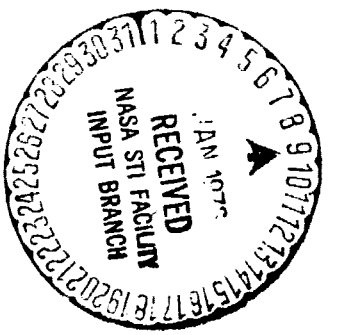
REDUCTION AND ANALYSIS OF DATA COLLECTED DURING THE ELECTROMAGNETIC TORNADO EXPERIMENT

NASA Contract NAS5-22489

L. D. Davisson

J. Bradbury

Techno-Sciences, Inc.
1856 Elba Circle
Costa Mesa, California 92626



TSI Report No. 75110
October 1975
Interim Report for Period July - September 1975

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
75110		

4. Title and Subtitle	5. Report Date
REDUCTION AND ANALYSIS OF DATA COLLECTED DURING THE ELECTROMAGNETIC TORNADO EXPERIMENT	October 1975
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
L D Davisson and J. Bradbury	75110
9. Performing Organization Name and Address	10. Work Unit No.
1856 Elba Circle Costa Mesa, Calif 92626	11. Contract or Grant No.
	NAS5-22489
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Type II Quarterly July - September 1975
R.L. Kutz Code 952 NASA Goddard Space Flight Center Greenbelt, Md 20771	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report reviews the first quarter's progress on the reduction and analysis of tornado data collected on analog tape. The work concentrated mainly on the strip chart recording of 7 tracks from all available analog data for quick look analysis

17. Key Words Suggested by Author	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

PREFACE

The purpose of this contract is to provide data processing and analysis in support of two GSFC programs: tornado detection by radio frequency techniques and short pulse radar measurements of ocean waves. The first quarter's effort was concentrated primarily on the former program - specifically on the strip chart recording of the tornado detection raw data and preliminary analyses of the data. The next quarter's work will concentrate on digitizing, displaying, and analyzing selected data portions of interest based on the strip chart recordings.

I. Introduction

The tornado data analog tapes are 14 track tapes containing the information shown in table I. The recordings cover 4 HF and VHF frequency bands with vertical and horizontal polarizations and with linear and logarithmic scales. In addition the outputs from 2 different lightning stroke detectors are recorded. Over 50 tapes have been currently generated by another contractor to GSFC. Recording speeds of 30 ips and 60 ips were used.

Techno-Sciences has provided analog strip charts of all available tapes on GSFC supplied equipment in coordination with the contract technical officer. A complete log of this processing is included with this report in table II. Because the strip chart recorder has only 7 useable channels, only half of the tracks on each tape were actually processed in most cases. The other tracks could have been processed by making a second pass through each tape. However, it was found that 7 tracks had most of the useful information anyway. In particular, the logarithmic scale and timing tracks were found to be of limited usefulness.

Current work is concentrating on digitizing selected analog tape portions for detailed analysis and display.

TABLE I

TORNADO ANALOG TAPE TRACK ASSIGNMENTS

Track	Mode	Assignment
1	Direct	V-3 Mhz Lin
2	Direct	V-3 Mhz Log
3	Direct	V-30 Mhz Lin
4	Direct	V-30 Mhz Log
5	Direct	V-VHF 139 Mhz Lin
6	Direct	V-UHF 295 Mhz Lin
7	Direct	H - VHF 139 Mhz Lin
8	Direct	H - UHF 295 Mhz Lin
9	FM	10 Khz Time Mark or 100 Khz at 60 ips
10	FM	WWVB BCD Time Code
11	Direct	V-Lightning Stroke Det-Lin
12	Direct	V-Lightning Stroke Det-Log
13	FM	Taylor Tornado Det-Far
14	FM	Taylor Tornado Det-Near

II. Analog Strip Chart Recordings

Table II is a processing log which summarizes the useful analog strip chart recording results by Techno-Sciences on GSFC supplied equipment. In addition to these results, other recordings were made but not kept because of various equipment problems which resulted in invalid or useless data displays. Many of the tapes were found to be very quiet, containing indiscernable signals or noise of a "white" rather than of the desired impulsive nature characterizing lightning discharges. Others, however contained considerable amounts of the desired impulsive noise across all frequencies. A short segment of one of these displays appears in figure "one".

