TD 869

Technical Document 869
February 1986

HF ABSOLUTE TIME OF ARRIVAL SENSING

R. B. Rose

Naval Ocean Systems Center
San Diego, California 92152-5000

NAVAL OCEAN SYSTEMS CENTER

San Diego, California 92152-5000

F. M. PESTORIUS, CAPT, USN
Commander

R. M. HILLYER
Technical Director

ADMINISTRATIVE INFORMATION

This task was performed for the Tactical HF Surveillance and Exploitation (THSE) program under program element 62712N, subproject SF12151 (NOSC MP47). The work is a cooperative effort performed by the Signals Exploitation Branch, Code 772 and the Ionospheric Modeling Branch, Code 542 of the Naval Ocean Systems Center, San Diego, CA, 92152. This work started in late 1981 and continued to the present.

Released by
R.B. Rose, Head
Signals Exploitation Branch

Under authority of
R.E. Shutters, Head
Signals Warfare Division

ACKNOWLEDGEMENT

The author would like to acknowledge the efforts of Dr. Ray Labahn, Naval Ocean Systems Center, for his work in the design and construction of both the TOA and LBTOA systems. He has also made noteworthy contributions in developing the data processing capability at NOSC needed to process the digital recordings from both sensors. The author would also like to acknowledge the assistance of Dr. A.K. Paul, who has been instrumental in interpreting and independently verifying some of the observations.

JJ

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) TD 869	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Ocean Systems Center 6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) San Diego, CA 92152-5000	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Space and Naval Warfare Systems Command 8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code) Washington, DC 20363-5100	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62712N; PROJECT NO. MP47; TASK NO.; Agency Accession No. DN088 710

11 TITLE (include Security Classification)
HF ABSOLUTE TIME OF ARRIVAL SENSING

12 PERSONAL AUTHOR(S)
R.B. Rose

13a TYPE OF REPORT	13b TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM Sep 1981 TO May 1985	February 1986	116

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Time of Arrival (TOA) Time Difference of Arrival (TDOA) cesium beam

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This effort involved establishing a continuous absolute Time of Arrival (TOA) experiment over the 1-hop mid-latitude path between San Diego, California and Fort Collins, Colorado. The system is fully digital and stabilized with a cesium beam standard.

20 DISTRIBUTION AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL R. Rose	22b TELEPHONE (include Area Code) (619) 225-2924 — 22c OFFICE SYMBOL Code 772

DD FORM 1473, 84 JAN

83 APR EDITION MAY BE USED UNTIL EXHAUSTED
ALL OTHER EDITIONS ARE OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DD FORM 1473, 84 JAN

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

TABLES

ILLUSTRATIONS

INTRODUCTION

In late 1980 questions arose concerning whether the ionosphere was sufficiently stable to allow precisely measured time of arrival of skywave signals to be used for geolocation in the high frequency (HF) band between 2 and 32 MHz. The chief limitation in the accuracy of this type of system is the amount of uncertainty in the ionospheric height estimation and its temporal stability. Traditional ionospheric research resources did not address the issue in sufficient detail and time resolution to be of any assistance. In order to understand the exact nature of the ionospheric uncertainties and to quantify their extent, experimentation was proposed to sense the variation in the refraction height of the ionosphere as it relates to the time of arrival of the HF signal. The objective of this work was to determine the range of environmentally induced errors in a skywave Time Difference of Arrival (TDOA) measurement, thereby bounding the ultimate geolocation accuracy one could expect from this technique.

The first experimental measurement system~~, described in Reference 1,~~ started operation in early 1981. This effort involved establishing a continuous absolute Time of Arrival (TOA) experiment over the one-hop midlatitude path between San Diego, California and Fort Collins, Colorado. The system is fully digital and stabilized with a cesium beam standard. This work was supplemented with vertical incidence sounder data at both ends of the path, a collateral Doppler sensing system, and coincident satellite solar data. A fully annotated database was prepared and is maintained by the Naval Ocean Systems Center Advanced Propagation Forecasting System (PROPHET). Figure 1 shows the TOA measurement hardware configuration.

In 1983 the Kenwood R1000 receiver was replaced with a newer R2000 which was microprocessor controlled. This allowed the receiver to now sequentially sample four frequencies at 1-second intervals. Because each frequency refracts from a different ionospheric height, the resulting data represent an almost (within 4 seconds) simultaneous look at different levels in the ionosphere. These multifrequency measurements were started in 1983 and have continued until the present. The data have produced startling results when compared to traditional concepts of how the ionospheric medium behaves.

Because of the high level of automation, both in the sensor system and in the processing system, it is expected that the TOA sensor will be maintained indefinitely.

In late 1983, a longer range adjunct was conceived to address new issues concerning TDOA signals. Dubbed the Long Baseline Time of Arrival (LBTOA) experiment, a sensor was placed in Hawaii that simultaneously measured time of arrival of signals from Fort Collins, Colorado (WWV) and Tokyo Japan (JJY). Although somewhat more ambitious than the original TOA sensor, the LBTOA was constructed and deployed in October 1983. The equipment, shown in Figure 2, was assembled at a modest cost.

From their inception, both TOA sensor experiments were fully digital, making the database more easily processed. Concurrent to the development of the TOA and LBTOA sensors, a significant effort was directed toward the computer processing of the data. This has led to an extensive data reduction capability which will be

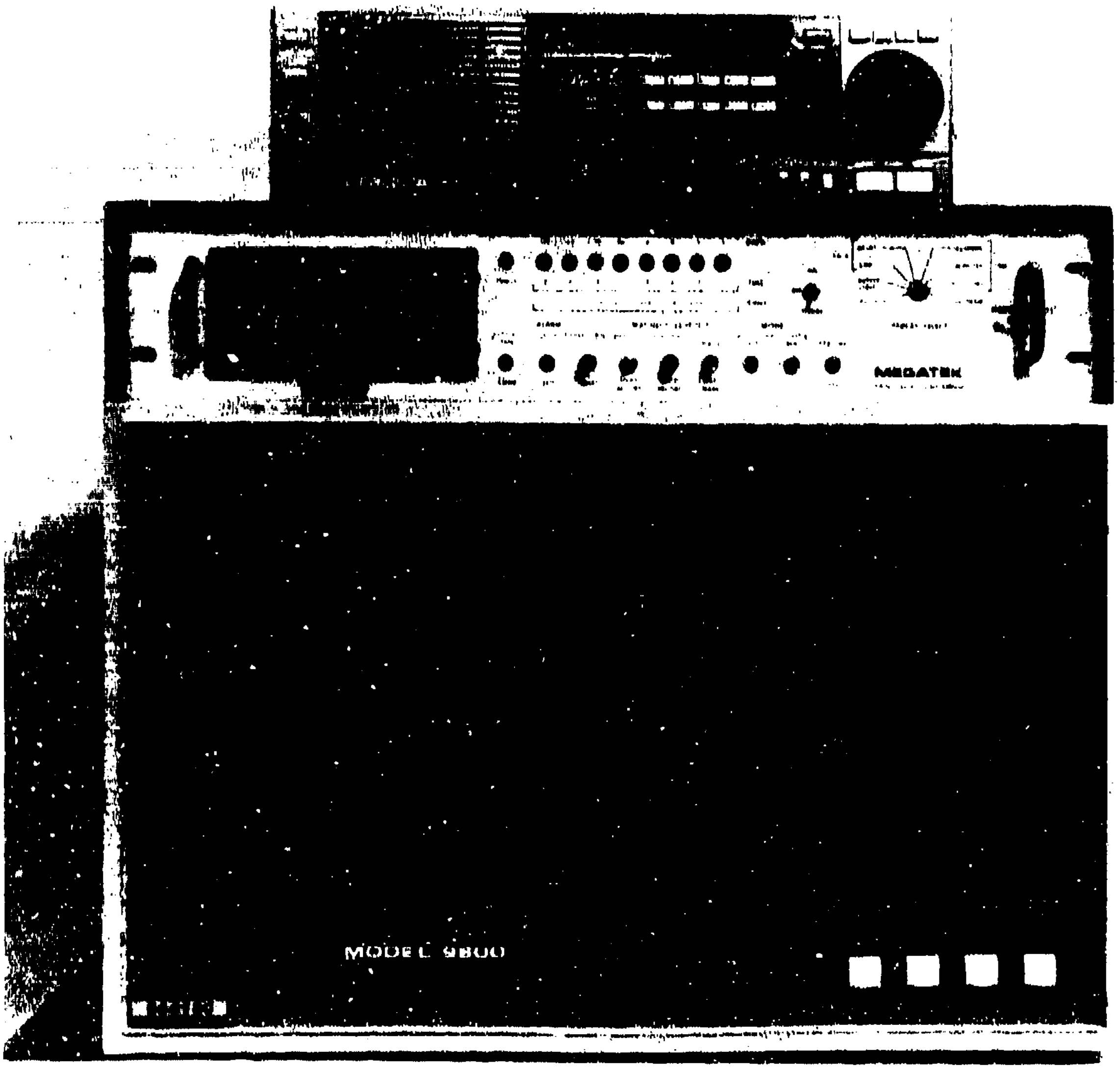


Figure 1. Version 1 absolute time of arrival sensor system.

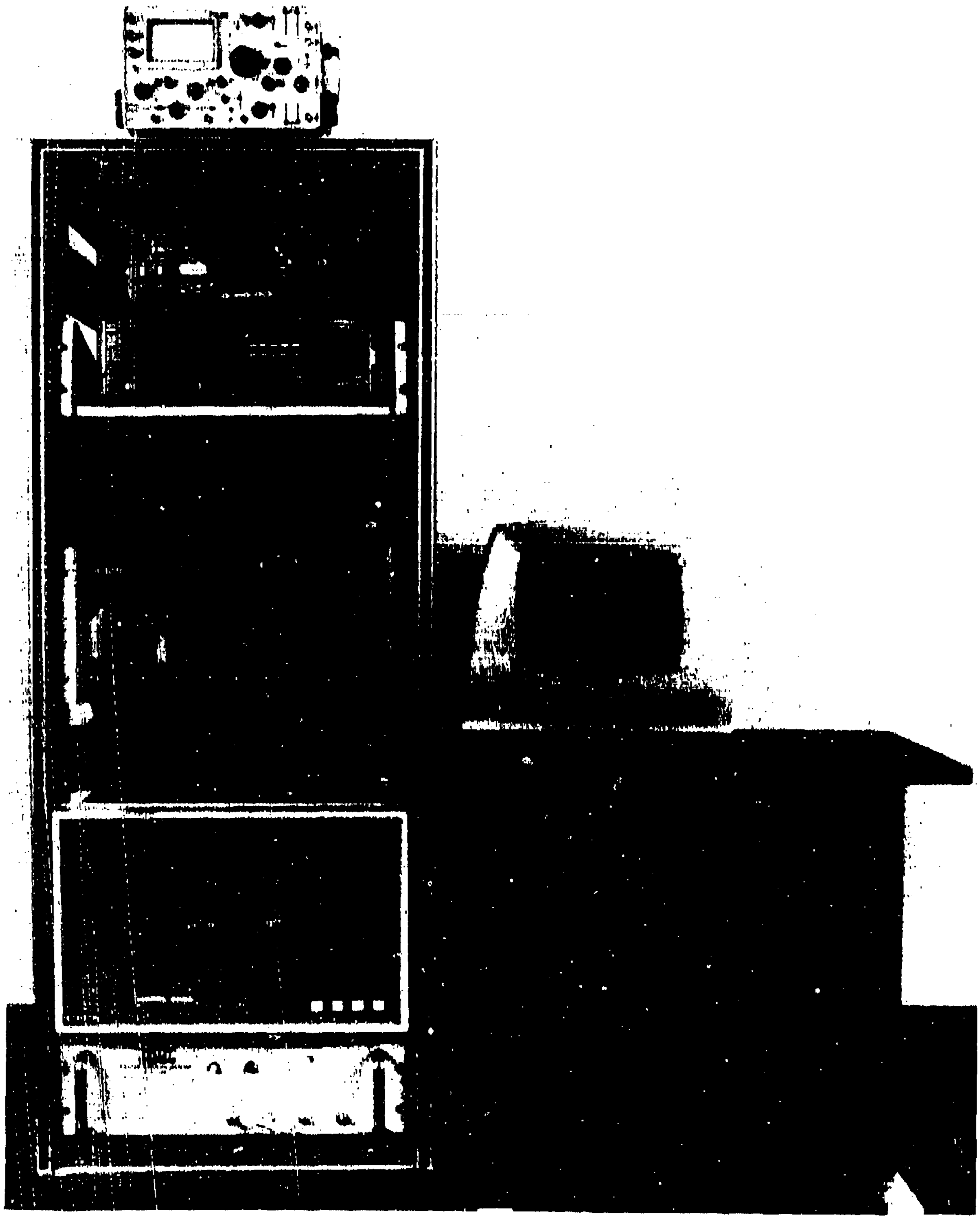


Figure 2. Version 2 Long Baseline Time Of Arrival Sensor (LBTOA) System.

evidenced in this report. Every time-standard "TIC" pulse is fully retained along with (1) time (UT), (2) frequency, (3) signal strength, and (4) frequency shift (Doppler) data. These data have been stored on magnetic tape since the project inception and now represent a sizable bank of information.

