**1995 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM**
**JOHN F. KENNEDY SPACE CENTER**
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# *LIGHTNING ELECTROMAGNETICS*

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## ABSTRACT

This project involved the determination of the effective radiated power of lightning sources and the polarization of the radiating source. This requires the computation of the antenna patterns at all the LDAR site receiving antennas. The known radiation patterns and RF signal levels measured at the antennas will be used to determine the effective radiated power of the lightning source. The azimuth and elevation patterns of the antennas in the LDAR system were computed using flight test data that was gathered specifically for this purpose. The results presented in this report deal with the azimuth patterns for all the antennas and the elevation patterns for three of the seven sites.

## SUMMARY

The objective of the research was to determine the effective radiated power of lightning sources and to arrive at a model for the antenna pattern and polarization for a lightning produced RF source . This data is useful in understanding the development of thunderstorms and for possibly predicting the end of a storm. In order to achieve this goal, flight test data and lightning data were collected at the seven antenna sites of the lightning detection and ranging (LDAR) system at Kennedy Space Center. Flight test data was gathered by flying an aircraft across each of the sites and also in circles around each site. The aircraft was equipped with a horizontal antenna at its tail and a vertical antenna at the bottom which allowed data on vertical and horizontal polarization to be obtained. From this data it is possible to compute the azimuth and elevation patterns of the antennas.

The LDAR system consists of seven antennas operating at a frequency of 66 MHZ. These antennas are conical spiral antennas providing broadband hemispherical coverage. The antennas record the signal levels from lightning occurrences at each antenna site. Using this information, the antenna patterns and the location of the antennas it is possible to model the antenna pattern of the lightning source. Information regarding the polarization of the source can also be deduced from this antenna pattern.

The research work conducted under this project was mainly theoretical. Vast amounts of lightning data and flight test data were available to carry out the necessary computations. During the time that was available the first part of this effort was completed. The azimuth patterns for all the antennas were computed for both horizontal and vertical polarizations. These patterns will have to be analyzed to look for any possible effects of structures close to the antenna site. The elevation patterns were determined for three of the seven antennas also for horizontal and vertical polarizations. Manufacturer's data on the antenna patterns are available for circular polarization. Due to the limited amount of time the lightning data could not be analyzed.

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# I. INTRODUCTION

The Lightning Detection and Ranging (LDAR) system was implemented at the Kennedy Space Center (KSC) in 1991. The Kennedy Space Center is located in a region where there are frequent lightning strikes throughout the year. Lightning activity or even the threat of lightning affects routine operations at KSC, the shuttle launches and associated operations. The LDAR system was developed in order to provide accurate information concerning lightning activity and potential lightning hazard in the KSC area.

## 1.1 THE LDAR SYSTEM

The LDAR system maps the location of cloud-to-ground lightning and in-cloud lightning at a frequency of 66 MHZ. It consists of one central site and 6 remote sites. The antennas at these sites detect lightning induced disturbances at this frequency and using the time of arrival of the radiation at the different sites a three dimensional position of the lightning source is computed [1,2]. The LDAR system generates up to 10,000 data points per second for a lightning flash and provides projections of the lightning in near-real time varying from 1 second to 2 minutes.

The LDAR antennas are located within a radius of 6 to 10 km from the LDAR central site. All the antennas are conical spiral left circularly polarized antennas. Lightning-produced pulses received st the remote sites are processed by log video detectors and the video pulses are transmitted to the central site via microwave links. The physical configuration of the system is such that the direct RF pulses arrive at the central site prior to the retransmitted pulses from the remote sites. The system is triggered when the pulse exceeds a certain threshold at the central site and a 100 microseconds data analysis period commences. During this analysis period the system determines the time of occurrence of the largest amplitude pulse for each of the sites. At the end of the analysis period, the time and amplitude data for each site is collected and tagged with the time of the day to the nearest microsecond. The system is rearmed within 10 microseconds. After the data has been gathered, it is transmitted to a set of computers for testing, calculations of the source locations and display.

The results presented in this report deal with the calculation of the antenna patterns for the LDAR system. The azimuth and elevation patterns computed using flight test data are presented.

## 1. 2 LDAR SITE INFORMATION

Survey data for the LDAR antenna sites is available as the WGS-84 geodetic latitude, longitude and the mean sea elevation of the antennas. Using the appropriate coordinate transformations the x, y, z locations of the sites are calculated with the central site being at (0,0,0).

The geodetic height for the central site used is the value measured to the top of the antenna. The reference geoid for the GPS (WGS-84) is 28.19 m . Figure 1-1 shows the locations of the LDAR sites and Table 1 provides the x,y,z coordinates for the sites.

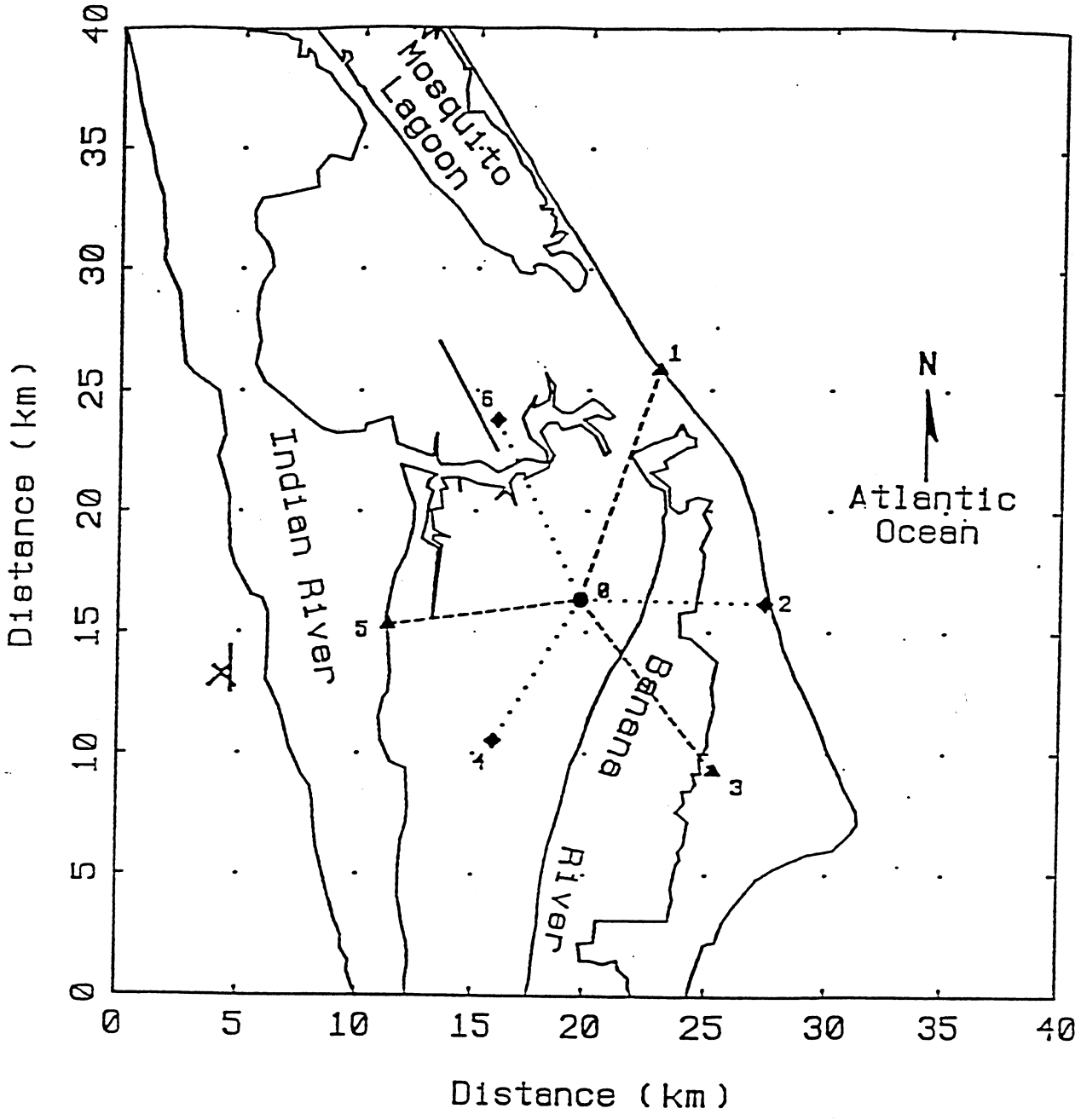



Figure 1-1: LDAR site locations

Table 1: Geodetic data and the x, y, z coordinates of the LDAR antennas

| Site # | Latitude (d, m, s) | Longitude (d, m, s) | Height (m) | Mean Sea Level Elevation (m) |
|---|---|---|---|---|
| 0 | 28 32 19.47637 | 80 38 34.29894 | -20.00580 | 4.2670 |
| 1 | 28 37 26.24000 | 80 36 35.10000 | -14.25760 | 13.9324 |
| 2 | 28 32 12.88000 | 80 33 54.47000 | -18.04630 | 10.1437 |
| 3 | 28 28 29.19000 | 80 35 11.75000 | -16.54970 | 11.6403 |
| 4 | 28 29 10.09000 | 80 40 56.06000 | - 8.83011 | 19.3599 |
| 5 | 28 31 45.65000 | 80 43 44.98000 | -11.00940 | 17.1806 |
| 6 | 28 36 20.79000 | 80 40 52.73000 | -17.38790 | 10.8021 |

| Site # | X (m) | Y (m) | Z (m) |
|---|---|---|---|
| 0 | 0.97 | 0.00 | 0.00 |
| 1 | 3241.46 | 9443.48 | 13.59 |
| 2 | 7608.28 | -205.54 | 6.49 |
| 3 | 5507.38 | -7090.74 | 9.79 |
| 4 | -3852.88 | -5830.96 | 15.02 |
| 5 | -8445.06 | -1044.40 | 14.67 |
| 6 | -3762.35 | 7428.39 | 8.07 |

# II. FLIGHT TEST DATA

The LDAR flight test was performed on June 1, 1995. The aircraft platform used was a NASA Wallops Island C-I30. A high power pulse amplifier was installed on the aircraft to simulate lightning discharges. The pulse was at 66 MHZ frequency with a pulse repetition frequency of 25 Hz. The position of the aircraft was recorded using a GPS receiver capable of measuring the aircraft position to one meter, rms. The GPS antenna is located on the top of the aircraft in front of the propeller line.

Two GPS systems designated receiver 1 and receiver 2 were used to simultaneously record the aircraft position from the same GPS antenna. The data was recorded as output from the GPS receiver. The receiver outputs an ASCII position record once per second. This record contains the aircraft position in WGS-84 coordinates and earth centered earth fixed coordinates and includes a GPS time tag for all position measurements.

## 2.1 TEST PLAN

The LDAR antennas are conical spiral left circularly polarized antennas. These are broadband antennas with a frequency range of 60 MHZ to 300 MHZ and provide hemispherical coverage. By using a circularly polarized antenna the variation in signal amplitude due to variation in the polarization of the radiating source is reduced.

Two coaxial antennas, one vertically polarized and the other horizontally polarized, were installed on the aircraft at the bottom and on the tail respectively. These antennas operate at 66 MHZ. The purpose of the flight test is to measure the antenna patterns of the LDAR antennas. The aircraft maintained a flight altitude of 25,000 feet above ground level. The test plan consists of two parts

(i) Fly circles of radius 8.2 statute miles around the 7 LDAR sites. Each circle is flown twice, for the bottom antenna and the tail antenna.

(ii) Fly a clover leaf pattern with each leg extending 8 statute miles beyond the closest LDAR site. The radials are to and from the central site, passing over each remote site. This pattern is also repeated for the bottom and tail antenna.

