXAS (continued)** NORTHERN | | | | | | | | | |
| Runnels and Coleman Counties | 10 | 9:17 p | 10 | 100 | 0 | 0 | ? | ? | Tornado |
| | The tornado moved across 10 miles of open country from near Crews in Runnels County, to Novice in Coleman County. Damage was apparently light. The tornado was first reported near Crews at 9:17 p.m. | | | | | | | | |
| Runnels and Coleman Counties | 10 | 9:30 p 10:10 p | 25 | 440 | 0 | 1 | 6 | 0 | Tornado and Hail |
| | A second severe thunderstorm that formed in Runnels County fostered this tornado, which touched down about 12 miles east-southeast of Ballinger. The tornado caused considerable damage to outbuildings, powerlines, and fences, before crossing Highway 67, 5 miles west of Valera. A car was blown off of Highway 67 and a home along the road was heavily damaged. Damage also occurred at Hord's Creek Lake and Lake Scarborough, where the Coleman Water Filter Plant and a tenant dwelling were destroyed. The residents of the house reported that the tornado ripped the door off of the tornado cellar where they took refuge. The tornado uprooted trees and destroyed barns near Highway 283, 5 miles north of Coleman, before lifting about 6 miles north-northeast of town. Total dollar damage was estimated to be $345,000. Golf ball size hail accompanied the parent thunderstorm in the Coleman area. | | | | | | | | |
| **LATE REPORTS** | | | | | | | | | |
| **OKLAHOMA (continued)** | | APRIL 1979 | | | | | | | |
| Haskell, Muskogee County | 10 | 9:30 p | | | 0 | 0 | ? | ? | Hail |
| | Hail of 1¾ inch diameter. | | | | | | | | |
| Garvin and Cleveland Counties | 10 | 9:45 p | | | 0 | 0 | 4 | ? | Windstorm |
| | Strong winds destroyed mobile homes northwest and northeast of Elmore City. Hail up to 1¾ inch diameter also fell there. A large hail path continued from Elmore City to past Pauls Valley. Many places received hail up to 2 inches in diameter with hail hitting Stratford and Byars at 9:30 pm. | | | | | | | | |
| Garvin, McClain, Cleveland Counties | 10 | 9:45 p | | | 0 | 0 | 5 | ? | Windstorm |
| | Wind damage occurred near Maysville around 945 pm. Thunderstorms moved northeast and heavily damaged a barn and a house at Wayne at 10:10 pm. At 10:30 pm, the storm destroyed a mile length of power lines and a barn 10 miles east of Lexington. | | | | | | | | |

## TABLE 2. 26 MAY 1979 STORM DATA

| PLACE | DATE | TIME - LOCAL STANDARD | LENGTH OF PATH (MILES) | WIDTH OF PATH (YARDS) | NO. OF PERSONS KILLED | NO. OF PERSONS INJURED | ESTIMATED DAMAGE PROPERTY | ESTIMATED DAMAGE CROPS | CHARACTER OF STORM |
|---|---|---|---|---|---|---|---|---|---|
| **NEW MEXICO** | | | | | | | | | |
| Carlsbad, Eddy County | 26 | 2:30 a. | | | 2 | 2 | ? | 0 | Flooding Arroyo |
| | Vehicle with 4 persons drove through barricade into flooding arroyo. Two rescued, two drowned, two firemen injured in rescue attempt. | | | | | | | | |