HF absolute TOA measurements assume that the precise time the signal is transmitted is known. The use of WWV and JJY TIC pulses make TOA measurement practical. The only required assumption is that the pulse is exactly transmitted at 00:00 seconds. Experience shows the U.S. Time Standard Station at Fort Collins, Colorado (WWV), and the Japanese Time Standard Station in Tokyo, Japan (JJY), are diligent in meeting this stability requirement. This being the case, TOA measurements are a straightforward process when the entire experiment is locked to a Cesium Beam Standard. In addition each station's TIC pulse is slightly different. WWV is a five-cycle pulse, WWVH (Hawaii) is six cycles, whereas JJY is eight cycles. In addition to normal pulse detection schemes that use the leading/falling edges of the pulse, recognition processors are used to identify the right signal for detection. Figure 3 shows examples of the measured WWV and JJY TIC pulses measured in Hawaii.

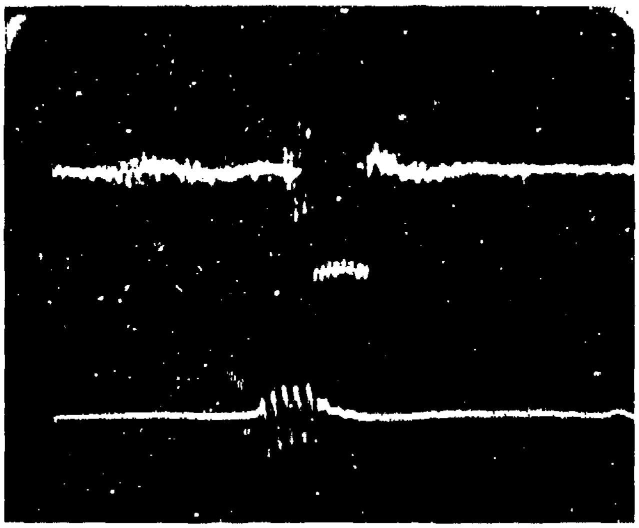
Because of the bizarre nature of the initial results obtained in 1981 and 1982, questions arose as to systematic error and stability of the original TOA system and the subsequent LBTOA hardware. To resolve these issues, care was exercised to identify, resolve, or mitigate error sources. A complete description of the TOA calibration procedures is contained in the appendix of Reference 1. It should suffice for this report to assure the reader that the ionospheric variations shown in subsequent sections are real.

A final consideration for the data presented in this report was collected during the decline of solar cycle 21. This cycle peaked in late 1979-early 1980 with a smoothed sunspot number (SSN) of 165. By March 1981, when the TOA experimentation started, the SSN was 145. By October 1983, when the LBTOA was started, the SSN had dropped to 58. It was apparent at that time, that the JJY signal had degraded significantly when compared to hearability tests conducted a year earlier. At this writing, the SSN is below 30 with conditions near solar minimum. Therefore, it is expected that solar cycle variations will be seen on the TOA data and to a lesser extent on the LBTOA data.

PURPOSE AND STRUCTURE OF THIS REPORT

This report is an extension of the data presented in Reference 2. It is primarily intended as a compilation of data gathered from May 1981 until mid-1985. The purpose of this report is to summarize and present the data and some analysis from the TOA and LBTOA experimentation. The report will contain examples of how the data are processed, examples of different propagation phenomena, and a complete set of TOA and LBTOA monthly average plots. While this report represents 4 years of experimentation, the effort continues.

Initially, this entire effort was started to develop statistically significant numbers on expected ionospheric uncertainty. This has been accomplished to a degree



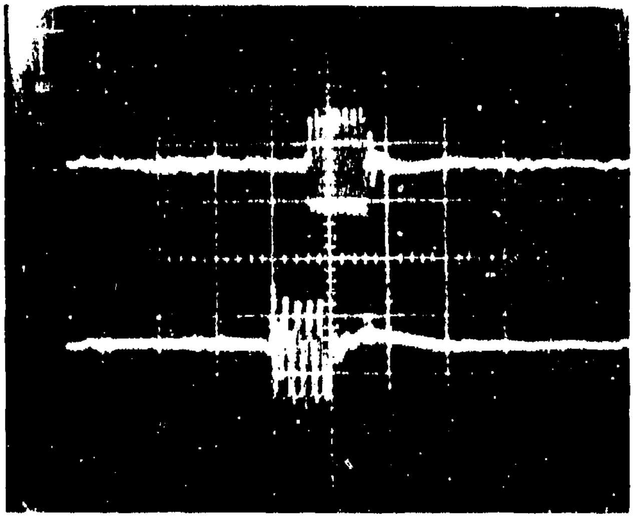


Figure 3. WWV and JJY time standard "TIC" pulses.

sufficient to allow HF geolocation system designers to know the constraints on the time-sensitive systems. However, it turned out that the TOA and LBTOA systems were highly sensitive ionospheric sensors. A new degree of temporal resolution is achieved when the medium is probed at 1-second intervals. Analysts have had the opportunity to try different time integration intervals to achieve the highest resolution in sensing ionospheric variation. The result is that a 2-minute integration time provided the ionospheric "focal point," allowing detailed viewing of both slowly varying and rapidly varying components of movement.

From this work emerges a picture of ionospheric movement that is very nontraditional. The reader will have difficulty in reconciling the data presented in this report and the traditional methods of typifying the ionospheric medium. It will be seen that the ionosphere moves much more than originally thought, is much more layered than is traditionally assumed, and has a very short temporal correlation period. This report will probably generate more questions than it answers. This is intended. The extensive databases developed under the TOA and LBTOA programs should be scrutinized by the entire HF signals research community to derive the maximum use of information.

DESCRIPTION OF THE DATA

Several types of data will be depicted in this report. Singular examples will be used to illustrate certain phenomena. However, because one objective of this report is to serve as a reference document, as much of the data as possible has been compiled into monthly average plots for the period between May 1981 and February 1985; 113 monthly average plots have been derived from the TOA sensor. The remaining portions of this section will be grouped according to sensor type.

ONE HOP TIME OF ARRIVAL (TOA) DATA

The data presented in this section consist of measurements of absolute propagation time over a 1394 km path for HF radio signals between 2.5 and 20 MHz. The signals originated from the National Bureau of Standards Time Standard Station, WWV at Fort Collins, Colorado, and were received at Naval Ocean System Center, San Diego.

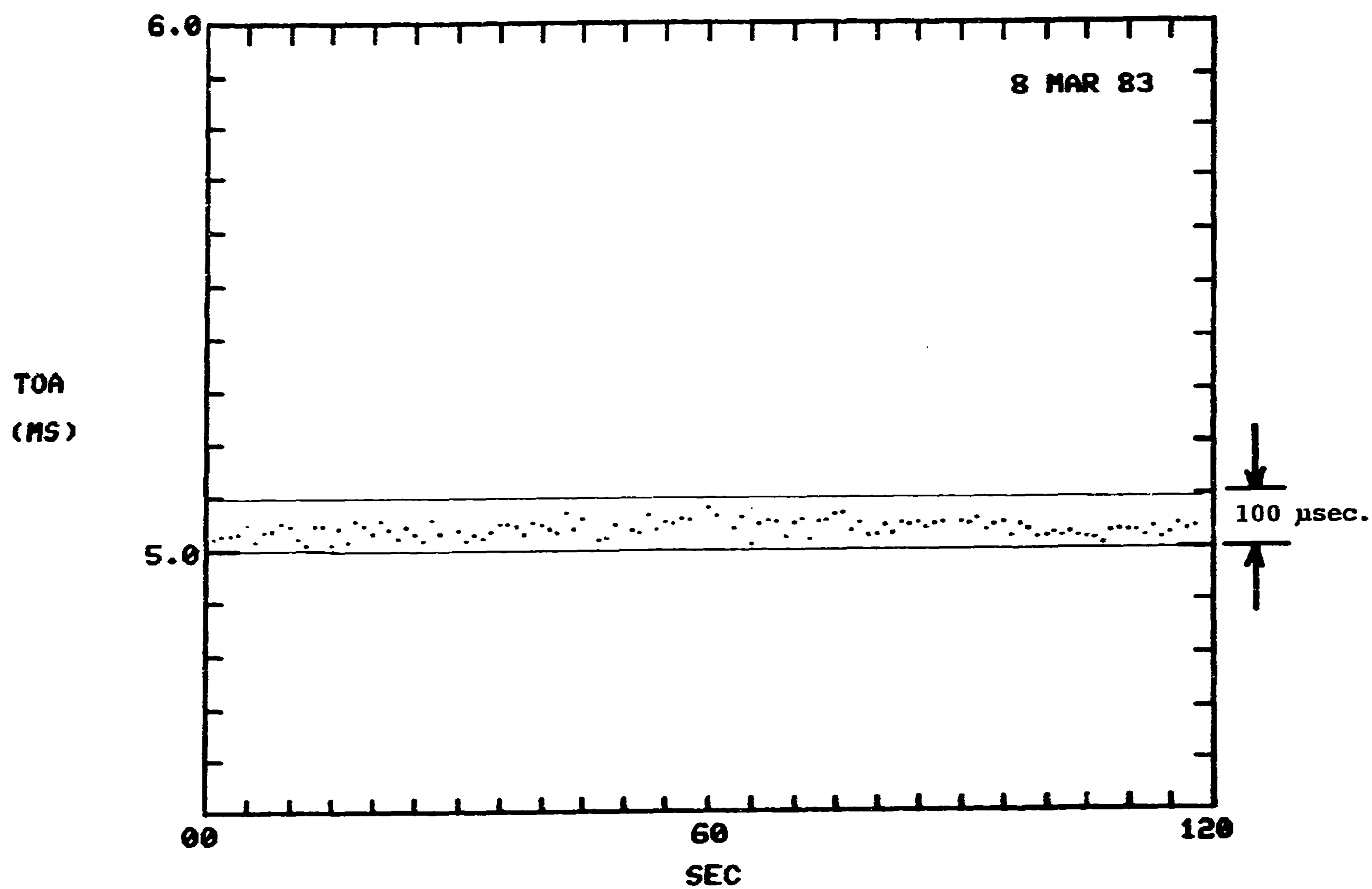
The bases for the measurements are the once a second (1/sec) "TIC" pulses present on the transmissions. These TICs correspond to 5 cycles of a 1-kHz tone which are accurately controlled by a primary frequency standard. A primary frequency standard is also maintained at the receiving site and the experimental procedure consists of determining the TOA of these pulses with respect to the local absolute second.

Primary detection of the 1/sec TIC is done first by recording the time in microseconds, after the second peak occurs, in the AM detected signals. These were accumulated, along with the time of day information, on magnetic tape. To minimize extraneous data, the received signals are windowed about the expected propagation time (4 to 12 milliseconds).

A threshold is used in the peak detection system so that only signals above a certain level will be detected. This eliminates low level noise. However, the system is still subject to high level noise. To reduce this problem, time averaging is used. The times when peaks were detected were accumulated over 2-minute periods. This creates enhancements in reoccurring events while random noise generally presents a low level background. The averaged data were then processed by searching for peak accumulations which matched the signature of the transmitted TIC. Figure 4 has been included to show what makes up a typical 2-minute TOA sample. This is a relatively stable example of 15-MHz signals and it is noted that the second-to-second "wander" is contained within a 100-microsecond window. While this may seem trivial, it should be kept in mind that a 10-microsecond error equates to an approximate 1.5-nmi range error in geolocation systems. Figure 4 implies that in a 2-minute period, the uncertainty in the emitter location due to ionospheric movement is between 10-15 nautical miles. If the observed period is expanded to a 24-minute interval, we can see the impact of sampling at 1-second intervals. Figure 5 shows a plot of all the 15-MHz TIC pulses received during a 24-minute interval. This "scatter-gram" shows the best-case (least) variability at about 25 microseconds, a nominal value of 50 microseconds, and excursions of up to 100 microseconds.