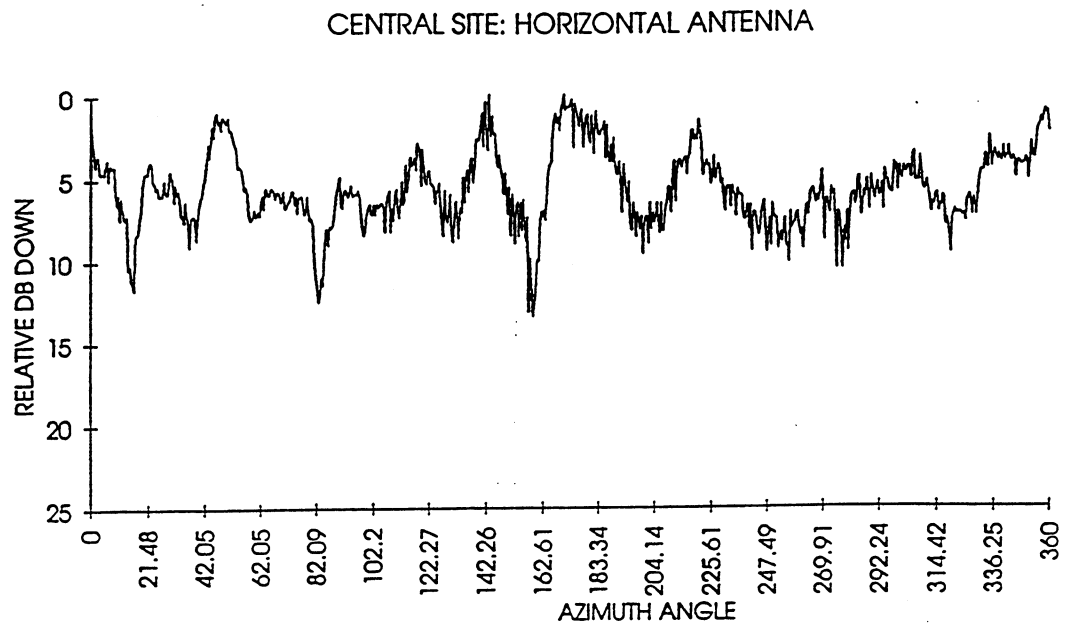
These two flight plans allow the calculation of the azimuth and elevation pattern variation of the antennas. The data recorded provides the x, y, z coordinates of the aircraft and the amplitude levels at all the antenna sites and the UTC time for all position measurements.

The x, y, z positions of the aircraft and its corresponding azimuth and elevation angles calculated with the GPS data were compared with those obtained with the LDAR data. The values for the angles were found to agree to within a tenth of a degree. Only results based on the LDAR data are presented in this report.

All the antennas are calibrated using a high powered impulse generator capable of producing a 400 V peak-to-peak pulse in a 50 ohm load. The calibration data is available for all the sites and is used in calculating the amplitude level of the received signal at the sites.

## III. AZIMUTHAL PATTERNS OF THE ANTENNAS

The azimuthal patterns of the antennas at all the seven sites computed using data obtained from the aircraft flying circles around each site are shown in Figures 3-1 to 3-7. In each case the pattern is presented for the vertical and the horizontal antenna. The patterns were obtained for a 30 degree elevation angle. The sharp null (about 20 db down) are due to problems with the transmitter which caused the signal level to drop drastically at all the sites. The azimuthal pattern for these antennas for a circular polarized signal is expected to have very slight variation of the order of 1 to 3 db over the complete range of the azimuth angle. The calculated patterns show a variation of the order of 10 to 15 db in some instances. The antenna at site 1 shows a variation with azimuth angle for both the horizontal antenna and the vertical antenna of about 8 db and appears to have a more acceptable pattern as compared to the other antennas. Sites 4 and 5 show major fluctuations in the amplitude level with angular variation. The antenna patterns are of course influenced by their locations and by structures, buildings etc. in their vicinity. Hence each of these patterns has to be analyzed individually with respect to its location to characterize the effect of its surrounding on the pattern.



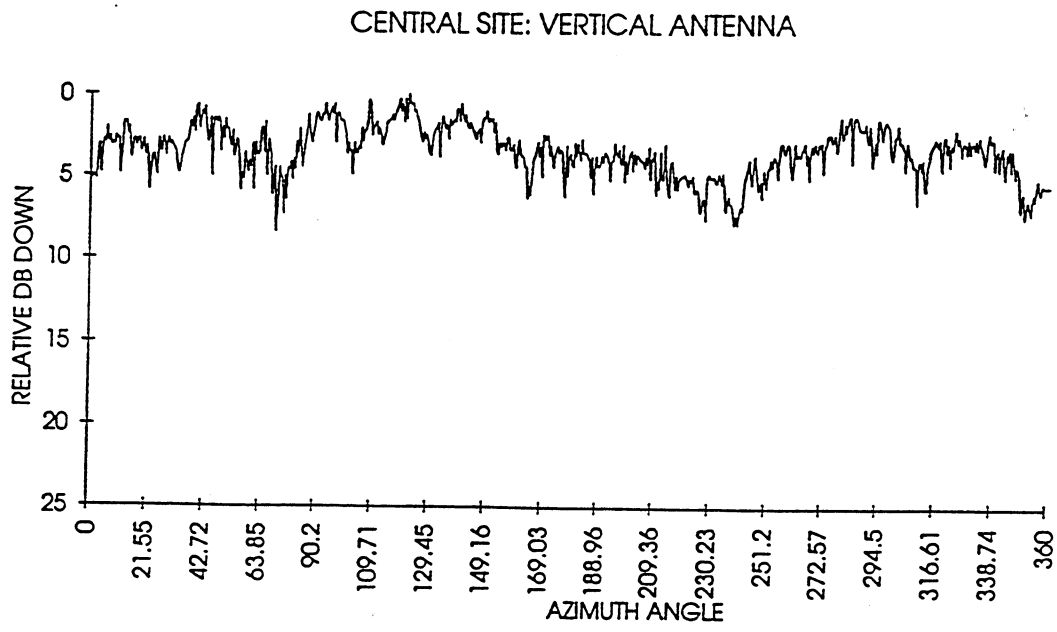
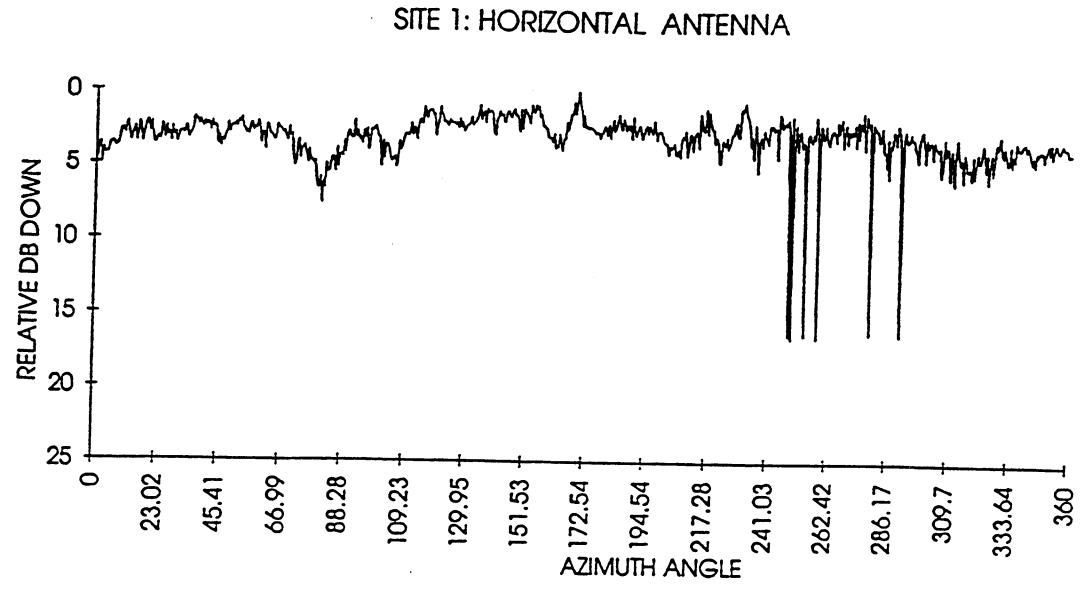




Figure 3-1: Central site azimuthal pattern. (30 degree elevation angle)



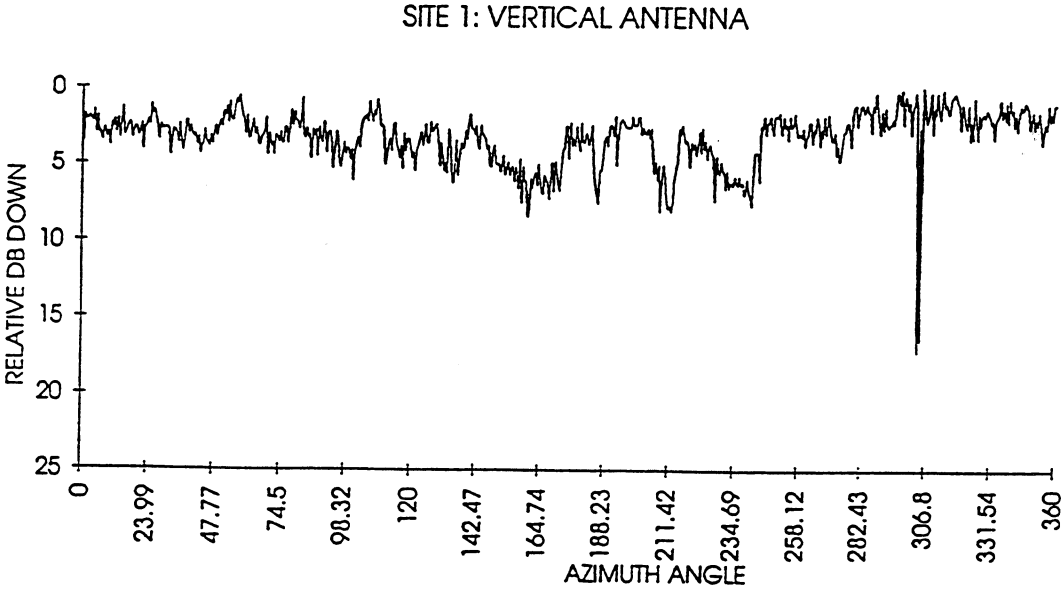
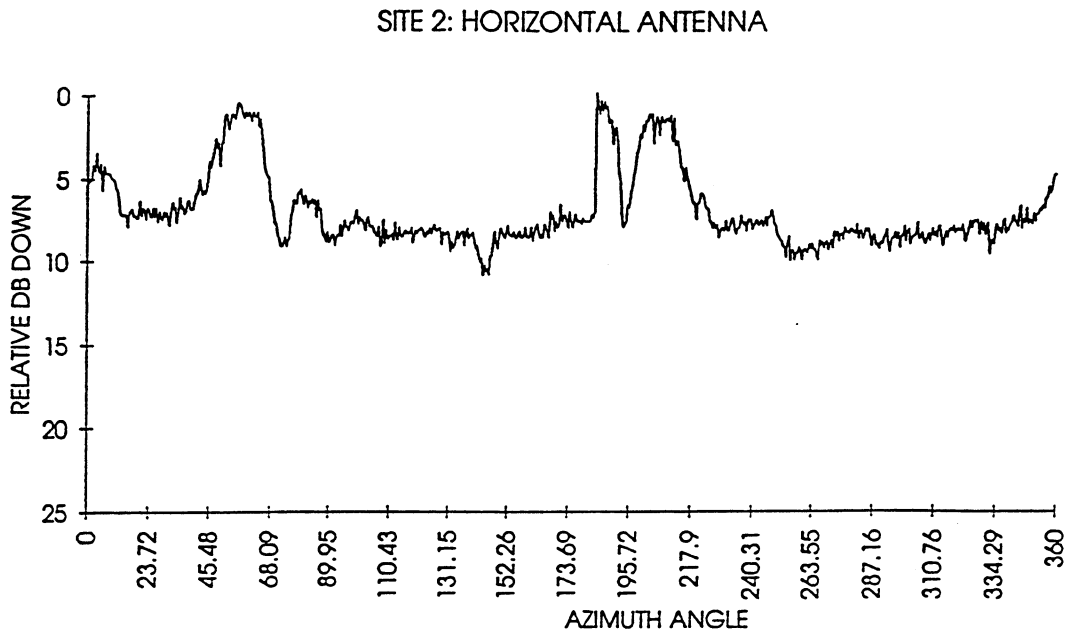




