THE RELATIONSHIP OF STORM SEVERITY TO DIRECTIONALLY RESOLVED RADIO EMISSIONS

FINAL REPORT

Contract NAS8-33371

By

R. L. Johnson

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

30 April 1986

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO HOUSTON

H. J. Christian

ED43

SOUTHWEST RESEARCH INSTITUTE
Post Office Drawer 28510, 6220 Culebra Road
San Antonio, Texas 78284

THE RELATIONSHIP OF STORM SEVERITY TO DIRECTIONALLY RESOLVED RADIO EMISSIONS

FINAL REPORT

Contract NAS8-33371

By

R. L. Johnson

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

30 April 1986

Approved:

Douglas N. Travers
Vice President
Electromagnetics Division

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. ABSTRACT

A program was begun in the Spring of 1981 to construct a phase linear DF interferometer to be deployed at the Anderson Road site at MSFC. The MSFC interferometer was used in conjunction with an existing interferometer at SwRI in San Antonio, Texas to monitor electrical emissions from tropical storm activity in the Gulf of Mexico. Simultaneous atmospheric electrical events observed at both sites were located by triangulation.

During the tropical storm season of 1982, no data were acquired. This period represented a 50 year low in hurricane activity; however, the experimental technique was tested and refined. During the storm season of 1983, the DF interferometer at MSFC was extensively damaged by nearby lightning strikes. Although the system at MSFC was not completely operational, simultaneous data were acquired from both sites during hurricane Alicia. Because of continual failures observed in the MSFC system, the equipment was returned to SwRI for refurbishment during the 1984 storm season. In 1985 the MSFC DF interferometer was again damaged by lightning currents coupled into underground RF cables.

Analysis of the hurricane Alicia data indicate a center of atmospheric electrical activity associated with the vortex of the storm. The center appears to rotate from the Northern side of the vortex to the Southern side during the period of observation.

An analysis of the atmospheric electrical burst rates associated with hurricane Alicia indicates that the electrical activity appears to maximize at the time of greatest storm intensity, i.e. maximum winds and lowest central pressure.

II. INTRODUCTION AND OBJECTIVE

There exists in the open literature little published data regarding the sources of greatest electrical energy in tropical cyclones. This includes data from seedlings which most frequently dissipate and from the mature storms known as hurricanes or typhoons. From technical descriptions of tropical cyclone dynamics, one readily gains an appreciation for the important role played by cumulonimbus clouds in the water vapor budget of the storm. Two recent descriptions are given by Anthes [1] and Simpson and Riehl.[2] Associated with deep convection of this type, one might reasonably expect to observe thunderstorm activity. In earlier, Dunn [3], reports that thunderstorms are frequently observed in the early and decaying stages and also about the periphery of the storm; however, they are not usually observed in the area of high winds (>110 km/h). One can, however, gather numerous eyewitness accounts of observed lightning activity from investigations who have flown reconnaissance aircraft into the storm. In the composite, these accounts cover relatively brief periods of time in the overall lifetime of the storm and are localized samples as opposed to synoptic scale observations.

One technique which has appeared in the literature is the location of atmospheric emissions using radio direction finding. An account is given by Weil [4] of tracking hurricanes through the observations of atmospherics on a crossed loop direction finder similar to that developed by Watson-Watt [5]. The paper discussed only the instrumentation and no results were presented.

Sashoff and Weil [6] described a four station network of crossed loop direction finders located at Gainesville, Florida, Miami, Florida, Pensacola, Florida, and at Rio Piedras, Puerto Rico. The net operated at 10 kHz and tracked six tropical storms during the 1937 storm season. One of the important suggestions which arose from the study was that "...the static does not apparently emanate from the center of the storm, but rather from its periphery." Further work was done on the direction finding network and Sashoff and Roberts [7] described observations made from a three station net, the Miami station having been dropped from the net. Although the investigators experienced extreme difficulty in routinely correlating atmospheric events, they were able to infer a reasonable source of origin for selected cases. Two significant conclusions were drawn from this study: (1) some of the peak periods of intense electrical activity may be associated with the forward movement of the storm, and (2) the electrical centers of activity, in these cases, were found to be 322-805 km (200-500 miles) back of the storm center and that relatively little activity was recorded from the eye of the storm.

Some of the properties of ELF lightning discharges from tropical cyclones were described by Hughes [8],[9]. Observations were made in the Hawaiian Islands on the 1966 typhoon Rita and hurricane Blanca. Range and direction of arrival measurements were made using group delay predictions. The waveforms analyzed were primarily associated with intracloud discharges. One of the points made in the study was that the technique of source location used in the analysis did not allow sufficiently accurate range resolutions to determine whether the waveforms emanated from the storm periphery or from the regions of intense winds.

The objective of work reported in this study was to provide continuous observation of atmospheric electrical activity occurring in association with tropical storms in the Gulf of Mexico. The observations were to include the location of all detected intracloud and cloud-to-ground lightning activity occurring in the storm. To provide synoptic scale coverage, a phase linear interferometer HFDF system was constructed and deployed at Marshall Space Flight Center (MSFC). This was used in concert with the existing HFDF interferometer at SwRI to provide lightning location data through triangulation. Atmospheric electrical events were synchronized through the use of WWV satellite receivers at each site.

The intent of the data analysis was to correlate the location of electrical centers of activity with radar and satellite imagry to identify areas of intense convection within the tropical storm system. This analysis would lead to a more complete understanding of the basic physical process within the storm and could provide a mechanism for more reliable and accurate storm forecasts regarding movement and intensity.

III. DATA ACQUISITION

Work was initiated in May 1981 to construct a phase linear interferometer HFDF system to be deployed at MSFC for the purpose of monitoring hurricane activity occurring in the Gulf of Mexico. The data from this system was to be used in concert with the DF data acquired from a similar HFDF system at SwRI to provide observations of the location of lightning activity. Fabrication of the interferometer was completed and the system was installed at the MSFC Anderson Road site during April 1982.