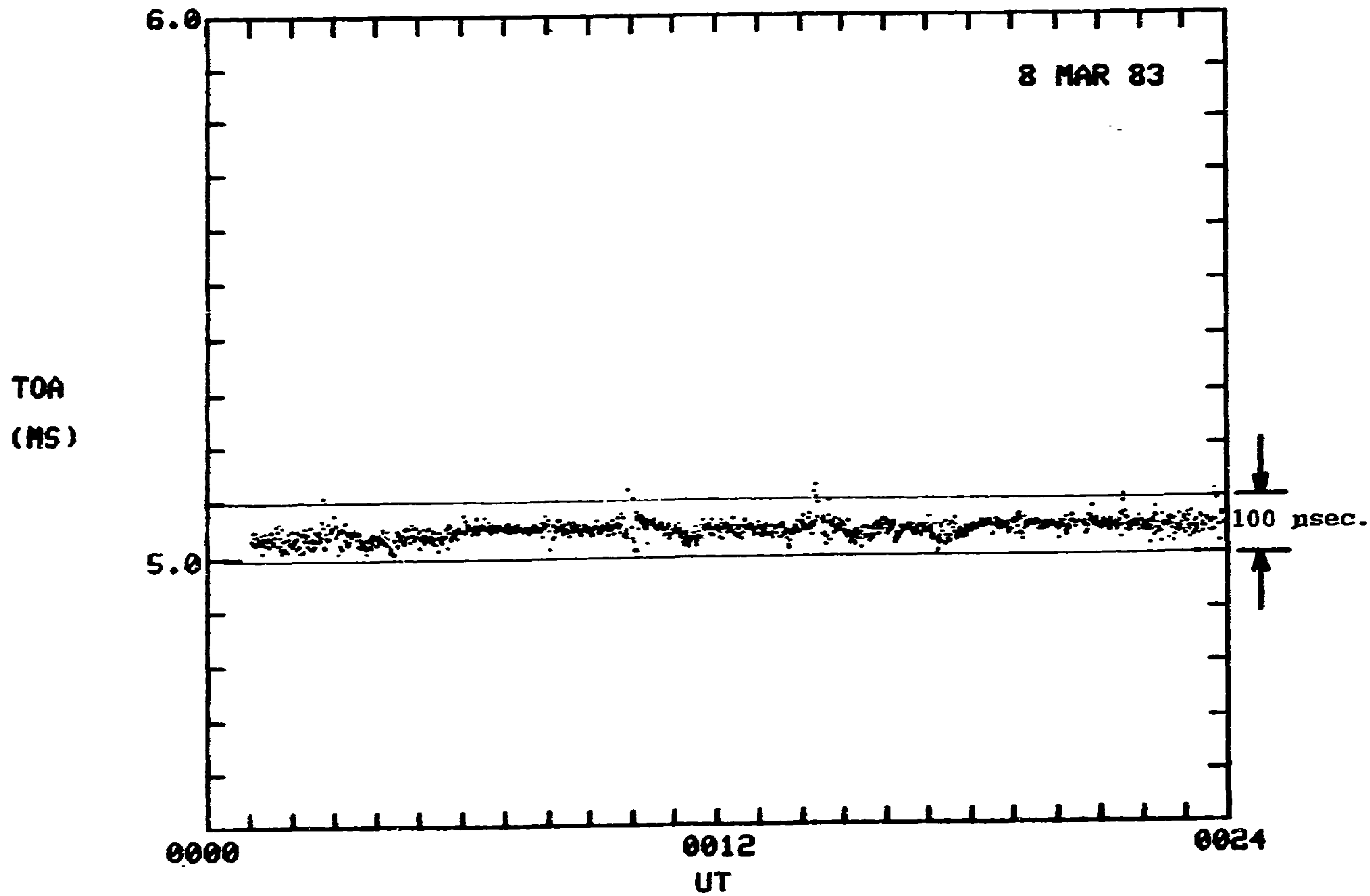
For the first year of operation, the TOA sensor could only sample one frequency at a time. The system would use two frequencies, normally 5 and 15 MHz, to assure continuous TOA sensing throughout the day. In early 1983, the receiver system was upgraded to provide microprocessor-controlled scanning. This allows 4 frequencies to be monitored sequentially, being revisited every 4 seconds. Figure 6 shows two days of four-frequency data. Here the 2-minute averages are plotted as a function of time. The important feature to note in Figure 6 is how each frequency (or more correctly the ionospheric control points) seems to vary almost independently of each other. TOAs of approximately 4.8 milliseconds are E-region modes. Above 5.0 milliseconds, TOAs are from the F-region. A later section will discuss some of these features in more detail. For now, it is only necessary to know that the TOA data shown in Figure 6 are fairly typical. The 510-microsecond TOA shift in the 10-MHz signal in Figure 6(a), between 0000UT and 0330UT equates to a range uncertainty of approximately 75 nautical miles. The uncorrelated movement at different reflection heights is illustrated in Figure 6(b) when 5, 10 and 15 MHz are compared between 14 and 17 UT. The period between 19 UT and 24 UT shows the same type of movement.

The principal product to be used for this report will be isometric population plots showing monthly averages of TOA as a function of time of day and time of arrival population. To achieve the desired monthly compilations, special processing was used. The initial processing consisted of performing a cross correlation of the TIC signature's 5-unit height events, spaced 1 millisecond apart; with the averaged data over the windowed period. Peaks in this cross-correlation function then locates areas within the average data which matches the TIC signature. For the significant peaks, the mean of the leading accumulation of pulses was calculated along with a count of the number of events which occurred within the pulse. If at least 10 percent of the expected events were within this pulse, TIC detection was assumed at



Frequency (MHz): 15

Figure 4. Plot of individual "TIC" pulses over a two minute period (relatively stable propagation).



Frequency (MHz): 15

Figure 5. Plot of individual WWV "TIC" pulses over a 24 minute period (relatively stable propagation).

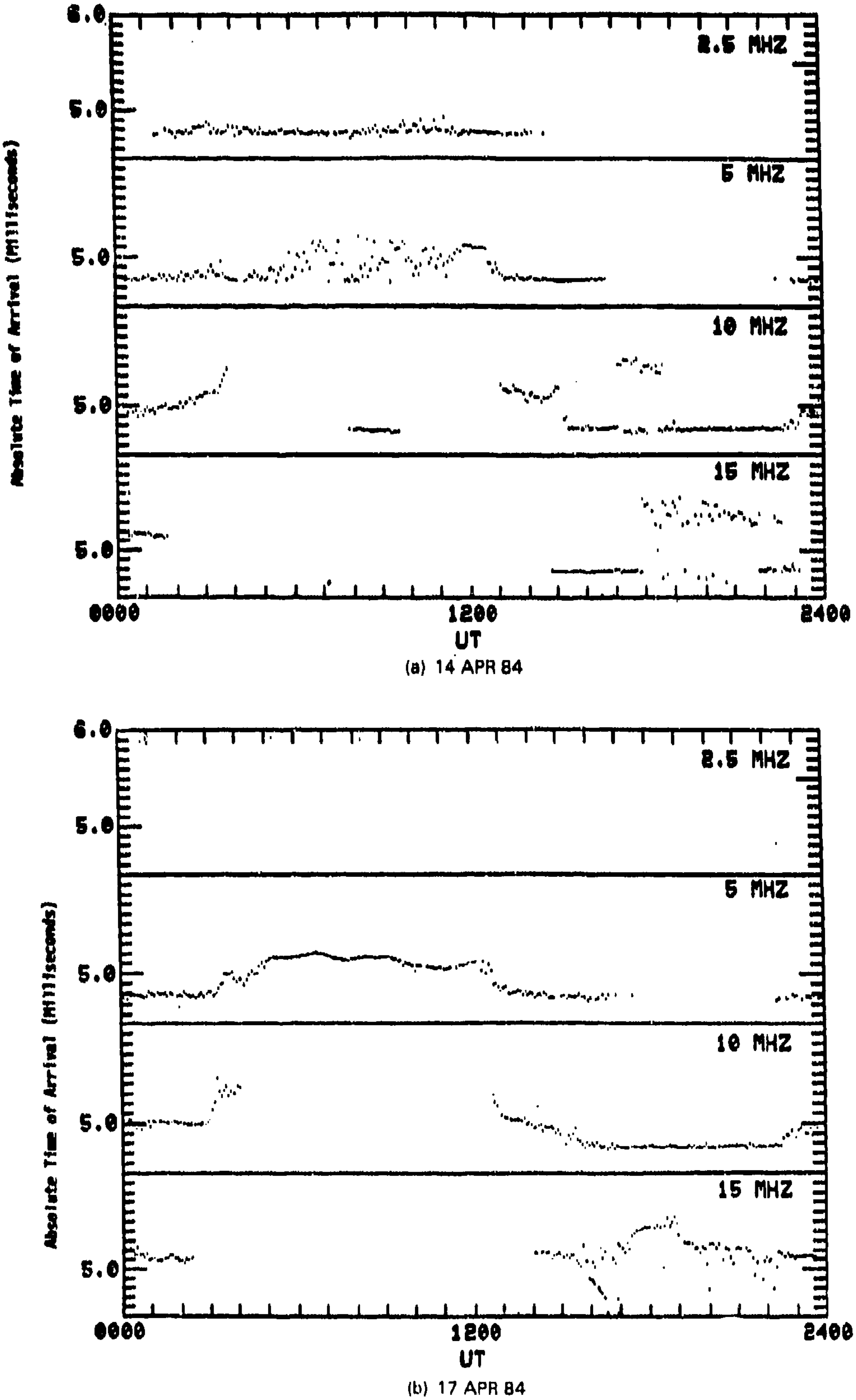


Figure 6. Four frequency absolute time of arrival plots (Ft. Collins, CO. to NOSC).

a propagation delay time equal to the calculated mean. Subsequent peaks in the cross-correlation function were examined in a like manner in case additional modes were propagating at different delays with sufficient amplitude to be detected by this system. The collection of 113 path months of these type data formed the basis for the monthly averages discussed in the next section. Table 1 contains a complete listing of the data to be presented.

Table 1. TOA DATA LISTING

(5/15 MHz) SINGLE CHANNEL	2.5 MHz	5.0 MHz	10 MHz	15 MHz	20 MHz
May 81	Feb 84	Apr 83	Jan 83	Apr 83	May 83
Jul 81	Mar 84	May 83	Feb 83	May 83	Jun 83
Aug 81	Apr 84	Jun 83	Apr 83	Jun 83	Jul 83
Oct 81	May 84	Jul 83	May 83	Jul 83	Aug 83
Nov 81	Jun 84	Aug 83	Jun 83	Aug 83	Sep 83
Dec 81	Jul 84	Sep 83	Jul 83	Sep 83	Oct 83
Jan 82	Aug 84	Oct 83	Aug 83	Oct 83	
Feb 82	Sep 84	Nov 83	Sep 83	Nov 83	
Mar 82	Oct 84	Dec 83	Oct 83	Dec 83	
Apr 82	Nov 84	Jan 84	Nov 83	Jan 84	
May 82	Dec 84	Feb 84	Dec 83	Feb 84	
Jun 82	Jan 85	Mar 84	Jan 84	Mar 84	
Jul 82	Feb 85	Apr 84	Feb 84	Apr 84	
Aug 82		May 84	Mar 84	May 84	
Sep 82		Jun 84	Apr 84	Jun 84	
Oct 82		Jul 84	May 84	Jul 84	
Nov 82		Aug 84	Jun 84	Aug 84	
Dec 82		Sep 84	Jul 84	Sep 84	
Jan 83		Oct 84	Aug 84	Oct 84	
Feb 83		Nov 84	Sep 84	Nov 84	
Mar 83	Nov 83	Dec 84	Oct 84	Dec 84	
	Dec 83	Jan 85	Nov 84	Jan 85	
		Feb 85	Dec 84	Feb 85	
			Jan 85		
			Feb 85		

113 Monthly Average Plots

DISCUSSION OF TOA DATABASE

The following section discusses the TOA database shown in Figures 7 through 122. The database spans data collected between May 1981 and February 1985. The data collection has some minor gaps due to equipment problems and tape outages which occurred overnight and weekends when the system was not attended. The largest gap in the data was in 1981 when data for part of the month of August and all of September were lost due to equipment problems.

The routine from May 1981 until early 1983 consisted of operation at 15 MHz during daylight hours and 5 MHz at night. In early 1983 the system was reconfigured to measure the delays for several frequencies sequentially. From that point on, data were collected either at 2.5, 5.0, 10.0, and 15.0 MHz or 5.0, 10.0, 15.0, and 20.0 MHz depending on when the measurement was made in the solar cycle. Therefore, the remaining discussion will look at the data blocked accordingly:

1.	Bi-frequency	May 1981 - Apr 1983
2.	10 MHz	Jan 1983 - Feb 1985
3.	15 MHz	Apr 1983 - Feb 1985
4.	5 MHz	Apr 1983 - Feb 1985
5.	2.5 MHz	Feb 1984 - Feb 1985
6.	20 MHz	May 1983 - Dec 1983

BI-FREQUENCY TOA DATA (FIGURES 7-27)

The most surprising aspect of the initial data collected for this program was the regular existence of a night E-mode. This is not to be confused with sporadic E (Es) which appears to peak in the May, June, and July months at the latitudes at which the measurements were made. Between May 81 and May 82 the night E mode remains although a gradual decline is noted. Regular E can be distinguished from sporadic E by the standard deviation (σTD) of the TOA. Regular E will have σTDs of 15-20 microseconds. Sporodic E will have about half that variation.

The impact of this finding is that present ionospheric modeling does not weigh the influence of E-region propagation heavy enough. Traditionally, the normal HF propagation prediction program treats the E-layer (if it has one at all) as a simple Chapman function layer that has a higher electron density at solar maximum than at solar minimum and for the most part disappears at night. This later assumption appears to be wrong. The winter months of November 1981 through February 1982 show that nighttime propagation (02-15UT) is a variety of E, F, and mixed modes (see Figures 11-14). The typical spread in the TOAs is approximately 50 microseconds for E-modes and in excess of 100 microseconds if a singular F mode can be identified. By the winter of 1982 the solar cycle had sufficiently declined from a SSN of 125 in December 1981 to 80 in December 1982. The occurrence of night E had also almost disappeared (Figures 23-26). From this, it is suspected that the influence of the solar cycle on E region ionization is greater than originally thought and HF prediction models will have to be revised accordingly.