Figure 3-2: Site 1 azimuthal pattern. (30 degree elevation angle)



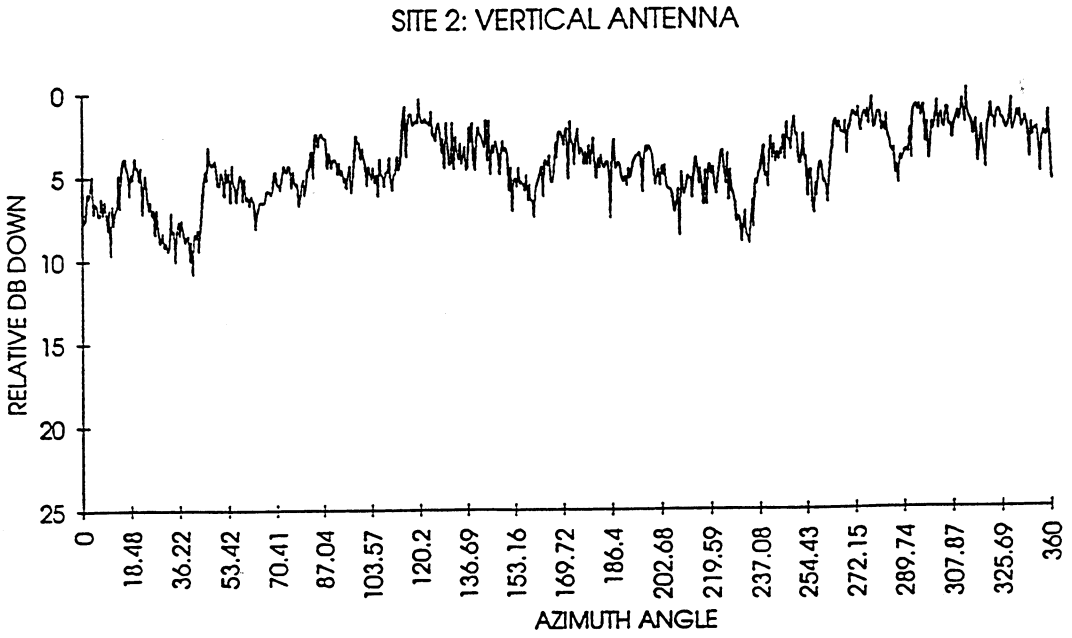
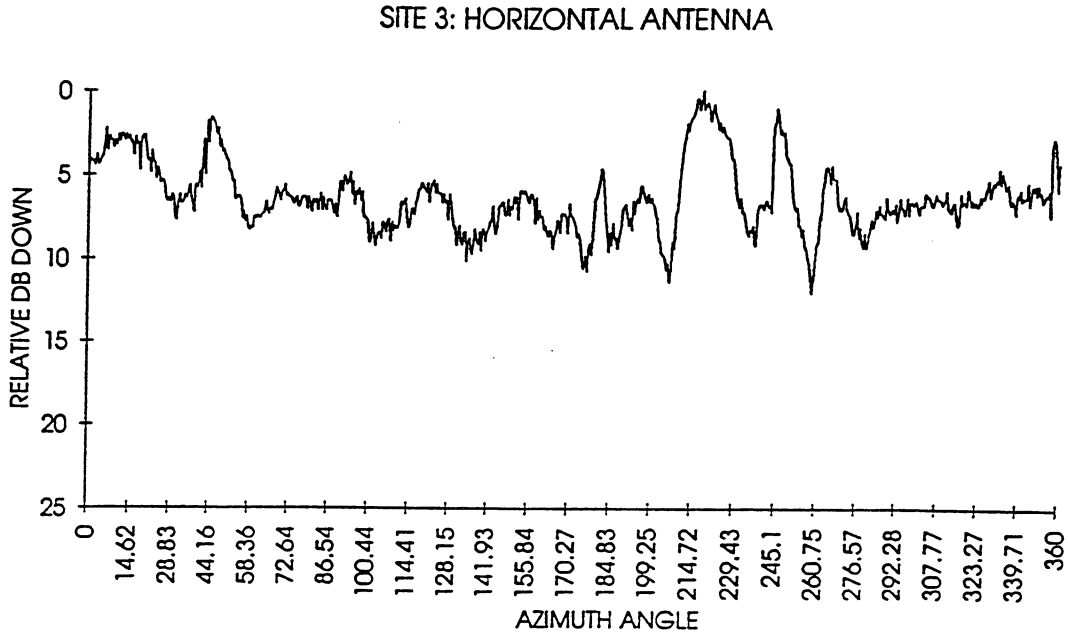




Figure 3-3: Site 2 azimuthal pattern. (30 degree elevation angle)



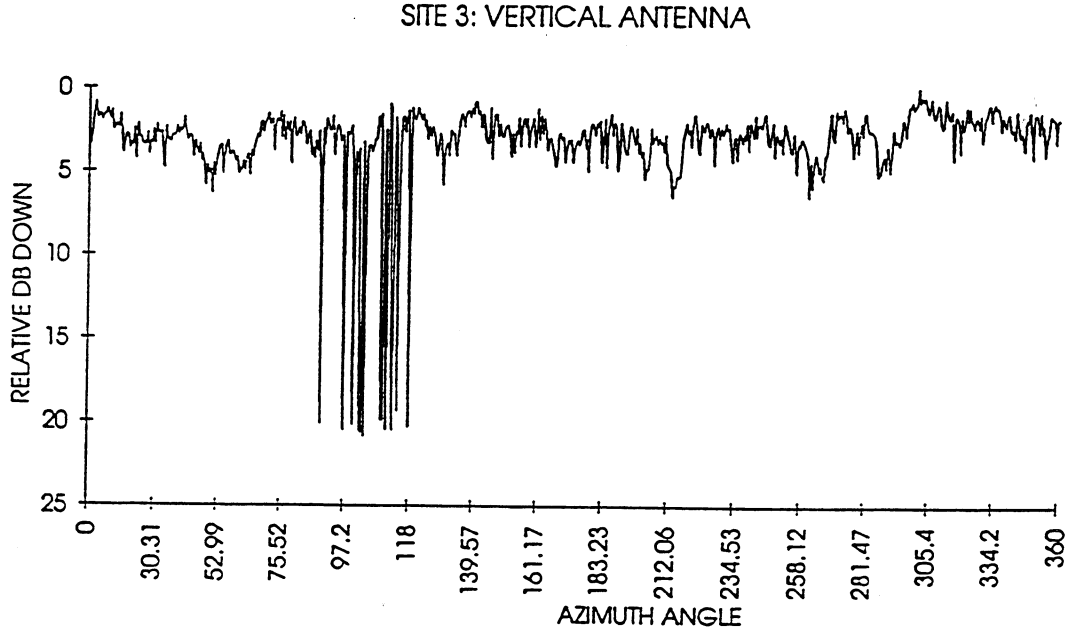
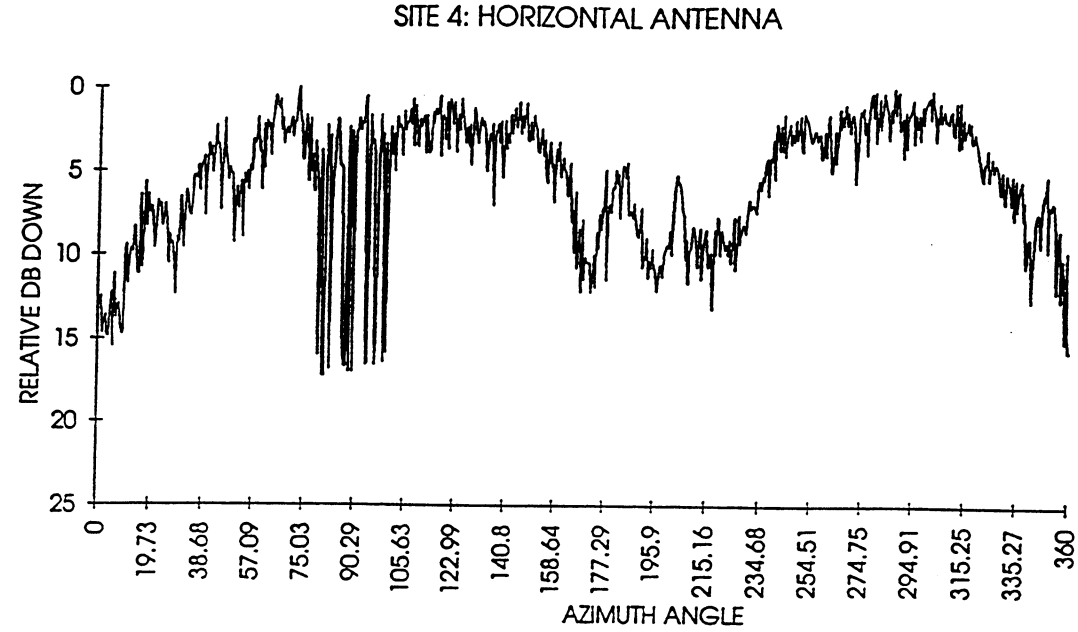




Figure 3-4: Site 3 azimuthal pattern. (30 degree elevation angle)