The data was recorded at a real time (one-sided) bandwidth of 300 khz. As shown in Appendix B, the strip chart recording technique used is physically limited to be able to show only about 20% of the actual bandwidth. Even this could only be achieved at 1-7/8 ips playback speeds and 50 cm/sec strip chart speeds, which would generate unacceptably large amounts of output Hence, the strip chart recordings can only be viewed as a "quick look" tool. Selected portions of the data must be digitized for processing and display.

As shown in Appendix C, the amount of digital data generated from even a short segment of analog tape is very large. Hence, the segments must be carefully selected. The addition of a timing track may be necessary in this regard as an aid in registration at some point.

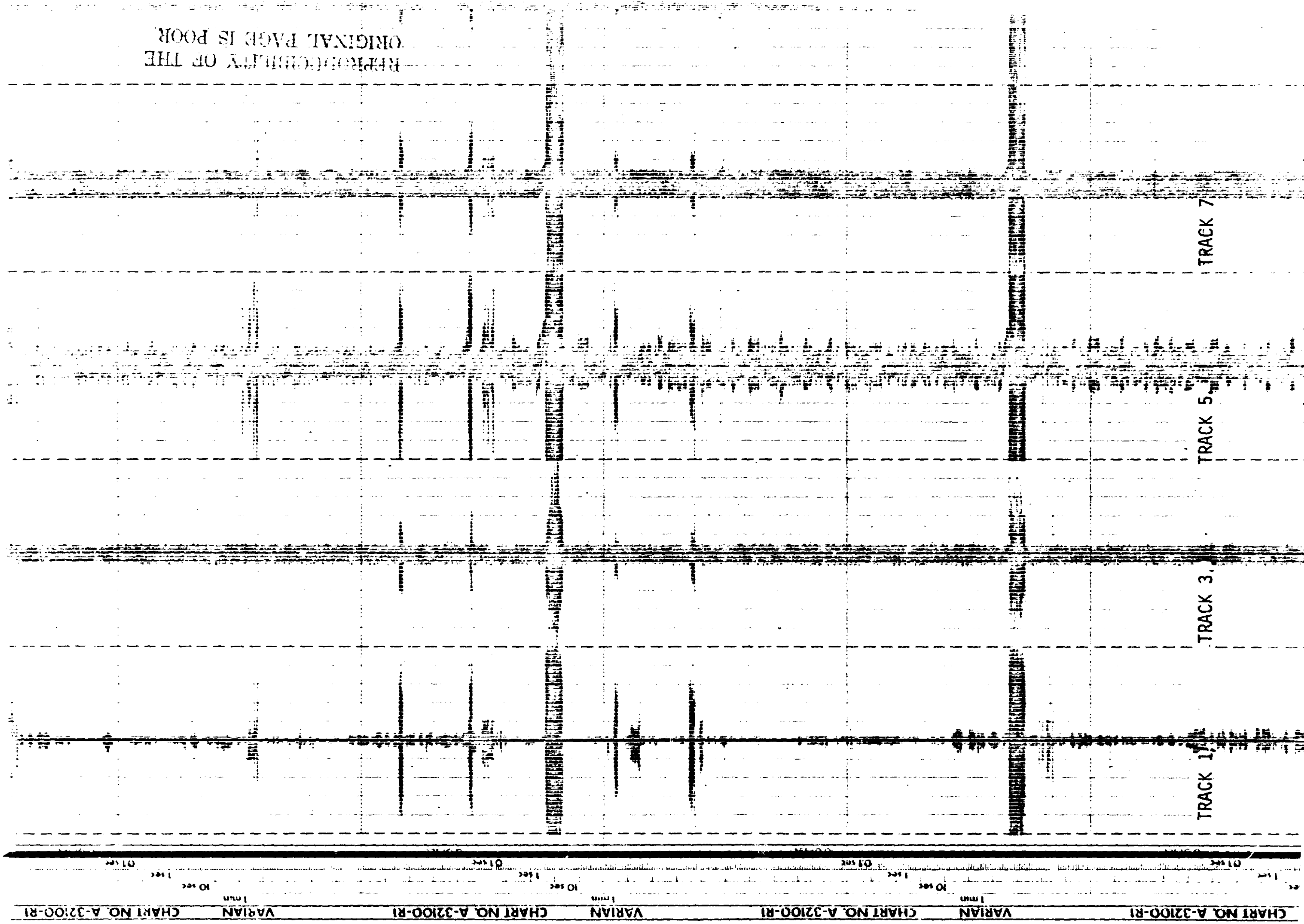


Figure 1. Sample Strip Chart Recording

TABLE II

TORNADO DETECTION ANALOG TAPE PROCESSING LOG

Date Processed	Time	Tape Designation	Record Speed	Playback Speed	Strip Chart Speed	Tracks	Operators	Comments
9/17/75	0920	8/5/75:1647	60 ips	60 ips	.5 cm/sec	1 - 7	LD, JB	Very active
9/17/75	1015	8/5/75:1647	60 ips	60 ips	.5 cm/sec	8 -14	LD, JB	1st minute sporadic Tr 14 inactive Timing pulses in tr 13 approx 8 sec period
9/17/75	1115	8/5/75:1702	30 ips	30 ips	.5 cm/sec	8 -14	LD, JB	Tr 13&14 as above, good BCD time code on tr 10
9/17/75	1155	8/5/75:1827	30 ips	30 ips	.5 cm/sec	8 -14	LD,JB,DL	Discontinued because of doubt about track assignments on tape. Printout not kept.
9/17/75	1225	8/5/75:1827	30 ips	30 ips	.5 cm/sec	1 - 7	LD,JB	Recorder gain low on first half of output. Strip recorder out at end of tape.
