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Transionospheric Scintillation and TEC Studies

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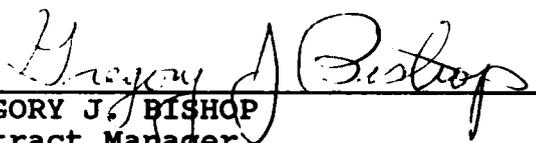
GREGORY J. BISHOP
Contract Manager
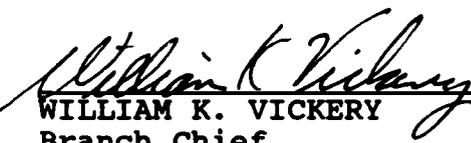
WILLIAM K. VICKERY
Branch Chief

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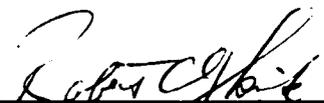
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This report describes engineering and technical support involving the operation, maintenance, and enhancement of a GPS data collection system that is operated at Thule AB, Greenland, and AFGL at Hanscom AFB, MA, for the purpose of studying transionospheric propagation effects. Software upgrades and improvements are described that relate to data acquisition, problem detection and recovery, and the production of quick-look data summaries containing TEC and amplitude scintillation measurements. An analysis made of data collected at Thule from October 1987 through March 1988 revealed that a direct relationship was observed between TEC enhancement and scintillation activity. Comparisons are made of fade depth statistics observed during the report period with earlier similar measurements taken throughout the peak of the last sunspot cycle. *Keywords (S*

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All other editions are obsolete.

CONVERSION TABLE

Conversion factors for U.S. customary to metric (SI) units of measurement.

To convert from	to	Multiply by
angstrom	meters (m)	$1.000\ 000 \times 10^{-10}$
atmosphere (normal)	kilo pascal (kPa)	$1.013\ 25 \times 10^{+2}$
bar	kilo pascal (kPa)	$1.000\ 000 \times 10^{+2}$
barn	meter^2 (m^2)	$1.000\ 000 \times 10^{-28}$
British thermal unit (thermochemical)	joule (J)	$1.054\ 350 \times 10^{+3}$
cal (thermochemical)/ cm^2	mega joule/m^2 (MJ/m^2)	$4.184\ 000 \times 10^{-2}$
calorie (thermochemical)	joule (J)	$4.184\ 000 \times 10^{+3}$
curie	giga becquerel (GBq)	$3.700\ 000 \times 10^{+1}$
degree Celsius	degree kelvin (K)	$t_x = t^\circ_c + 273.15$
degree (angle)	radian (rad)	$1.745\ 329 \times 10^{-2}$
degree Fahrenheit	degree kelvin (K)	$t_x = (t^\circ_F + 459.67)/1.8$
electron volt	joule (J)	$1.602\ 19 \times 10^{-19}$
erg	joule (J)	$1.000\ 000 \times 10^{-7}$
erg/second	watt (W)	$1.000\ 000 \times 10^{-7}$
foot	meter (m)	$3.048\ 000 \times 10^{-1}$
foot-pound-force	joule (J)	$1.355\ 818$
gallon (U.S. liquid)	meter^3 (m^3)	$3.785\ 412 \times 10^{-3}$
Gauss	Tesla	$1.000\ 000 \times 10^{-4}$
inch	meter (m)	$2.540\ 000 \times 10^{-2}$
joule/kilogram (J/kg) (radiation dose absorbed)	gray (Gy)	$1.000\ 000$
kilotons	terajoules	4.183
kip (1000 1 bf)	newton (N)	$4.448\ 222 \times 10^{+3}$
kip/inch^2 (ksi)	kilo pascal (kPa)	$6.894\ 757 \times 10^{+3}$
ktap	newton-second/m^2 (N-s/m^2)	$1.000\ 000 \times 10^{+2}$
micron	meter (m)	$1.000\ 000 \times 10^{-6}$
mil	meter (m)	$2.540\ 000 \times 10^{-5}$
mile (international)	meter (m)	$1.609\ 344 \times 10^{+3}$
ounce	kilogram (kg)	$2.834\ 952 \times 10^{-2}$
pound-force (1bf avoirdupois)	newton (N)	$4.448\ 222$
pound-force inch	newton-meter (N-m)	$1.129\ 848 \times 10^{-1}$
pound-force/inch	newton/meter (N/m)	$1.751\ 268 \times 10^{+2}$
pound-force/foot^2	kilo pascal (kPa)	$4.788\ 026 \times 10^{-2}$
pound-force/inch^2 (psi)	kilo pascal (kPa)	$6.894\ 757$
pound-mass (1bm avoirdupois)	kilogram (kg)	$4.535\ 924 \times 10^{-1}$
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 (kg·m^2)	$4.214\ 011 \times 10^{-2}$
rad (radiation dose absorbed)	gray (Gy)	$1.000\ 000 \times 10^{-2}$
roentgen	coulomb/kilogram (C/kg)	$2.579\ 760 \times 10^{-4}$
shake	second (s)	1.000×10^{-8}
slug	kilogram (kg)	$1.459\ 390 \times 10^{+1}$
torr (mm Hg, 0°C)	kilo pascal (kPa)	$1.333\ 22 \times 10^{-1}$

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1.   Introduction

This report describes work performed by Northwest Research Associates on contract with the Air Force Geophysics Laboratory (AFGL), Ionospheric Effects Branch (LIS), to provide hardware and software support enabling the presentation of a special scaled data set characterizing ionospheric effects at Thule, Greenland.

Hardware support consisted of the responsibility of insuring operation and maintenance of the monitoring equipment; repair of associated equipment including computers, tape drives, receivers and other components; implementation of system upgrades; and installation of additional systems.

Software support of the TRN objective included installing and customizing operating system upgrades, installing and learning new vendor software to assist others on the team, writing utilities and software tools, and upgrading existing routines.

Additional activities included the organization and cataloging of tapes and charts coming from the study site and acquisition of necessary materials required for the study.

The study consisted of a five step process:

(1) Collecting five channels of raw data determined from signals received from GPS system satellites onto tape and chart records.

(2) Cataloging these items as they were received at the AFGL.

(3) Identifying elements of the data for potential analytical significance to the study.

(4) Converting the raw data and performing first-phase analysis.

(5) Performing final analysis on data passing the first phase. The results of this process were plotted and provided to the sponsor, as required by the TRN.

2.   Objectives

The objectives of this TRN were to provide engineering and technical support for the enhancement and operation of ground-based satellite monitoring equipment that provide data important in the evaluation of ionospheric effects on transionospheric RF systems.

These entailed:

a. Development and enhancement of the GPS data acquisition system at Thule AB, Greenland, and AFGL at Hanscom AFB, Massachusetts.

b. Installation, maintenance, and operation of the aforementioned systems.

c. Organization, categorization, and analysis of the various information measures obtained from these systems.

d. Improvement and development of new systems which facilitate analysis and which will accommodate various resources available at AFGL (such as: DEC pdp 11/03's, DEC Micro pdp 11, DEC VAX, CDC Cyber, and various PC systems).

e. Utilization of existing systems and enhancment and creation of new analysis systems to develop parameter statistics and plots.

2. Operation and Maintenance of GPS Monitoring Equipment

One of the key elements in the GPS monitor system, and a primary focus of attention, is the GPS satellite receiver. Installation, calibration, repair, and maintenance of the receiver systems at Thule require one- to two-week trips every two to three months.

Often it is necessary to ship equipment back to the laboratory at AFGL for repair. Other situations are dealt with by phone, analyzing the problems and instructing the Danish technicians how to proceed.

In November, 1987, an on-site receiver evaluation at Thule revealed the necessity of replacing a receiver component for which there was no readily available spare. While there, a new receiver arrived at AFGL, prompting the decision to curtail the trip, bench-check the new receiver at AFGL, and obtain the necessary replacement component. Another trip to Thule was made to install the new receiver and repair and retain the old receiver on site as a backup.

In early 1988 a decision was made to expand observation at Thule. A second system was assembled from spare parts which would allow observation of high-elevation satellites on the current system and concurrent observation of low-elevation satellites on the newly assembled system. In early June the new system was installed, and upgraded acquisition software was installed on both systems at that time.

The GPS development system at AFGL was deployed to Kwajalein Island in the South Pacific in late July, 1988, to participate in

the DNA-sponsored Propagation Effects Assessment-Kwajalein (PEAK) campaign. NWRA personnel installed and operated the system for the six-week duration under TRN #13. The system was subsequently shipped to Thule to participate in another campaign to be conducted in December, 1988, and to serve as a complete backup for the two systems on-site.

4. Software Upgrades and Enhancements

A preparatory effort was undertaken at the outset of the TRN to implement refinements and anticipate potential problems. This entailed upgrading and enhancing the software portions of the GPS collection and analysis systems, and correcting and improving the hardware portions of the GPS acquisition system. Additionally, software tools were created to extend ability to deal with known data requirements.

4.1 Data Acquisition Software

The data acquisition system software, which operates on the DEC pdp 11/03's, was analyzed and upgraded. The satellite 'window' portions were streamlined, and enhancements were devised to:

a. Improve satellite 'window' information entry, deletion, and revision.

b. Provide for automatic update of satellite 'window' elements that previously had become gradually obsolete over a few weeks. This eliminated a cause for frequent attention to satellite 'window' elements.

c. Offer a choice of Danish instructions as an alternative to English to reduce the possibility of misunderstanding by the technicians who perform day-to-day operations. The translations were performed by NWRA's Mr. C. Charley Andreasen.

4.2 Improvements to the Real-Time Routine

a. The real-time routine that acquires data was streamlined as well. The following corrections were made:

(1) Solving an intermittent failure to detect the end of a satellite pass, which caused the system to lose useful data over the succeeding 24 hours.

(2) Performing a check to prevent an operator from erroneously instructing the system immediately to start taking data from a satellite that is not available at that time.

(3) Allowing the system to detect the loss of 'lock' by the receiver on the current satellite, thereby halting acquisition of invalid data.

b. Enhancements to the real-time routine included:

(1) Creation of a Danish language version of the acquisition routine, automatically invoked according to the choice made in the 'window' routines (Separate English and Danish version of this routine were necessary due to its size and hardware restrictions).

(2) Implementation of a header that records the satellite (space vehicle) number, Julian date and year of the pass, and the session operator. (Previously, the satellite number and Julian date/year were determined and added manually during the analysis phase.) Automation eliminated the potential for error and reduced manpower requirements. Recording the session operator provided a means for tracking operator errors.

4.3 Problem Detection and Recovery

Software tools were created to facilitate problem detection and recovery, which included:

a. A routine to allow a quick look at raw data, averaged to six-second quantities (data are collected at 20 values per second in binary format), enabling trace-back of faults noted.

b. A routine to select valid data from a satellite pass file that failed to end appropriately and save it in a separate file.

c. A program to copy selected files to a separate tape to enable analysis of only those files.

4.4 Primary Analysis Routine

Refinements were made to the primary analysis routine, which converts the raw GPS measurements into slant Total Electron Content (TEC) values, enhancing functionality. Access to the header information, now recorded in the acquisition system, was added. Multipath correction of Differential Group Delay procedures, developed under TRN #13, was added. Other enhancements were attempted, but architectural/system constraints of the CDC Cyber, the primary analysis system, prevented their implementation. Alternative solutions are under consideration.

4.5 Quick-Look Summaries

Procedures were established for the generation of 'quick-look' data summaries. An activity quantifier measure (see the Table on page 6) was established whereby hourly activity levels in GPS TEC measurements and polar beacon satellite 250-MHz amplitude scintillation measurements were tabulated. A visual examination of chart records from Thule would be performed as they arrived and a tabulation made according to the standard developed. This enabled analysis to be focused on pass files with significant ionospheric activity.

5. Production

Production work and preparatory work were performed concurrently in the early stages of the TRN. Production work consisted of reviewing the tapes and charts arriving from Thule, cataloging them, visually examining the chart records, and tabulating the activity levels according to the criteria described above. Using criteria outlined in the Table, active periods of significant TEC gradients or significant fades from 250-MHz beacon satellite measurements were identified. Raw data occurring during these active periods were then processed by the first level of GPS analysis, which converted GPS differential carrier phase measurements to slant TEC variation.

Differential carrier phase measurements were considered the best available measure to indicate the rapidity of change in the ionosphere. Absolute TEC measurements, available from a measure of differential group delay output from the GPS receiver, are less suitable for this study because of susceptibility to system noise and multi-path effects.

To perform the final analysis, an 'event' analyzer was developed. This enabled large quantities of 'significant' activity to be efficiently analyzed and quantified according to activity level.

Several approaches were examined and tested for characterizing TEC measurements specific to a particular satellite pass. It was decided to assess the TEC data by determining a measure of the TEC gradient over a sliding 360-second sampling period. The measured 'event' gradient was determined by the difference of the means of five samples at 40-second intervals in the first half and the second half of the sampling period. An 'event' level of '1' was defined as a measured difference of 3.3×10^6 electrons/m^2 occurring in the 40-second time difference interval.

A routine was developed to tabulate slant TEC measurements, 'event' magnitude, and satellite azimuth and elevation over the duration of the pass. These routines were further upgraded to determine the probability of an event occurrence and the probability of no event during a period twice the defined 'event' length and display the results. Twelve representative samples of

Table 1. Activity quantifier for GPS and 250 MHz beacon data.

		GPS	250 MHz Beacon	Comment
Quiet	1	$\Delta > 0.5$ TEC u/10 min	SI>2 dB	No detectable activity.
Small	2	$\Delta < 0.5$ TEC u/5 min	$2 \leq SI < 4$ dB	Detectable TEC variation, detectable scintillation.
Moderate	3	$\Delta > 1$ TEC u/5 min	$5 \leq SI < 9$ dB	Smooth rolling structures.
Disturbed	4	$\Delta < 1$ TEC u/30 sec	$10 \leq SI < 15$ dB	Sharp, short gradients.
Very Disturbed	5	$\Delta < 1$ TEC u/30 sec	$SI \geq 15$ dB	Very sharp, sustained gradients.

the data, averaging about 2 samples per month, are presented in Appendix A, covering the analysis period.

Amplitude scintillation data at 250 MHz was categorized and tabulated and compared with simultaneous TEC data provided by the 'event' analyzer. A standard procedure was applied to derive fade depth measures from the charts at fifteen-minute intervals. The procedure, presented in Appendix B, was identical to that used by AFGL to generate fade depth occurrence statistics since 1979.

A database structure was constructed to allow accumulation of event-occurrence data according to various parameters. The data selected from the 'event' analyzer were incorporated into it, as was the probability of non-occurrence of events as described above. Additional data include tabulated 250 MHz fade depth values, solar and magnetic indices, and several other parameters.

6. Final Data Analysis

The database utilized for final analysis included approximately 130 records (pass files) from October 1987 through March 1988. After culling of incomplete records, about 100 records were available for analysis.

The AFGL measurement data base obtained during the reporting period is summarized in Appendix C and is entitled "GPS Sunspot Activity Special Report." Tabulated data are presented that show, for corresponding record ID's, 'event' levels as a function of observed fade depth. As shown, an additional field was added to the database called 'QA' (quality assurance), which denoted whether the record was valid (V) for analysis or invalid (I). The records were retained, nonetheless, to allow correction of their deficiencies for inclusion at a later time.

Final analysis involved the statistical evaluation of valid database entries. This required the development of a set of statistical analysis programs written in DBASE III programming language for use on the Zenith PC.