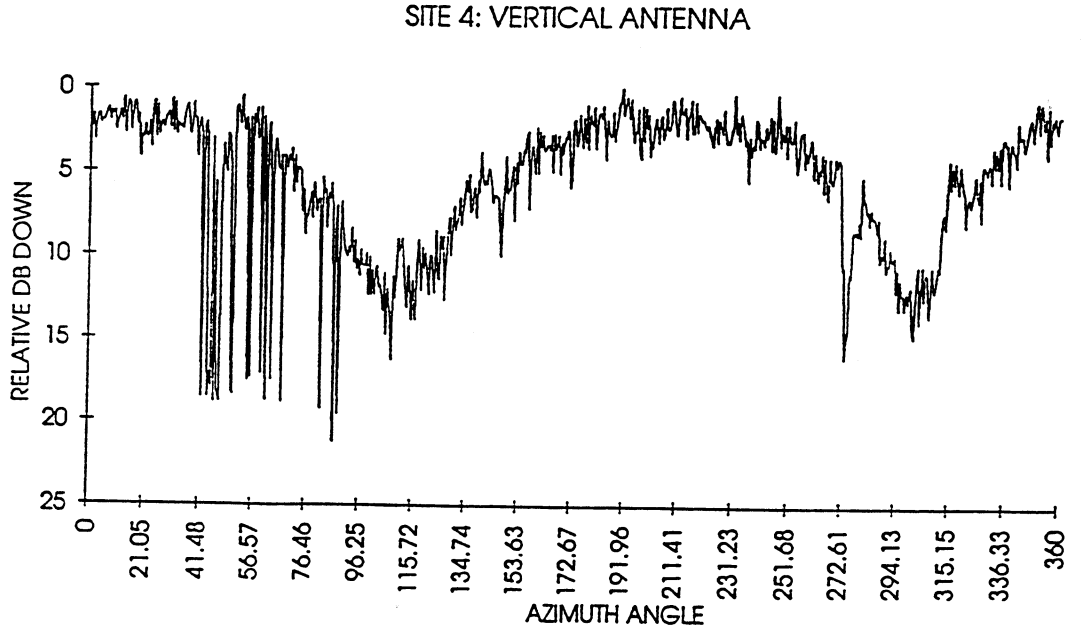
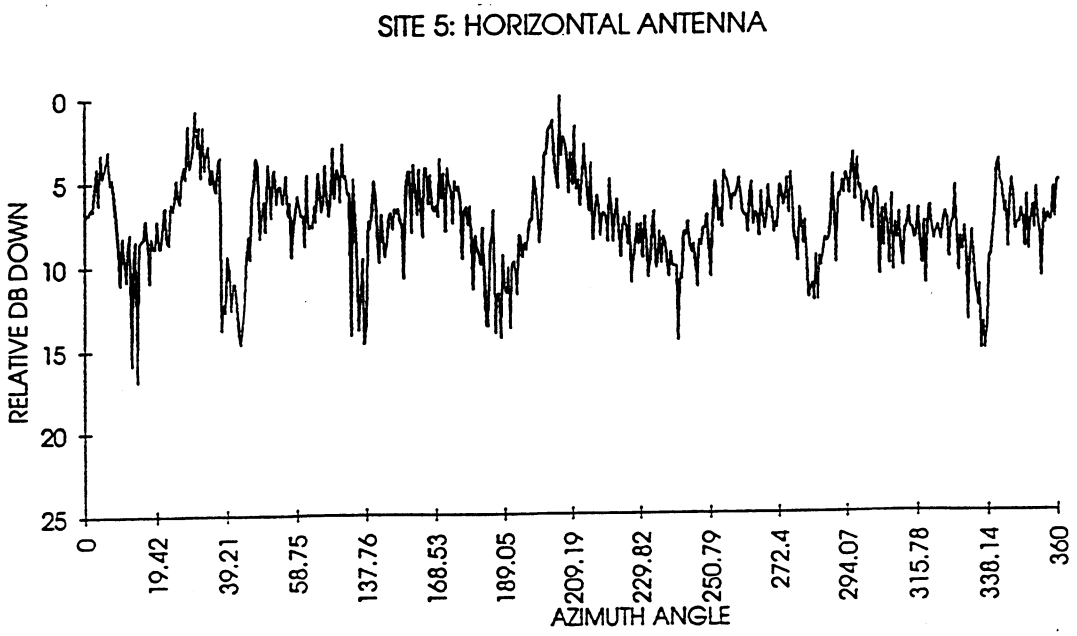




Figure 3-5: Site 4 azimuthal pattern. (30 degree elevation angle)



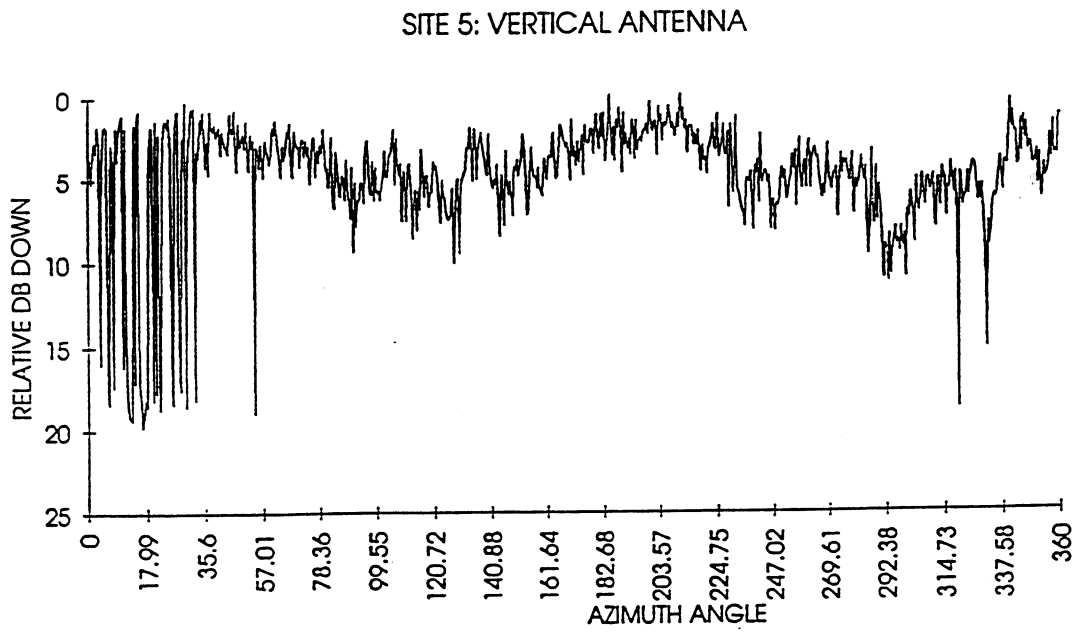
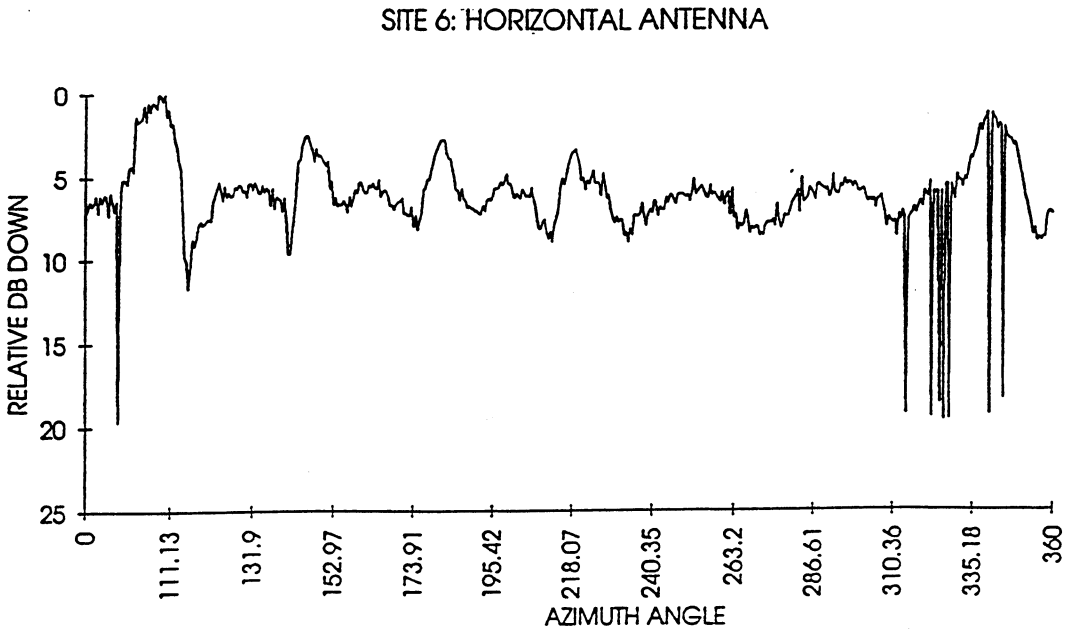




Figure 3-6: Site 5 azimuthal pattern. (30 degree elevation angle)



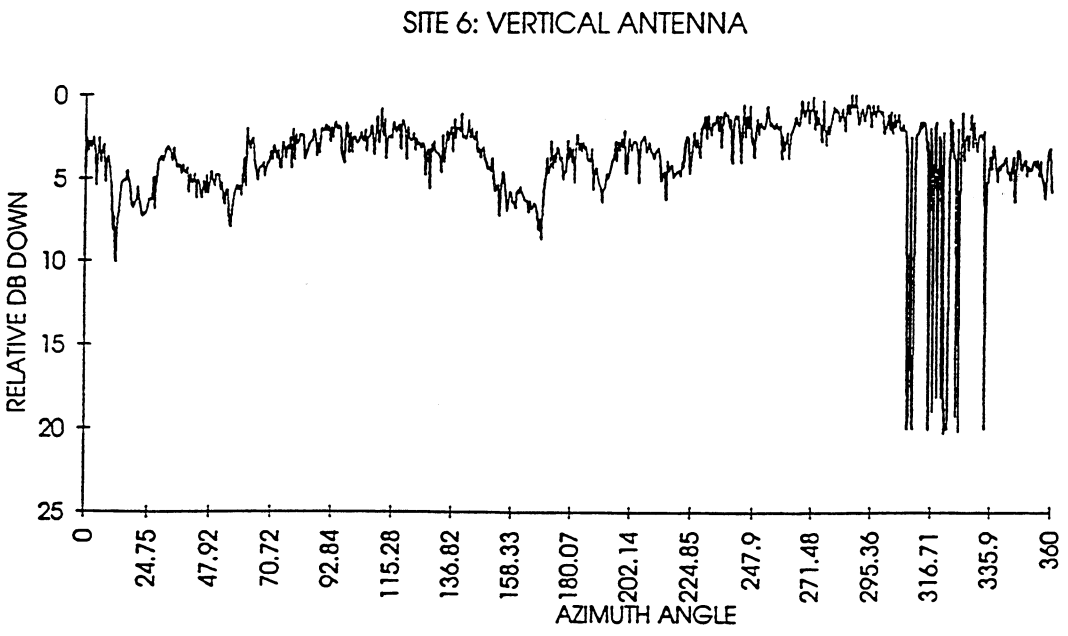
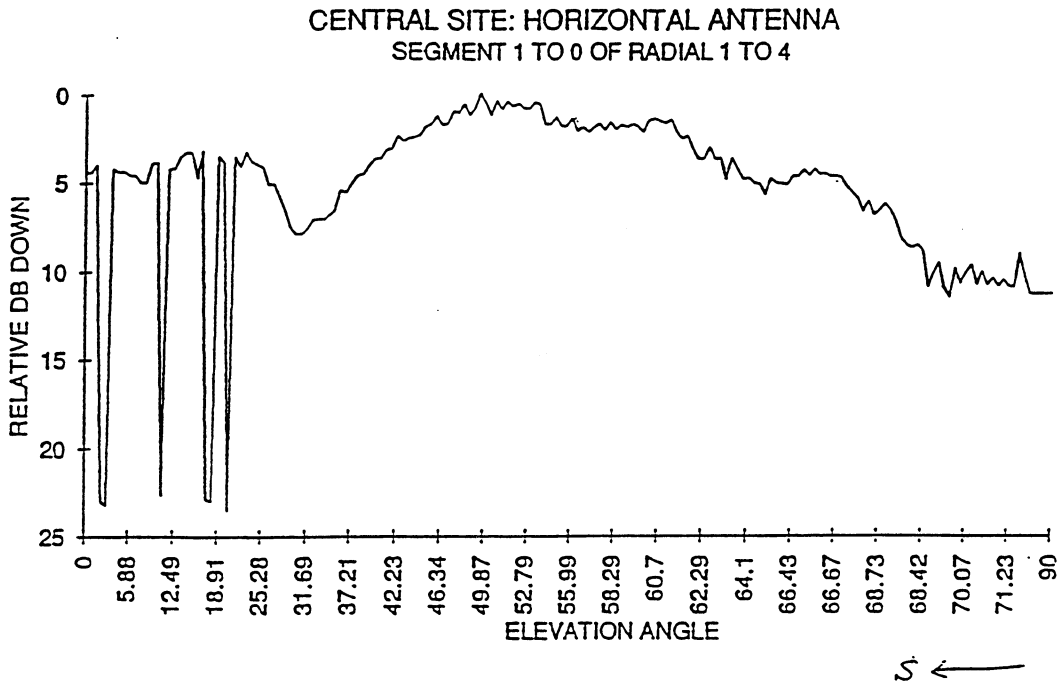