9/17/75	1600	6/29/75:#5	60 ips	60 ips	.5 cm/sec	1,3,5,6 8,11,13	LD,JB	Quiet data. Tr 13 blank
9/17/75	1625	6/29/75:#3	60 ips	60 ips	.5 cm/sec	1,3,5,6 8,11,13		Quiet data. Tr 13 blank.
9/17/75	1645	8/5/75:1909	30 ips	30 ips	.5 cm/sec	1,3,5,6 8,11,13		Very active data.
9/19/75	1430	8/26/75:1630 #3	60 ips	120 ips	1 cm/sec	1,3,5,6 8,11,13	JB	Very active, low background noise Tr 13 blank
9/19/75	1455	8/26/75:1645 #4	60 ips	120 ips	1 cm/sec	1,3,5,6 8,11,13	JB	Very active, low background noise Tr 13 blank

TORNADO DETECTION ANALOG PROCESSING LOG

Date Processed	Time	Tape Designation	Record Speed	Playback Speed	Strip Chart Speed	Tracks	Operators	Comments
9/19/75	1510	8/26/75 # 5	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Very active Sferics Low background noise Tr 13 blank
9/22/75	1230	8/26/75 # 2	30 ips	120 ips	2 cm/sec	1,3,5,6, 8,11,13	JB,LD	Tr 5 appears to limit on all of the 8/26/75 tapes. Tr 11 has a periodic waveform & Tr 13 has occasional spikes, but is otherwise inactive. Trs. 1,3,5,6,8 all very active sferics.
9/22/75	1300	8/26/75 #1	60 ips	120 ips	1 cm/sec	1,3,5,6 8,11,13	JB,LD	see above
9/22/75	1325	8/5/75:1853 # 1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB,LD	Tr 13 active near end Tr 11 has periodic pattern. Trs 1,3,5,6, 8 active
9/22/75	1342	8/19/75:1722 # 1	60 ips	120 ips	1 cm/sec	1,3,5,6 8,11,13	JB	
9/22/75 9/23/75 9/23/75 9/23/75	1400 0900 0935 1100	7/8/75:# 1 7/8/75:# 2 7/8/75:# 3 7/8/75:# 4	60 ips	120 ips	1 cm/sec	1,3,5,6 8,11,13	JB	Moderate actvity on all channels.Taylor's detector(Tr 13) working:spikes emitted at lightning bursts. Lightning stroke detector(tr 11) puts out noise&timing only