The following data presentations were produced:

a. Curves of the probability of a period without an event for all active data in the dataset are presented in Appendix D. Curves of the probability of a period without an event are shown for each discrete fade depth category observed. The first part of the appendix presents the fade depth algorithm and indicates several methods of categorizing the data.

b. Histograms of the number of hours and percentage of occurrence of fade depth levels within **active** TEC and **all** TEC observations are presented in Figure 1 and

# Fade Percent Occurrence

DATA QUANTITY
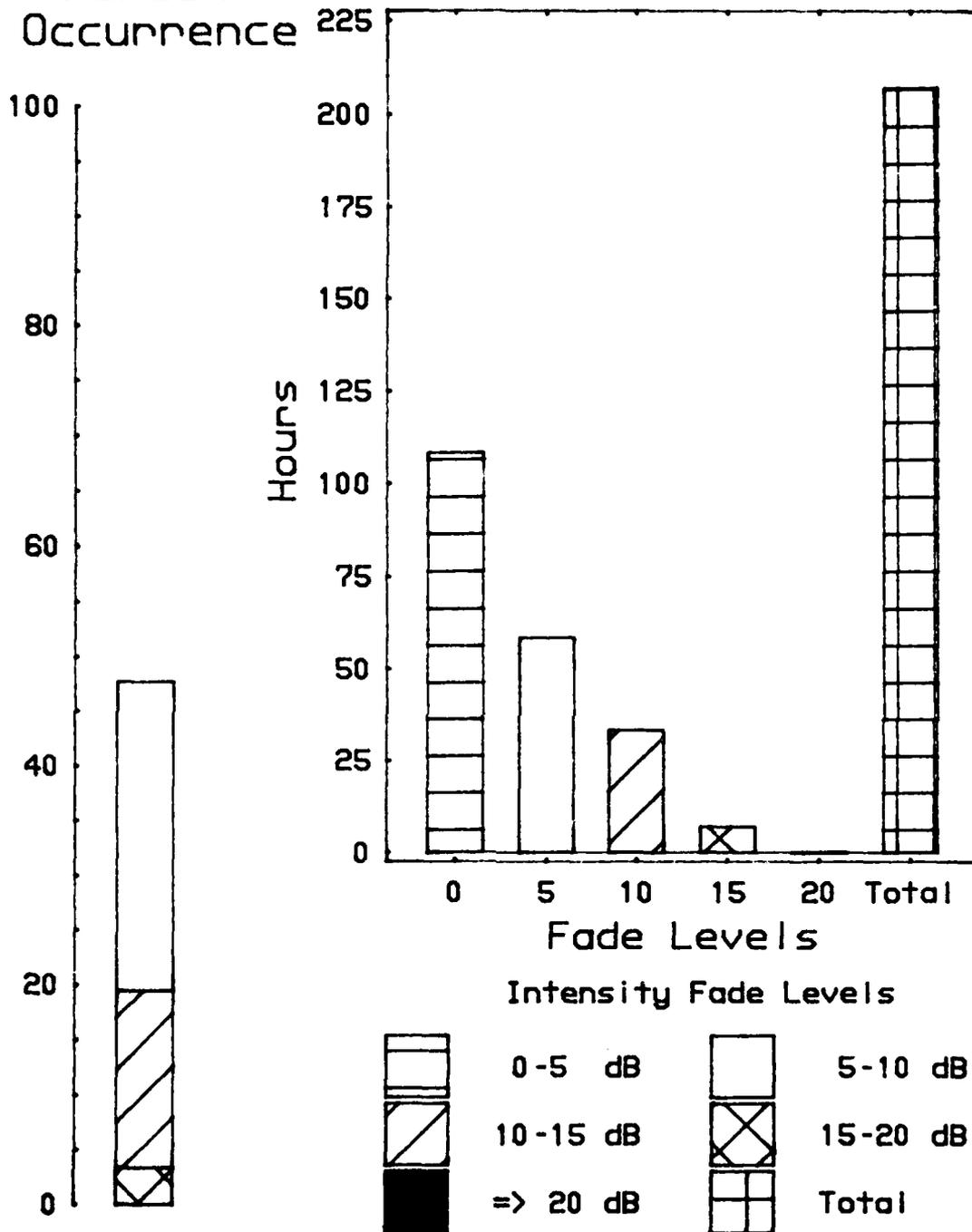
Figure 1. Percent occurrence of various fade levels with <u>active</u> TEC observations, from Thule, Greenland, October 1987 through March 1988.

Figure 2 respectively. Active TEC corresponded to those times when quick-look analysis indicated that the 'event' level was 3 or greater.

c. Histograms combining monthly summaries of diurnal occurrence of TEC activity and 250-MHz amplitude scintillation over the study period are presented in Figure 3. Review of these data showed that times of TEC activity corresponded to times of active 250-MHz amplitude scintillation. A specific case study, summarized in Figure 4, highlighted a fortuitous intersection of the GPS and polar beacon look directions during high TEC activity. This study showed that there was a direct relationship between the observed TEC enhancement and 250-MHz scintillation.

d. Histograms are presented in Figure 5 that show the occurrence of 15-minute fade depth indices from 1979 through 1984. Data are broken down into categories comparable to Total, Active, and Exceeding Active.

Results from the histograms of fade depth occurrence during the study periods showed that:

a. The fade depth activity levels occurring throughout the entire reporting period corresponded to the very lowest monthly activity levels that occurred during the previous (1979-1980) solar maximum, and are tabulated in Figure 5.

b. These data indicate that the fade depth activity levels occurring during periods of active TEC of the study corresponded to less than those during the lowest activity month observed during the previous solar maximum.

c. A study was made comparing the occurrence of 15-minute, 250-MHz fade depth in the data set obtained during the current study period with published statistics of fade occurrence over the period 1979 through 1984. Fade depths were manually determined from chart records of 250-MHz intensity scintillation using the identical process applied to obtain published fade depth statistics (see Appendix B). As shown in Figure 5, the greatest intensity fade levels occurred during the previous sunspot maximum. From a review of the data it can be seen that in any given month the second highest fade and highest fade category can occur up to 60 percent and 45 percent of the time respectively. The occurrence of fade depth during the current study period summarized in Figure 1 reveals that the highest fade depth was not observed to occur.
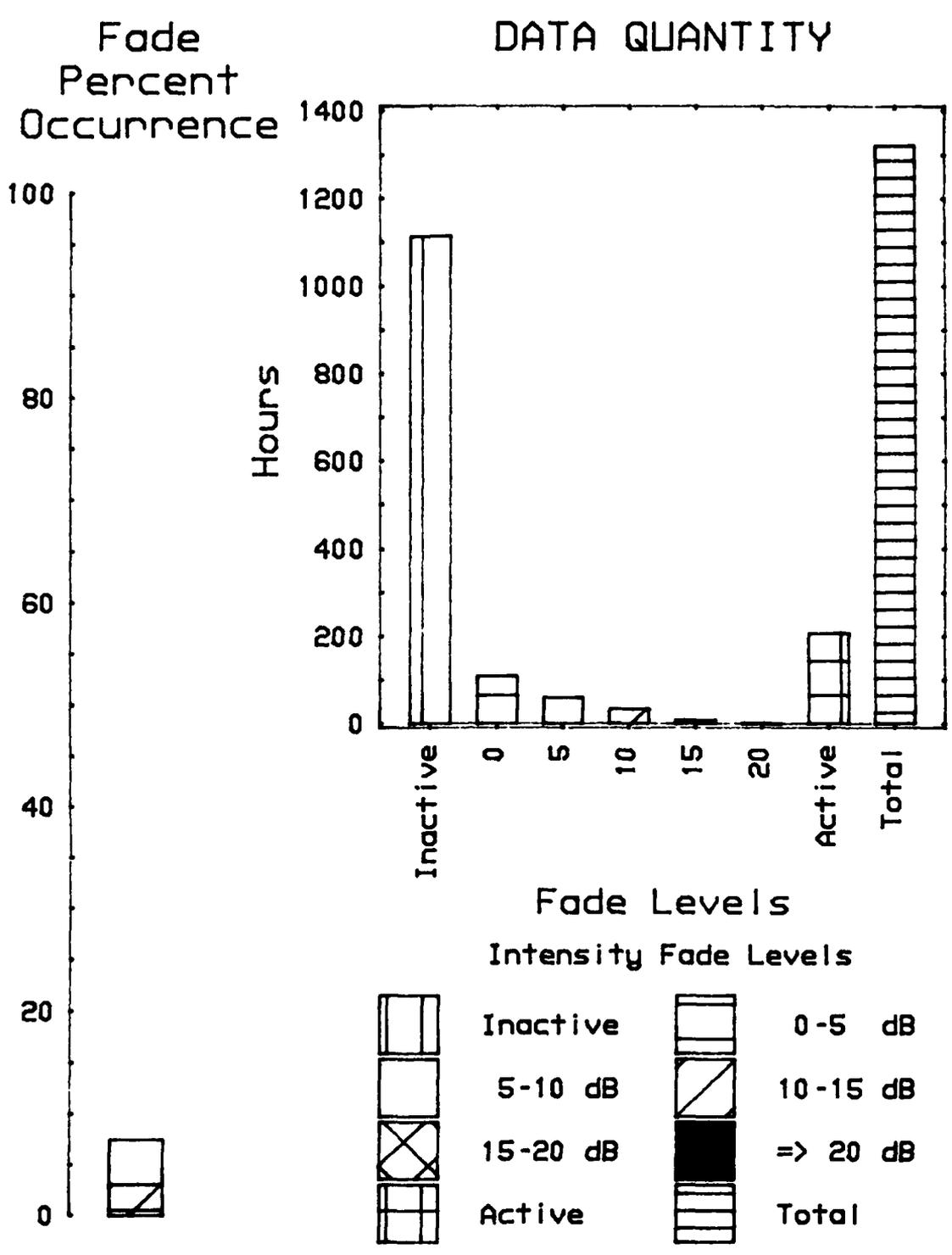
Figure 2. Percent occurrence of various intensity fade levels within all TEC observations, from Thule, Greenland, October 1987 through March 1988.
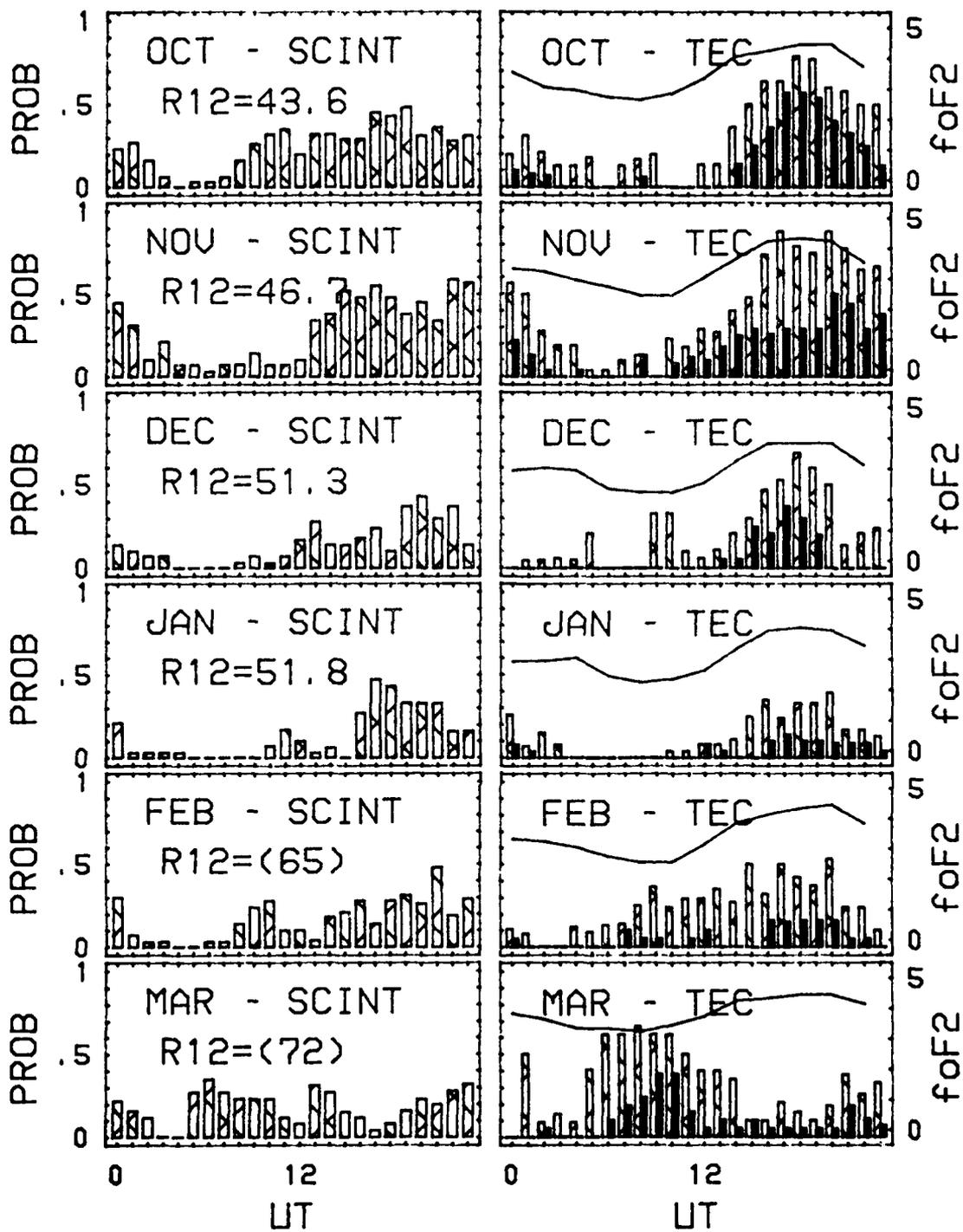
Figure 3. Monthly summaries over the study period showing occurrence of TEC, Scintillation Activity, and foF2 as a function of universal time.
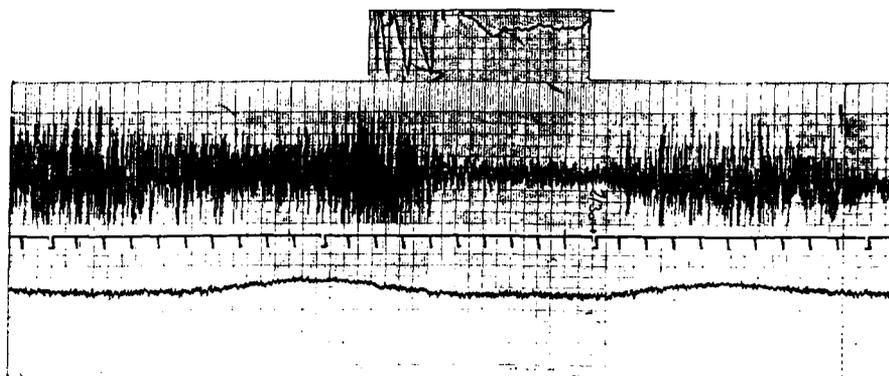
Figure 4. Measurements from GPS and polar beacon satellite passing within 1 degree show TEC variations linked to strong amplitude scintillations at 250 MHz.
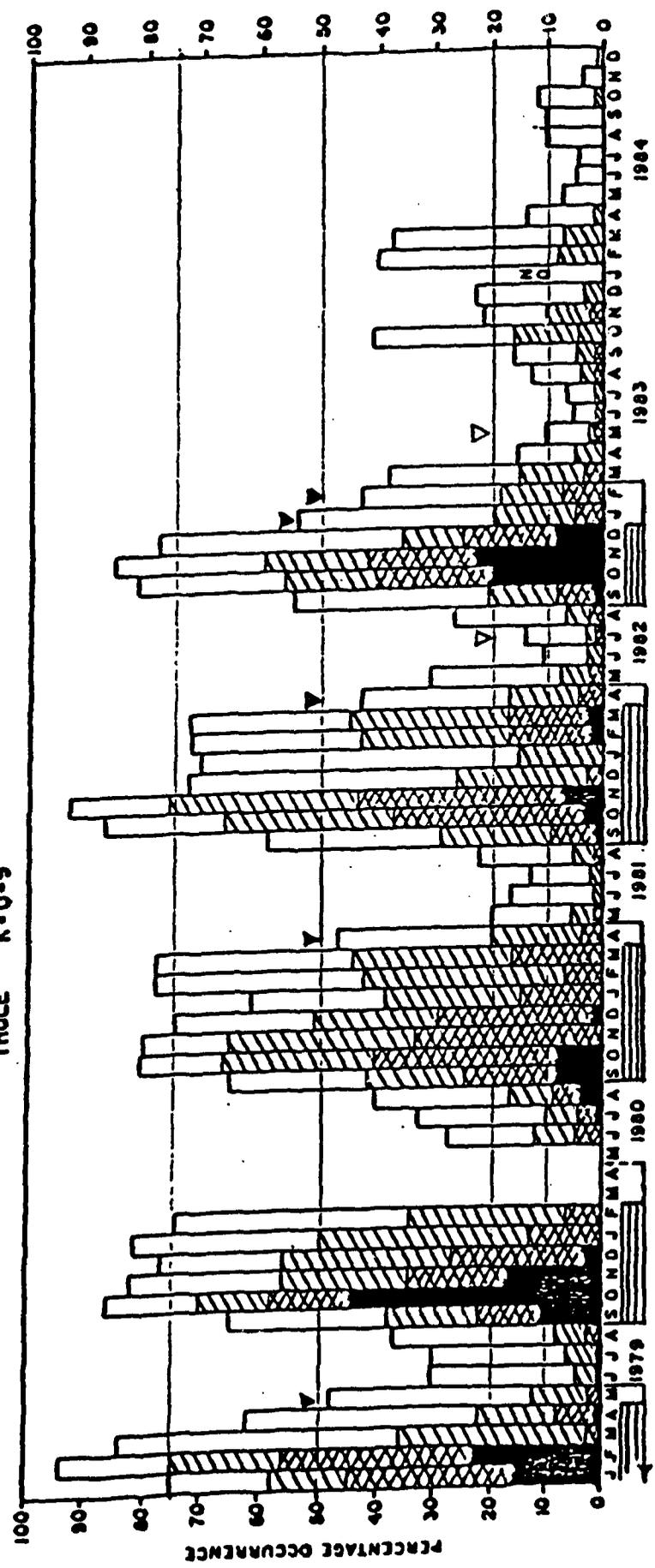
Figure 5. Occurrence of 15-minute fade depth indices from 1979 through 1984 - (dB relative to median signal).