A block diagram of the DF interferometer is shown in Figure 1. The sensors are seven antennas displayed in a crossed baseline configuration and are crossed loops. The apex antenna is used as a reference for relative phase measurements at each of the remaining six antennas. The short baseline antennas, separated 13 meters from the apex, are used to resolve phase ambiguities on each baseline. The intermediate antennas, separated 100 meters from the apex, are used to test the propagating wavefront for phase linearity. The long baseline antennas, at a distance of 150 meters from the apex, are used to compute angle of arrival. To avoid radio interference from other on the air stations, an operating frequency of 2 MHz has been selected. For this frequency, the long baseline provides a 1λ aperture.

The relative phase measurements are made sequentially across the array. Including a calibration measurement of the phase shift between receiver channels, a single scan across the array occurs every 14 msec. A threshold editing circuit ensures that a signal is present and exceeds a predetermined threshold value before the data are presented to the computer. Thus, an atmospheric electrical event must persist for at least 14 msec in order to be detected by the DF interferometer.

The receiver is a commercial twin channel HF receiver whose outputs are applied to a fast response phase meter. The result of the phase measurement is digitized and input into the computer which calculates azimuth and elevation angle of arrival. Each data frame is tagged if the phase linearity criterion were satisfied and time coded to the nearest 10 msec. The frame of data is logged to disk as four 16 bit words. The words consist of azimuth, elevation and two words of day number and GMT. The disk subsystem has a 10 MByte capacity. The 5 MByte removeable platter is used for data storage. It is configured to hold 9600 blocks of 128 words on 32 frames of data. The total capacity is 307,200 frames of data. Under normal operating conditions, this is typically 5 hours of observation.

Figure 2 shows the antenna array deployment at the Anderson Road site. Each of the antennas is enclosed by a 5 foot high fence to protect them from grazing cattle. The view is taken from the north looking south to the apex antenna. The east-west baseline is shown running parallel to the tree line. At the left of the figure is the trailer which housed the electronics rack. Figure 3 shows one of the crossed loops in a fenced enclosure. The RF feed cables and DC power lines for the preamplifiers

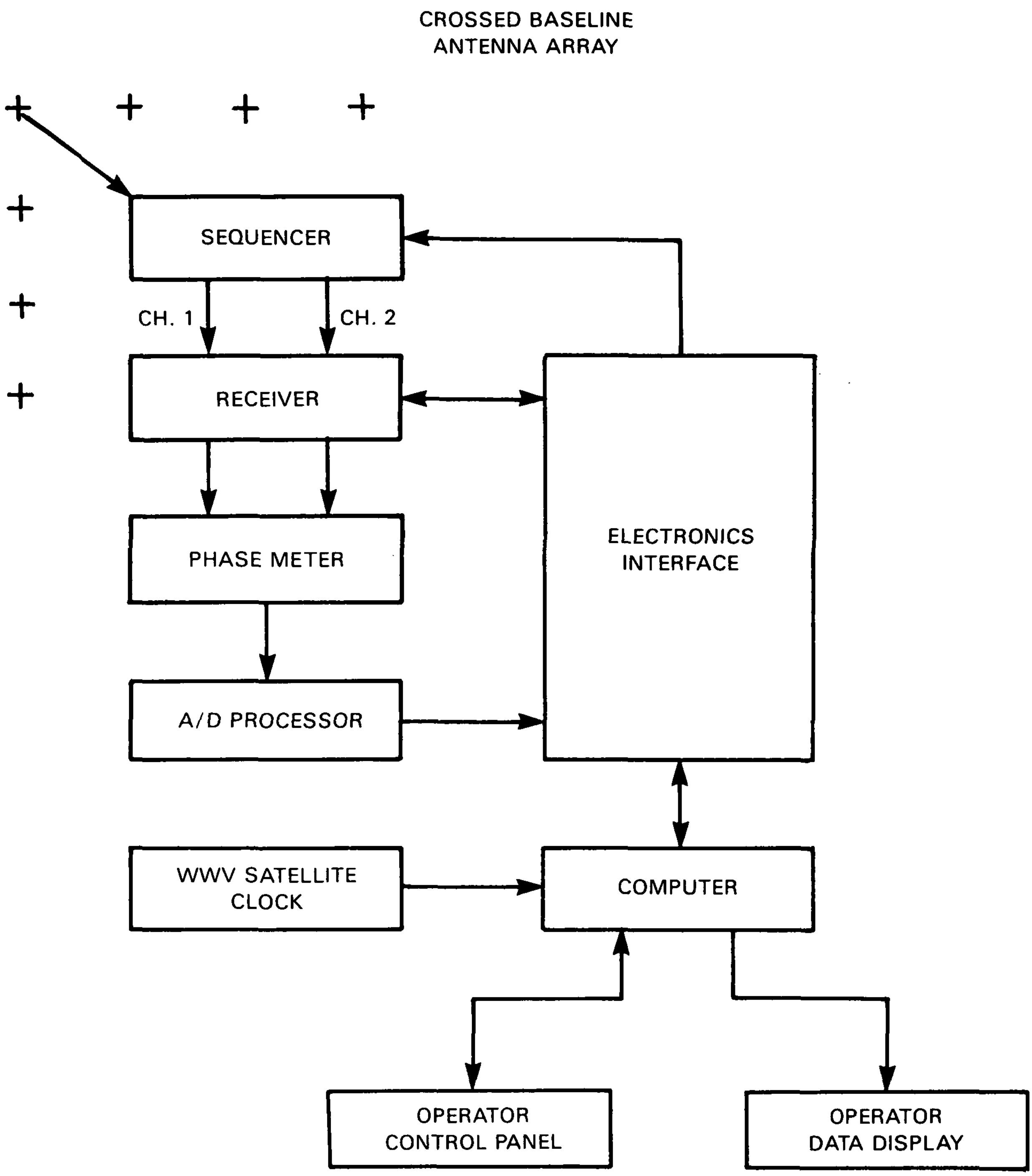

FIGURE 1. DF INTERFEROMETER BLOCK DIAGRAM

FIGURE 2. ANTENNA ARRAY DEPLOYMENT AT THE ANDERSON ROAD SITE

FIGURE 3. CROSSED LOOP ANTENNA AND ENCLOSURE

were buried. The electronics box at the base of the antennas includes preamplifiers and a quadrature hybrid to provide left circularly polarized signal reception.