TORNADO DETECTION ANALOG TAPE PROCESSING LOG

Date Processed	Time	Tape Designation	Record Speed	Playback Speed	Strip Chart Speed	Tracks	Operators	Comments
9/23/75	1330	6/28/75:#1	30 ips	120 ips	2 cm/sec	1,3,5,6	JB	Not rewound
9/23/75	1400	6/28/75:#2	60 ips	120 ips	1 cm/sec	8,11,13		Inactive data Tr 13 not working
9/24/75	0925	6/28/75:#3	30 ips	120 ips	2 cm/sec	1,3,5,6,	LD	Inactive data-almost no signal,tape deck noise only. Timing marks on tr 11, occasional spikes on tr 13.
	1005	6/28/75:#4	60 ips	120 ips	1 cm/sec	8,11,13		
9/26/75	0855	6/25/75:#1 1656	30 ips	120 ips	2 cm/sec	1,3,5,6 8,11,13	JB	Quiet data. Lightning Stroke Det(tr 11) & Taylor's detector(tr 13) working sporadic-al'y at best.
	0930	:#2	30 ips	120 ips	2 cm/sec			
	1030	:#4	30 ips	120 ips	2 cm/sec			
	1100	:#3	30 ips	120 ips	2 cm/sec			
9/26/75	1325	6/29/75:#1	60 ips	120 ips	1 cm/sec	1,3,5,6 8,11,13	JB	Quiet data. Track 13 has a periodic pulse train.
	1425	:#2	30 ips	120 ips	2 cm/sec			
	1500	:#4	30 ips	120 ips	2 cm/sec			
	1520	:#6	60 ips	120 ips	1 cm/sec			
	1545	:#7	60 ips	120 ips	1 cm/sec			
9/26/75	1620	7/5/75:#1	30 ips	120 ips	2 cm/sec	1,3,5,6 8,11,13	JB	Low to moderate activity. LS det(tr 11) works sporadically. Tr 13 has a periodic pulse train
	1640	:#2	60 ips	120 ips	1 cm/sec			

TORNADO DETECTION ANALOG TAPE PROCESSING LOG

Date Processed	Time	Tape Designation	Record Speed	Playback Sp	Strip Chart Speed	Tracks	Operators	Comments
9/30/75	1000	8/12/75: 1610 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Not good data
	1025	8/12/75: 1624 #2	30 ips	120 ips	2 cm/sec		JB	
9/30/75	1045	8/18/75: 1645 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Something on chan. 5 only.
	1055	8/18/75: 1735 #2	30 ips	120 ips	2 cm/sec		JB	
9/30/75	1155	9/12/75: 1547 #2	30 ips	120 ips	2 cm/sec	1,3,5,6, 8,11,13	JB	Disconnected from DC offset board. Works better now.
9/30/75	1205	7/6/75 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Good data
9/30/75	1420	9/10/75: 1645 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Good data
9/30/75	1435	9/11/75	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Very good data
9/30/75	1500	9/10/75: 1700 #2	30 ips	120 ips	2 cm/sec	1,3,5,6, 8,11,13	JB	Small related pattern nothing on chan. 11 & 13.
9/30/74	1510	9/12/75: 1533 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Data on all chan. but 13.
	1530	9/12/75: 1625 #3	60 ips	120 ips	1 cm/sec			
	1550	9/12/75: 1640 #4	30 ips	120 ips	2 cm/sec			
	1605	9/12/75: 1710 #5	60 ips	120 ips	1 cm/sec			