Figure 3-7: Site 6 azimuthal pattern. (30 degree elevation angle)

## IV. ELEVATION PATTERNS OF THE ANTENNAS

The elevation patterns of the antennas were computed using the data obtained from the radial flights over the antenna sites. Referring to Figure 1-1, the flight paths were flown staring from site 1 to site 4, clover leaf from 4 to 3, radial from 3 to 6, a clover leaf from 6 to 5 and finally the radial from 5 to 2. All the radials passed over the central site. The elevation patterns for the central site obtained for the horizontal antenna are shown in Figures 4-1 to 4-3 and for the vertical antenna in Figures 4-4 to 4-6. For each radial path the results are presented in two segments. ----> S indicates the aircraft approaching the site and S ----> indicates the aircraft leaving the site. The elevation pattern for a circularly polarized signal for these antennas is expected to be symmetric, with a 3 db beamwidth of about a 144 degree and a variation in amplitude of about 12 db. In our case we had the aircraft flying over the antenna in one direction only, i.e. the aircraft did not cross the site again in two opposite directions. Instead we had three separate radial paths crossing the central site and this data was used to obtain complete information on the elevation pattern of the antenna. Elevation patterns for sites 1 and 4 were also computed using the radial from site 1 to site 4 for the two antennas. Figures 4-7 and 4-8 show the elevation pattern for site 1 for the horizontal and vertical antennas respectively and Figures 4-9 and 4-10 show the patterns for the site 4. In these cases also the sharp null in the pattern are due to problems with the transmitter. Sites 1 and 4 appear to have a more acceptable elevation angle variation as compared to the antenna at the central site.



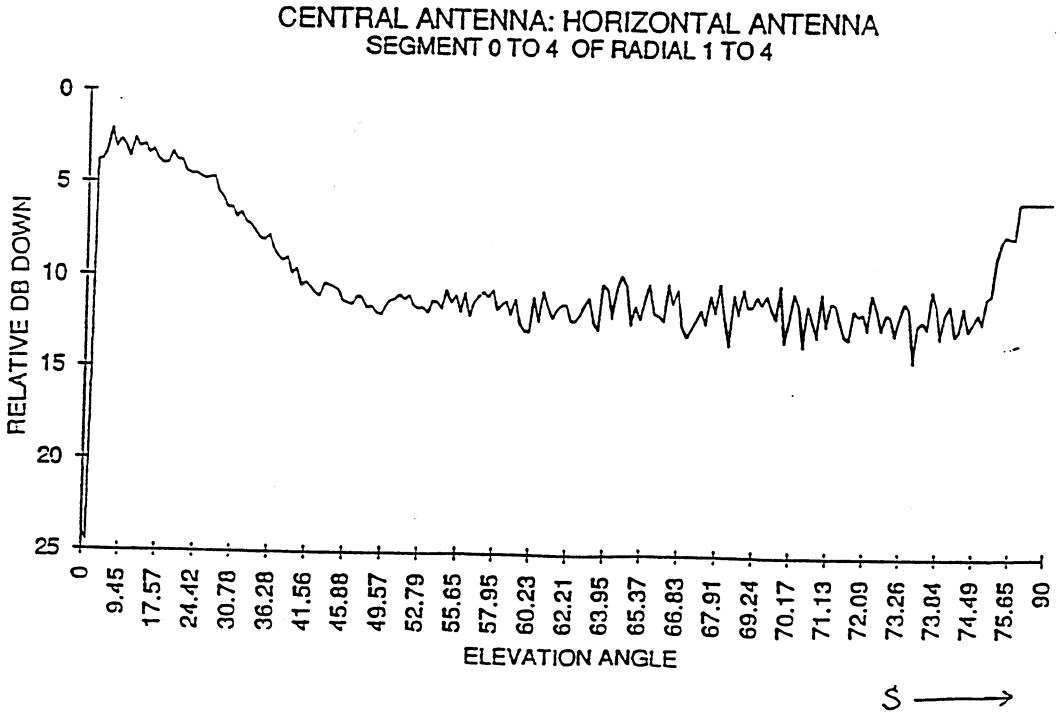
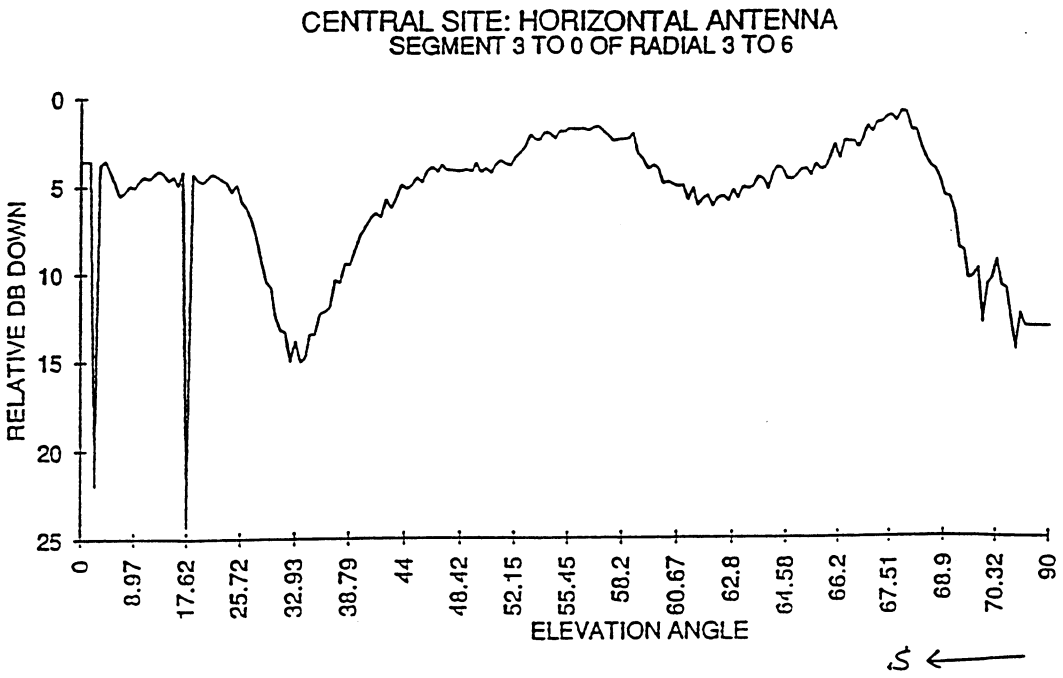




Figure 4-1: Central site elevation pattern; Radial from site 1 to 4 - Horizontal antenna.



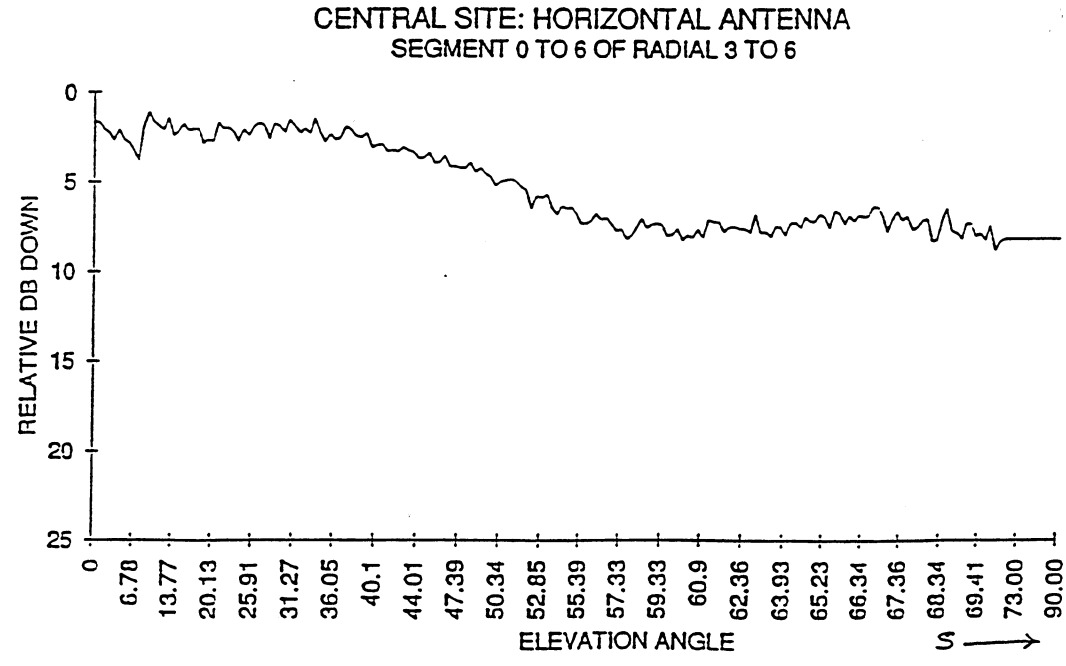
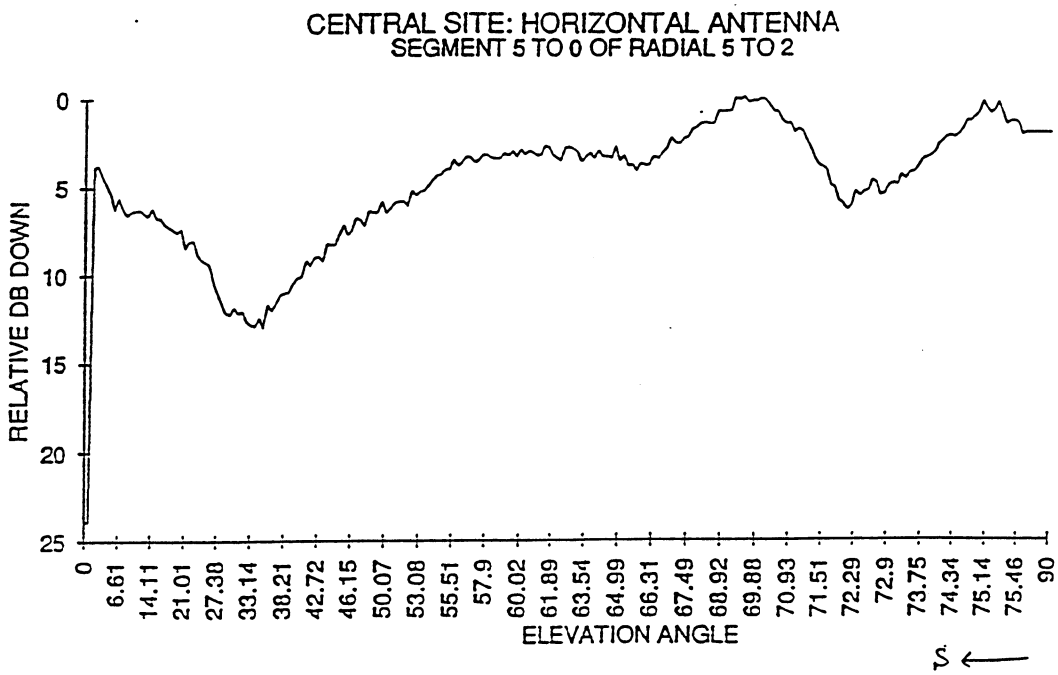




Figure 4-2: Central site elevation pattern; Radial from site 3 to 6 - Horizontal antenna.