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Appendix A:

Twelve representative examples of equivalent slant TEC
covering period day 290, 1987, through day 88, 1988
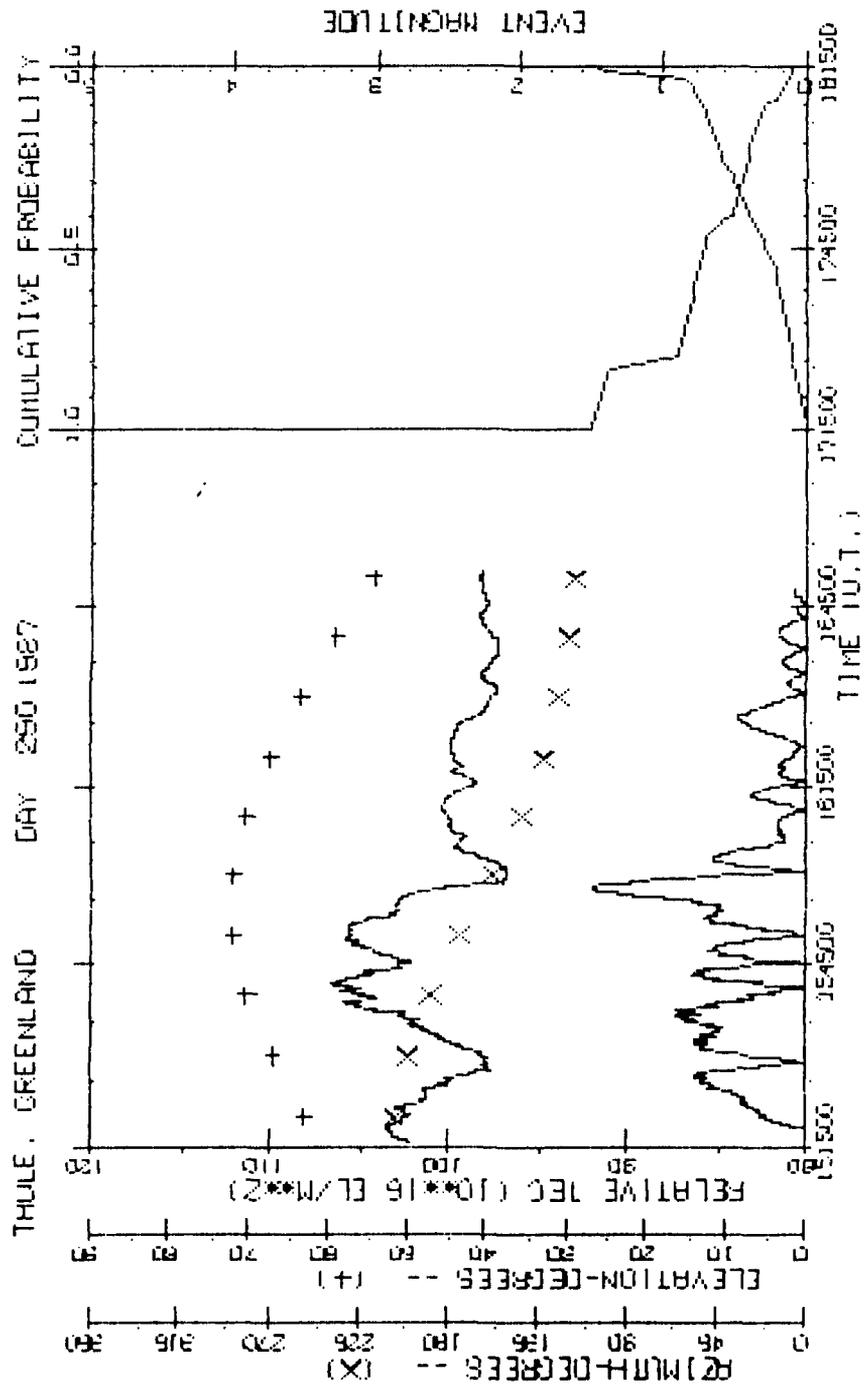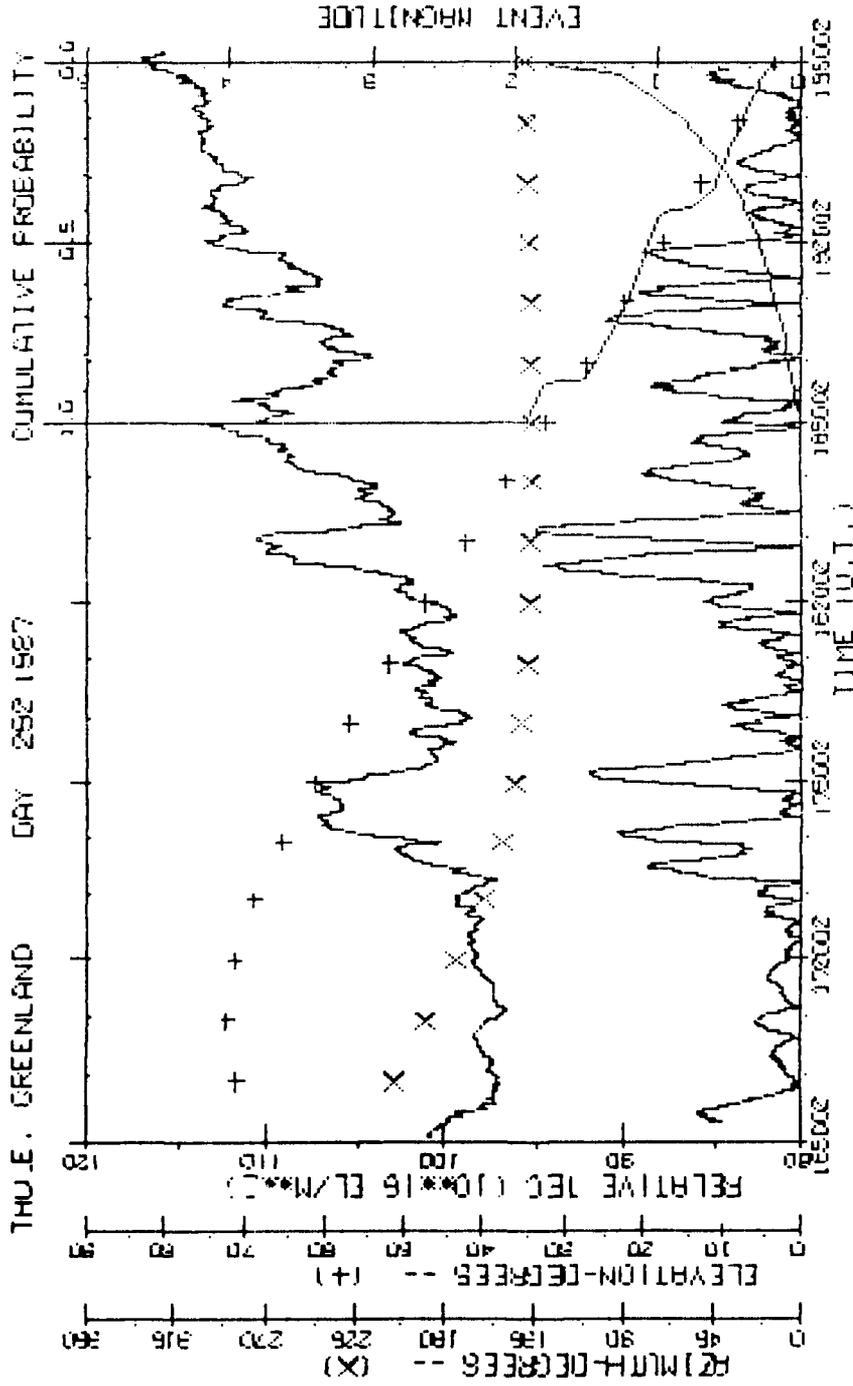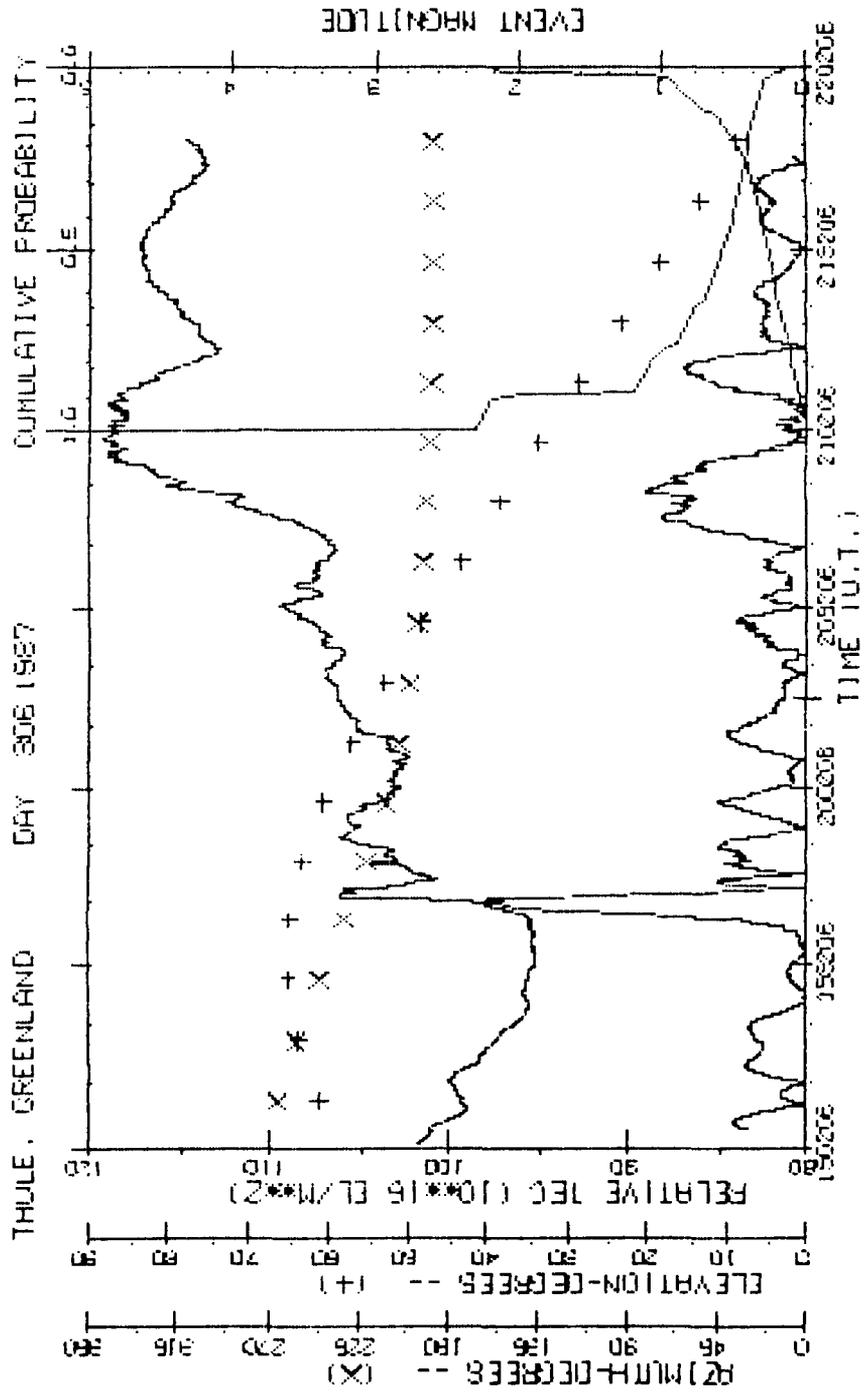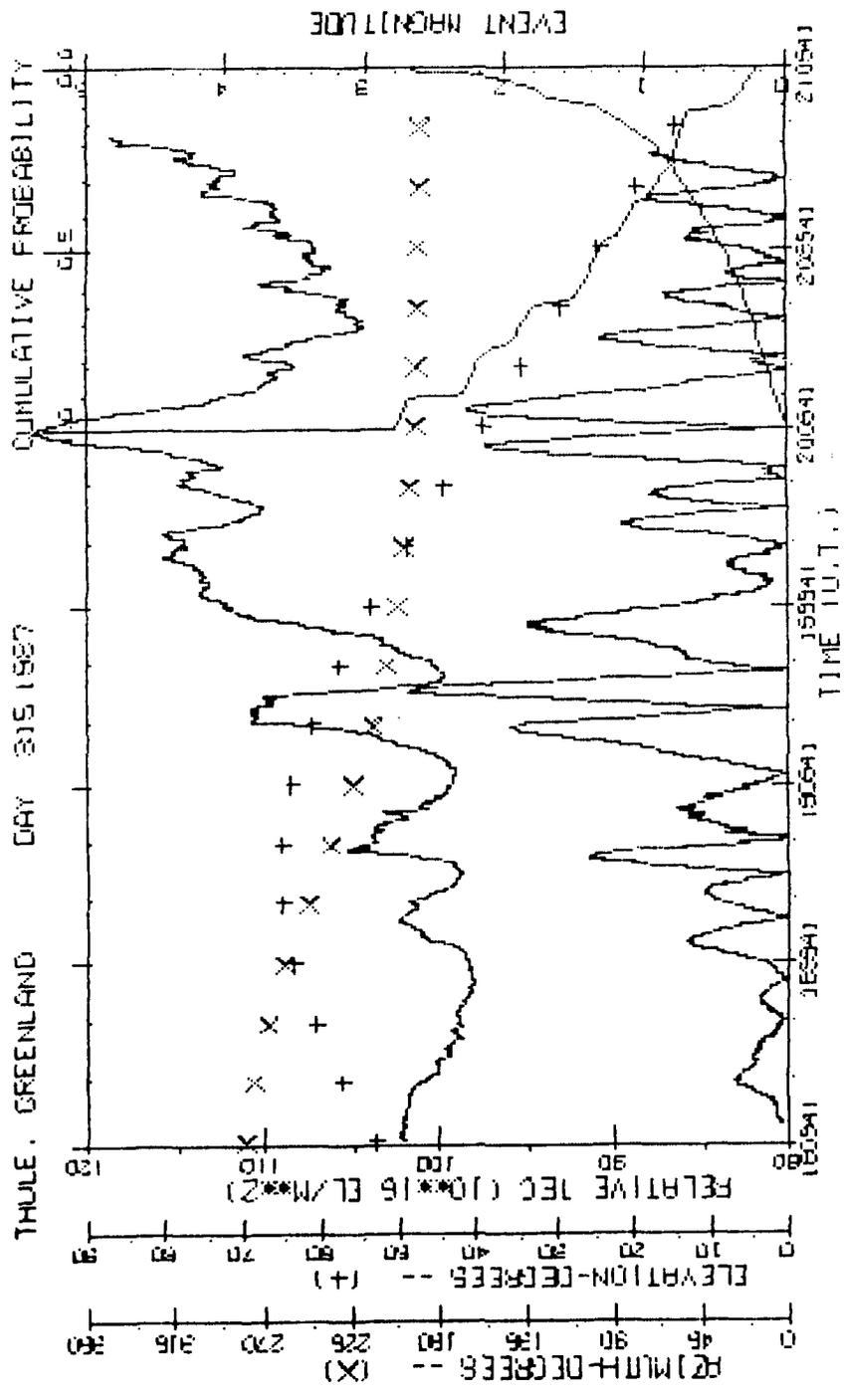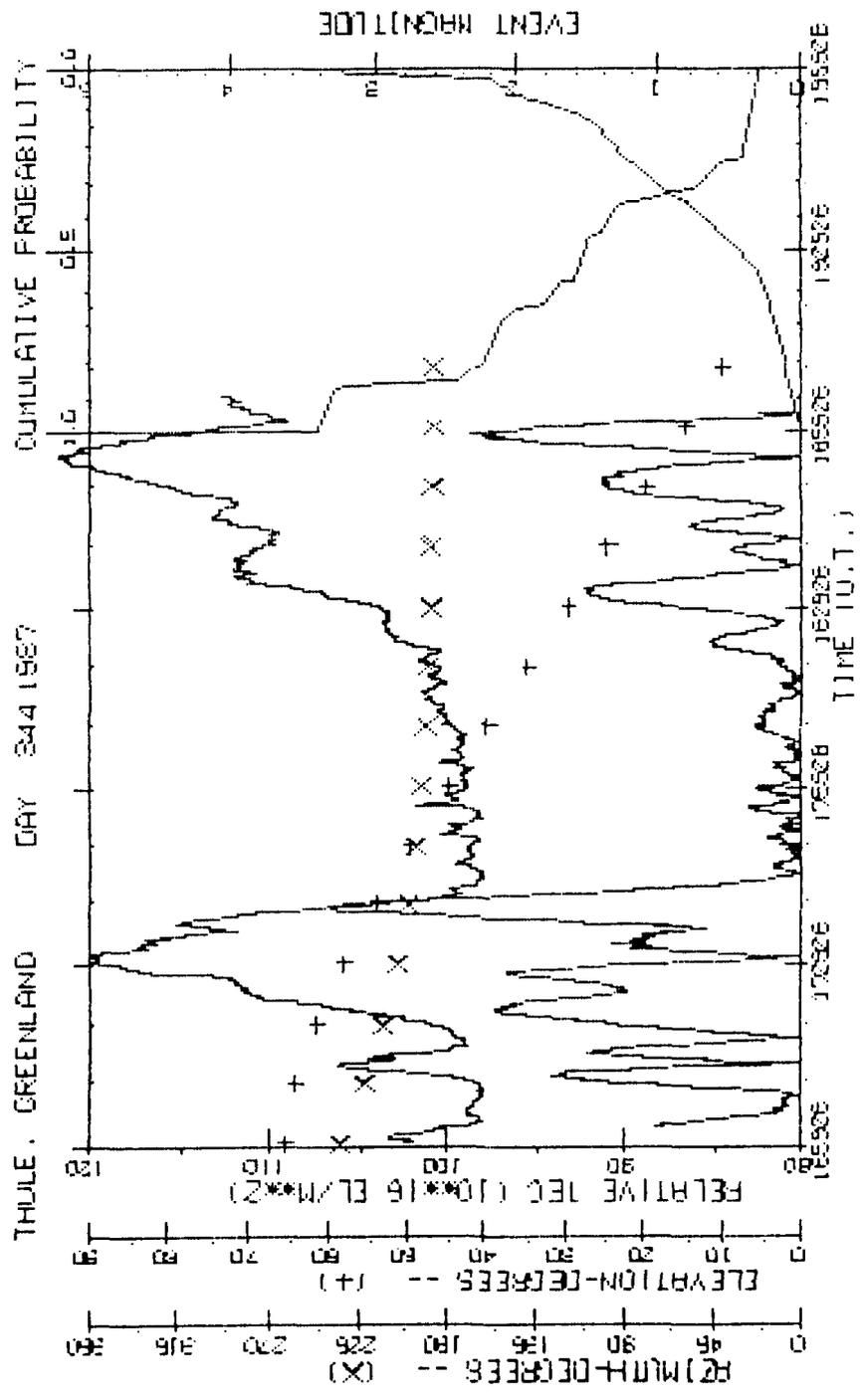
THULE, GREENLAND   DAY 315 1987