TORNADO DETECTION ANALOG TAPE PROCESSING LOG

Date Processed	Time	Tape Designation	Record Speed	Playback Speed	Strip Chart Speed	Tracks	Operators	Comments
9/30/75	1615	7/6/75 #2	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Data on all chan. but 13.
10/7/75	900	8/26/75: 1645 #4	60 ips	120 ips	1 cm/sec	1,3,5,6, 8, 11,13	JB	Nothing on chan. 11
10/7/75	920	9/12/75: 1547 #2	30 ips	120 ips	2 cm/sec	1,3,5.6, 8,11, 13	JB	Nothing on chan. 13
10/7/75	1000	6/24/75: #1 noon test	30 ips	120 ips	2 cm/sec	1,3,5,6, 8,11,13	JB	Nothing on chan. 13
	1140	6/24/75 Noon test #2	un-deter-mined	120 ips	2 cm/sec and 1 cm/sec			
	1100	6/24/75 #1 PM flight	30 ips	120 ips	2 cm/sec			
	1120	6/24/75: 1729 #2	30 ips	120 ips	2 cm/sec			
10/7/75	1210	8/12/75: 1624 #2	30 ips	120 ips	2 cm/sec	1,3,5,6, 8,11,13	JB	No data
10/7/75	1230	8/18/75: 1645 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Light data
		8/18/75: 1735 #2	30 ips	120 ips	2 cm/sec			
10/21/75	945	8/12/75: 1610 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Something on 5 & 11 only.
10/21/75	1000	9/12/75: 1533 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Data on all Chan. but 8 and 13.
10/21/75	1020	7/6/75 #1	60 ips	120 ips	1 cm/sec	1,3,5,6, 8,11,13	JB	Data on all chan. but 8 and 13. Not much on 3.

TORNADO DETECTION ANALOG TAPE PROCESSING LOG

Date Processed	Time	Tape Designation	Record Speed	Playback Speed	Strip Chart Speed	Tracks	Operators	Comments
10/21/75	1035	7/6/75 #2	60 ips	120 ips	1 cm/ sec	1,3,5,6, 8,11,13	JB	Data on all chan. but 8 & 13
	1040	7/6/75 #3	30 ips	120 ips	2 cm/sec			Light data in beginning then everything stops half way through.
10/21/75	1300	9/12/75	varies	as designa-ed	.1 cm/sec	1,3,5,6, 8,11,13		5 tapes on one chart with strip chart slowed down to .1 cm/sec

III. Data Digitization

One of the more interesting tapes (8/26/75 - #3) was selected for digitization and preliminary analysis and display. A request was made to GSFC for its digitization in September. However, as a result of the inavailability of equipment and appropriate software, the digitization has not been accomplished to date. Therefore an alternate digitization plan is being pursued.

The Ampex PR-2200 tape recorder used in the Georgia Institute of Technology research instrumentation is temporarily available to playback selected tapes for digitization. This recorder is being used as an input to the A/D hardware developed at GSFC for data compression. Computer programs are being written by Techno-Sciences to ingest the sampled data to core memory. Initial output will be to digital tape which has a basic (burst) limitation of 20,000 bytes per second (10 or 20 thousand samples per second dependent on quantization). Next programs will be developed to support rates to 100,000 bytes per second for transfer to disk storage.

IV. Plans for the Next Quarter

Digitization will be accomplished as discussed in section III. As the digital data becomes available, analysis efforts will begin. The first analytical effort will be the isolation, display and analysis of individual lightning pulses. Time and frequency display will be accomplished using Fourier transforms. The time signal will be compared with earlier published results. The transformed data will be investigated to determine actual bandwidth utilization. If the lightning stroke generates true impulses, the frequency content should be approximately flat to 300 khz and an individual pulse in time should approximate the impulse response of the system filter.