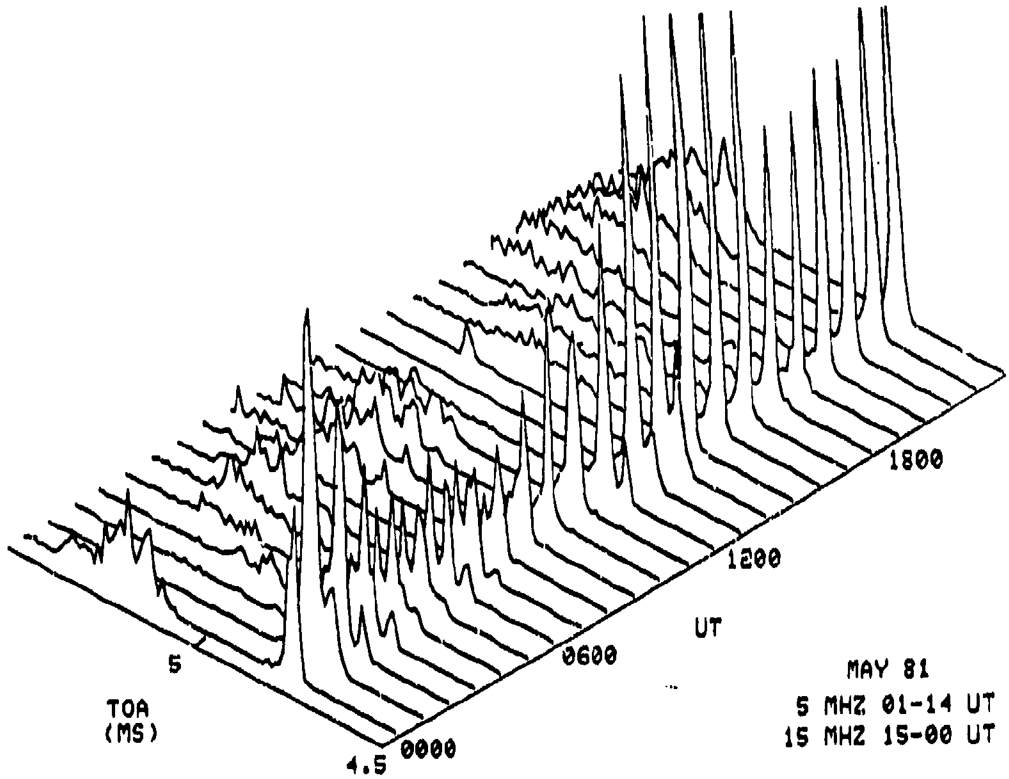


Figure 7. Hourly TOA averages May 1981 — WWV to NOSC.

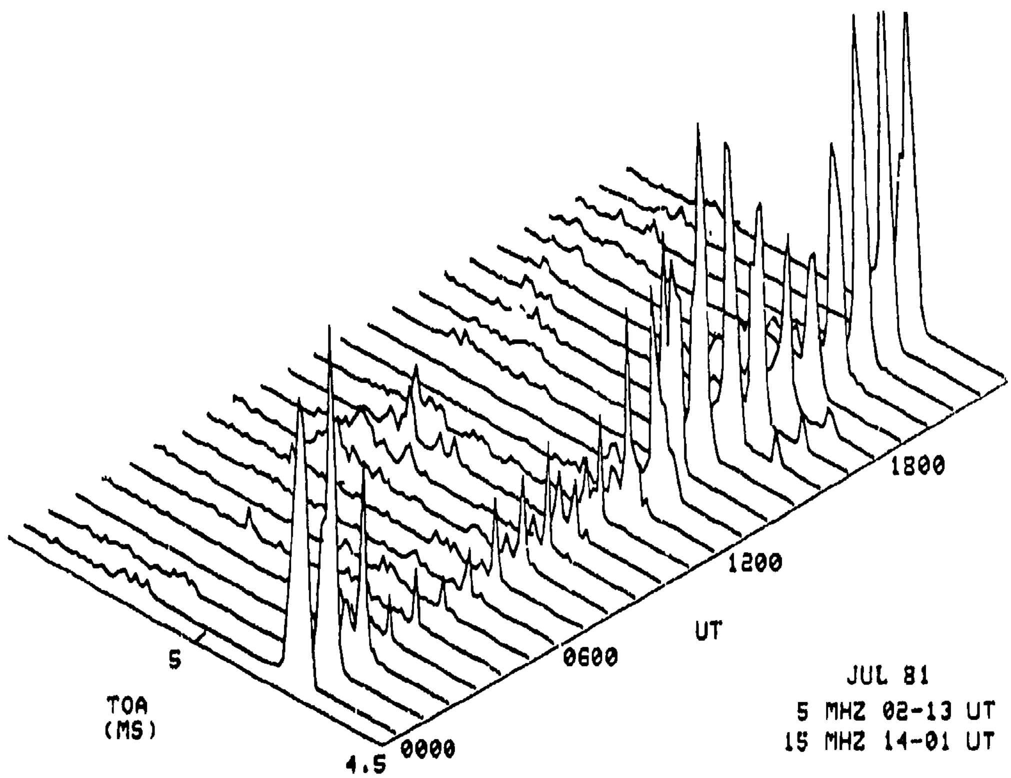


Figure 8. Hourly TOA averages Jul 1981 — WWV to NOSC.

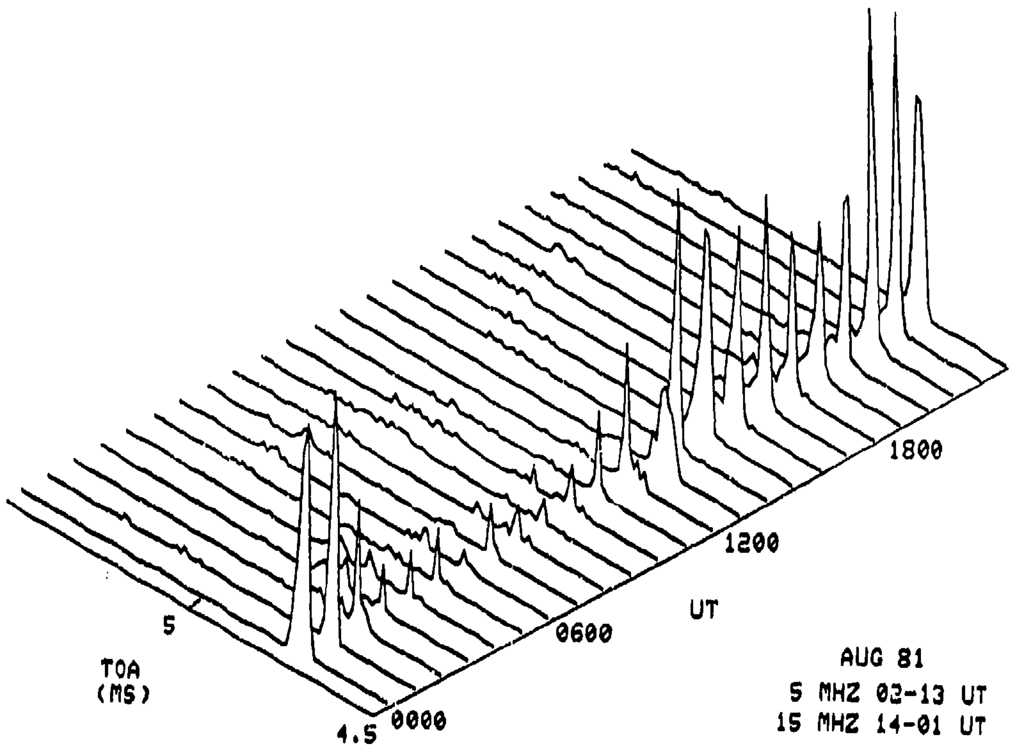


Figure 9. Hourly TOA averages Aug 1981 — WWV to NOSC.

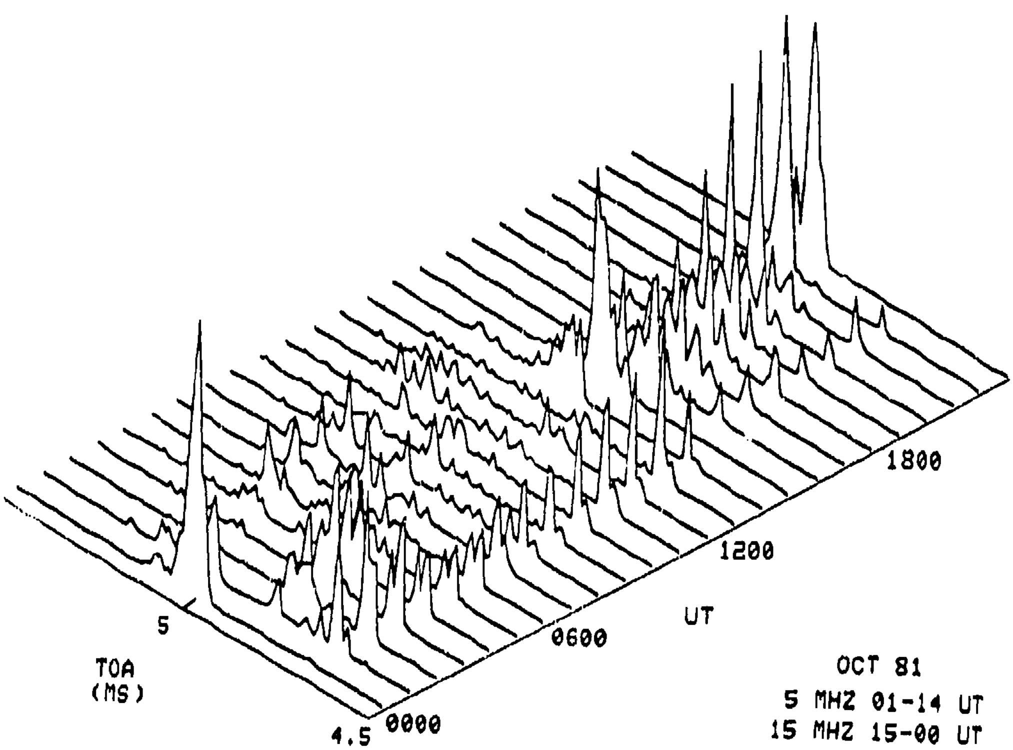


Figure 10. Hourly TOA averages Oct 1981 — WWV to NOSC.

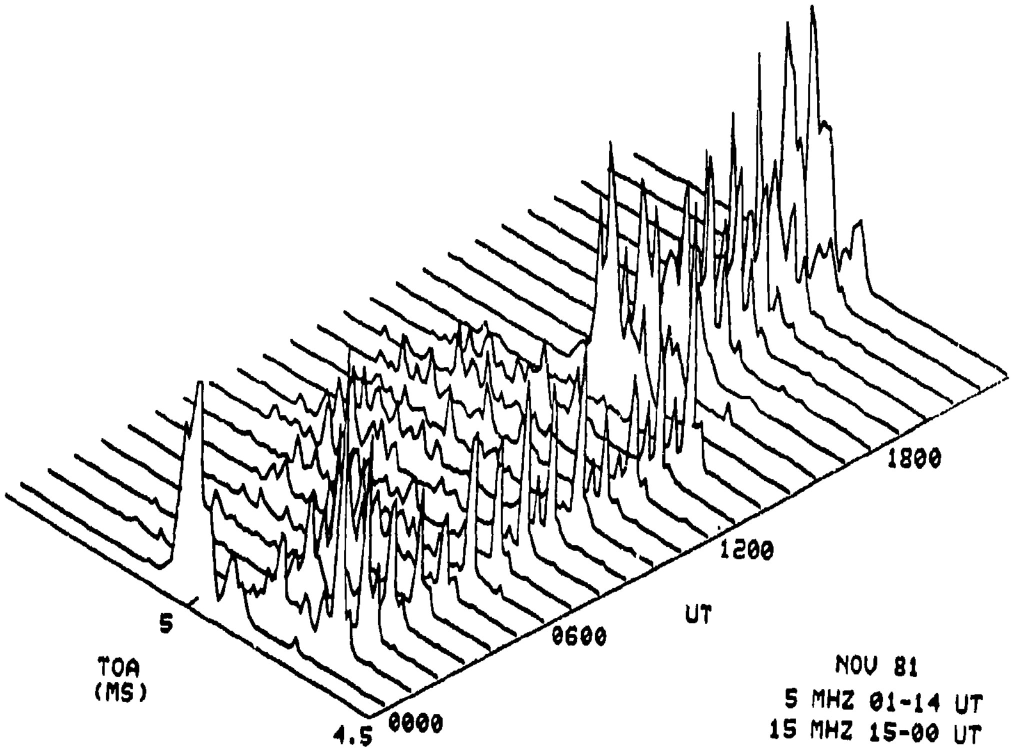


Figure 11. Hourly TOA averages Nov 1981 — WWV to NOSC.