The electronics rack housed in the trailer is shown in Figure 4. The oscilloscope at the top of the rack indicates whether or not the sequencer is properly scanning the antenna array. The scope is also used for general troubleshooting in the system. Below the scope is the WWV clock which is synchronized to either the GOES east or west satellite. Below the clock is the phase meter. Underneath the phase meter is the sequencer electronics boards and the A/D processor board. These boards were designed and fabricated at SwRI. In the center of the rack are two commercial HF receivers whose local oscillators are slowed to provide phase coherence between channels. In the lower portion of the rack is the Nova computer and the 10 MByte moving head disk. To the right of the rack is a display terminal which may be used to observe angle of arrival information.

ORIGINAL PAGE IS
OF POOR QUALITY

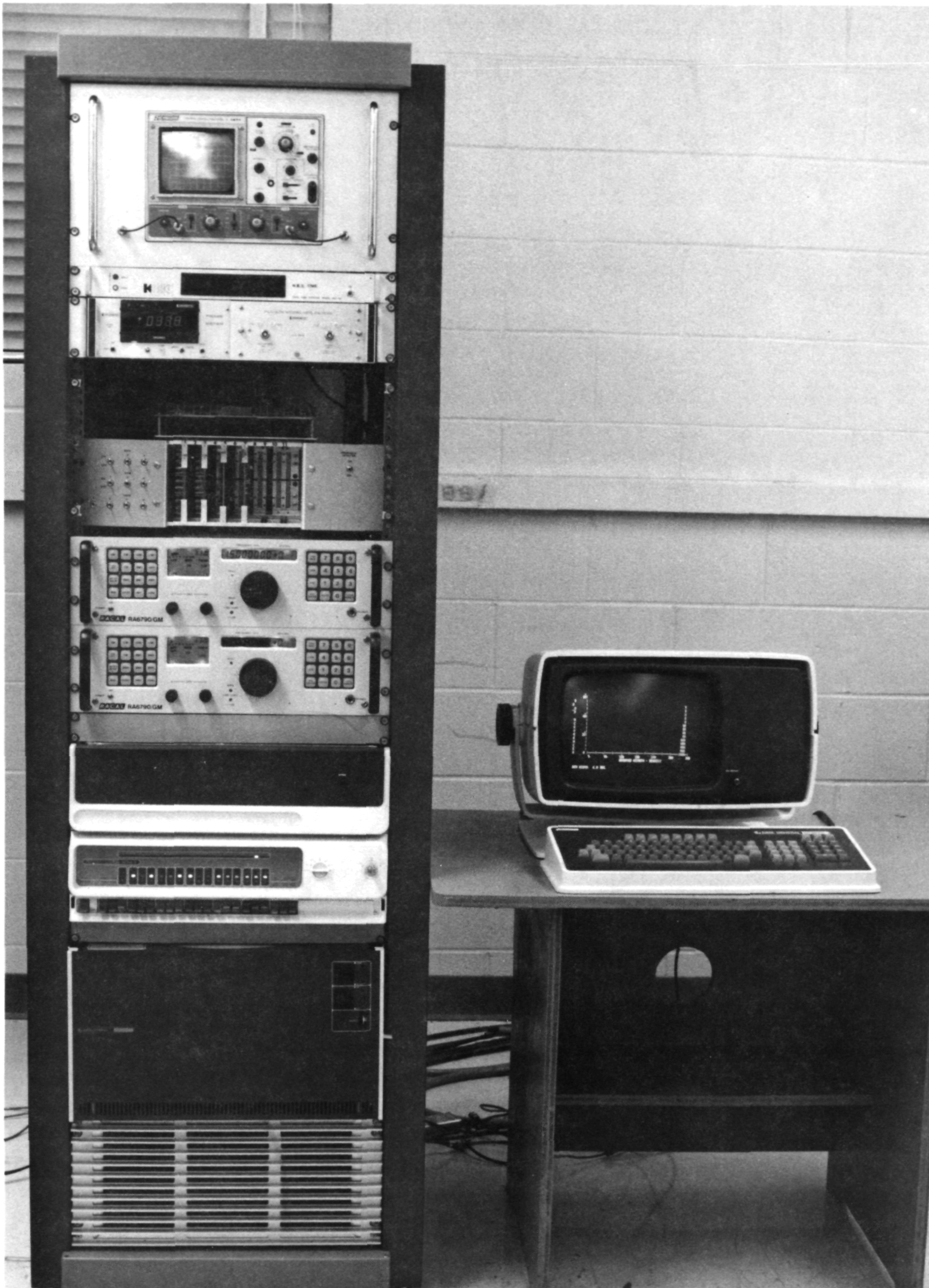

FIGURE 4. HFDF INTERFEROMETER ELECTRONICS RACK

IV. DATA ANALYSIS

A. Software Developed

All data taken were transferred to magnetic tape for archive. The 5 MByte disc platters of data were shipped to SwRI from MSFC, the data were transferred to tape, and the disc platter was returned to MSFC for reuse. The initial step in the data analysis was to unpack the four 16 bit words of azimuth, elevation, day number and time of day into a floating point format which could be used by FORTRAN programs. All programs were initially developed in FORTRAN V on a Data General S230 Eclipse computer. Later in the project, the programs were translated into FORTRAN 77 for use on the Data General MV/8000 computer.

The second step in the data analysis was to correlate event times and to compute locations of activity. As input parameters to the program, the operator would specify day number, start time and end time, satellite clock delay time at each station, and azimuth sector of interest relative to each station. The output of the program was a disc file giving day number, time of day, and latitude/longitude of each event resolved to the nearest second. The time interval for the search of simultaneous events was also an input variable and typically was set to 100-500 msec.