Burst counts, interpulse statistics and amplitude probability distributions will be generated as an initial approach to determining a statistical model for lightning discharges. If sufficient data is available, tornado and non-tornado statistics will be segregated and contrasted for a possible tornado detection methadology.

Appendix A

The Sampling Theorem

Suppose that x(t) is an analog waveform containing frequencies from zero up to some maximum value B h_z . The sampling theorem states that you must sample at a rate of at least 2B samples per second to reconstruct the waveform without error. The sampling rate, 2B, is called the Nyquist rate. To see the necessity for this, consider the simple co-sinusoids cos 2 $(B-\epsilon)t$ and cos 2 $(B+\epsilon)t$ for any ϵ . The nth sample at the sampling rate 2B per second of each is

$$\cos 2\pi(B-\epsilon)\frac{n}{2B} = (\cos n\pi)\cos\frac{n\pi\epsilon}{B} + (\sin n\pi)\sin\frac{n\pi\epsilon}{B}$$

$$= (-1)^n \cos\frac{n\pi\epsilon}{B}$$

and $$\cos 2\pi(B+\epsilon)\frac{n}{2B} = (\cos n\pi)\cos\frac{n\pi\epsilon}{B} - (\sin n\pi)\sin\frac{n\pi\epsilon}{B}$$

$$= (-1)^n \cos\frac{n\pi\epsilon}{B} .$$

It is clear that there is no way of distinguishing between the two waveforms based upon the sample values at the rate 2B. The characteristic problem of confusing two such waveforms due to under-sampling is called aliasing or folding and can be avoided only by sampling fast enough or by filtering (with concurrent loss of high frequency content) to remove all frequencies higher than 1/2 the sampling rate.

Conversely it can be intuitively justified that sampling at twice the highest frequency present is sufficient to reconstruct the

the waveform by arguing that the 2 samples per cycle can be used to find the 2 degrees of freedom in a sinusoid - the amplitude and the phase.

Quantitative proofs of the sampling theorem can be found in many textbooks on linear systems.

Appendix B

Strip Chart Recorder Display Limitations

The Varian strip chart recorder used for the processing of the analog tape recordings under this contract is limited in usefulness by sampling theorem considerations presented in Appendix A. The plotting density of the strip chart recorder is 200 points per inch, which by the sampling theorem allows for a maximum frequency resolution of a waveform of 100 cycles per inch. The maximum strip chart speed is 50 cm/sec or approximately 20 inches/sec. Thus the maximum frequency content of a signal which can be resolved is approximately 2000 hz.

At the recorded speed, the anlog tapes have frequencies up to 300 khz . The maximum record speed used was 60 ips. At a minimum playback speed of 1-7/8 ips, the highest frequency present is then $300/32 \approx 10$ khz or 5 times the strip chart recorder's frequency resolving capability.

Thus digital methods must be used to accurately represent and display the analog tape data. From the preceding considerations it is seen that a minimum sampling rate of 20,000 samples per second must be used. Higher sampling rates are desirable to avoid analog tape flutter/wow problems at 1-7/8 ips by running higher playback (and hence higher sampling) speeds.

Appendix C

Digital Tape Limitations

Based on the sampling rate considerations presented in Appendices A and B, it can be easily shown that great selectivity must be exercized in choosing the data to be digitized for display/analysis. Each of the 14 300 khz analog tape tracks requires 600,000 samples per second in real time or, at a recording speed of 60 ips, 10,000 samples per inch of analog tape per channel for a total of 140,000 samples per inch for all channels. Assuming 8 bit samples and continuous recording (no record gaps), a 2400 ft. 800 bpi digital tape can hold only (2400 x 12 x 800)/140,000 = 165 inches of analog tape or less than 3 seconds of real time sampled data. Hence the channels chosen for sampling and the actual segments of time should be carefully chosen for maximum information content.