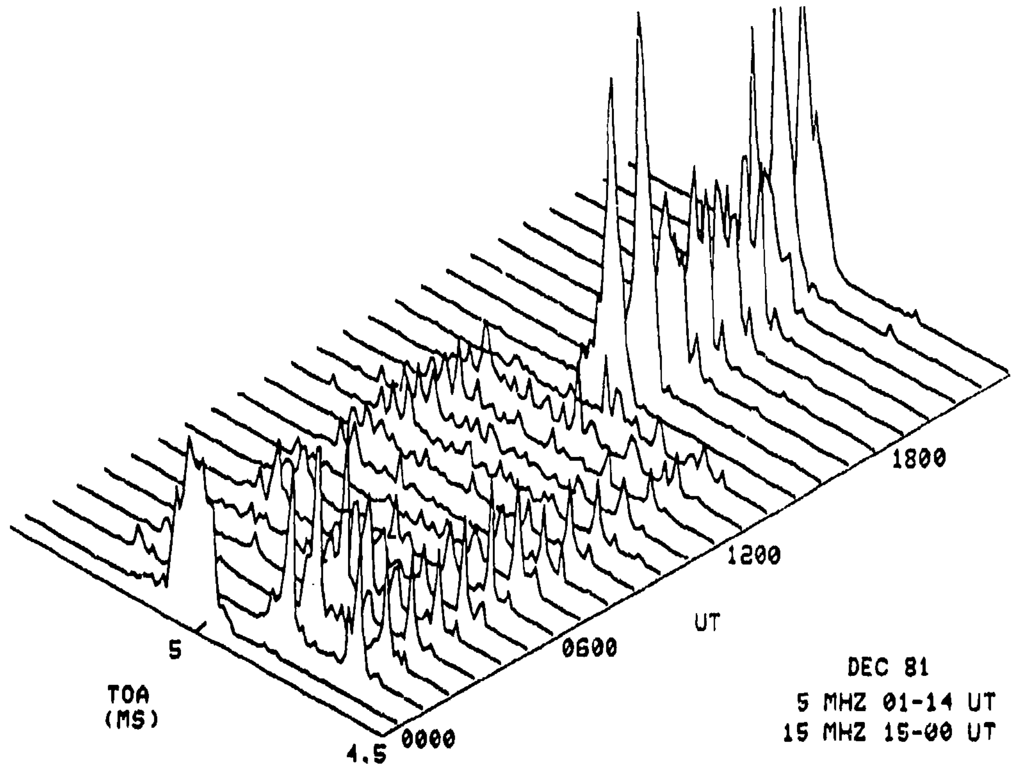


Figure 12. Hourly TOA averages Dec 1981 — WWV to NOSC.

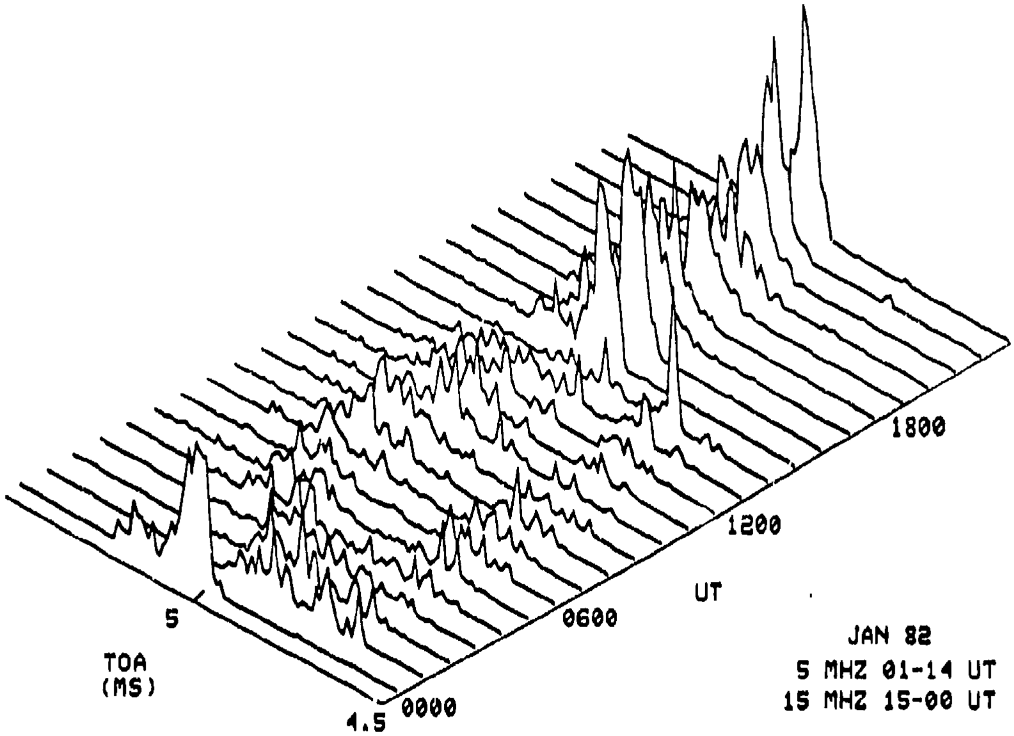


Figure 13. Hourly TOA averages Jan 1982 — WWV to NOSC.

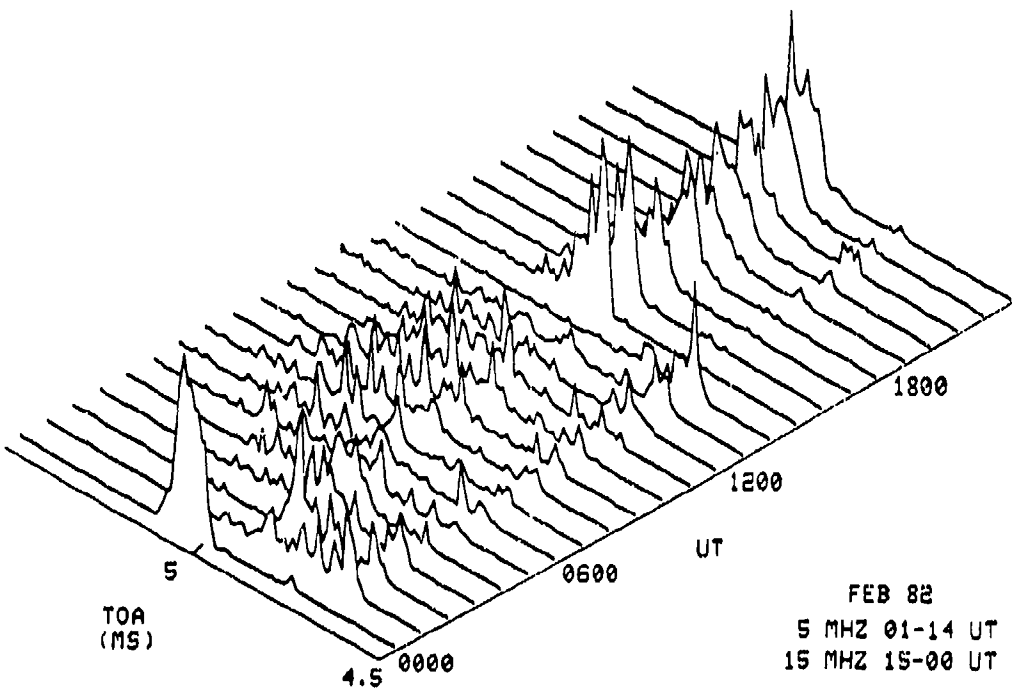


Figure 14. Hourly TOA averages Feb 1982 — WWV to NOSC.

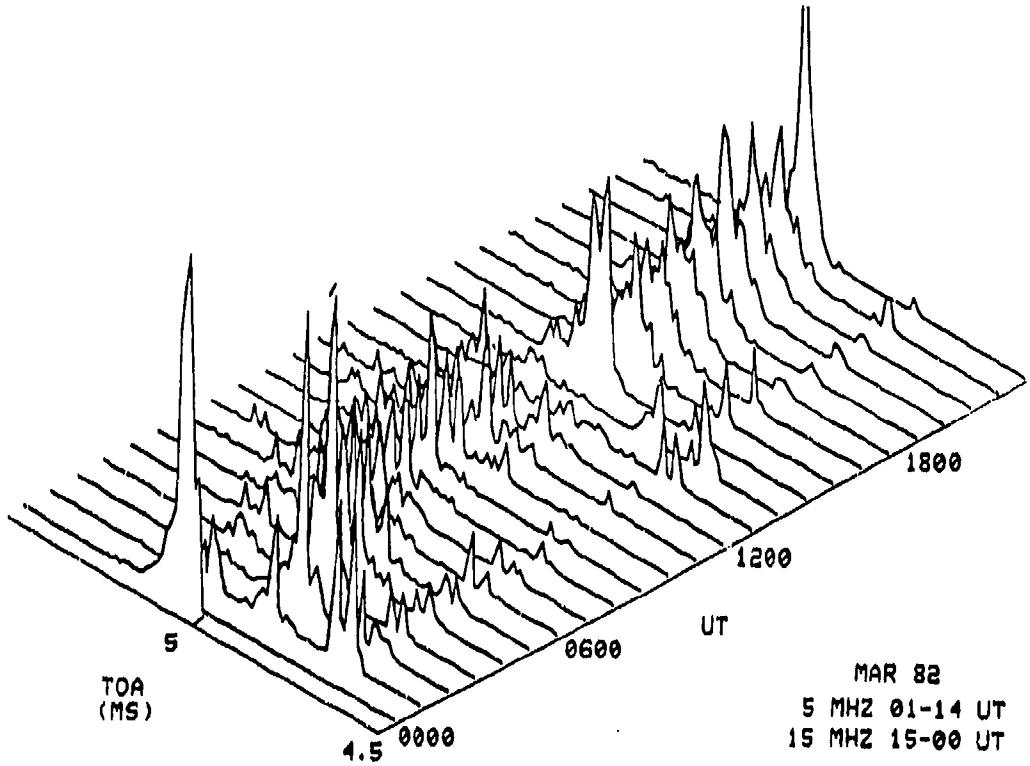


Figure 15. Hourly TOA averages Mar 1982 — WWV to NOSC.

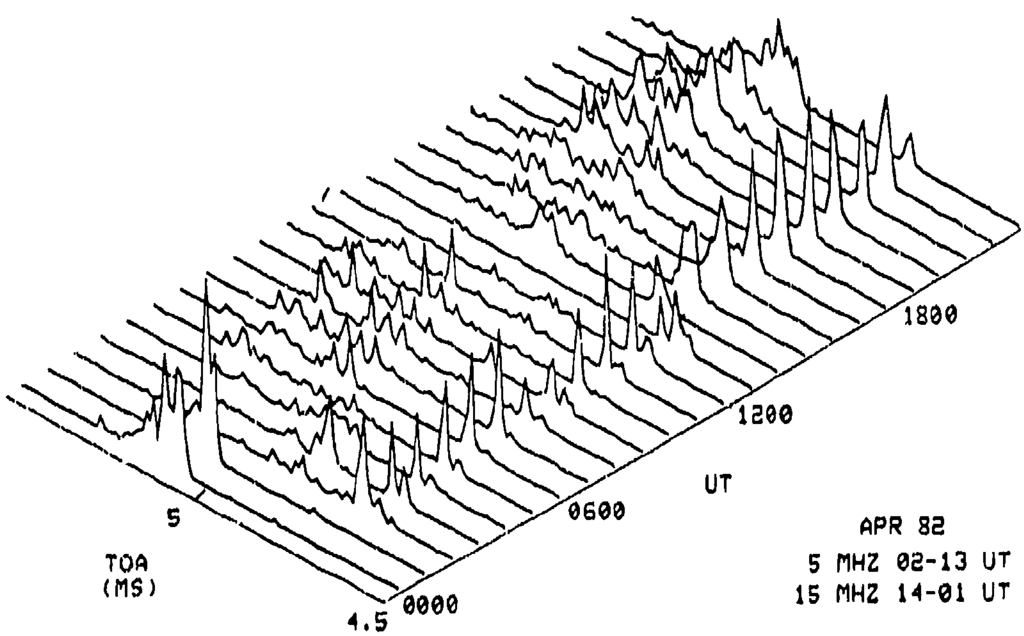


Figure 16. Hourly TOA averages Apr 1982 — WWV to NOSC.

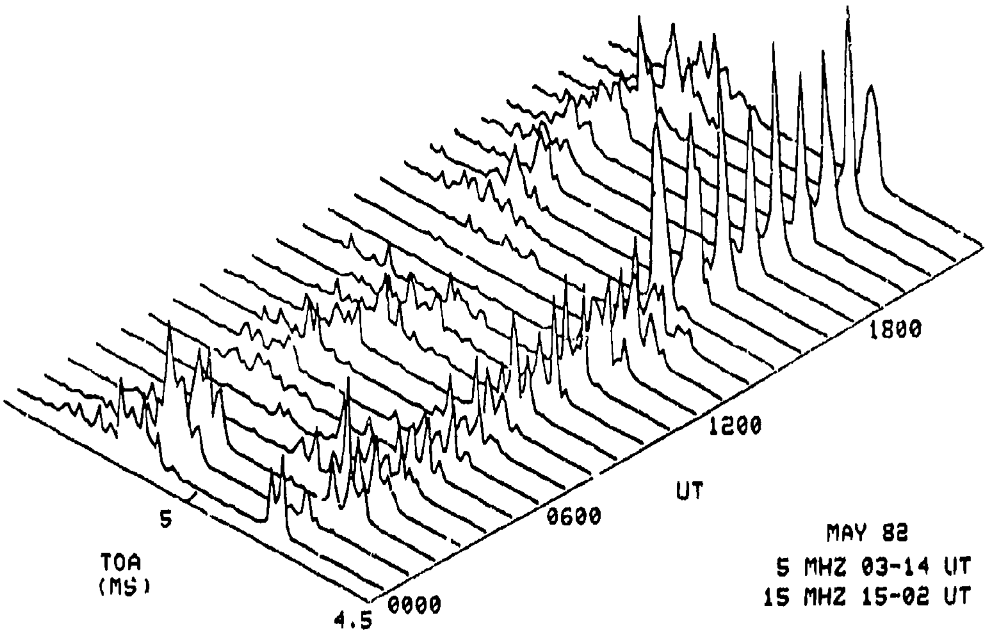


Figure 17. Hourly TOA averages May 1982 — WWV to NOSC.