A third step in the analysis proceeded from the use of the location data file. This program was used to identify clusters of atmospheric electrical activity. These centers of activity were enhanced by averaging individual events over specified windows. Three windows were used simultaneously and these were program input parameters. Upon entry into the program, the operator was asked to specify number of events, time window and spatial window. The location data file was then scanned for multiple events which had occurred within the time and space windows. When these were found, an averaged location was then computed. The running average provided an enhanced clustering of atmospheric electrical centers of activity.

The next step in the analysis was to produce a scatter plot of electrical events on a geographical grid. Initially the plots were appropriate to the spatial scale of satellite imagry and included a large portion of the Gulf of Mexico. Later in the project, a plot capability was also developed for shore-based NWS weather radar imagry.

The final step in the analysis was to transfer the location data to magnetic tape for entry into the MCIDAS data base at MSFC. This involved a translation of Data General tape format to Hewlett-Packard format.

B. Tropical Storm Observations

The initial observation period was during the tropical storm season of 1982. A minimal hurricane CHRIS occurred during this period but no simultaneous data were collected at the SwRI and MSFC sites. During this storm season it became clear that the two sites could not be left running in an unattended state. It would be necessary to provide direct coordination. Also the air conditioner had failed at the Anderson Road site which resulted in the failure of the receivers. The receivers were repaired and a thermal protection circuit was designed and installed. A circumstance over which no control could be exercised resulted from the fact that the storm season of 1982 represented a twenty year low in the number of storms occurring in the Gulf of Mexico.

The second storm season of operation, 1983, began with a nearby lightning strike at the site which resulted in numerous failures to the system electronics. The primary source of concern was the replacement of the antenna preamplifiers, and this could not be accomplished until mid-July. Intermittent failures continued to be indicated in the system throughout the storm season. Data were acquired from hurricane ALICIA during mid-August. In late August, a lightning transient coupled into the system through the telephone modem and caused extensive damage.

No data were acquired during the 1984 tropical storm season because of the extensive failures being experienced in the MSFC phase linear DF interferometer. The system was returned to SwRI during August of this season for the purpose of refurbishment. The system was subsequently rebuilt, extensively tested at SwRI and redeployed at MSFC.

The refurbished DF interferometer was returned to MSFC during the latter part of June in the 1985 tropical storm season. The system was checked out and readied for data acquisition in mid-July. In late August the system was being prepared to monitor data during hurricane ELENA. It was found that a lightning strike had shorted an RF feed cable and had opened one contact on the RF switch assembly. Analysis of the data later indicated that the failures appeared to be more extensive.

A meteorological review of tropical storm activity during the 1982-1985 storm periods indicates that 1982 was the quietest season in more than 50 years. There were five named tropical cyclones in the Atlantic-Caribbean, Gulf of Mexico region. Three of these were tropical storms and only two attained hurricane status. The last recorded season with only two hurricanes was 1931 and since that time, only one other year, 1972, had fewer tropical storms.

The hurricane season of 1983, with a total of four named cyclones, was the least active season since 1930. The hurricanes that did occur were short lived. A total of five hurricane days made the 1983 season the one with least hurricane days since 1931. Additionally, this year became the first since 1871 that no storms or hurricanes formed south of latitude 25 N. Moreover, the 1982 and 1983 seasons became the first consecutive years since 1871 that no tropical storms or hurricanes formed in the Caribbean. Hurricane ALICIA was the only major hurricane of the 1983 season.

Tropical cyclone activity returned to near normal during the 1984 season after two quiet years. There were twelve named tropical cyclones and one subtropical storm. Five reached hurricane force and the remaining systems were of storm strength. Not one significant storm system entered the Gulf of Mexico during this storm season. A tropical storm named EDUARDO formed at 20 N off the East coast of Southern Mexico; however, it formed and dissipated within two days.

The 1985 season produced 11 tropical cyclones, 7 of which reached hurricane strength. A total of five hurricanes occurred in the Gulf of Mexico in 1985. The storms were BOB (July 21-26), DANNY (August 12-20), ELENA (August 28-September 4), JUAN (October 26-November 1), and KATE (November 15-23). This year, six hurricanes and two tropical storms struck the coastline of the United States making this the most active season for strikes on the U. S. coast since 1916.

In summary, the data observations during the storm season of 1982 resulted in a refinement of the experimental technique and the development of methods of coordination between the two DF sites. The cyclone season of 1983 was marked by repeated lightning strikes and equipment damage at the MSFC site, although some marginal quality data were acquired from hurricane ALICIA. At the onset of the 1984 storm season, the Principal Investigator and the COTR at MSFC reached mutual agreement that the DF interferometer at the Anderson Road site should be returned to SwRI, and that the remaining contract funds should be expended in refurbishment and redeployment for the 1985 season. In view of the total absence of hurricane activity in the Gulf of Mexico during the 1984 season, hindsight clearly supports the soundness of the plan.

After redeployment of the MSFC interferometer at the onset of the 1985 storm season, it was known that there would be limited opportunity to gather data since the contract funds had been depleted in the repair; however, it was believed that the experimental technique had been completely developed and that a single storm opportunity could provide extremely significant results. However, a lightning strike which occurred in the vicinity of the site appeared to have surgically removed the intermediate antennas, and it was assumed that data could be acquired in an "all" mode versus a "phase linear" mode on hurricane ELENA. Subsequent analysis of the data indicated that the system had suffered more extensive damage and that the data were of no value. At the end of this experiment no funds remained in the contract. The system was shut down and no further attempts at data acquisition were made.

V. DISCUSSION

In this section, the results of the data analysis are presented for hurricane ALICIA. Details of the preliminary data analysis can be found in Johnson and Goodman.[10] The data reported here were taken from the poster paper [10] which was presented by Goodman.

The observations made are based on the data base of computed locations using both the MSFC data and the SwRI data. As was noted in the previous section, the receiver at MSFC was operating intermittently while these data were being acquired. It is believed, however, that because the DF performance at the SwRI site appears to have been excellent, some observations can be made regarding the overall aspects of the atmospheric electrical activity in hurricane ALICIA.