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# TABLE 3. 16-17 JUNE 1979 STORM DATA

| PLACE | DATE | TIME - LOCAL STANDARD | LENGTH OF PATH (MILES) | WIDTH OF PATH (YARDS) | NO. OF PERSONS | | ESTIMATED[1] DAMAGE | | CHARACTER OF STORM |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | KILLED | INJURED | PROPERTY | CROPS | |
| **LATE REPORTS** | | | | | | | | | |
| **KANSAS** (continued) | | | JUNE | 1979 | | | | | |
| Graham County | 16 | 11:30 p | 3 | 33 | 0 | 0 | 6 | 0 | Tornado |
| | A tornado touched down 3 miles north of St. Peter and moved east-northeast for about five miles on the ground about 20 percent of the time. Extensive damage was caused to farm homes and buildings, mostly north of St. Peter. | | | | | | | | |
| Graham County | 16 / 17 | 11:00 p - 3:00 a | | | | | 5 | 5 | Hail, wind |
| | Severe thunderstorms moved east through the county causing damage to homes, farm buildings, and utility lines. Winds to 80 mph were reported and hail ranged up to 3 inches in diameter. | | | | | | | | |

# TABLE 4. 9 JULY 1979 STORM DATA

| PLACE | DATE | TIME - LOCAL STANDARD | LENGTH OF PATH (MILES) | WIDTH OF PATH (YARDS) | NO. OF PERSONS | | ESTIMATED[1] DAMAGE | | CHARACTER OF STORM |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | KILLED | INJURED | PROPERTY | CROPS | |
| **TEXAS** (continued) | | | | | | | | | |
| WESTERN | | | | | | | | | |
| Paducah, Cottle County | 9 | 8:50p | ¼ | 30 | 0 | 0 | 4 | 0 | Tornado |
| | A very small, short-lived tornado was reported first by the public and then confirmed by Civil Defense Spotters 14 miles west of Paducah in open country. The tornado damaged a house before returning to the cloud. The winds accompanying the tornado were estimated at 60 mph. Pea-sized hail was also reported as well as heavy rain. | | | | | | | | |
| Plainview, Hale County | 9 | 8:55p | | | 0 | 0 | 6 | 6 | Hailstorm |
| | Large hail was reported over west of Plainview by Civil Defense Spotters in a storm that broke windows, stripped vegetation bare and damaged automobiles. Extensive crop damage was reported to cotton crops on the north side of the city as well. Hail was reported to be as large as baseballs, with the largest and most damaging hail reported on the west and southwest sides of town. | | | | | | | | |
| Matador, Motley County | 9 | 8:50p | | | 0 | 0 | 3 | 0 | Windstorm |
| | Brief thunderstorm winds estimated by Civil Defense personnel at 60 mph or greater damaged trees on the south side of Matador. Limbs were broken off the trees with leaves stripped from many limbs. No other damage was noted. | | | | | | | | |
| Kent County | 9 | 9:00p | 2 | 50 | 0 | 0 | 5 | 0 | Tornado |
| | A tornado caused considerable damage 10 miles west of Clairemont in Kent County. It took the roof off a barn, moved a mobile home 5 to 8 feet off its foundation, destroyed a shed, and pulled 24 power poles out of the ground. Winds accompanying the storm were estimated at 60 mph. | | | | | | | | |
| Olton, Lamb County | 9 | 9:00p | | | 0 | 0 | 0 | 0 | Hailstorm |
| | Golfball-sized hail along with one quarter inch of rain and 40 to 45 mph winds were reported in Olton. No damage was indicated. | | | | | | | | |
| Tahoka, Lynn County | 9 | 9:08p | | | 0 | 0 | 4 | 5 | Wind and Hailstorm |
| | Windows were reported knocked out on the northwest side of Tahoka by baseball-sized hail. The damage was confined to an area from one mile northwest of the city to seven miles southwest of the city. High winds blew a dutch trailer across U.S. 380 into a implement building and broke a plate glass window. The combination of the wind and hail caused damage to cotton crops on the northwest side of Tahoka. | | | | | | | | |
| Rotan, Fisher County | 9 | 9:10p | small | narrow | 0 | 0 | 0 | 0 | Tornado |
| | A small, short-lived tornado was spotted by the Sheriff's Department 5 miles northeast of Rotan moving toward the southeast. No damage was indicated. | | | | | | | | |
| Paducah, Cottle County | 9 | 9:10p | 1 | 40 | 0 | 0 | 4 | 0 | Tornado |
| | A small tornado was reported by Civil Defense to have destroyed two wooden and one metal outbuildings just south and west of Paducah. No other damage was noted. | | | | | | | | |
| Dumont, King County | 9 | 9:32p | | | 0 | 0 | 3 | 0 | Windstorm |
| | An Amateur Radio Spotter reported some damage to trees in the Dumont area due to straight-line thunderstorm winds estimated at 70 mph or greater. No rain or hail accompanied the storm and no other damage was noted. | | | | | | | | |