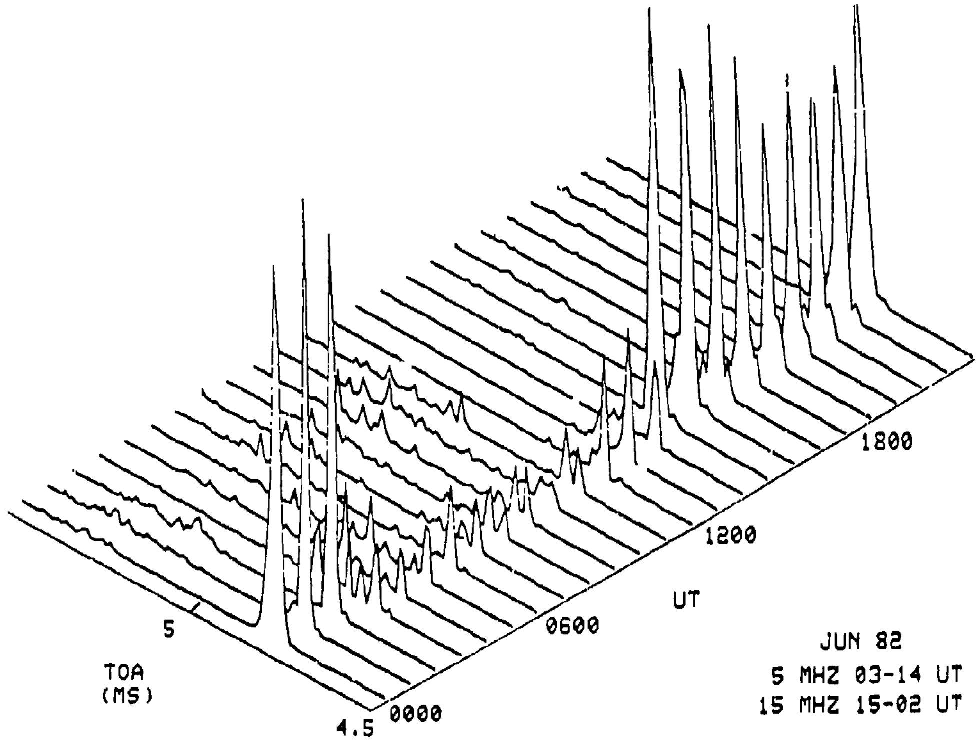


Figure 18. Hourly TOA averages Jun 1982 — WWV to NOSC.

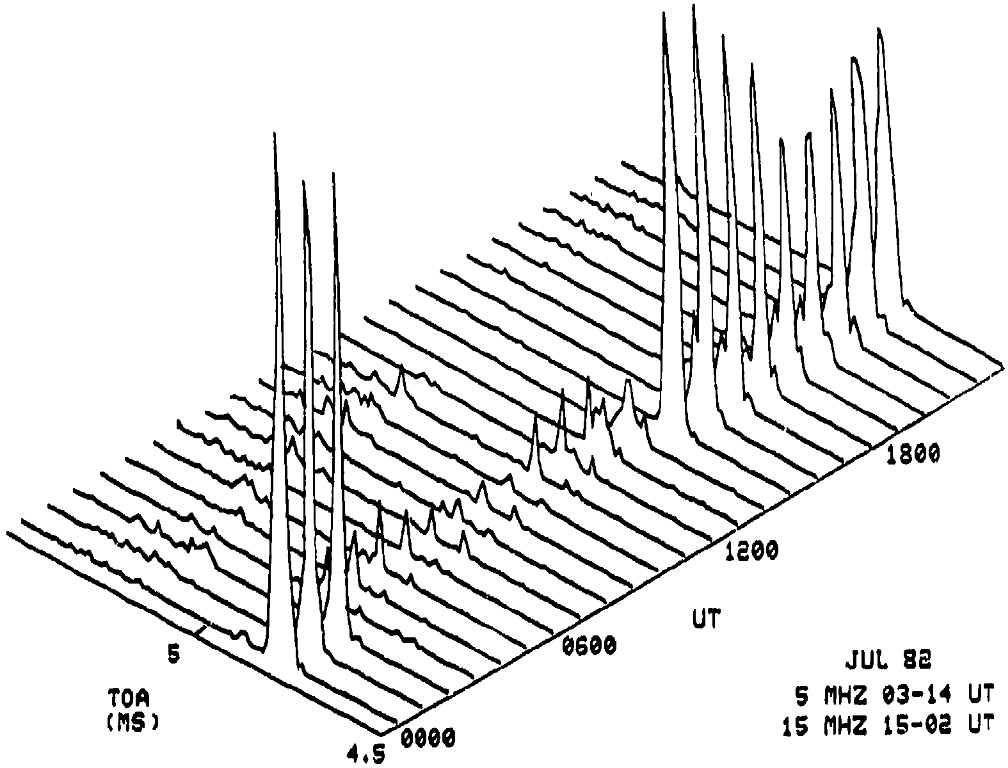


Figure 19. Hourly TOA averages Jul 1982 — WWV to NOSC.

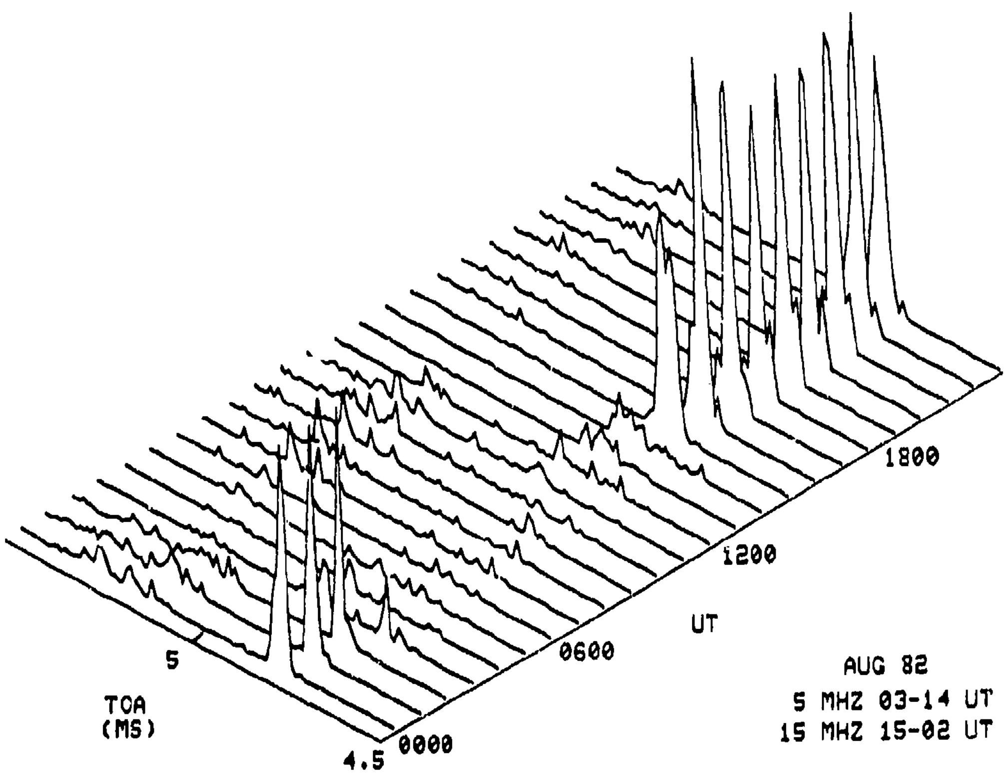


Figure 20. Hourly TOA averages Aug 1982 — WWV to NOSC.

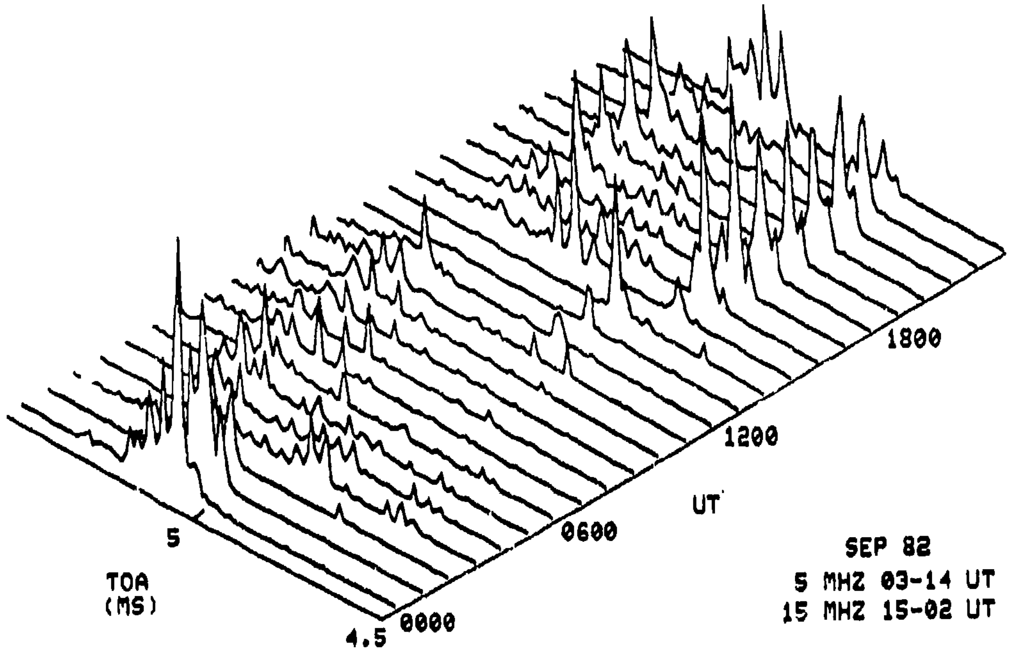


Figure 21. Hourly TOA averages Sep 1982 — WWV to NOSC.

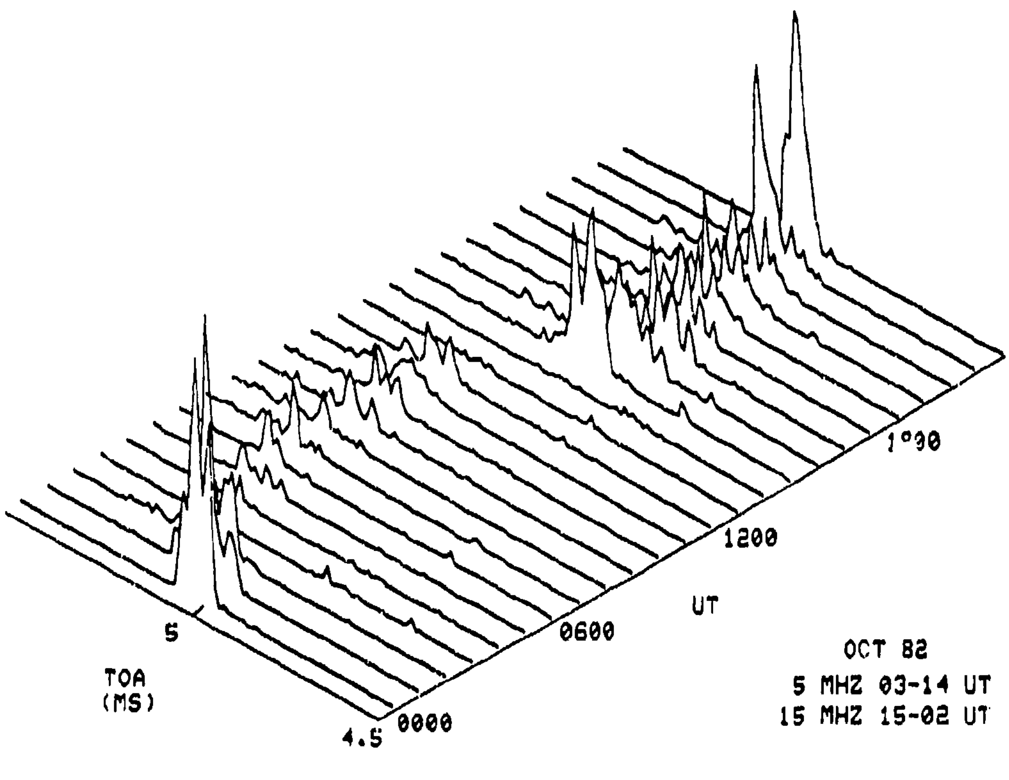


Figure 22. Hourly TOA averages Oct 1982 — WWV to NOSC.