Shown in Figure 5 is the data acquired from the cyclone at 0230 hours UT on 18 August 1983. At this time the DF data from SwRI indicate that the primary source of atmospherics appears to be north of the hurricane vortex. Shown in Figures 6 and 7 and the data acquired at 0330 hours and 0430 hours UT on 18 August 1983. The DF data from San Antonio, Texas show a transition period in which the primary source of electrical activity appears to shift from the north side of the vortex to the south side. Figure 8 is a plot of the data acquired at 0530 hours UT. The DF data from SwRI indicate that the source of atmospheric is located to the south of the vortex.

These observations are in contrast to the DF data observed at SwRI in four hurricanes during the 1979 storm season and one hurricane during the 1980 storm season [11]. In these storms there was very little activity recorded near the vortex but all activity appeared to be in the rain feeder bands. Hurricane ALICIA is the first storm observed in which the primary source of atmospheric electrical activity appeared to be associated with the vortex.

Twelve hours of sferic burst rates are shown in Figure 9. The burst rates are plotted in conjunction with minimum pressure and minimum wind speeds. Again these data are essentially based upon DF data from the San Antonio site and are believed to be accurate in an overall sense. The figure shows that the greatest rate of electrical activity in the storm tends to follow somewhat after a buildup of wind speed and coincides with ninimum pressure.