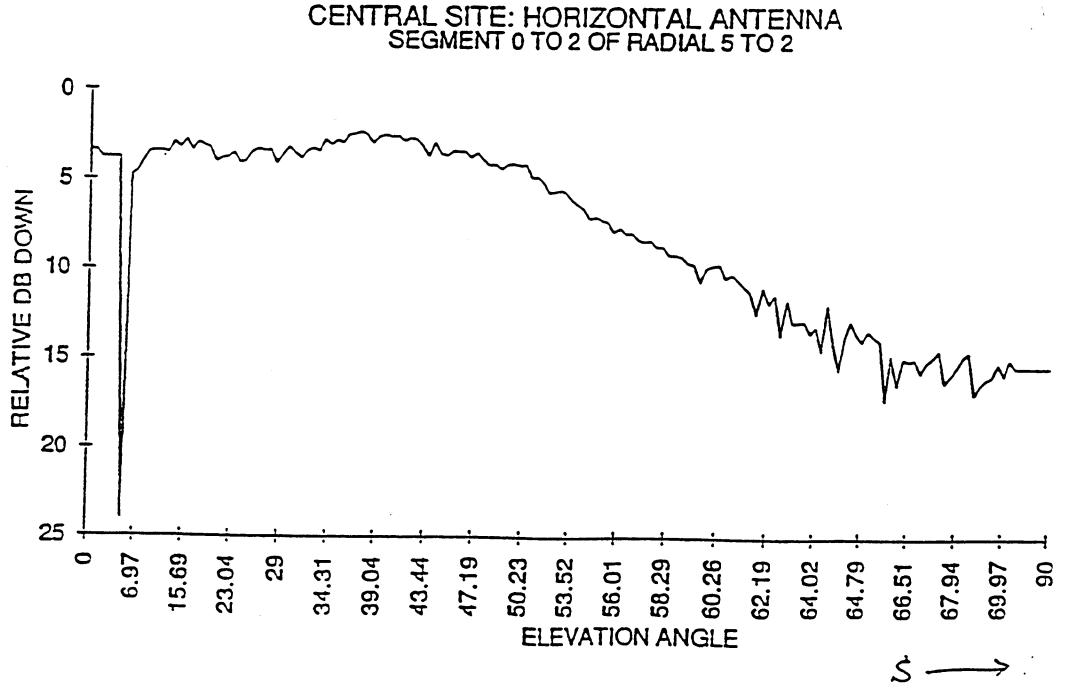
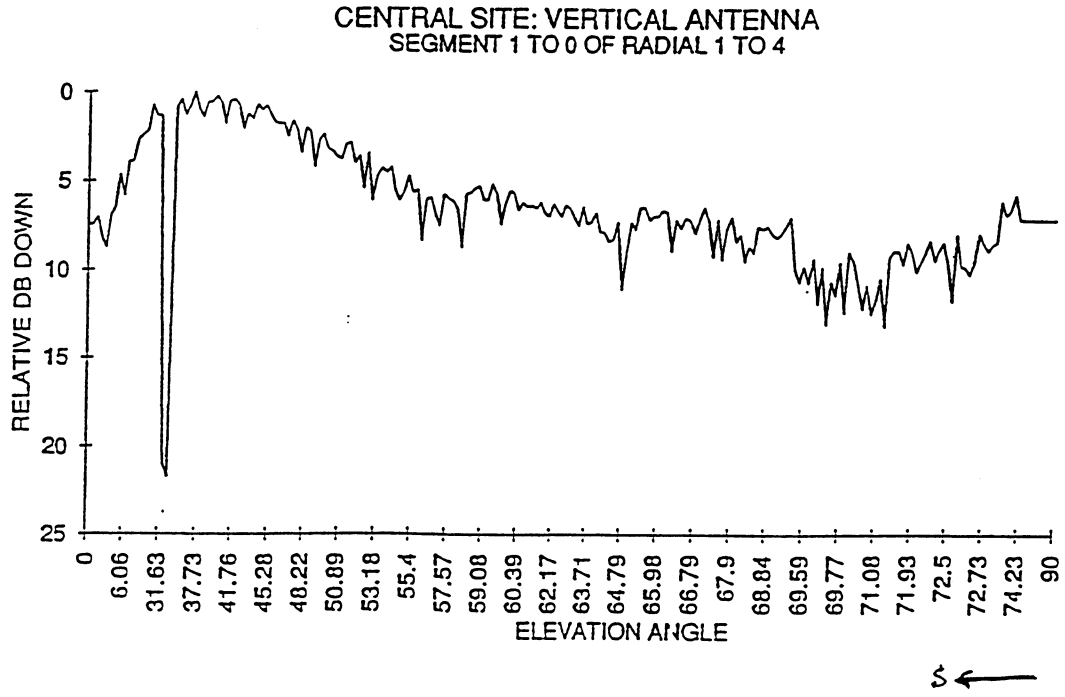




Figure 4-3: Central site elevation pattern; Radial from site 5 to 2 - Horizontal antenna.



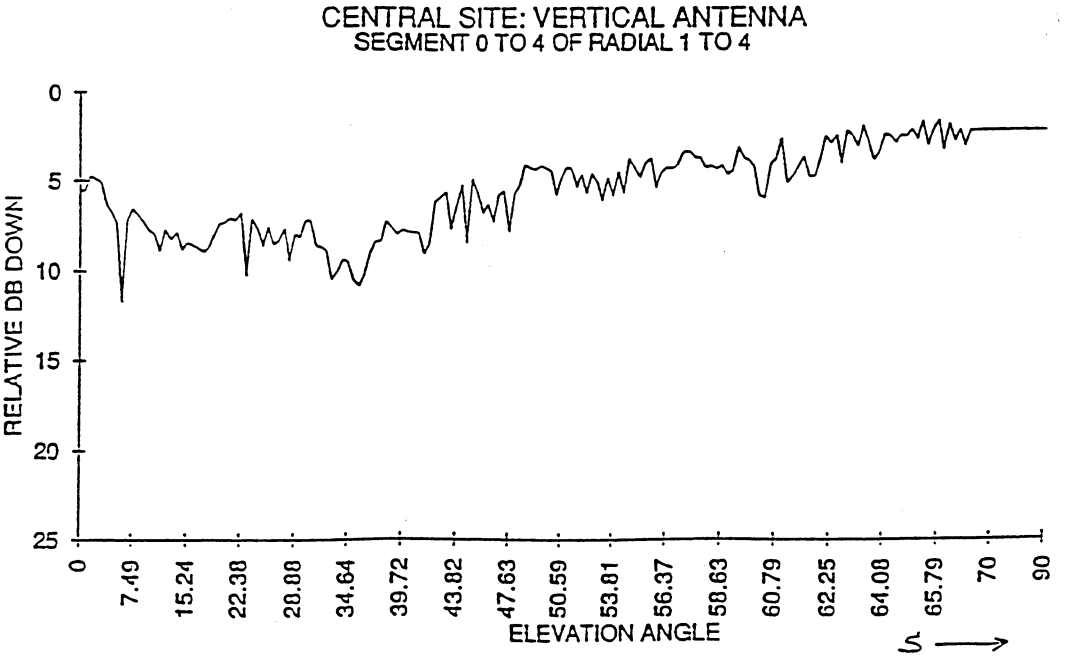
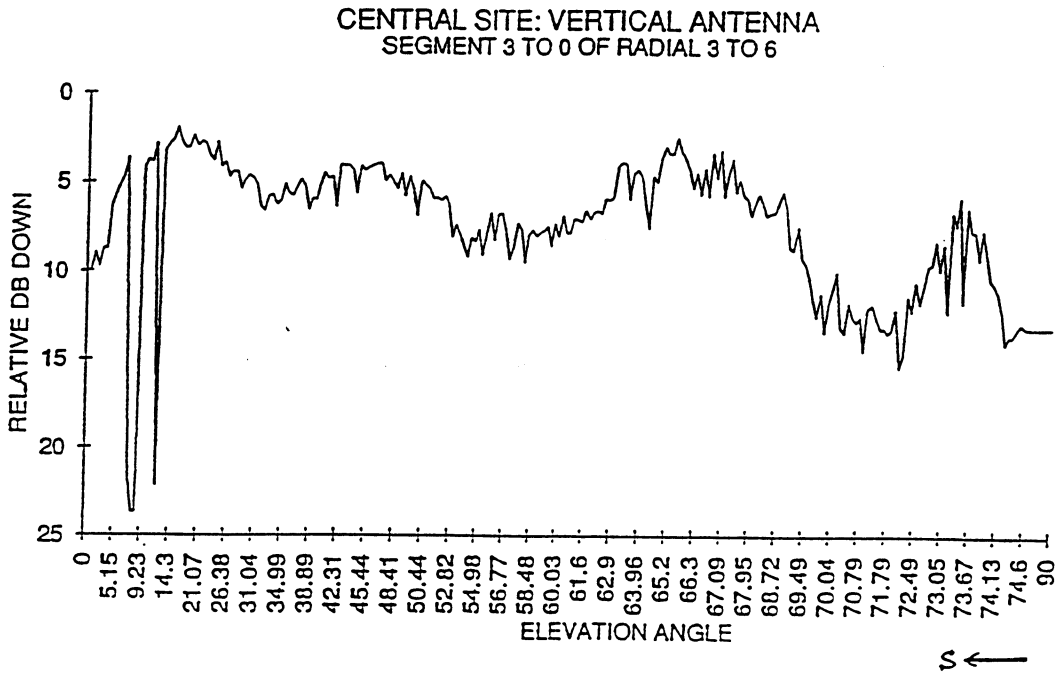




Figure 4-4: Central site elevation pattern; Radial from site 1 to 4 - Vertical antenna.