# TABLE 5. 29-30 MAY 1979 STORM DATA

| PLACE | DATE | TIME - LOCAL STANDARD | LENGTH OF PATH (MILES) | WIDTH OF PATH (YARDS) | NO. OF PERSONS: KILLED | NO. OF PERSONS: INJURED | ESTIMATED DAMAGE: PROPERTY | ESTIMATED DAMAGE: CROPS | CHARACTER OF STORM |
|---|---|---|---|---|---|---|---|---|---|
| **TEXAS (continued)** NORTHERN | | | | | | | | | |
| Corsicana, Navarro County | 29 | 10:00 p | | | 0 | 0 | 5 | ? | Flash Flooding |
| | Over 6 inches of rain caused considerable flooding in Corsicana. Water entered several homes, flooded cars, and washed out several bridges. | | | | | | | | |
| Tyler area, Smith County | 30 | 7:30 a | | | 0 | 0 | ? | ? | Windstorm and Flash Flooding |
| | Thunderstorm winds and flash flooding on creeks combined to produce minor damage in Tyler. One radio tower was toppled by the winds, while Turkey Creek rose out of its banks in South Tyler. | | | | | | | | |
| **LOUISIANA** | | | | | | | | | |
| Evangeline Parish | 30 | Evening | ? | ? | 0 | 0 | 3 | 0 | Windstorm |
| | A thunderstorm caused minor damage to a barn and overturned two agricultural aircraft causing major damage to them. Location was west of Ville Platte. | | | | | | | | |

# TABLE 6. 8 JUNE 1979 STORM DATA

| PLACE | DATE | TIME - LOCAL STANDARD | LENGTH OF PATH (MILES) | WIDTH OF PATH (YARDS) | NO. OF PERSONS: KILLED | NO. OF PERSONS: INJURED | ESTIMATED DAMAGE: PROPERTY | ESTIMATED DAMAGE: CROPS | CHARACTER OF STORM |
|---|---|---|---|---|---|---|---|---|---|
| **TEXAS (continued)** NORTHERN | | | | | | | | | |
| Coleman, Coleman County | 8 | 6:13 p | | | 0 | 0 | 4 | 0 | Windstorm and Funnel Cloud |
| | Thunderstorm straight-line winds destroyed a drive-in theater screen in Coleman. The winds also toppled trees and signs and damaged several roofs and barns. A funnel cloud was sighted 9 miles northeast of Coleman at about the same time. | | | | | | | | |
| Lake Kemp, Baylor County | 8 | 8:00 p | | | 0 | 0 | 0 | 0 | Funnel Cloud |
| | Storm spotters reported that the funnel cloud did not touchdown. | | | | | | | | |
| 6 N Crowell, Foard County | 8 | 8:00 p | | | 0 | 0 | 0 | 0 | Tornado |
| | The brief tornado was observed in open areas 6 miles north of Crowell by storm spotters. No damage could be found. | | | | | | | | |
| **OKLAHOMA (continued)** | | | | | | | | | |
| Pottawatomie County | 8 | evening | | | 0 | 0 | 5 | ? | Flash Flooding |
| | About 75 county bridges were destroyed or severely damaged by high water. The rainfall, which measured from 3 inches in the north to more than 7 inches near Tecumseh, fell within 3 hours. | | | | | | | | |
| Turner Falls, Murray County | 8 | 6:30p | | | 0 | 0 | 3 | 0 | Rain, Flooding |
| | About 4½ inches of rain caused Honey Creek to overflow its banks on the evening of June 8. It remained out of banks until the early afternoon of June 9. Damage, at the park, was mainly to tables. | | | | | | | | |
| Seminole, Seminole County | 8 | evening | | | 0 | 0 | ? | ? | Flash Flooding |
| | A 3 to 4 inch rain caused flooding of some residential areas and at the Municipal Park where water was 4 feet deep. Several trees were toppled due mainly to the wet ground. Salt Creek overflowed its banks south of Maud on the 9th. | | | | | | | | |