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THULE, GREENLAND   DAY 354 1987

EVENT MAGNITUDE

CUMULATIVE PROBABILITY

0.5. 10. 2. 1

TIME 10.1.1

07 JUL 88

RELATIVE TEC (10**16 EL/M**2)

ELEVATION-DEGREES -- (+)

AZIMUTH-DEGREES -- (X)

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THULE, GREENLAND   DAY 14 1988   07 JUL 88

A-8
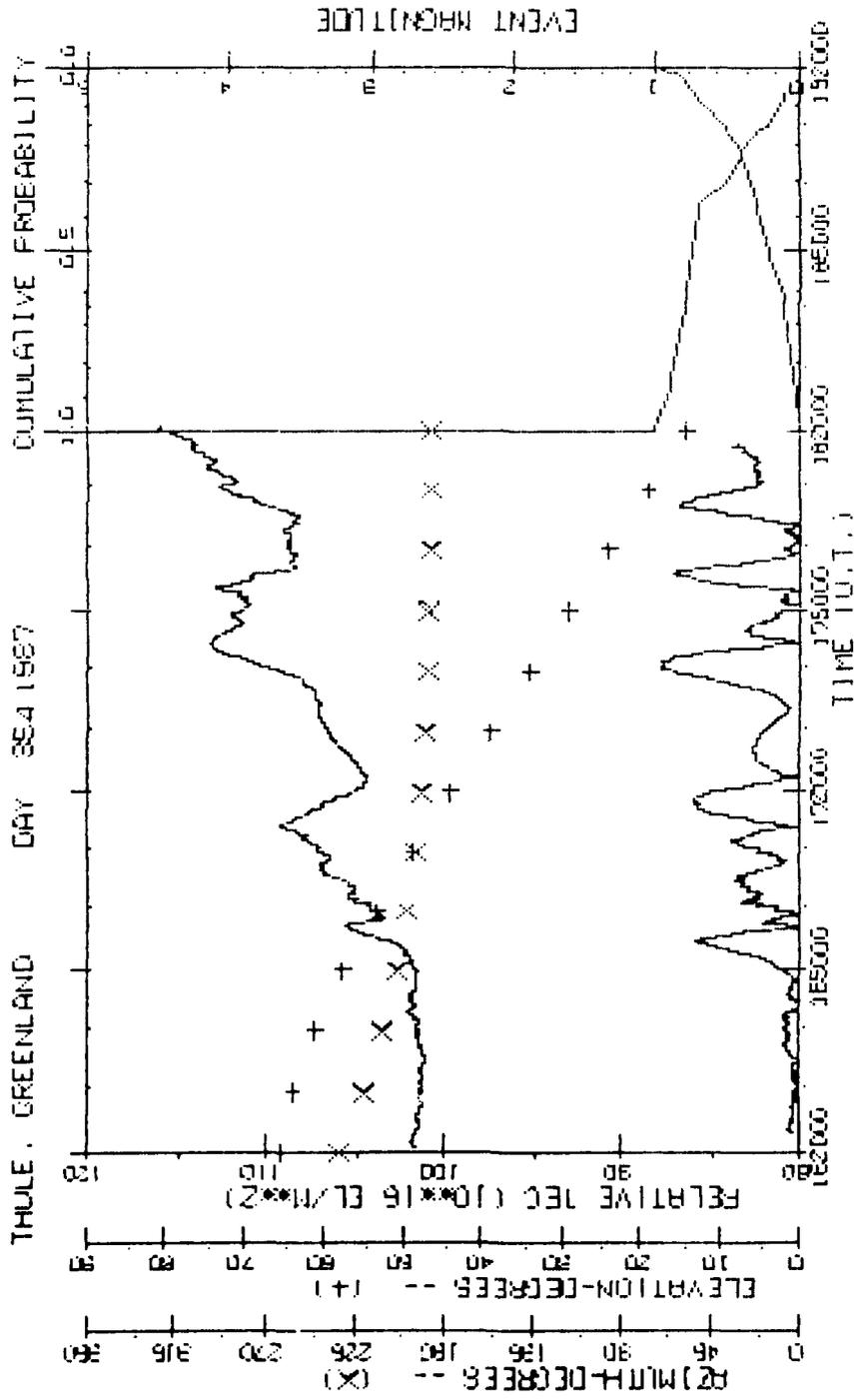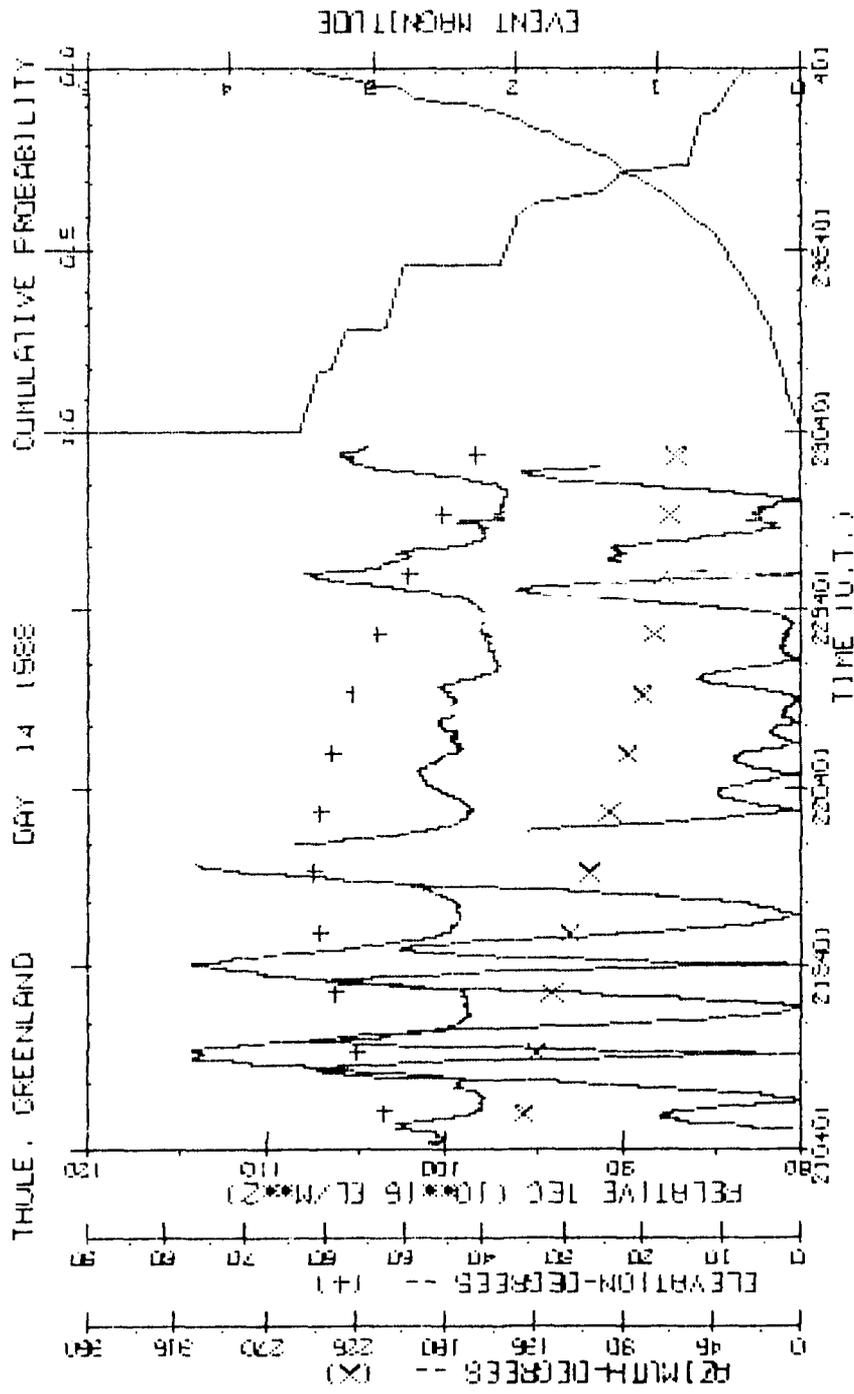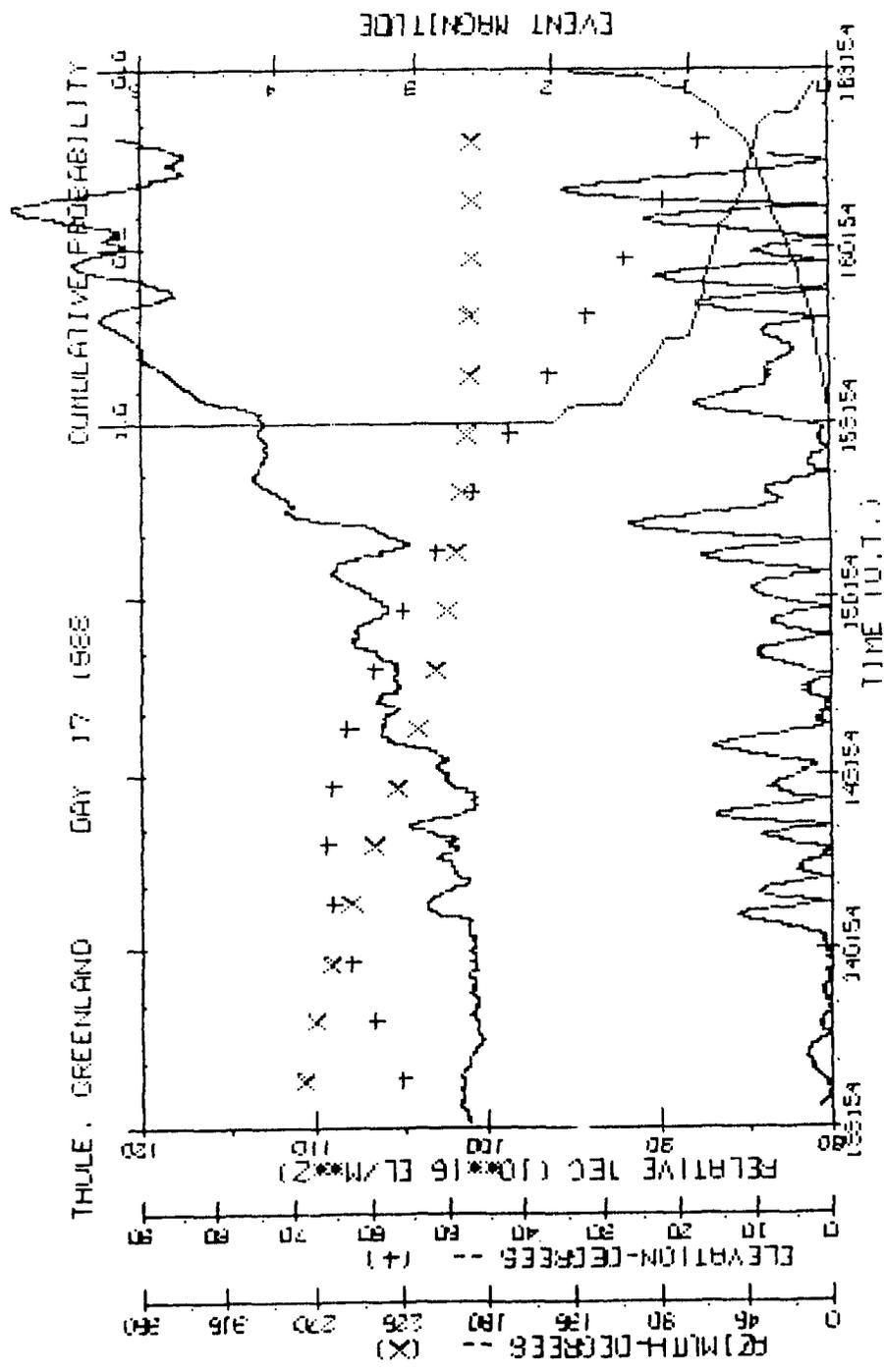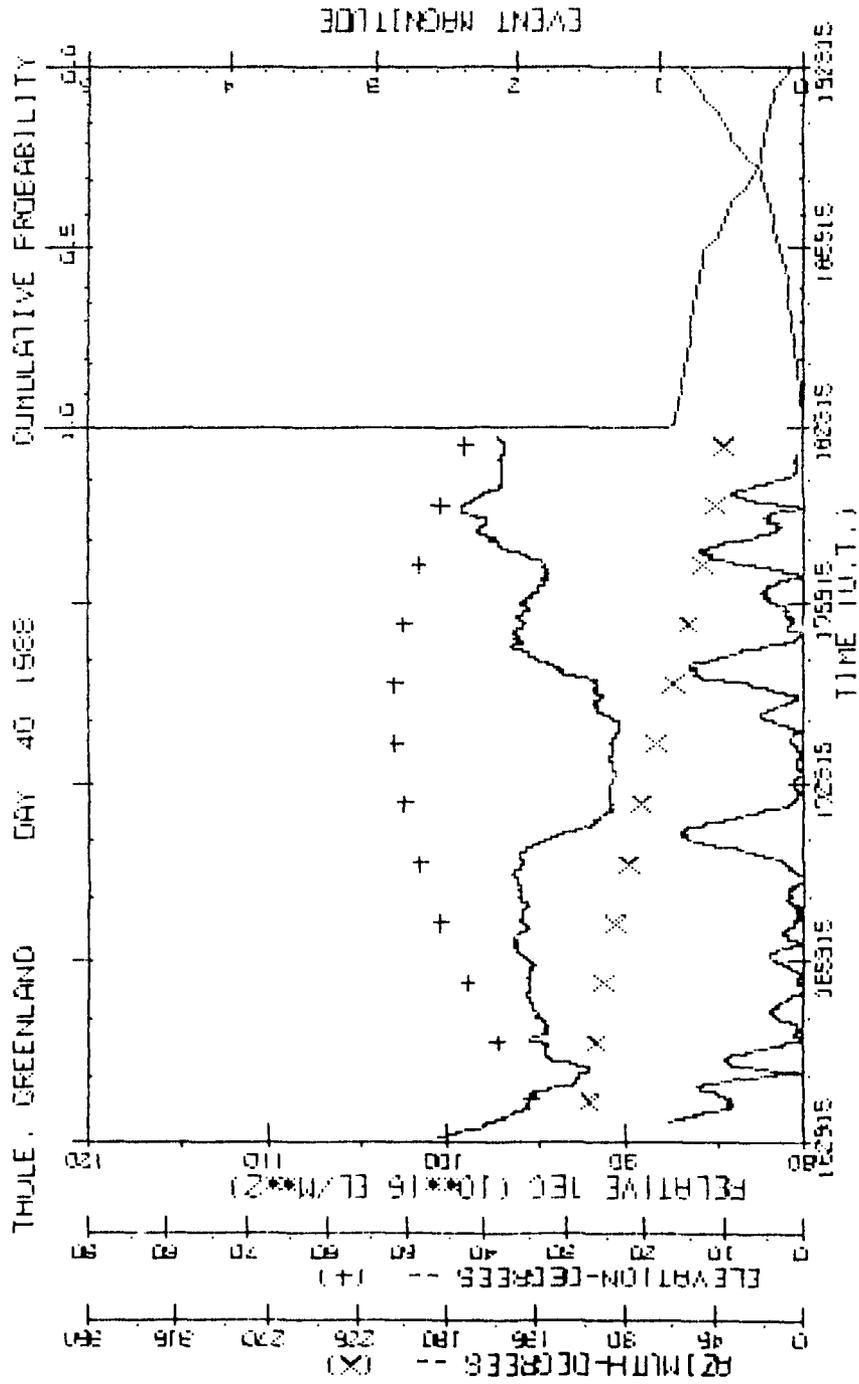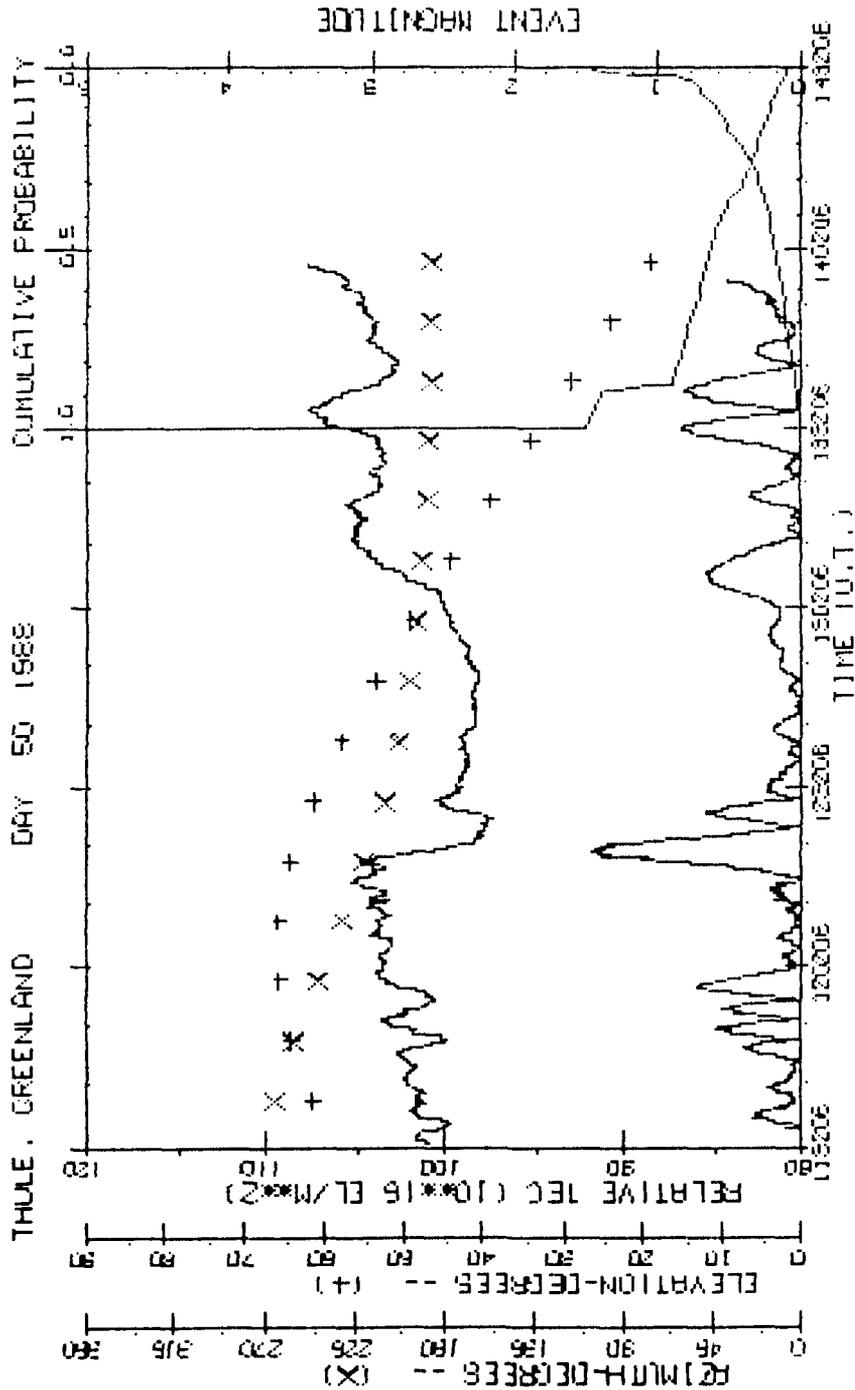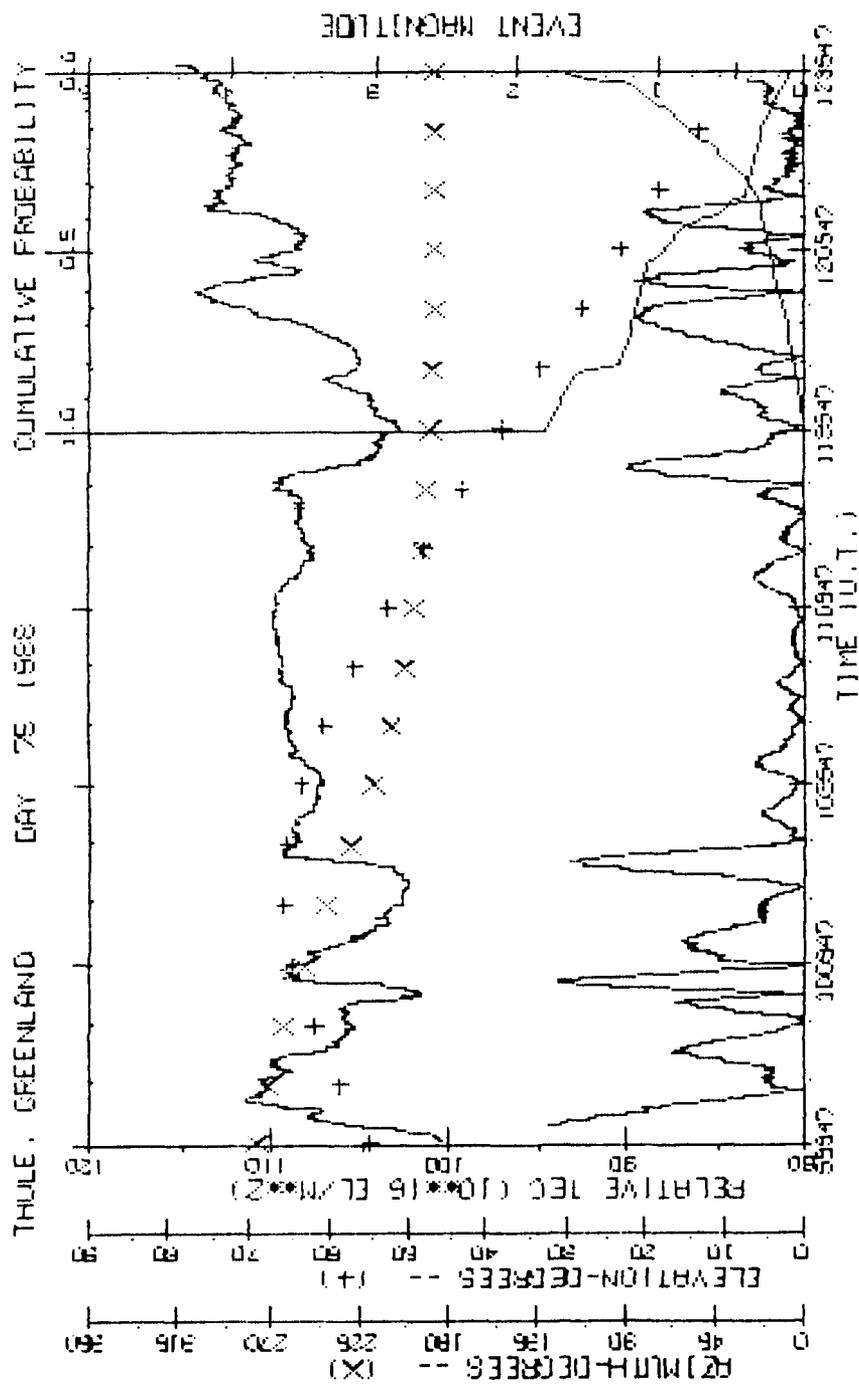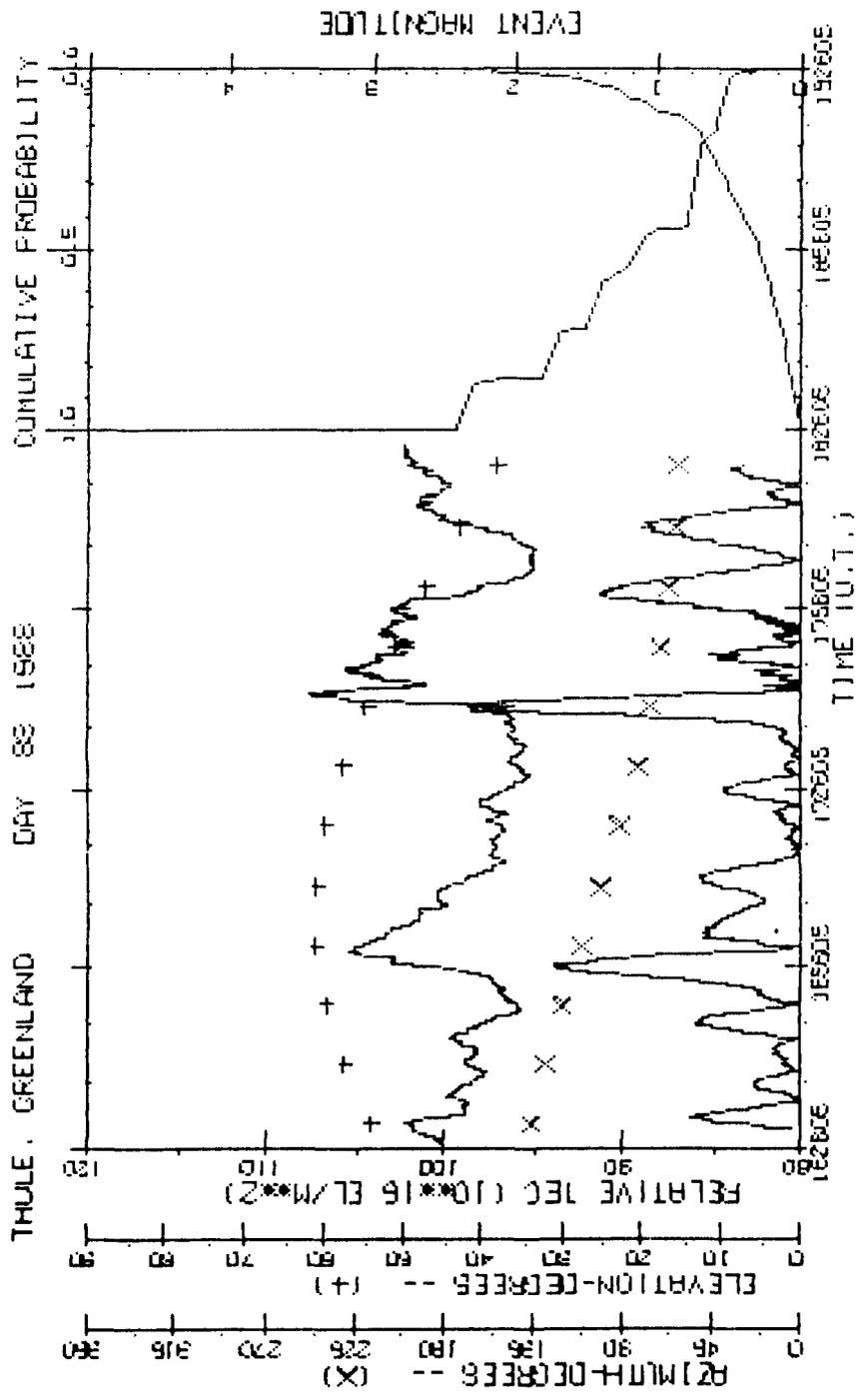
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Appendix B:

Description of the standard AFGL procedure to measure fade
depth.