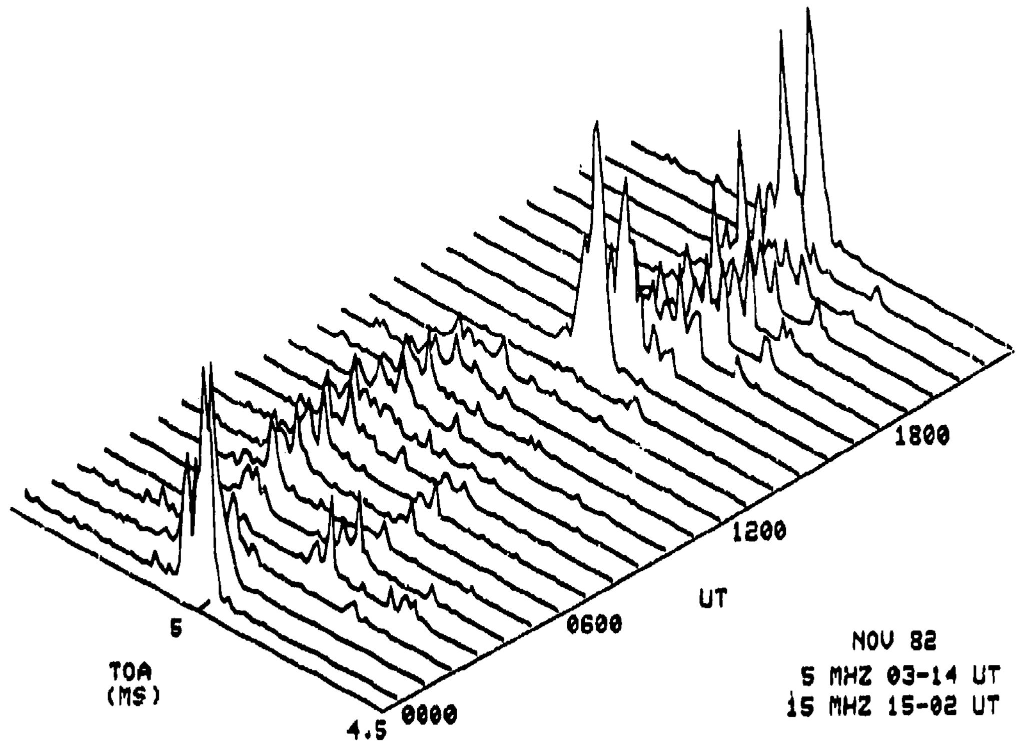


Figure 23. Hourly TOA averages Nov 1982 — WWV to NOSC.

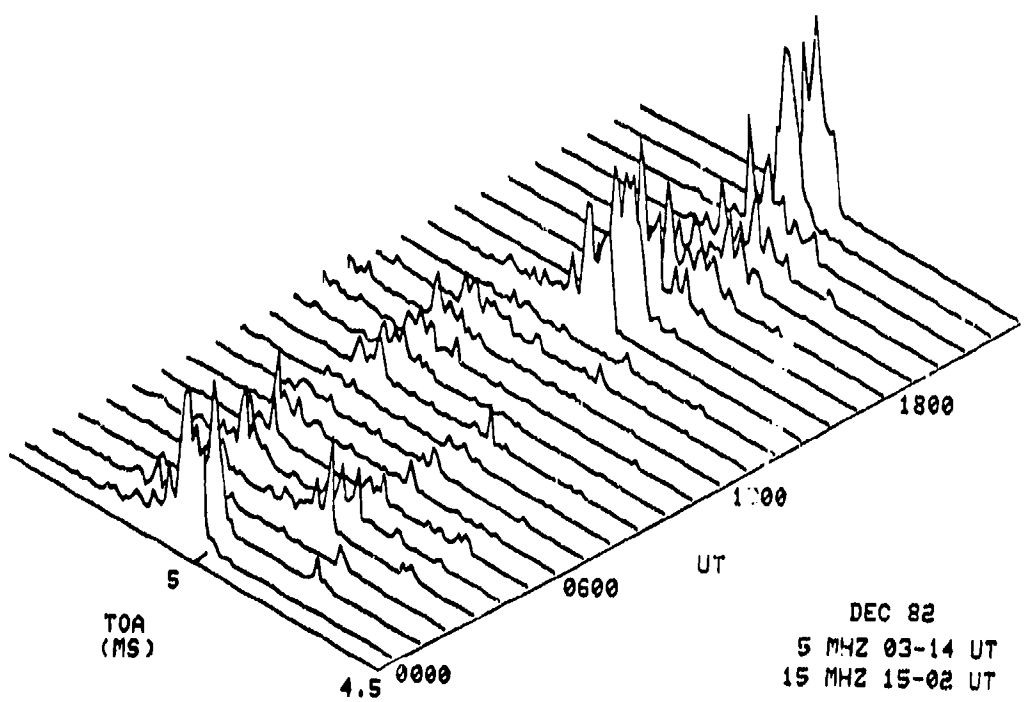


Figure 24. Hourly TOA averages Dec 1982 — WWV to NOSC.

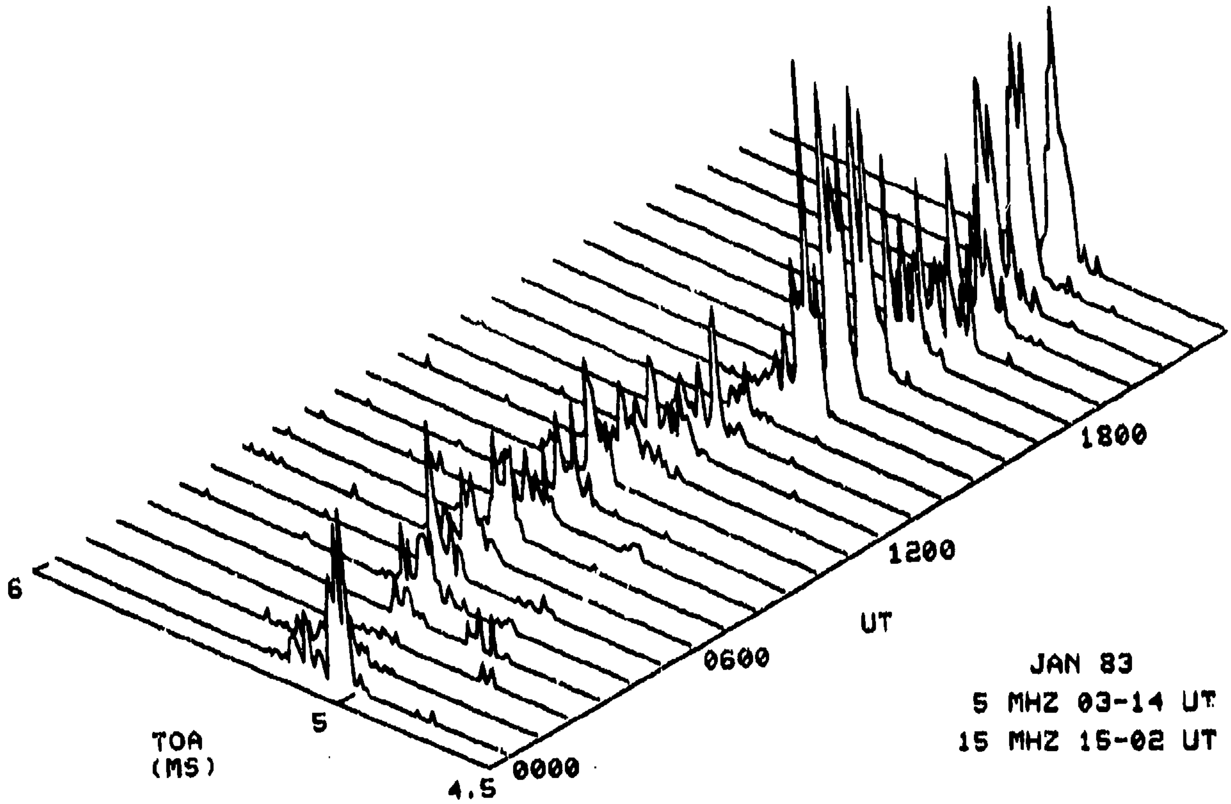


Figure 25. Hourly TOA averages Jan 1983 — WWV to NOSC.

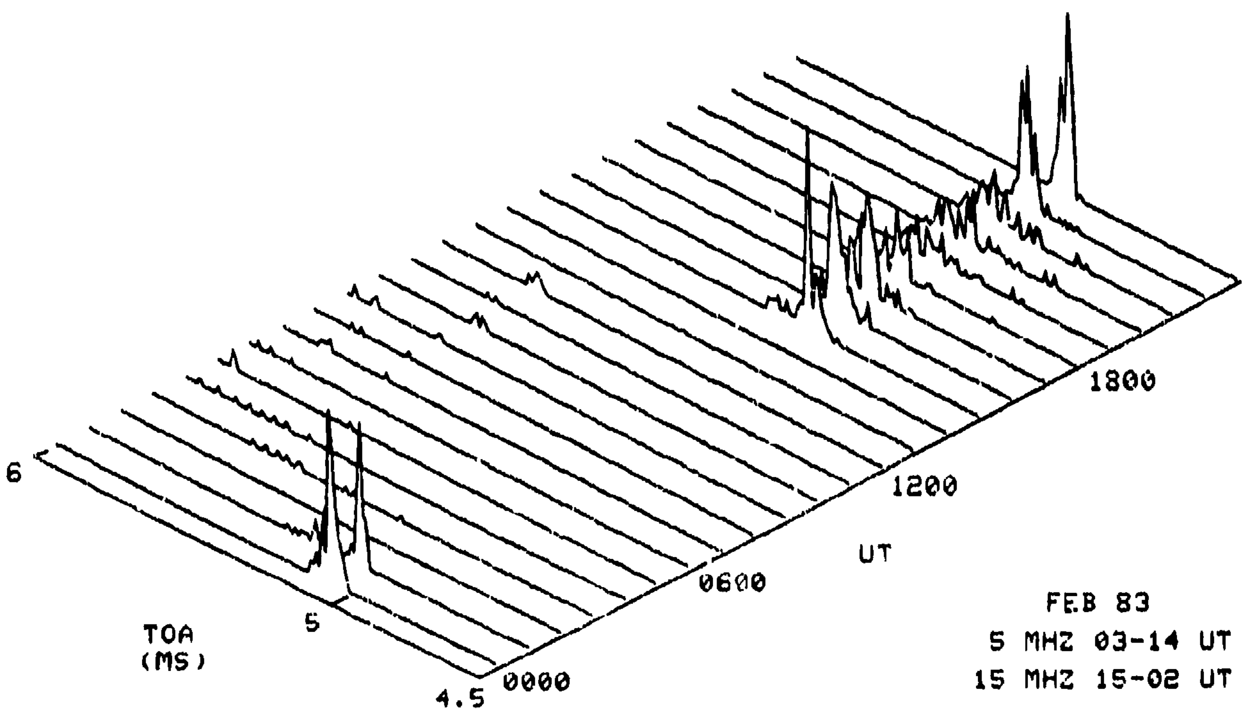


Figure 26. Hourly TOA averages Feb 1983 — WWV to NOSC.

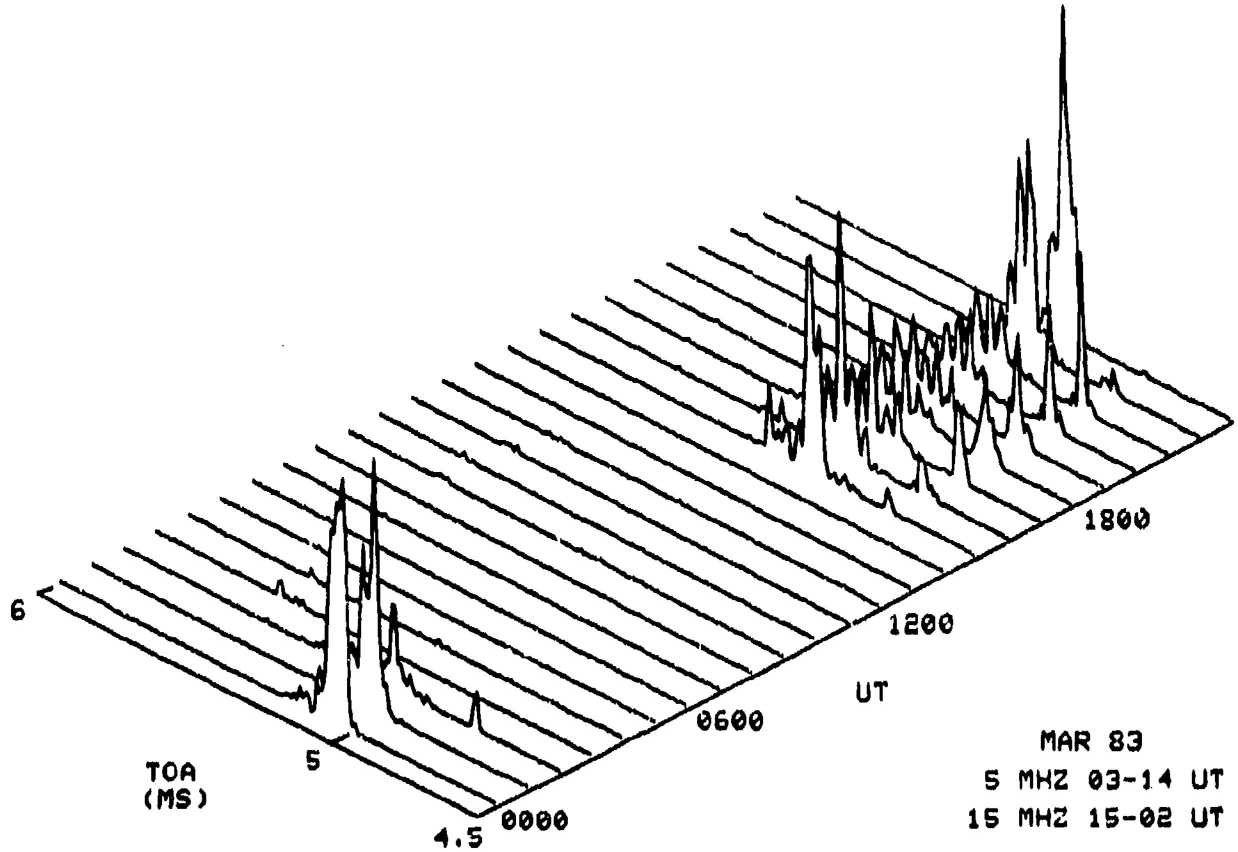


Figure 27. Hourly TOA averages Mar 1983 — WWV to NOSC.