ORIGINAL PAGE
COLOR PHOTOGRAPH

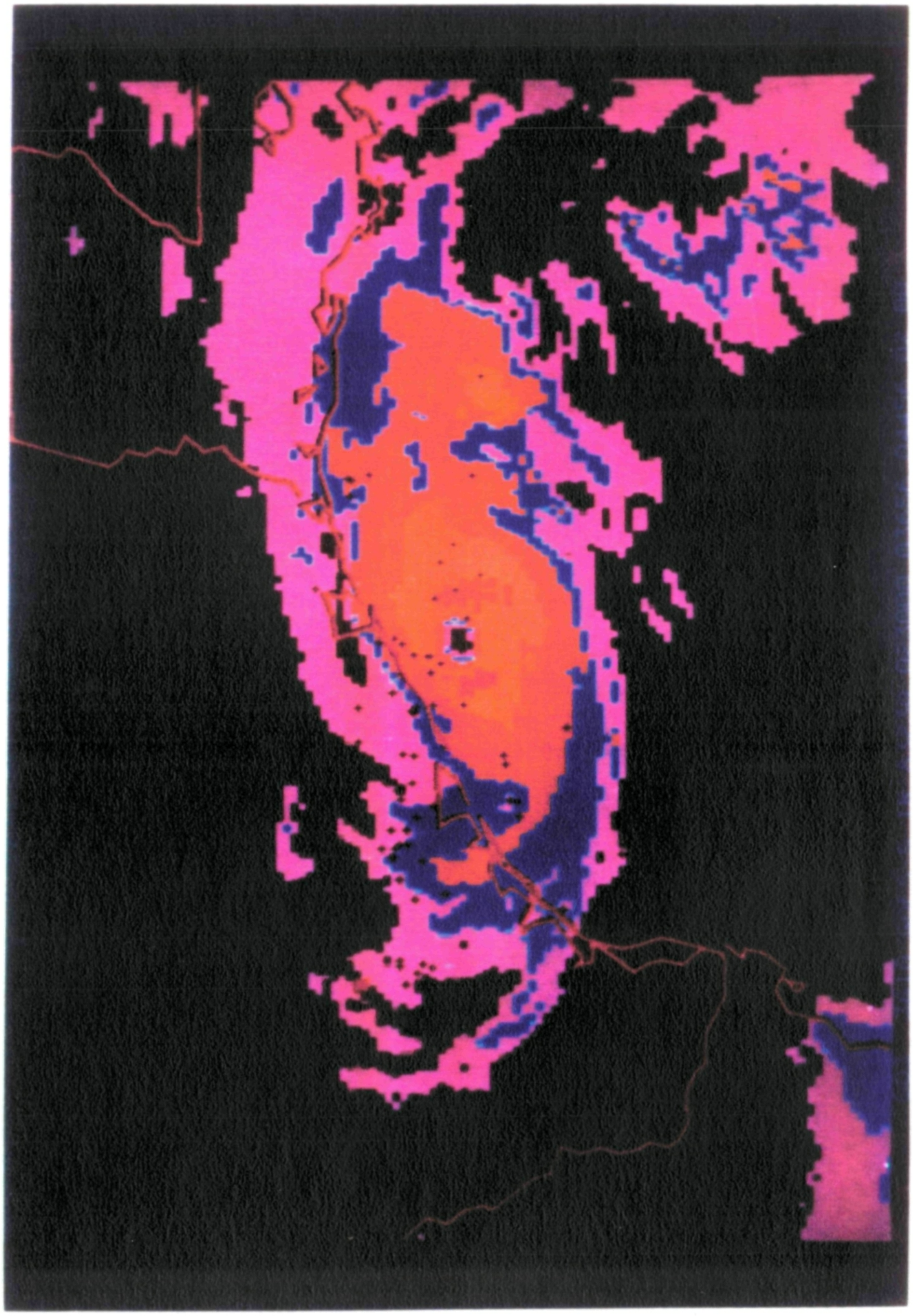

FIGURE 5. HURRICANE ALICIA, 0230 HOURS GMT, 18 AUGUST 1983

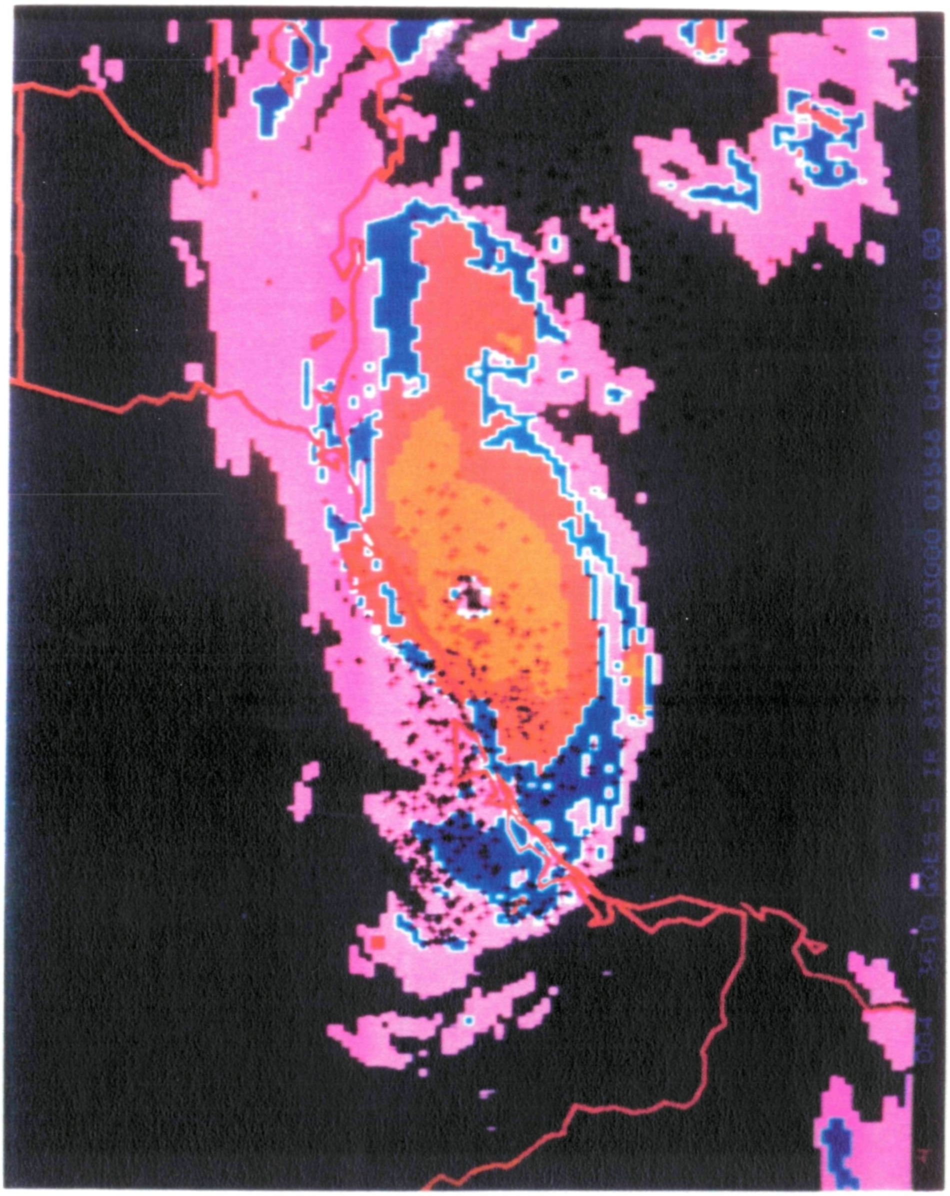

FIGURE 6. HURRICANE ALICIA, 0330 HOURS GMT, 18 AUGUST 1983

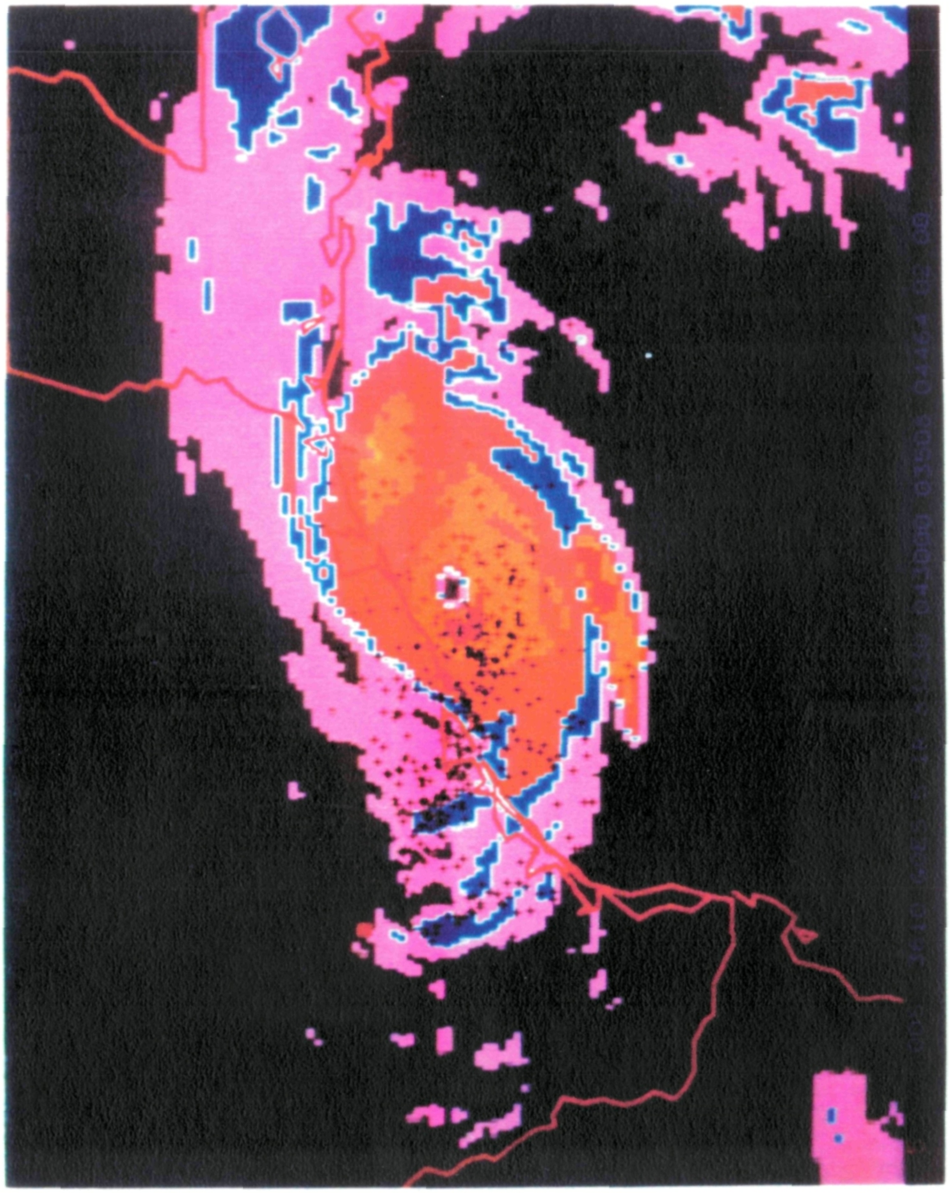

FIGURE 7. HURRICANE ALICIA, 0430 HOURS GMT, 18 AUGUST 1983

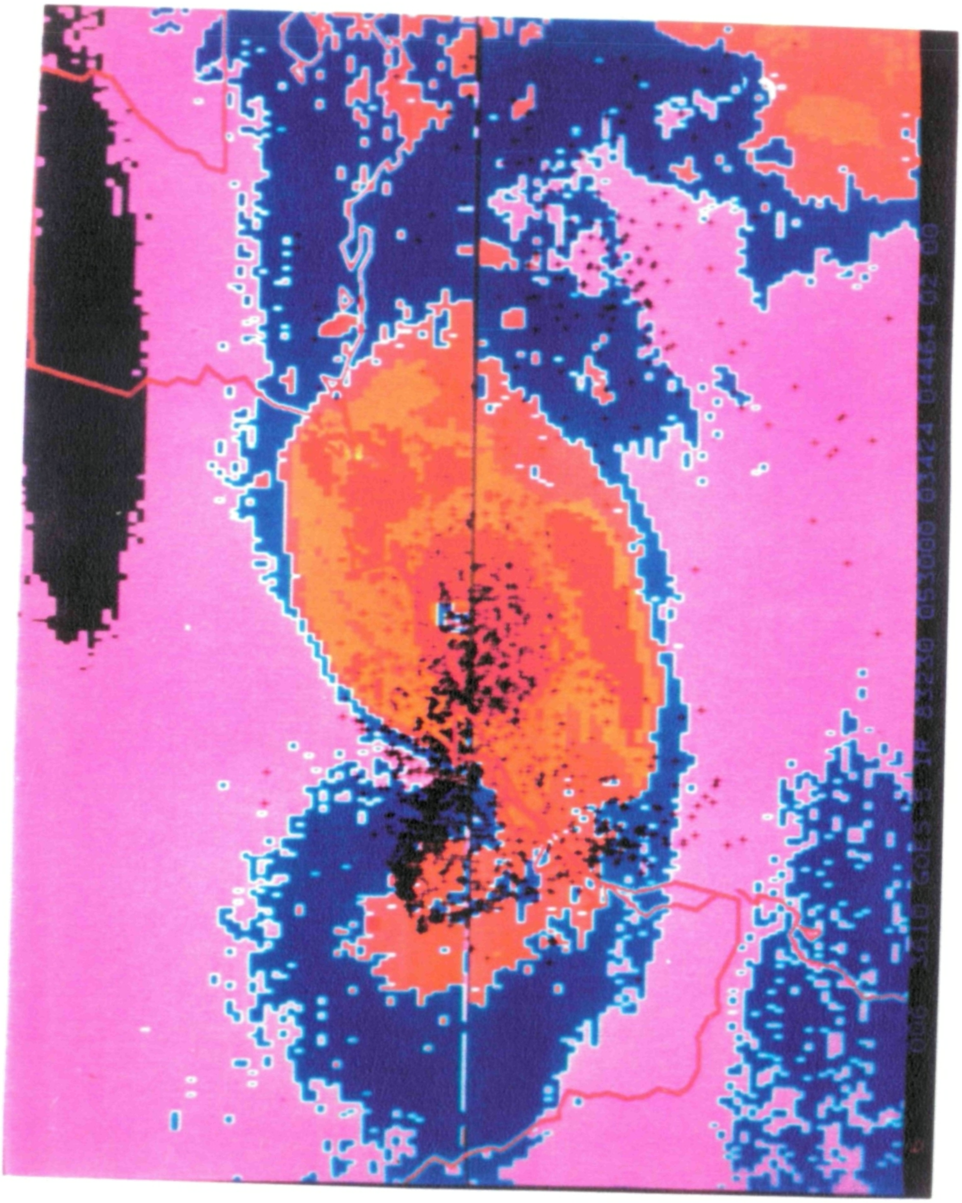

FIGURE 8. HURRICANE ALICIA, 0530 HOURS GMT, 18 AUGUST 1983

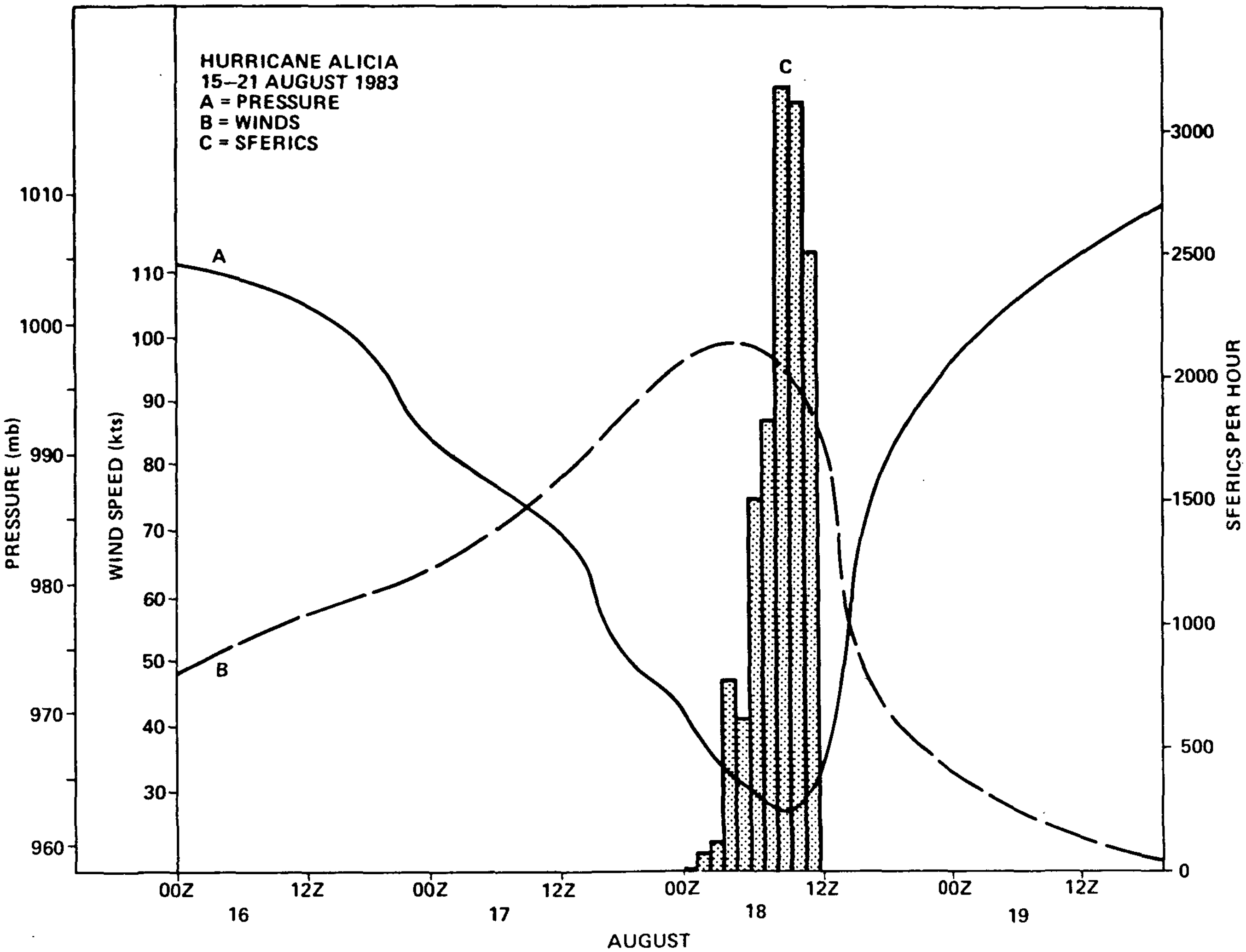

FIGURE 9. HURRICANE ALICIA ATMOSPHERIC BURST RATES versus STORM INTENSITY

VI. CONCLUSIONS

As a result of the data acquisition experiments, the following conclusions have been reached.

(1) The greatest single factor which prevented additional data acquisition was the reduced incidence of tropical storm activity in the Gulf of Mexico during the period of this experiment.

(2) A second major contributing factor which prevented data acquisition was the extended periods of system outage at the MSFC site due to nearby lightning strikes.

(3) An unexpectedly high cost in the conduct of the experiment was the travel and manhours required to maintain the MSFC DF interferometer.

As a result of the data analysis of the hurricane ALICIA data, the following conclusions have been reached.

(1) There appears to be highly active centers of atmospheric electricity in the proximity of the cyclone vortex.