Instructions for Measuring Beacon Signal Strength Variation

Beacon signal strength can measure ionospheric fading of the satellite signal during ionospheric disturbances. Beacon signal strength is recorded concomitantly with the several measurements used by GPS to determine Total Electron Content (TEC) and written to a chart record.

To determine a measure of beacon signal strength variation, a measuring device must be made. A step calibration of the signal is normally performed daily by the technicians at the receiver site. The measuring device can be made from the chart record of this calibration. Attached is a sample of such a calibration (attachment 1). It will be referred to in the following explanation of how to create the measuring device.

Although, the step calibration of the signal strength is usually done once per day, this is not always possible. Therefore a step calibration which preceeds the data to be analyzed should be used to make the measuring device rather than one which succeeds the data even though the succeeding step calibration may be closer in time to the data under consideration. (This is because the subsequent calibration may effect altered receiver tuning.)

A 3x5 card is the easiest item to use as a measuring tool. Place the top edge of the card along the top graph line, of the signal strength channel, which runs above the calibration marks (see A in attachment 1). Place it so the right edge abuts the first/highest step of the stair-step calibration marks (see B). Make a line on the right edge of the card which corresponds to that highest mark. Identify that mark as '0'. Now, advance the card along the top line (A) to the second step from the first mark (C). Again, make a mark on the card and label this '2'. Repeat this for '4' and '6' (see D & E). After these, slide the card until its edge covers the long pulse step (see F). Make a mark on the card which corresponds to a point halfway down from that step and the next and label that '8'.

The calibration changes after this. Marks are made at every step rather than at alternate steps. Each of these steps represents an increment of two. For example, the card is now advanced to the next step (see G), marked and labeled '10'. The position after that (see H) is labeled '12'. Repeat this until '24' (see I).

The creation of the measuring device is now complete. The zero mark is equivalent to 66dB; the twenty-four mark is equivalent to a range of about 91dB.

Locating a desired pass file for analysis can vary in degree of effort depending on the annotation of the corresponding chart record. Minimal annotation usually consists of a time and date written at the 24 hour delineation and/or a time written at the step calibration.

Time is denoted on a chart record by a continuous straight ink line with tick marks at regularly spaced intervals. The tick marks vary in type; there are three (see attachment 2). One type is the minute mark (see A); another type is the ten-minute mark (see B); the last mark is the hour mark (see C).

Assuming the chart record is minimally annotated, to locate the desired GPS pass file flip through the chart record page by page until a 24 hour annotation or step calibration that immediately preceeds the desired period is found. Now locate the hour mark after that. Count the hours until the one preceeding the pass file start is reached. (Hour marks are approximately in the same place on alternate pages.) Between this hour mark and the next a GPS calibration mark in the chart record will be apparent on one or several channels of the chart record (see D). This cal mark denotes the beginning or end of a GPS pass file. From this mark until the succeeding one is the extent of a particular GPS pass file.

Beacon signal strength is determined by locating the largest events on the Beacon channel in fifteen minute intervals and measuring their widths. Define fifteen minute intervals from the first ten minute tick. An interval should begin at every alternate ten minute tick. Observe the number of ticks from the first GPS cal mark to the first ten minute tick. If the number of minutes is seven or greater, determine a beacon signal strength for this interval (include the area prior to the cal mark so fifteen minutes are used). Determine a signal strength value for each interval until the ending cal mark is reached or passed.

Measuring the signal strength is accomplished by the following method. Observe a fifteen minute interval. Find the third highest signal level in the interval and draw a line at its peak. Next, locate the third lowest signal level in the interval and draw a line at its nadir. Take the 3x5 card/measuring device created earlier, align its edge with the top graph line of the channel, near the mark made for highest signal level. Note the corresponding value on the card. Repeat this for the nadir mark. Again, note the corresponding value. Calculate the difference between these two values and note it on the chart record. This is the value for Beacon signal strength.

When the positive excursions of the Beacon signal strength exceed both the 'zero' mark on the measuring card and the top graph line (A), one additional dB unit should be added to the Beacon signal strength value determined. When several negative excursions reach the 'twenty-four' mark on the measuring card (minimum that the calibration can qualify) then 2dB should be added to the Beacon signal strength value. When 'many' negative excursions reach the 'twenty-four' mark, then four or more dB should be added.
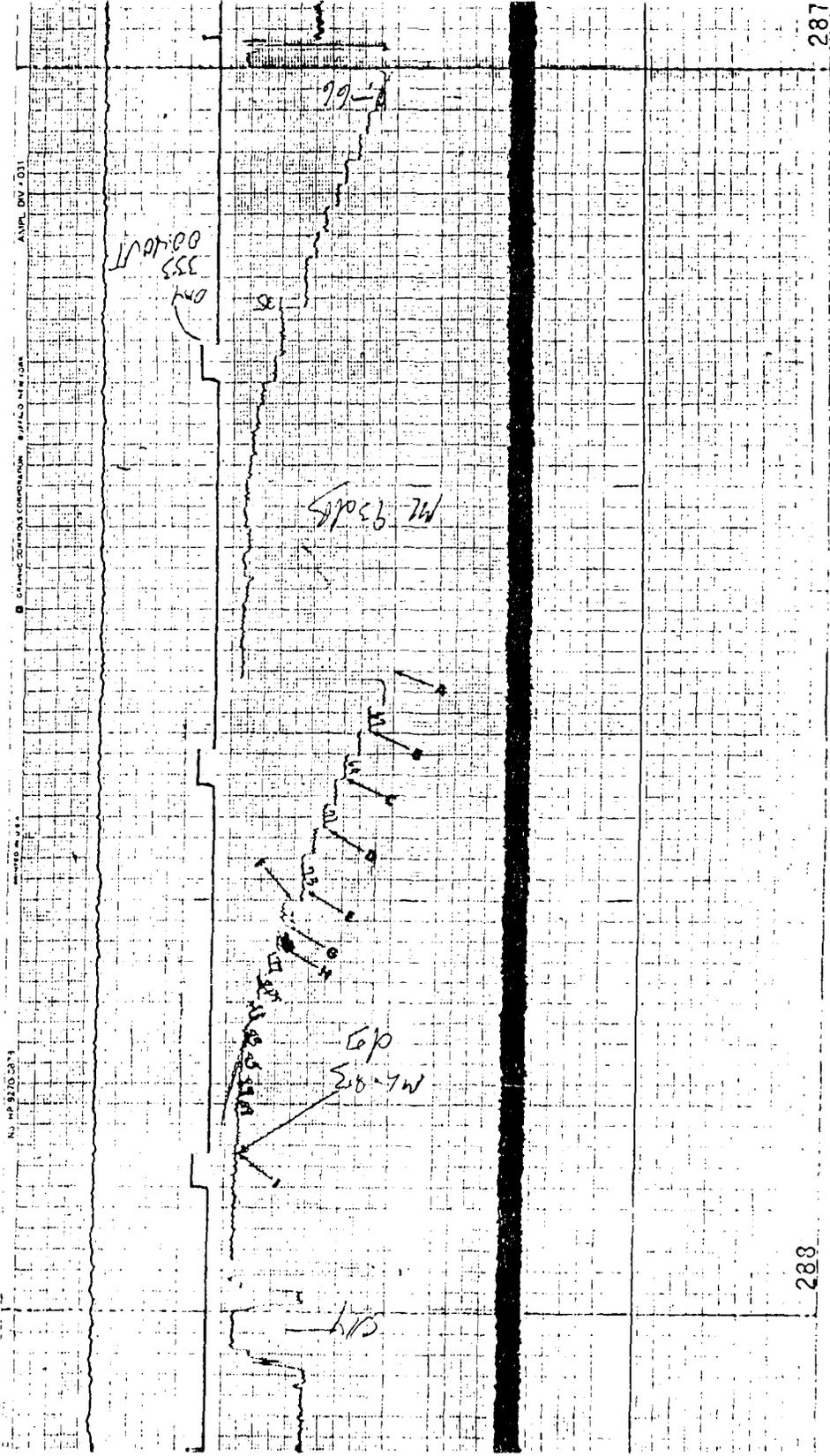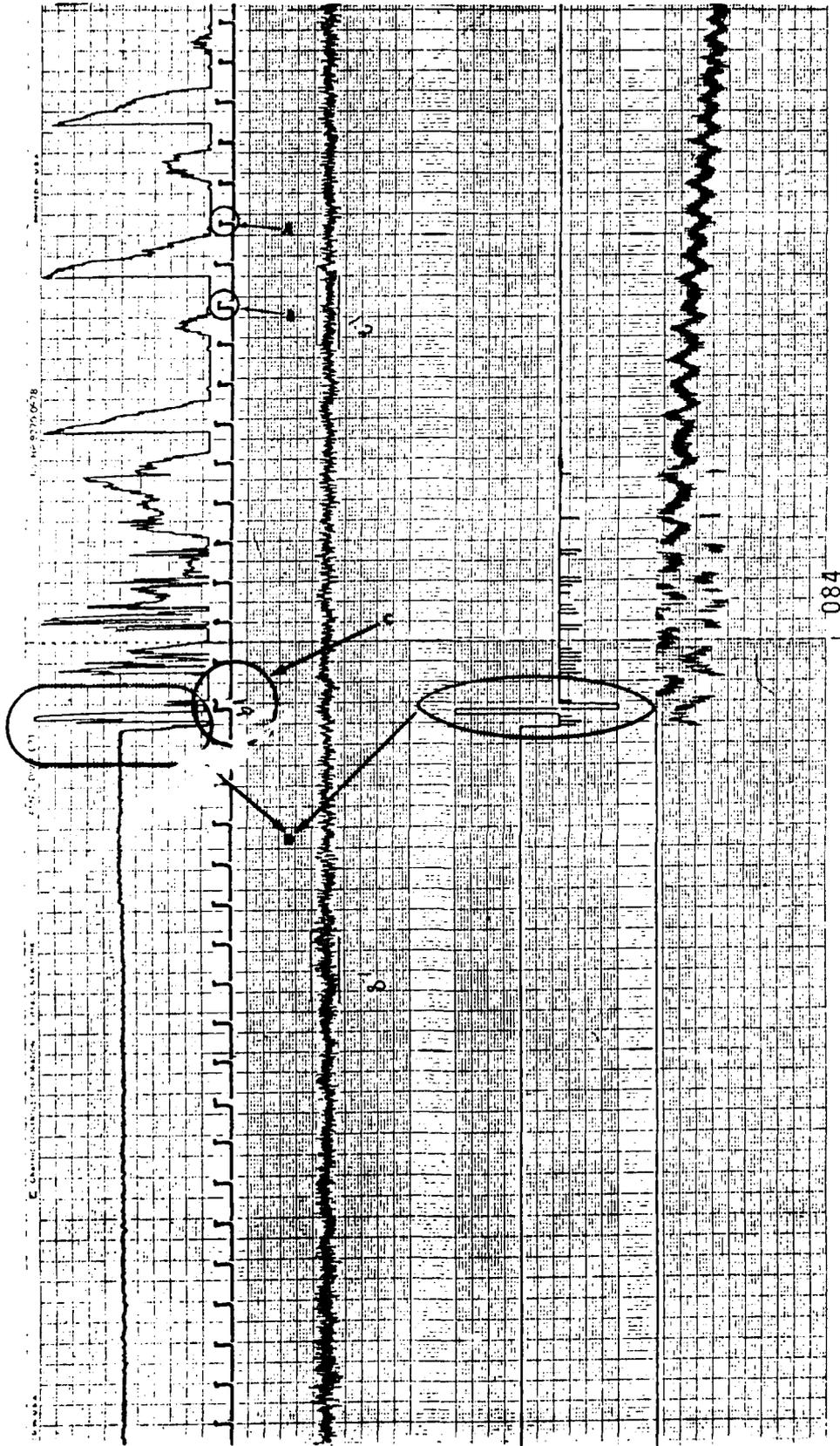
Beacon Scintillation Data Analysis

Fade	Peak to Peak*	
5 dB	8.6	
10 dB	15.7	
15 dB	22.2	Just inside cal extremes
20 dB	29.6	At edges of chart

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*Peak means 3rd from extreme.

Appendix C:

Database utilized in final data analysis.

GPS SUNSPOT ACTIVITY
Special Report

REC ID	JULIAN DAY	DATE	UT START	UT STOP
1	281	10/08/87	171754	203434
2	282	10/09/87	171309	203036
3	282	10/09/87	203348	220050
4	282	10/09/87	221134	233135
5	286	10/13/87	170517	225921
6	290	10/17/87	124446	151048
7	290	10/17/87	151500	165033
8	292	10/19/87	165002	200649
9	293	10/20/87	162110	175841
10	293	10/20/87	180205	193835
11	293	10/20/87	194153	223937
12	294	10/21/87	14442	25857
14	306	11/02/87	62704	90351
15	306	11/02/87	114117	134847
16	306	11/02/87	172117	185848
17	306	11/02/87	190206	214934
18	307	11/03/87	184209	214938
19	307	11/03/87	225243	3842
20	308	11/04/87	4212	15842
21	309	11/05/87	195849	213750
22	309	11/05/87	224640	2641
23	311	11/07/87	181907	212537
24	313	11/09/87	151144	163848
25	313	11/09/87	164231	181831
26	313	11/09/87	182137	210937
27	313	11/09/87	221108	1839
28	314	11/10/87	181818	210548
29	314	11/10/87	220313	1043
30	315	11/11/87	180941	205742
31	315	11/11/87	215912	641
32	318	11/14/87	162157	175857
33	318	11/14/87	180139	204938
34	319	11/15/87	192451	204550
35	324	11/20/87	140026	155655
36	324	11/20/87	155955	173654
37	324	11/20/87	173948	203752
38	327	11/23/87	95709	122440
39	327	11/23/87	122746	134447
40	328	11/24/87	95310	122041
41	328	11/24/87	122353	134053
42	328	11/24/87	134405	154034
43	328	11/24/87	154340	172040
44	331	11/27/87	121205	135804
45	331	11/27/87	140134	152833
46	331	11/27/87	153139	165838
47	332	11/28/87	3116	21845
48	332	11/28/87	22151	30851
51	332	11/28/87	160705	215502
53	335	12/01/87	152346	165045
54	335	12/01/87	165357	195156

GPS SUNSPOT ACTIVITY
Special Report

REC ID	JULIAN DAY	DATE	UT START	UT STOP
55	340	12/06/87	163336	193137
56	344	12/10/87	144752	161452
57	344	12/10/87	161758	191557
58	346	12/12/87	22401	33031
59	346	12/12/87	33325	62154
60	354	12/20/87	114947	131648
61	354	12/20/87	132624	153654
62	354	12/20/87	154000	183759
63	4	01/04/88	215747	235447
64	4	01/04/88	235805	4435
65	5	01/05/88	4747	15447
66	5	01/05/88	235341	4041
67	6	01/06/88	4453	10652
68	6	01/06/88	183912	203642
69	6	01/06/88	203954	214652
70	8	01/08/88	143136	172936
71	14	01/14/88	141453	163153
72	14	01/14/88	174312	194042
73	14	01/14/88	194342	210043
74	14	01/14/88	210401	230030
75	17	01/17/88	133154	161954
76	17	01/17/88	173112	192842
77	18	01/18/88	172709	192439
79	38	02/07/88	181535	192235
80	38	02/07/88	192547	211247
81	39	02/08/88	194936	213634
83	40	02/09/88	162315	182046
84	40	02/09/88	182352	193053
85	40	02/09/88	193347	212045
86	41	02/10/88	192547	211247
87	43	02/12/88	120800	143531
88	43	02/12/88	160707	180437
89	43	02/12/88	180737	191437
90	43	02/12/88	191749	210453
91	43	02/12/88	210818	220448
92	46	02/15/88	100412	114040
93	46	02/15/88	114352	141152
94	49	02/18/88	83004	95635
95	49	02/18/88	95959	113258
96	50	02/19/88	40112	62842
97	50	02/19/88	63148	81848
98	50	02/19/88	82212	94842
99	50	02/19/88	95254	112854
100	50	02/19/88	113206	135906
101	51	02/20/88	70618	83512
102	51	02/20/88	81415	94039
103	51	02/20/88	94346	112034
104	51	02/20/88	112329	135159
105	51	02/20/88	152313	172047
106	54	02/23/88	201557	211257