# TABLE 7. 22-23 JUNE 1979 STORM DATA

| PLACE | DATE | TIME - LOCAL STANDARD | LENGTH OF PATH (MILES) | WIDTH OF PATH (YARDS) | NO. OF PERSONS | | ESTIMATED DAMAGE | | CHARACTER OF STORM |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | KILLED | INJURED | PROPERTY | CROPS | |
| **OKLAHOMA (continued)** | | | | | | | | | |
| Pawhuska, Osage Co. | 22 | 11:00p | | | 0 | 0 | ? | ? | Windstorm |
| | Extensive tree and power line damage reported. | | | | | | | | |
| Fairfax, Osage Co. | 22 | 11:15p | | | | | | | Funnel Cloud |
| | Police unit spotted a funnel about 2 miles north of Fairfax. | | | | | | | | |
| Tulsa County | 23 | 12:30a | | | 0 | 0 | 5 | 0 | Flash Flood |
| | Up to 5 inches of rain occurred in the downtown Tulsa area. Waters flooded City buildings and destroyed a great deal of communications equipment. Several cars were washed into flooded creeks and several buildings were flooded. | | | | | | | | |

## TABLE 8. PRELIMINARY BEST TRACK

### HURRICANE "BOB"
### 9-16 July 1979

| DATE | TIME (GMT) | LAT. | LONG. | PRESSURE (MB) | WIND (KT) | STAGE |
|---|---|---|---|---|---|---|
| 7/9 | 1200 | 22.0 | 96.0 | 1012 | 20 | DEPRESSION |
| | 1800 | 22.5 | 95.3 | 1010 | 25 | |
| 7/10 | 0000 | 23.0 | 94.6 | 1007 | 30 | |
| | 0600 | 23.5 | 93.8 | 1004 | 35 | TROPICAL STORM |
| | 1200 | 24.0 | 93.0 | 998 | 50 | |
| | 1800 | 25.0 | 92.3 | 996 | 55 | |
| 7/11 | 0000 | 26.2 | 91.6 | 988 | 65 | HURRICANE |
| | 0600 | 27.8 | 91.1 | 991 | 65 | |
| | 1200 | 29.1 | 90.6 | 956 | 65 | |
| | 1800 | 31.0 | 90.2 | 992 | 40 | TROPICAL STORM |
| 7/12 | 0000 | 32.5 | 89.9 | 998 | 30 | DEPRESSION |
| | 0600 | 34.0 | 89.7 | 1002 | 25 | |
| | 1200 | 35.9 | 89.1 | 1004 | 25 | |
| | 1800 | 37.2 | 87.8 | 1006 | 25 | |
| 7/13 | 0000 | 38.5 | 86.5 | 1006 | 25 | |
| | 1200 | 39.0 | 84.0 | 1007 | 25 | |
| 7/14 | 0000 | 39.0 | 81.3 | 1009 | 20 | |
| | 1200 | 38.3 | 78.8 | 1010 | 20 | |
| 7/15 | 0000 | 37.5 | 76.5 | 1011 | 20 | |
| | 1200 | 36.0 | 76.0 | 1012 | 20 | |
| 7/16 | 0000 | 34.0 | 76.5 | 1013 | 20 | |
| | 1200 | 33.0 | 75.0 | 1014 | 20 | |

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