(2) The centers of atmospheric electrical activity associated with the cyclone vortex appear to rotate slowly about the proximity of the eyewall.

(3) The peak periods of atmospheric electrical activity in the cyclone appears to follow a buildup of maximum wind speeds and is coincident with minimum pressure in the vortex.

VII. RECOMMENDATIONS

Because this experiment can provide significant and valuable insight into the physical processes of tropical cyclone systems, it is recommended that the task be pursued. Recommendations are made which will ensure a higher probability of success in future experiments.

(1) The DF interferometer should be moved from the Anderson Road site to a location which has reduced vulnerability to lightning.

(2) A complete set of spare parts should be acquired and maintained at MSFC. This would significantly reduce down time.

(3) A new initiative should be undertaken to monitor tropical storm activity during the 1987 and 1988 storm seasons. Data acquisition during two storm seasons would increase the probability of observing tropical cyclone activity in the Gulf of Mexico.

VIII. REFERENCES

[1] Anthes, R. A., Tropical Cyclones-Their Evolution, Structure and Effects, AMS, Boston, MA, 1982.

[2] Simpson, R. H. and H. Riehl, The Hurricane and Its Impact, Louisiana State Univ. Press, Baton Rouge, La, 1981.

[3] Dunn, G. E., "Tropical Cyclones," Compendium of Meteorology, Ed. by T. F. Malone, 1951.

[4] Weil, J., "Hurricane!" Radio-craft, Apr. 1937.

[5] Watson-Watt, R. A. and J. F. Herd, "An Instantaneous Direct Reading Radio-goniometer," Jour. of the IEE, vol. 64, 1926.

[6] Sashoff, S. P. and J. Weil, "Static Emanating from Six Tropical Storms and Its Use in Locating the Position of the Disturbance," Proc. IRE, Nov. 1939.

[7] Sashoff, S. P. and W. K. Roberts, "Directional Characteristics of Tropical Storm Static," Proc. IRE, Mar. 1942.

[8] Hughes, H. G., "Reception of Extremely Low-Frequency 'Atmospherics' from Tropical Storms," Jour. of Appl. Meteor., vol. 6, Aug. 1967.

[9] Hughes, H. G., "Current Moments at ELF of Lightning Discharges Associated with a Mature Tropical Hurricane," Jour. of Geomag. and Geoelect., vol. 19, 1967.

[10] Johnson, R. L. and S. J. Goodman, "Atmospheric Electrical Activity Associated with hurricane Alicia," Preprint Volume: VII International Conference on Atmospheric Electricity, June 3-8, 1984, Albany, NY, pub. by AMS, Boston, MA.

[11] Johnson, R. L., "Measurements of Atmospheric Electrical Emissions from Hurricanes," 14th Technical Conference on Hurricanes and Tropical Meteorology, San Diego, CA., June 1982.