GPS SUNSPOT ACTIVITY
Special Report

REC ID	JULIAN DAY	DATE	UT START	UT STOP
107	61	03/01/88	215341	2742
108	68	03/08/88	51554	70254
109	72	03/12/88	64927	81657
110	72	03/12/88	81939	94640
111	72	03/12/88	94940	125609
112	74	03/14/88	45156	63855
113	74	03/14/88	64149	80848
114	74	03/14/88	81148	93849
115	75	03/15/88	93947	124045
116	75	03/15/88	194828	205458
117	75	03/15/88	205753	232752
118	76	03/16/88	93417	123948
119	79	03/19/88	75137	91837
120	79	03/19/88	92155	122925
121	80	03/20/88	74742	91442
122	80	03/20/88	91730	122501
123	80	03/20/88	132713	152444
124	81	03/21/88	91342	122111
125	82	03/22/88	90936	121706
126	83	03/23/88	135111	151242
127	83	03/23/88	151548	162247
128	83	03/23/88	162605	182235
129	83	03/23/88	182547	191248
130	83	03/23/88	191606	202206

GPS SUNSPOT ACTIVITY
Special Report

REC ID	QA	FADE DPTH 1	FADE DPTH 2	FADE DPTH 3	FADE DPTH 4	FADE DPTH 5	FADE DPTH 6	FADE DPTH 7	FADE DPTH 8	FADE DPTH 9	FADE DPTH 10	FADE DPTH 11	FADE DPTH 12
1	V	14	7	7	7	5	6	4	14	6	2	5	9
2	V	8	3	4	6	4	4	3	4	6	4	7	6
3	V	6	12	18	12	18	22	-1	-1	-1	-1	-1	-1
4	V	20	9	4	4	5	-1	-1	-1	-1	-1	-1	-1
5	V	9	6	11	10	3	9	13	22	17	23	18	20
6	V	8	13	9	25	6	7	8	8	2	7	-1	-1
7	V	12	22	16	18	11	10	-1	-1	-1	-1	-1	-1
8	V	6	6	6	14	17	14	7	6	4	6	4	6
9	V	17	8	12	15	-1	-1	-1	-1	-1	-1	-1	-1
10	V	7	15	11	18	11	12	-1	-1	-1	-1	-1	-1
11	V	5	3	4	4	3	2	3	3	4	3	5	5
12	V	21	10	7	9	16	-1	-1	-1	-1	-1	-1	-1
14	V	4	6	6	3	4	4	4	5	4	4	-1	-1
15	V	2	11	4	5	4	4	8	14	-1	-1	-1	-1
16	V	18	21	24	10	6	15	14	-1	-1	-1	-1	-1
17	V	13	8	7	8	18	15	15	21	20	24	6	-1
18	I	9	7	7	6	3	2	3	1	2	18	2	2
19	I	20	22	17	16	13	19	17	-1	-1	-1	-1	-1
20	I	14	16	4	17	10	-1	-1	-1	-1	-1	-1	-1
21	I	10	23	22	4	4	5	5	-1	-1	-1	-1	-1
22	I	20	15	23	3	12	21	12	-1	-1	-1	-1	-1
23	I	10	12	7	13	10	12	10	12	12	17	14	10
24	I	10	15	17	8	9	11	-1	-1	-1	-1	-1	-1
25	I	20	8	7	4	15	2	7	-1	-1	-1	-1	-1
26	I	14	14	19	14	24	17	18	18	8	4	10	-1
27	I	14	4	12	10	20	8	16	20	-1	-1	-1	-1
28	I	7	6	13	16	13	6	7	8	18	13	14	-1
29	I	16	20	25	22	10	24	12	10	6	-1	-1	-1
30	V	5	13	12	16	13	14	14	4	4	5	11	-1
31	V	23	11	5	4	20	20	15	24	20	-1	-1	-1
32	V	17	24	14	25	11	21	24	-1	-1	-1	-1	-1
33	V	22	18	16	5	6	8	9	12	14	20	8	8
34	V	7	8	6	10	11	-1	-1	-1	-1	-1	-1	-1
35	V	10	20	23	10	23	24	20	-1	-1	-1	-1	-1
36	V	12	17	14	18	8	17	10	20	8	16	21	18
37	V	14	18	8	17	10	20	8	16	21	18	14	22
38	V	22	23	4	13	22	11	10	11	17	10	-1	-1
39	V	6	12	10	16	15	-1	-1	-1	-1	-1	-1	-1
40	V	5	6	4	4	6	8	5	5	7	-1	-1	-1
41	V	7	14	10	15	14	-1	-1	-1	-1	-1	-1	-1
42	V	6	14	12	8	4	12	21	4	-1	-1	-1	-1
43	V	2	2	8	9	5	4	4	-1	-1	-1	-1	-1
44	V	14	9	6	10	14	19	12	-1	-1	-1	-1	-1
45	V	12	6	5	8	20	9	-1	-1	-1	-1	-1	-1
46	V	3	4	7	8	9	18	-1	-1	-1	-1	-1	-1
47	V	6	4	1	4	4	3	3	4	-1	-1	-1	-1
48	V	4	2	2	1	2	2	-1	-1	-1	-1	-1	-1
51	I	3	4	4	6	4	4	18	16	11	12	10	10
53	V	12	16	13	16	10	10	-1	-1	-1	-1	-1	-1

GPS SUNSPOT ACTIVITY
Special Report

REC ID	QA	FADE DPTH 1	FADE DPTH 2	FADE DPTH 3	FADE DPTH 4	FADE DPTH 5	FADE DPTH 6	FADE DPTH 7	FADE DPTH 8	FADE DPTH 9	FADE DPTH 10	FADE DPTH 11	FADE DPTH 12
54	V	7	5	4	5	8	6	8	6	8	6	10	-1
55	V	10	14	9	5	6	5	19	20	6	12	7	9
56	V	5	8	14	16	13	4	-1	-1	-1	-1	-1	-1
57	V	8	11	10	14	12	9	12	8	4	6	2	12
58	V	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1
59	V	2	1	1	1	1	1	1	1	-1	2	2	2
60	V	2	4	4	14	7	10	-1	-1	-1	-1	-1	-1
61	V	10	13	18	14	3	6	20	12	18	-1	-1	-1
62	V	19	16	15	22	18	12	19	19	19	13	18	-1
63	V	14	18	20	22	10	12	10	20	-1	-1	-1	-1
64	V	23	13	23	-1	-1	-1	-1	-1	-1	-1	-1	-1
65	V	22	15	14	16	21	-1	-1	-1	-1	-1	-1	-1
66	V	9	11	25	8	-1	-1	-1	-1	-1	-1	-1	-1
67	V	10	9	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
68	V	17	18	13	19	21	19	18	24	-1	-1	-1	-1
69	V	23	16	8	19	-1	-1	-1	-1	-1	-1	-1	-1
70	V	4	4	4	5	9	12	8	8	8	-1	-1	-1
71	V	4	3	3	4	2	2	3	20	4	-1	-1	-1
72	V	9	8	14	14	11	22	6	7	-1	-1	-1	-1
73	V	10	16	18	11	22	-1	-1	-1	-1	-1	-1	-1
74	V	25	26	24	22	4	6	20	24	-1	-1	-1	-1
75	V	6	6	8	8	12	10	12	18	10	7	22	25
76	V	19	22	19	24	22	22	23	27	25	-1	-1	-1
77	V	13	13	5	2	22	7	22	3	-1	-1	-1	-1
79	V	12	5	3	4	10	-1	-1	-1	-1	-1	-1	-1
80	V	10	12	6	2	2	4	6	18	-1	-1	-1	-1
81	V	6	14	13	4	6	8	6	4	-1	-1	-1	-1
83	V	9	7	18	4	12	9	16	7	-1	-1	-1	-1
84	V	17	17	14	18	19	-1	-1	-1	-1	-1	-1	-1
85	V	14	6	19	7	14	9	18	-1	-1	-1	-1	-1
86	I	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
87	V	3	7	2	5	5	2	2	2	2	-1	-1	-1
88	V	1	1	2	9	6	5	4	4	-1	-1	-1	-1
89	V	7	5	7	16	8	-1	-1	-1	-1	-1	-1	-1
90	V	4	8	14	5	17	19	8	-1	-1	-1	-1	-1
91	V	7	6	4	6	-1	-1	-1	-1	-1	-1	-1	-1
92	V	3	5	3	3	8	2	9	-1	-1	-1	-1	-1
93	V	3	4	3	2	1	3	2	1	4	6	-1	-1
94	I	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
95	I	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
96	V	2	2	3	2	3	3	3	5	4	5	-1	-1
97	V	11	10	7	4	1	3	3	10	-1	-1	-1	-1
98	V	10	12	5	9	5	10	-1	-1	-1	-1	-1	-1
99	V	8	8	3	6	3	6	13	-1	-1	-1	-1	-1
100	V	8	10	10	13	14	16	14	12	8	28	9	5
101	I	2	3	3	5	5	8	7	-1	-1	-1	-1	-1
102	V	6	7	8	5	8	6	-1	-1	-1	-1	-1	-1
103	V	11	4	1	2	2	2	2	-1	-1	-1	-1	-1
104	V	12	7	8	6	4	7	6	4	5	8	-1	-1

GPS SUNSPOT ACTIVITY
Special Report

REC IO	QA	FADE DPTH 1	FADE DPTH 2	FADE DPTH 3	FADE DPTH 4	FADE DPTH 5	FADE DPTH 6	FADE DPTH 7	FADE DPTH 8	FADE DPTH 9	FADE DPTH 10	FADE DPTH 11	FADE DPTH 12
105	V	3	2	3	4	1	2	1	1	-1	-1	-1	-1
106	V	17	10	3	4	-1	-1	-1	-1	-1	-1	-1	-1
107	V	6	6	8	10	13	12	7	4	6	4	3	7
108	I	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
109	V	12	16	7	5	15	17	-1	-1	-1	-1	-1	-1
110	V	7	13	8	11	11	11	-1	-1	-1	-1	-1	-1
111	V	9	10	15	19	6	6	8	6	9	5	12	4
112	V	7	5	9	7	7	7	5	-1	-1	-1	-1	-1
113	V	15	6	11	15	11	13	-1.	-1	-1	-1	-1	-1
114	V	7	5	7	8	7	6	-1	-1	-1	-1	-1	-1
115	V	7	14	8	10	9	7	6	4	6	8	6	15
116	V	4	9	12	20	7	-1	-1	-1	-1	-1	-1	-1
117	V	17	20	4	21	22	16	25	11	10	16	-1	-1
118	I	0	0	0	0	0	0	0	0	0	0	0	0
119	V	12	6	8	7	6	2	-1	-1	-1	-1	-1	-1
120	V	6	6	6	6	6	8	13	11	5	3	3	2
121	V	7	8	13	8	11	10	-1	1	-1	-1	-1	-1
122	V	13	13	9	10	5	17	7	15	9	15	9	5
123	V	14	14	19	17	18	5	4	-1	-1	-1	-1	-1
124	V	6	7	7	6	4	4	5	2	4	2	2	2
125	V	6	6	6	6	8	9	6	10	10	11	7	6
126	V	12	16	6	6	7	9	16	8	-1	-1	-1	-1
127	V	10	17	8	15	18	-1	-1	-1	-1	-1	-1	-1
128	V	10	12	12	13	18	14	14	6	-1	-1	-1	-1
129	V	6	6	10	-1	-1	-1	-1	-1	-1	-1	-1	-1
130	V	16	18	19	11	10	-1	-1	-1	-1	-1	-1	-1

Appendix D:

Curves of the probability of a period without an event for all
active data given several methods of categorizing the data.

Fade Depth Algorithm

Peak-to-Peak Values Measured	Corresponding Fade Depth Value
0 $\geq$ P to P < 8.6	0 dB
8.6 $\geq$ P to P 15.7	5 dB
15.7 $\geq$ P to P < 22.8	10 dB
22.8 $\geq$ P to P < 28.0	15 dB
28.0 < P to P	29 dB

(Usually 5-12 P to P numbers per pass.)

Fade Depth Analysis Algorithms

Method 1: Take mean of all peak-to-peak numbers in a pass and determine corresponding fade depth value to characterize the period;

Method 2: Determine corresponding fade depth value for each peak-to-peak value in a pass, sort fade depth values in ascending order and take value just greater than half as characterizing the period;

Method 3: Same as Method 2 except take value just greater than upper 1/3 as characterizing the period:

Method 4: Determine the highest peak-to-peak value for the pass period and determine the corresponding fade depth value to characterize the period;

Method 5: Determine corresponding fade depth for all peak-to-peak values and use all of them to characterize the period.

```
0
131   464   938  1553  2125  2621  3032  3444  3821  4045
4283  4433  4692  4834  4935  5078  5140  5227  5307  5357
5377  5404  5441  5473  5481  5482  5483  5498  5498  5498
5499  5502  5503  5510  5510  5511  5518  5518  5518  5518
5518  5518  5518  5518  5518  5518  5518  5518  5518  5518
```

Fade	Fade	Fade	Fade	Fade	Total
DB 0	DB 5	DB 10	DB 15	DB 20	DB's
----	----	-----	-----	-----	-----
433	234	133	28	0	828