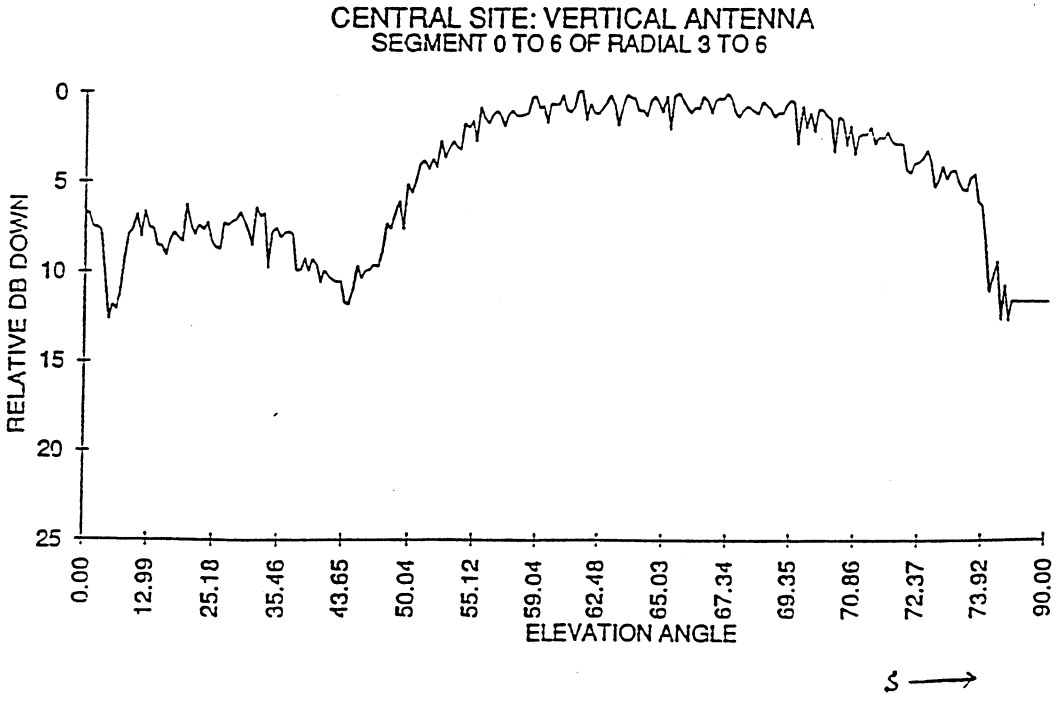
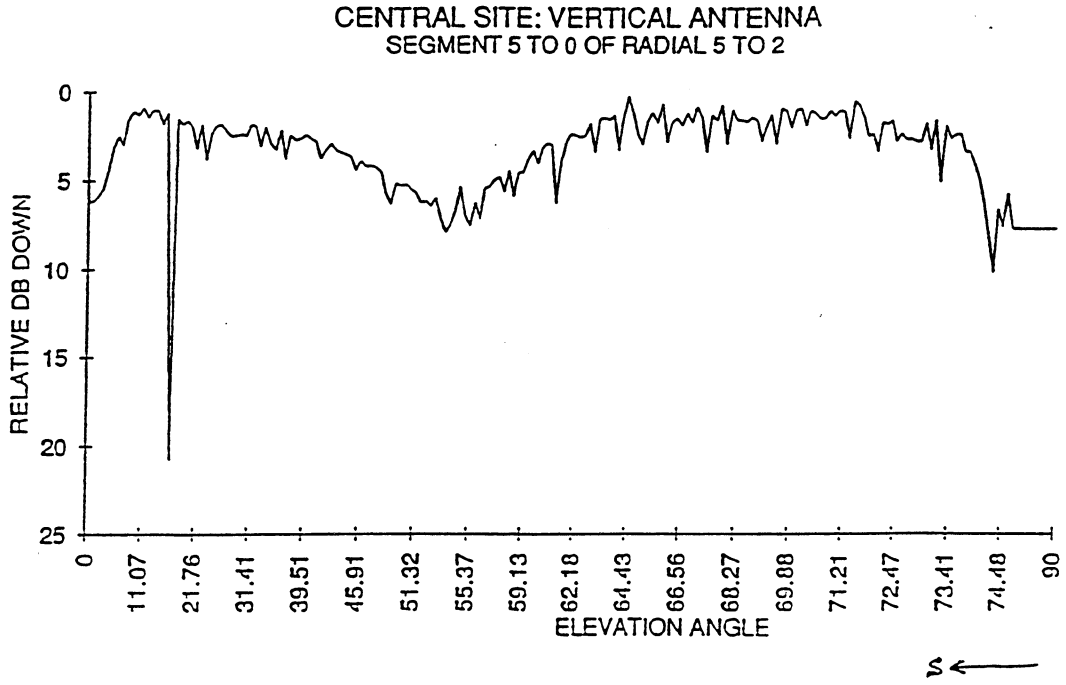




Figure 4-5: Central site elevation pattern; Radial from site 3 to 6 - Vertical antenna.



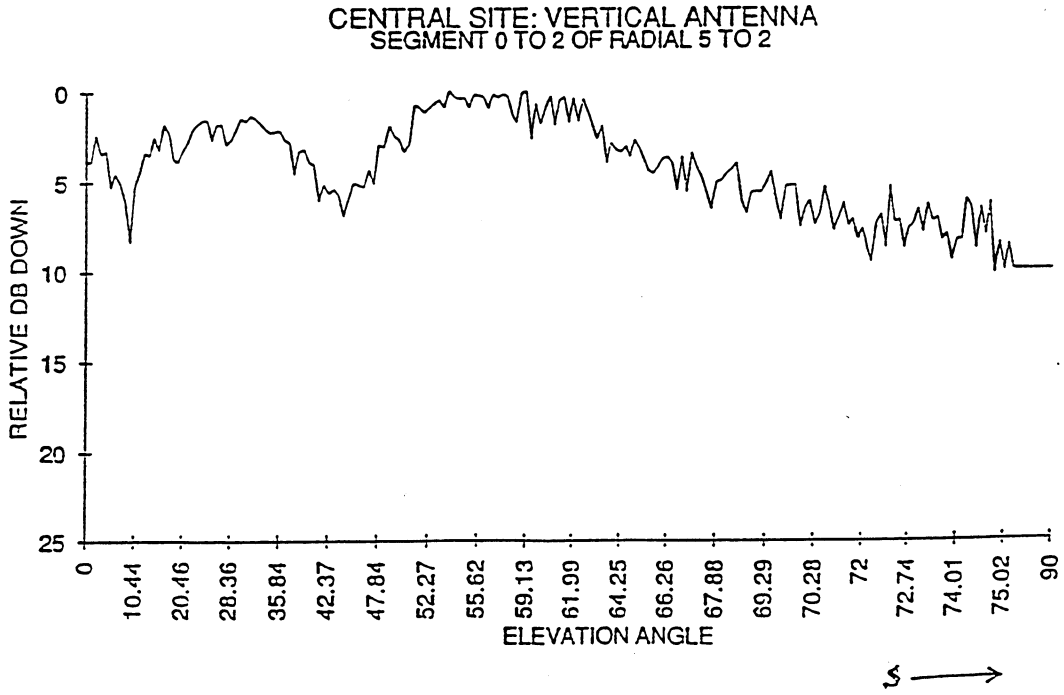
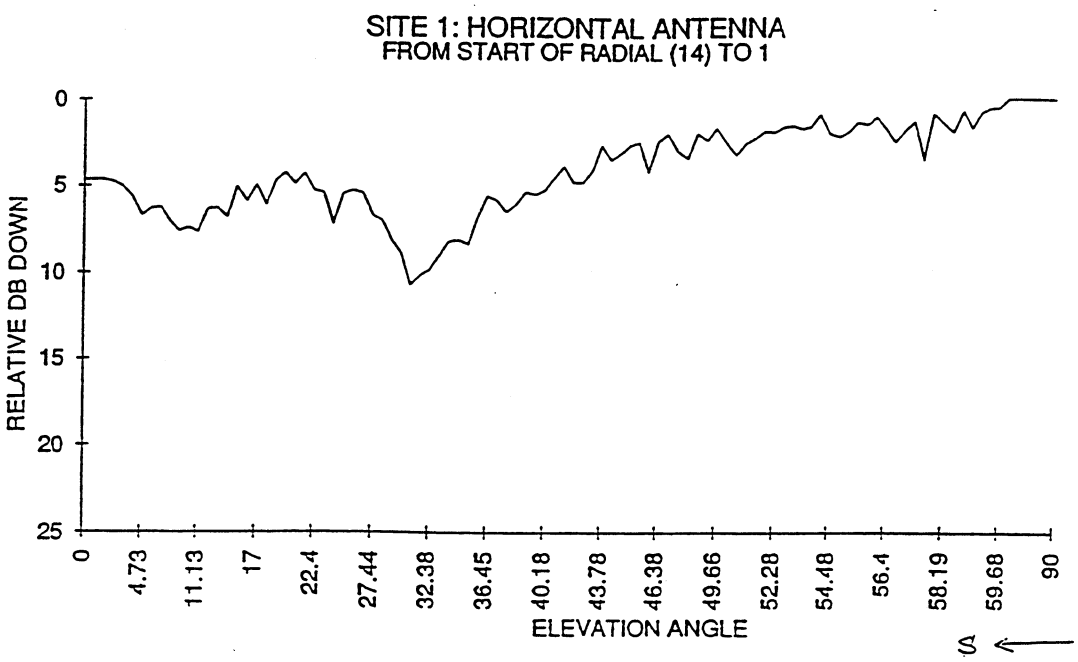




Figure 4-6: Central site elevation pattern; Radial from site 5 to 2 - Vertical antenna.



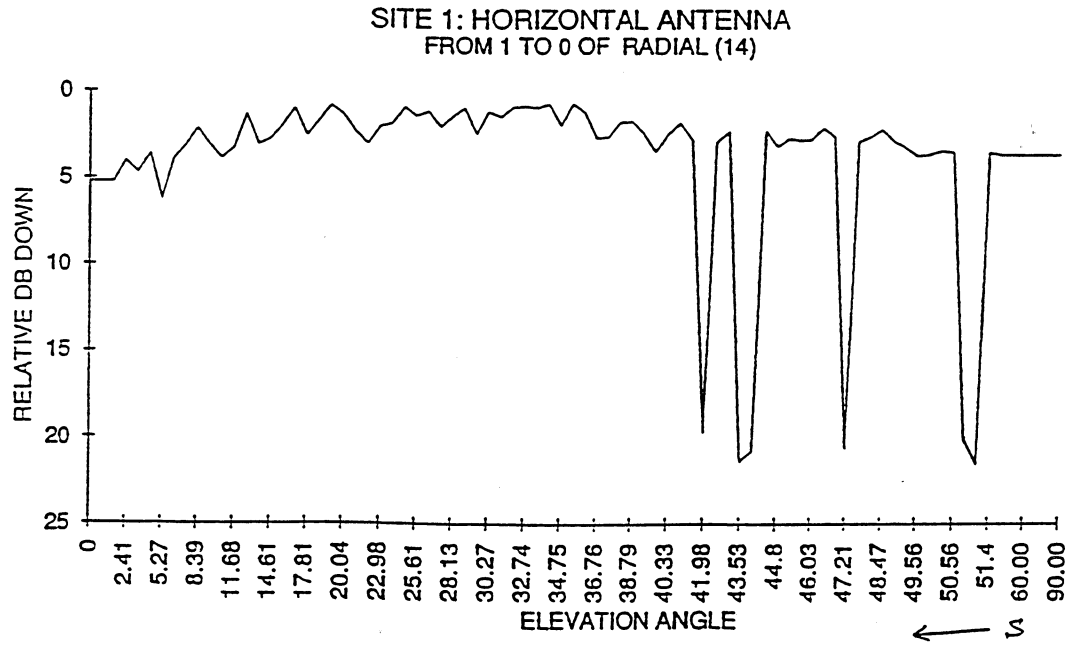




Figure 4-7: Site 1 elevation pattern; Radial from site 1 to 4 - Horizontal antenna.