METHOD 0
FADE DEPTH LEVEL ALL

METHOD 1
FADE DEPTH LEVEL 0

METHOD 1
FADE DEPTH LEVEL 5

METHOD 1
FADE DEPTH LEVEL 10
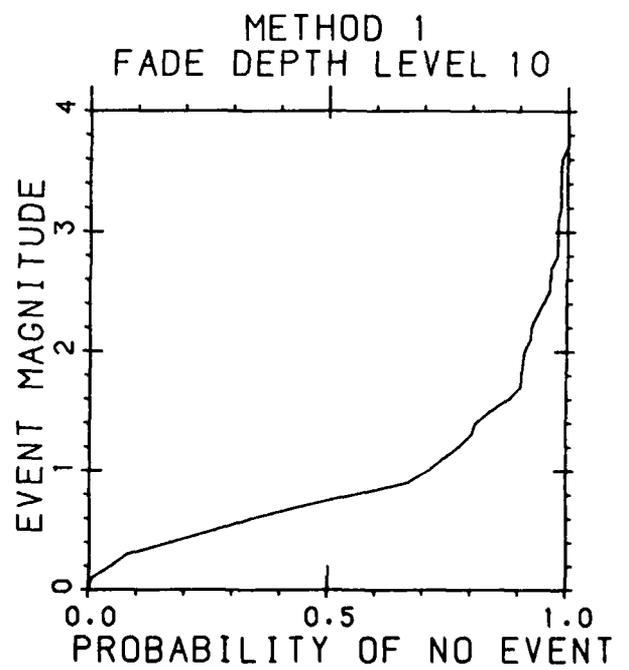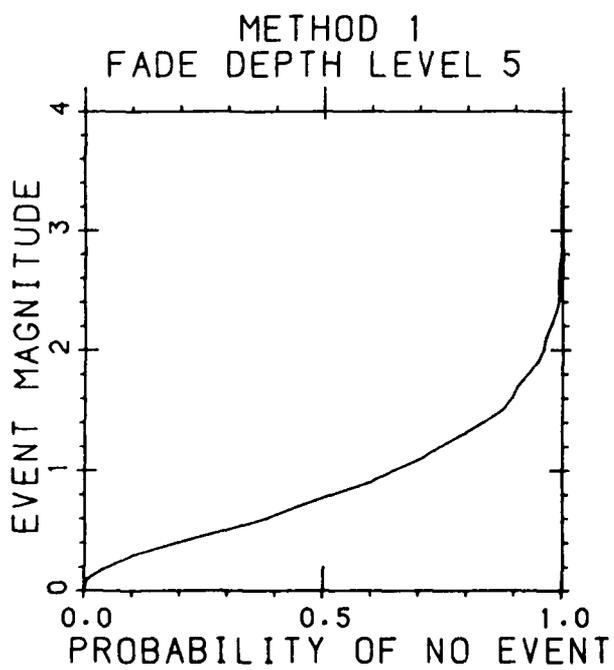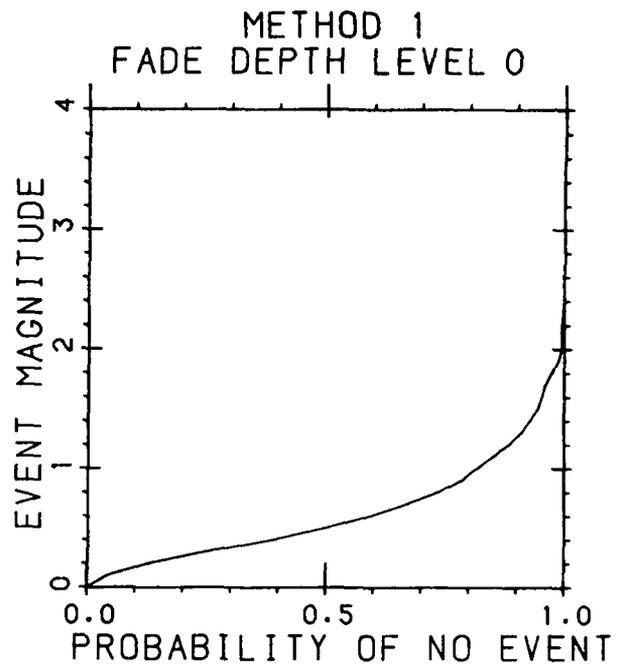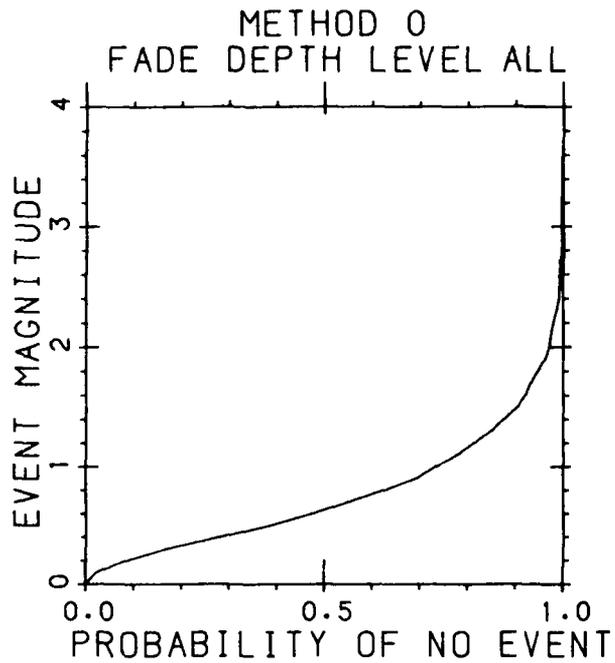
METHOD 2
FADE DEPTH LEVEL 0
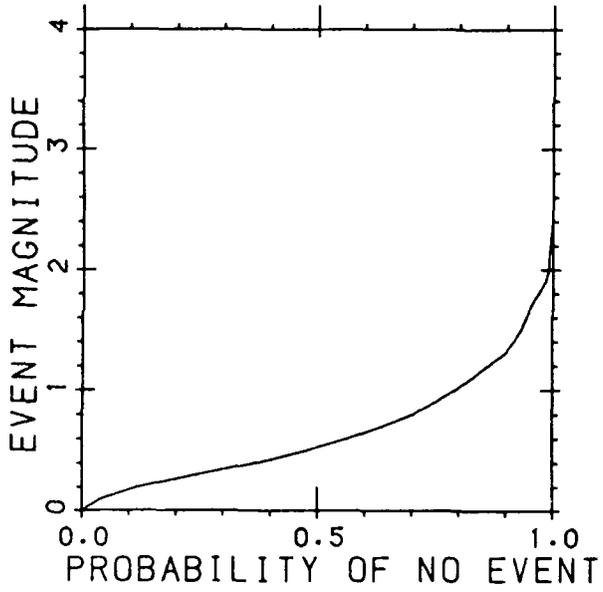
METHOD 2
FADE DEPTH LEVEL 5

METHOD 2
FADE DEPTH LEVEL 10

METHOD 2
FADE DEPTH LEVEL 15

METHOD 3
FADE DEPTH LEVEL 0

METHOD 3
FADE DEPTH LEVEL 5
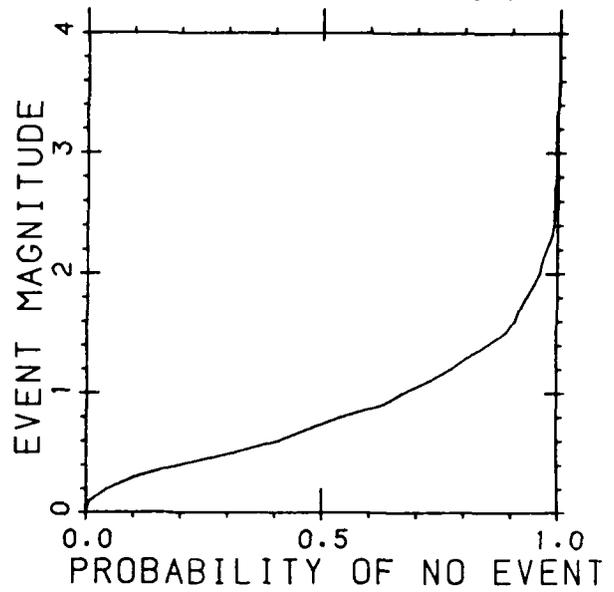
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FADE DEPTH LEVEL 10
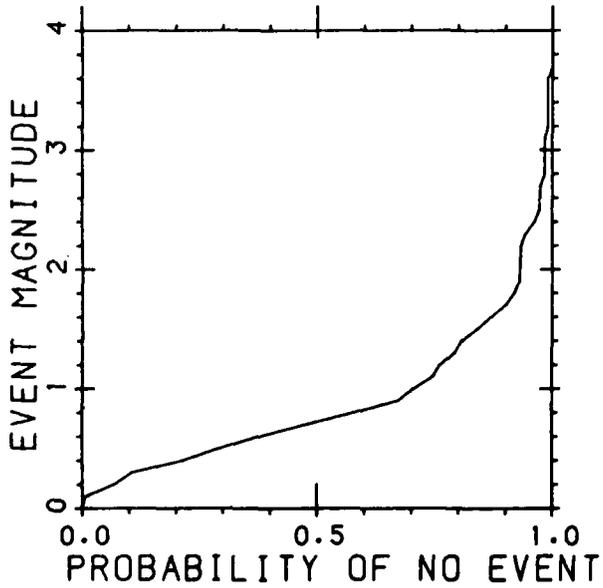
METHOD 3
FADE DEPTH LEVEL 15
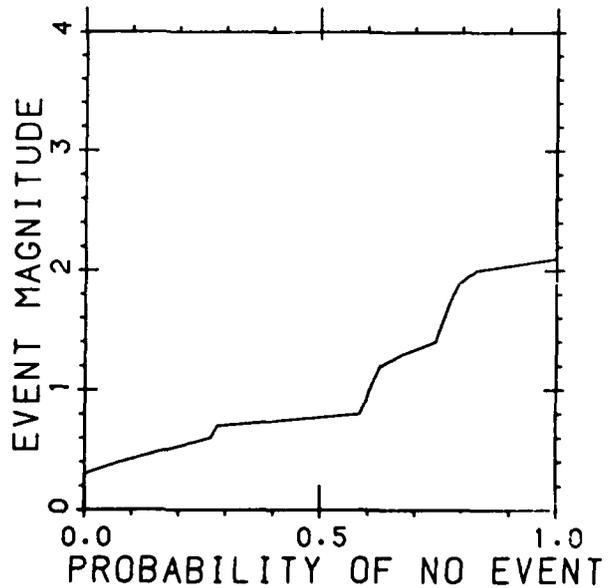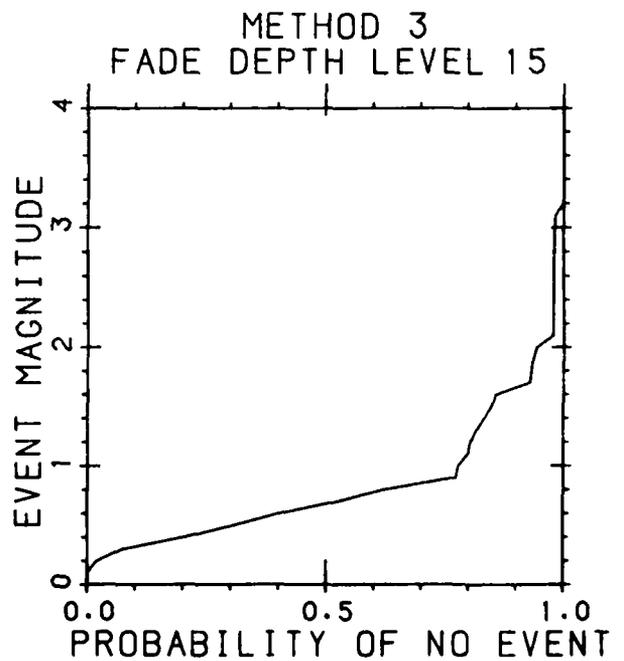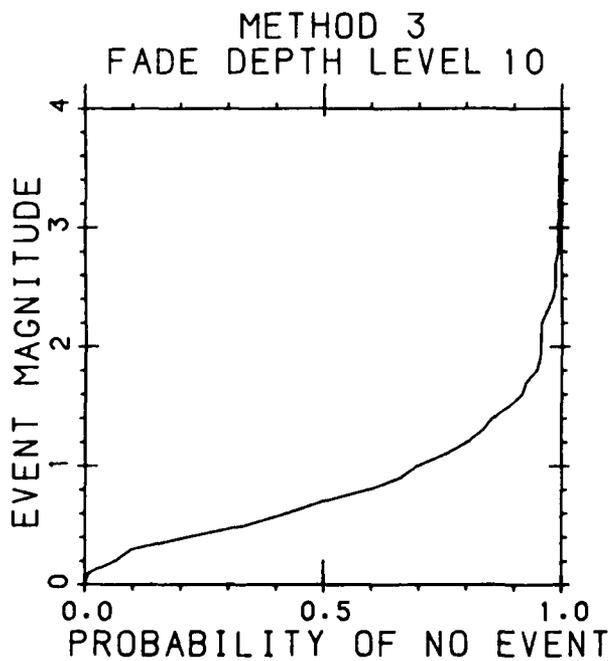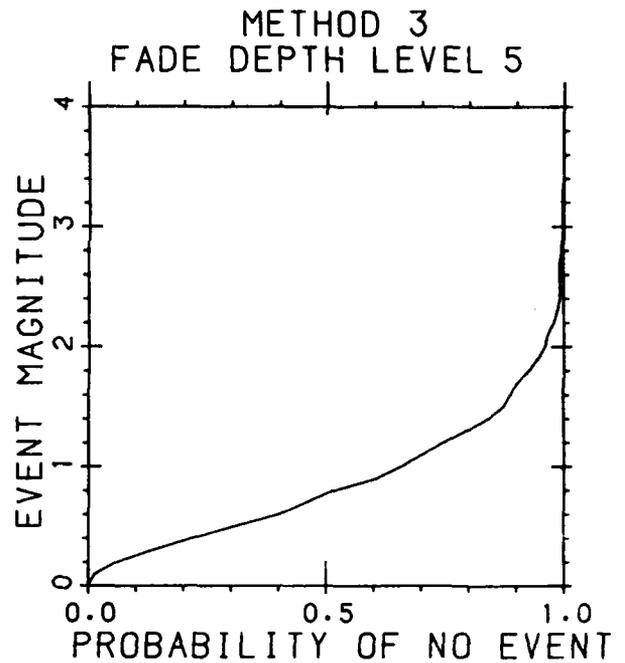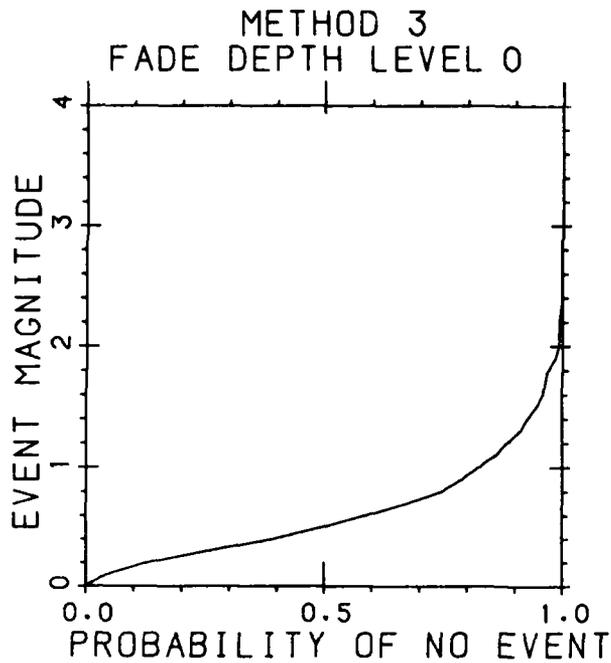
METHOD 4
FADE DEPTH LEVEL 0
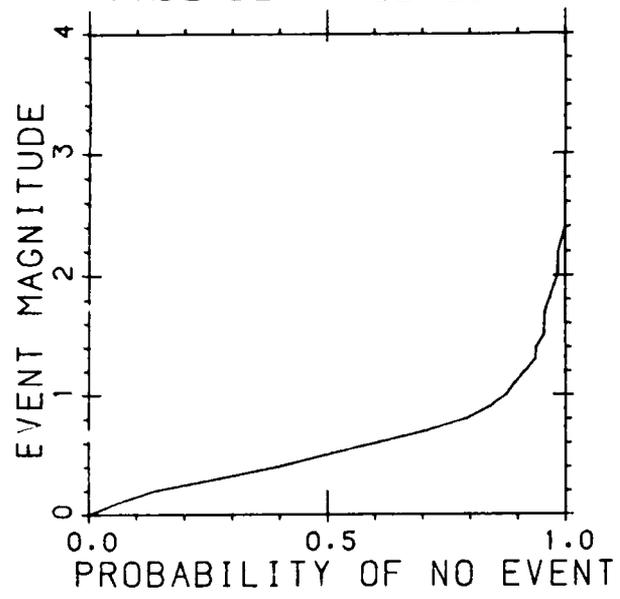
METHOD 4
FADE DEPTH LEVEL 5
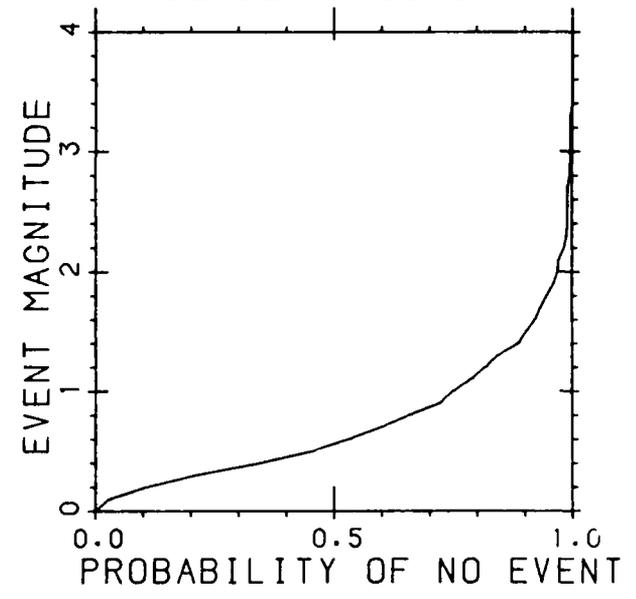
METHOD 4
FADE DEPTH LEVEL 10

METHOD 4
FADE DEPTH LEVEL 15