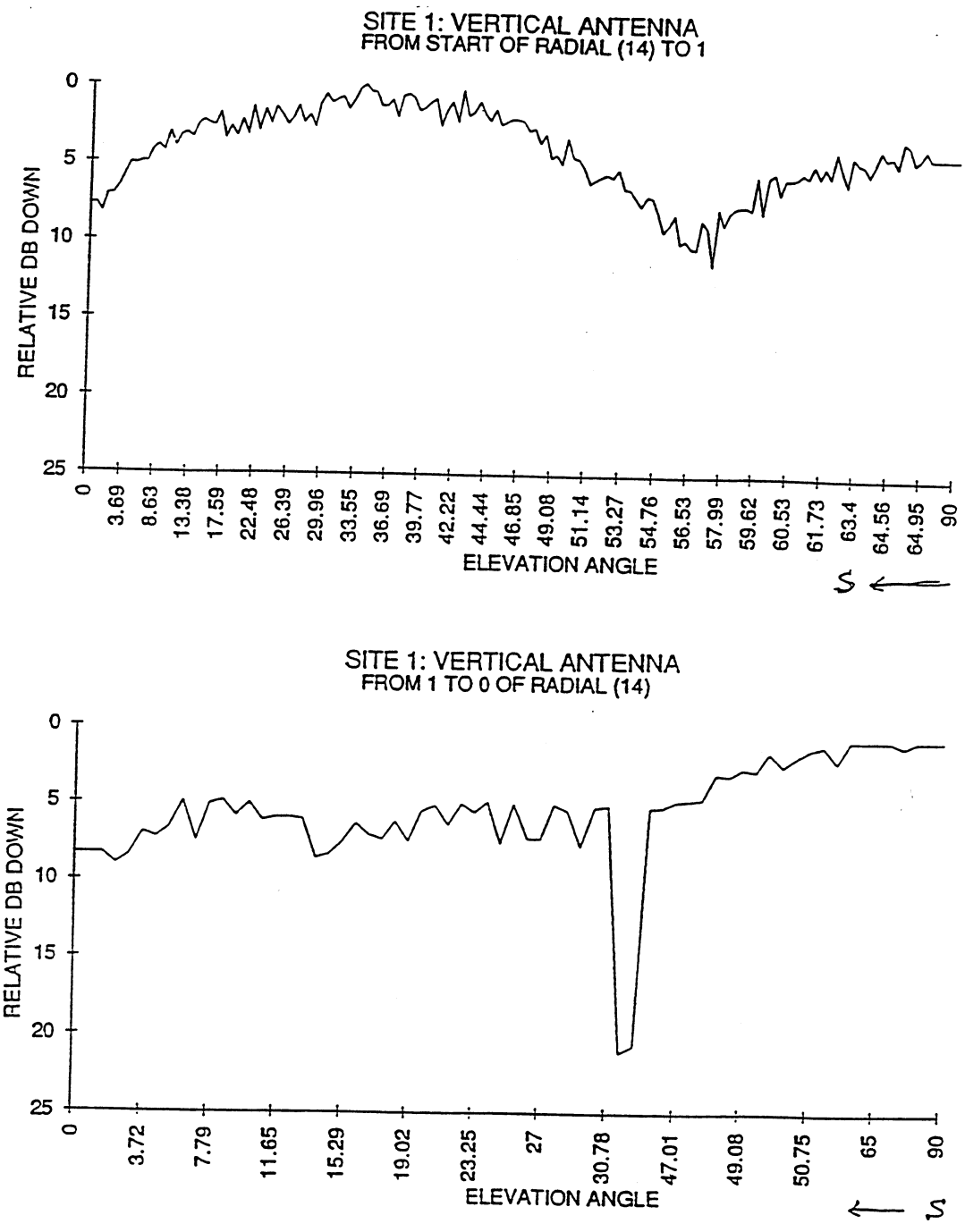



Figure 4-8: Site 1 elevation pattern; Radial from site 1 to 4 - Vertical antenna.

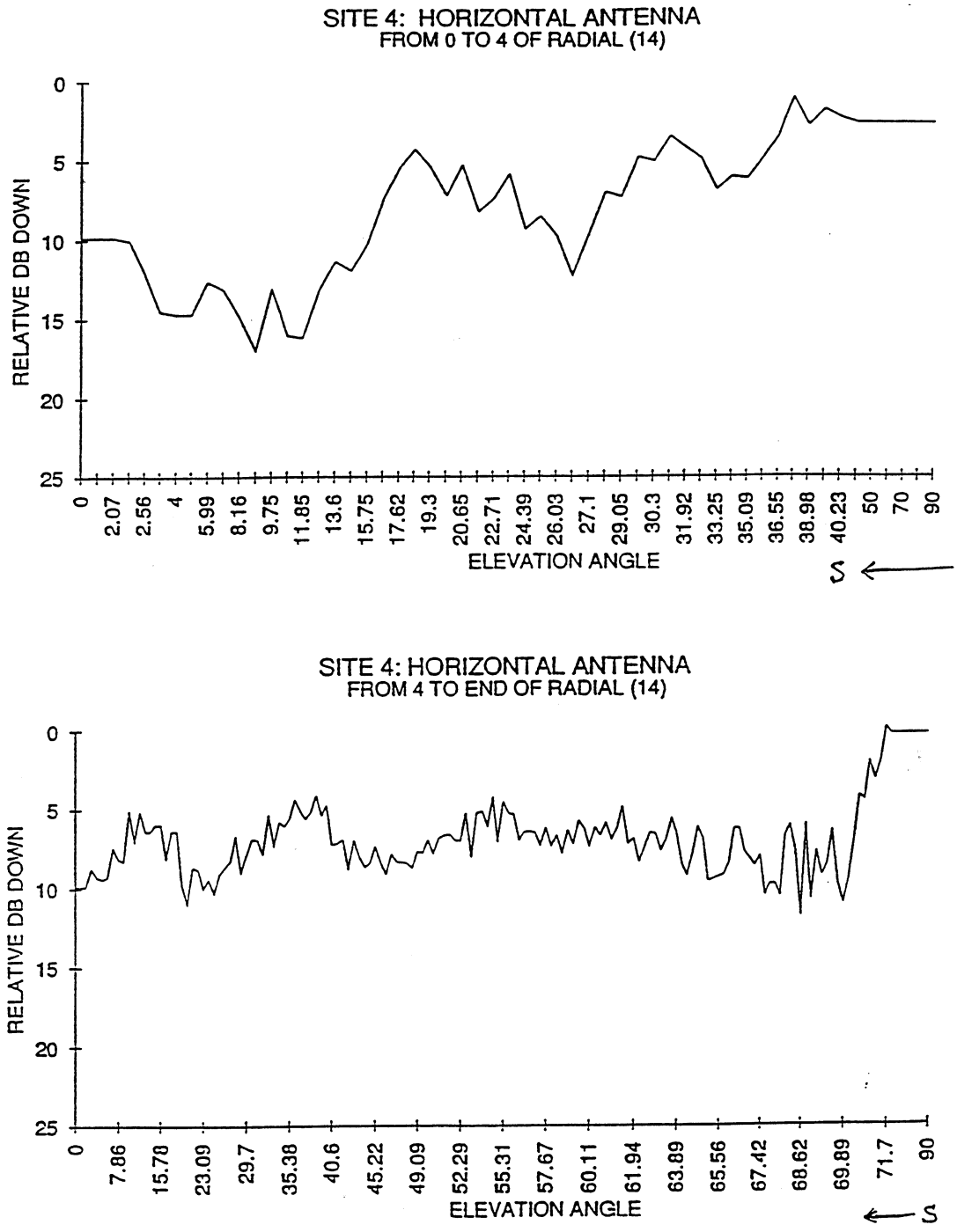
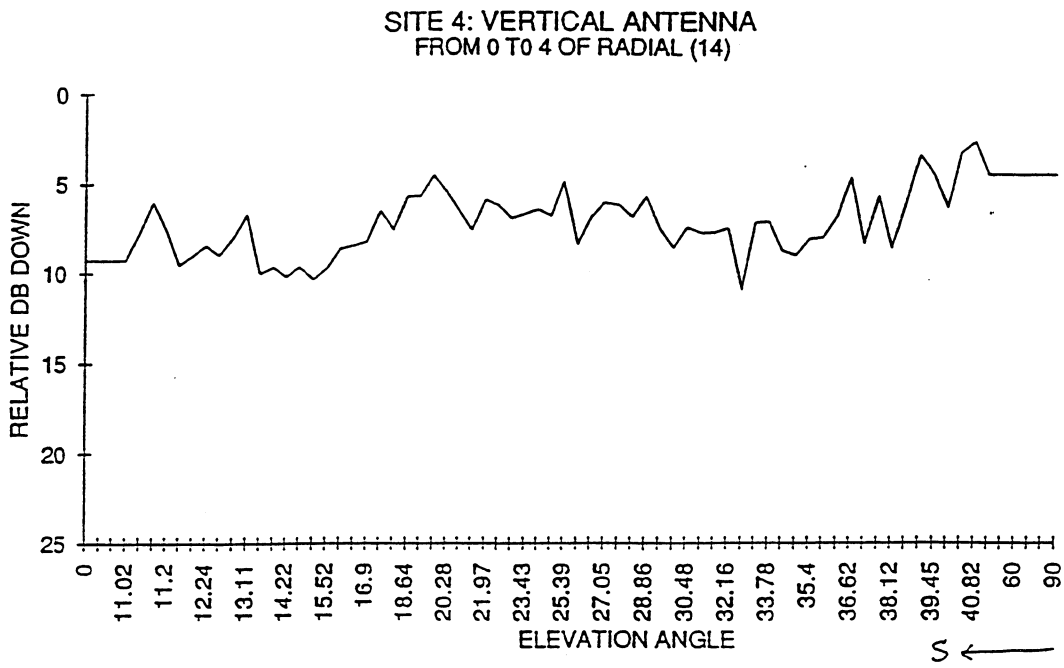



Figure 4-9: Site 4 elevation pattern; Radial from site 1 to 4 - Horizontal antenna.



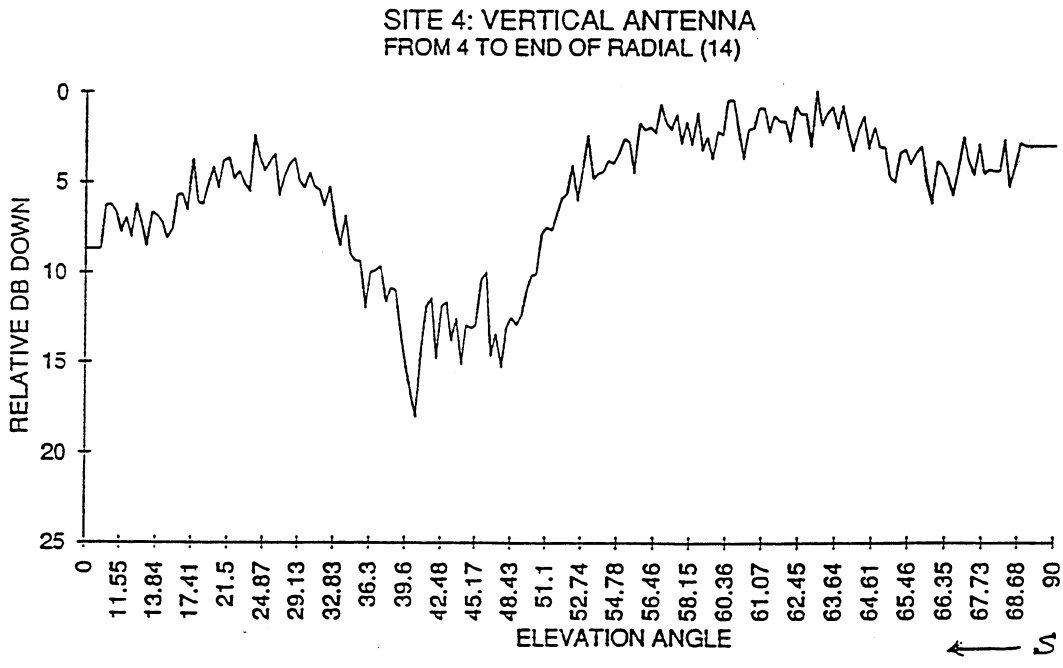




Figure 4-10: Site 4 elevation pattern; Radial from site 1 to 4 - Vertical antenna.

# V. CONCLUDING REMARKS

Investigators have for many years been attempting to understand the complex phenomenon of the electromagnetics of lightning. Many models have been put forth, but due to the complex nature of the formation of the lightning channel many question are still left unanswered. The LDAR system at NASA, KSC offers a unique means and opportunity to track the lightning activity and to record the signal levels from the lightning sources. From a knowledge of the LDAR antenna patterns and using information on the signal levels of the lightning generated RF sources, it is possible to model the antenna pattern of the lightning source. The research reported here was undertaken with this goal in mind. The author was able to compute the antenna patterns for the LDAR system for vertical and horizontal polarization. The author proposes to continue this work with a graduate student, to analyze the lightning data that is already available. This continued work should lead to the determination of the effective radiated power of lightning sources and to the evaluation of a model for the antenna pattern of the lightning source.

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