10-MHz TOA (FIGURES 28-52)

Of all the frequencies probed, the 30-meter signals were the most consistent and productive. This single frequency channel has produced data from January 1983 (Figure 28) through February 1985 (Figure 52). Here again the reoccurrence of night time E provided a major surprise. While its durability was somewhat of a surprise at 5 MHz in 1981 and 1982, its consistency on 10 MHz throughout 1983 and 1984 was even more surprising. This indicates that f_oE_s (f_oE_s of 2-3 MHz) at night exists on a routine basis. Most HF assessment systems based on pure physics do not make this provision which means night and sunrise transition estimates can be grossly in error. Experience has shown this to be the case when the accuracy of PROPHET, HFMUFES IV, and ITS-78 were being studied. Even in December 1984 when the SSN had dropped to 36, the nighttime E still persisted.

The winter of 1983/84 (Figures 37-47) shows a precise, repeatable pattern of solid night E and a stable daytime F-region mode. The E-region TOA spread is approximately 50 microseconds while the F-region TOAs are distributed over 120 microseconds. Through February 1985, these trends persist. Throughout the entire data set, the gradual decline due to solar cycle is evident. In 1983, a strong daytime E mode is evident, blanketing F-region modes. In 1984, the E region dominance weakened.

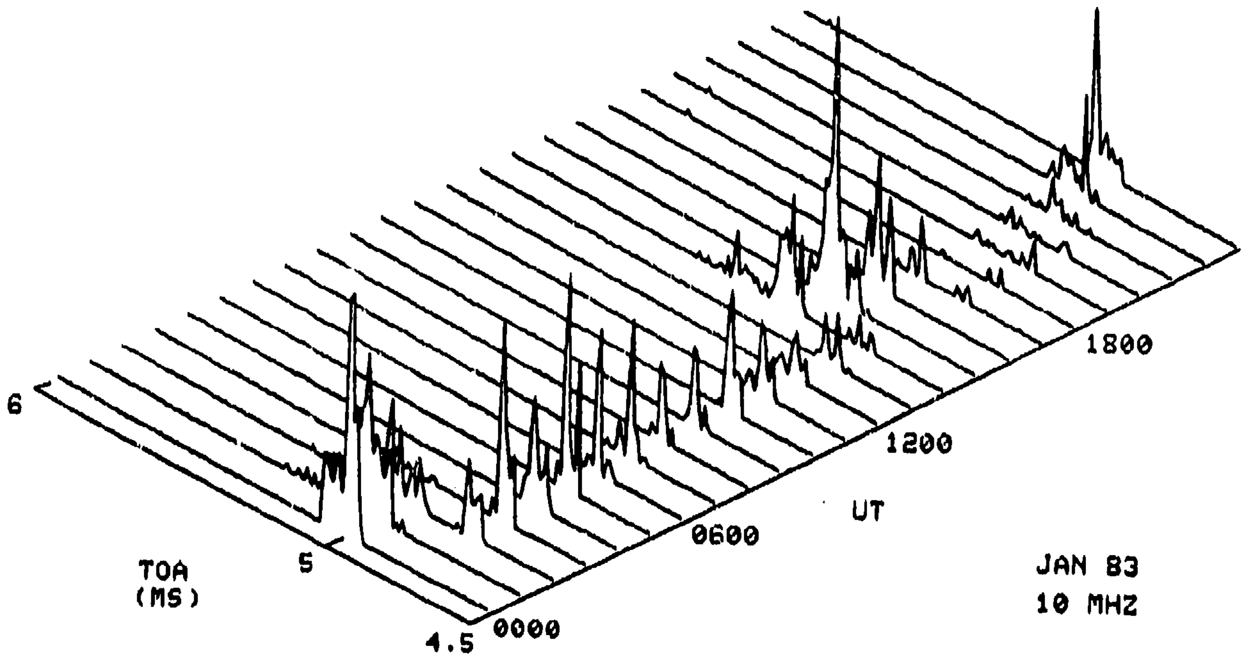


Figure 28. Hourly TOA averages Jan 1983 — WWV to NOSC.

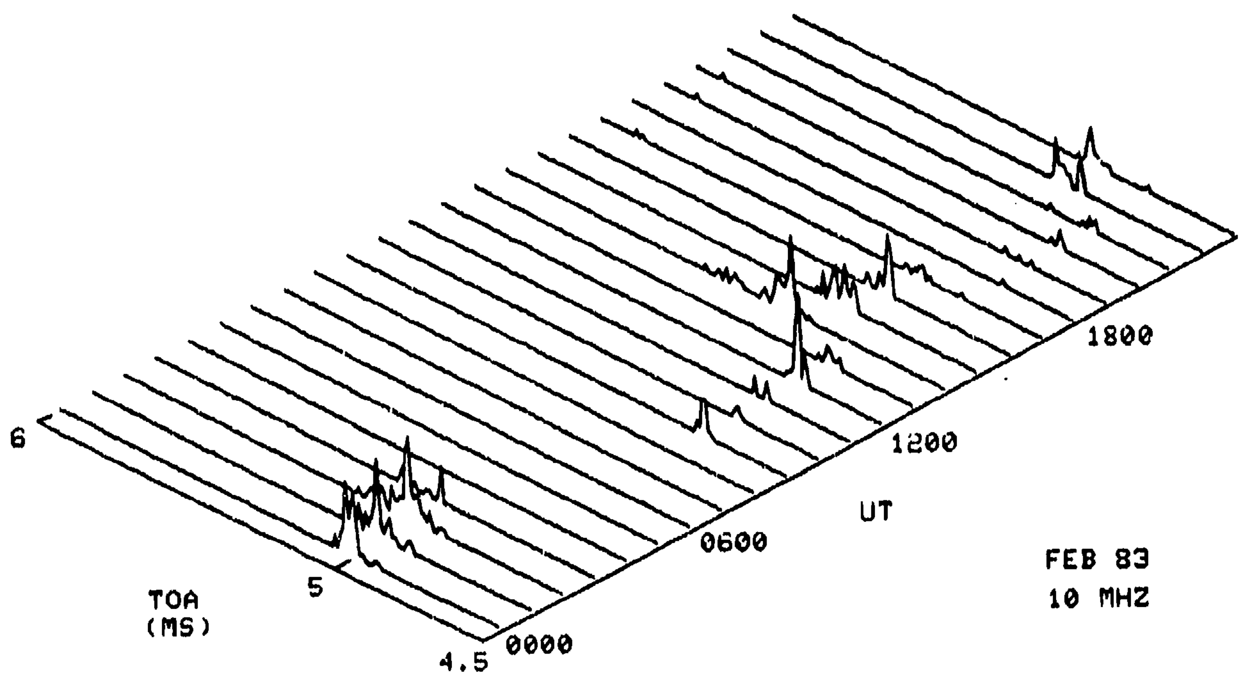


Figure 29. Hourly TOA averages Feb 1983 — WWV to NOSC.

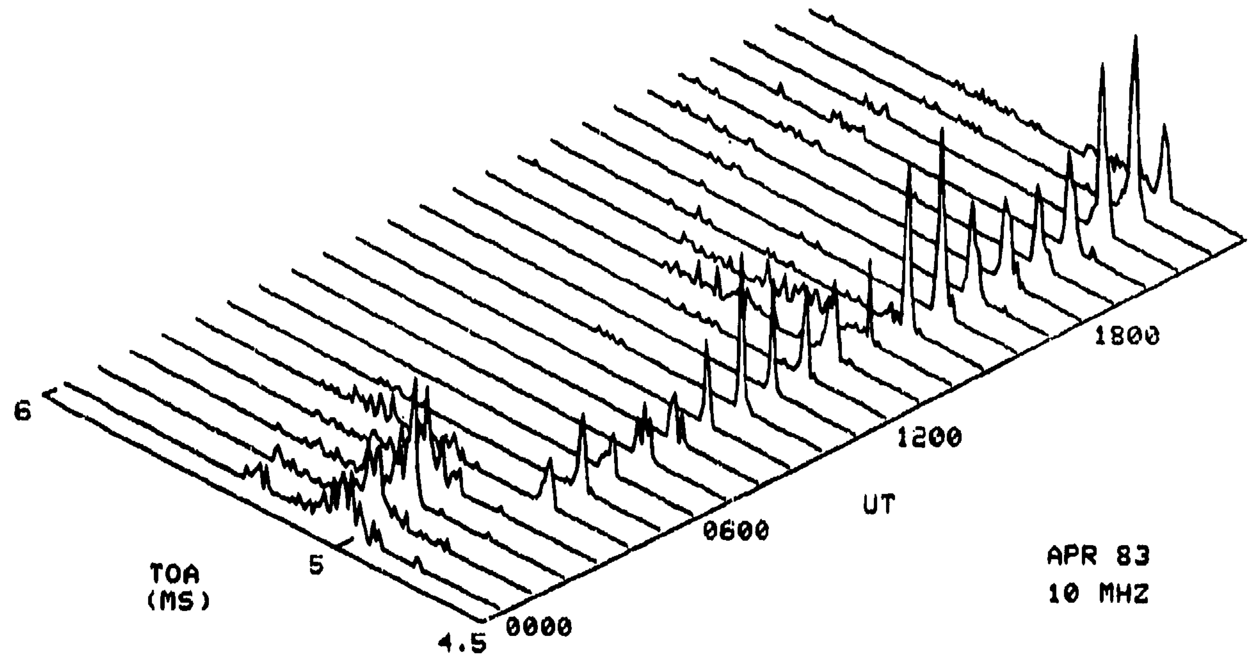


Figure 30. Hourly TOA averages Apr 1983 — WWV to NOSC.

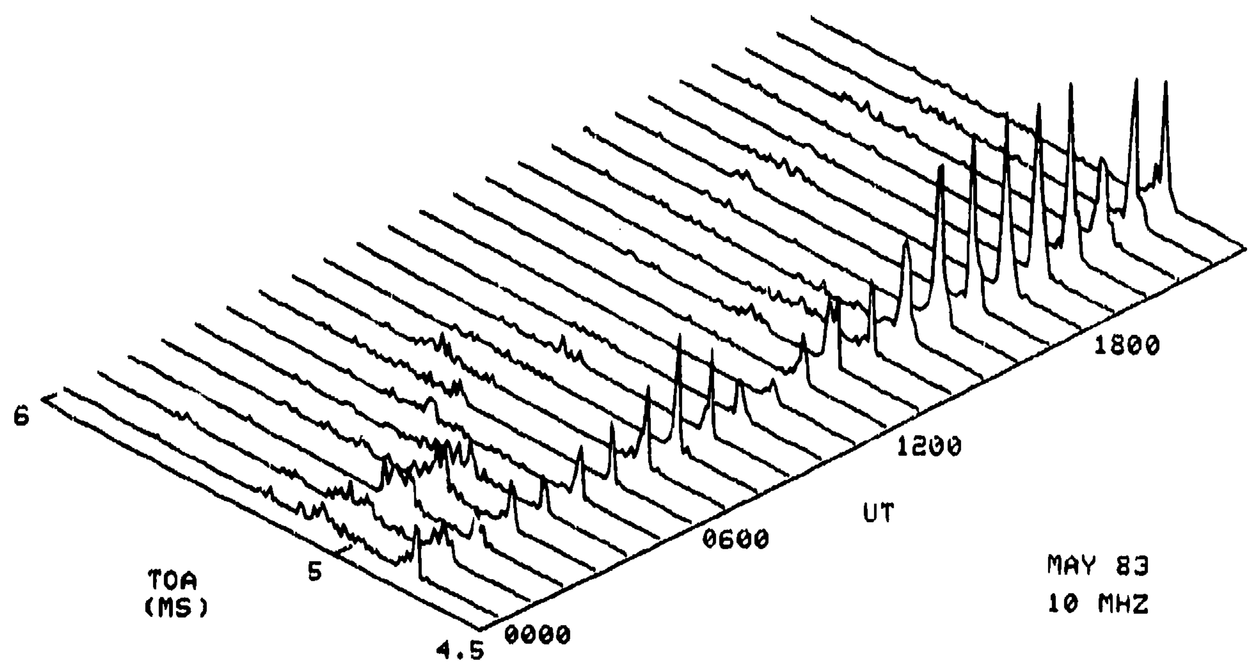


Figure 31. Hourly TOA averages May 1983 — WWV to NOSC.

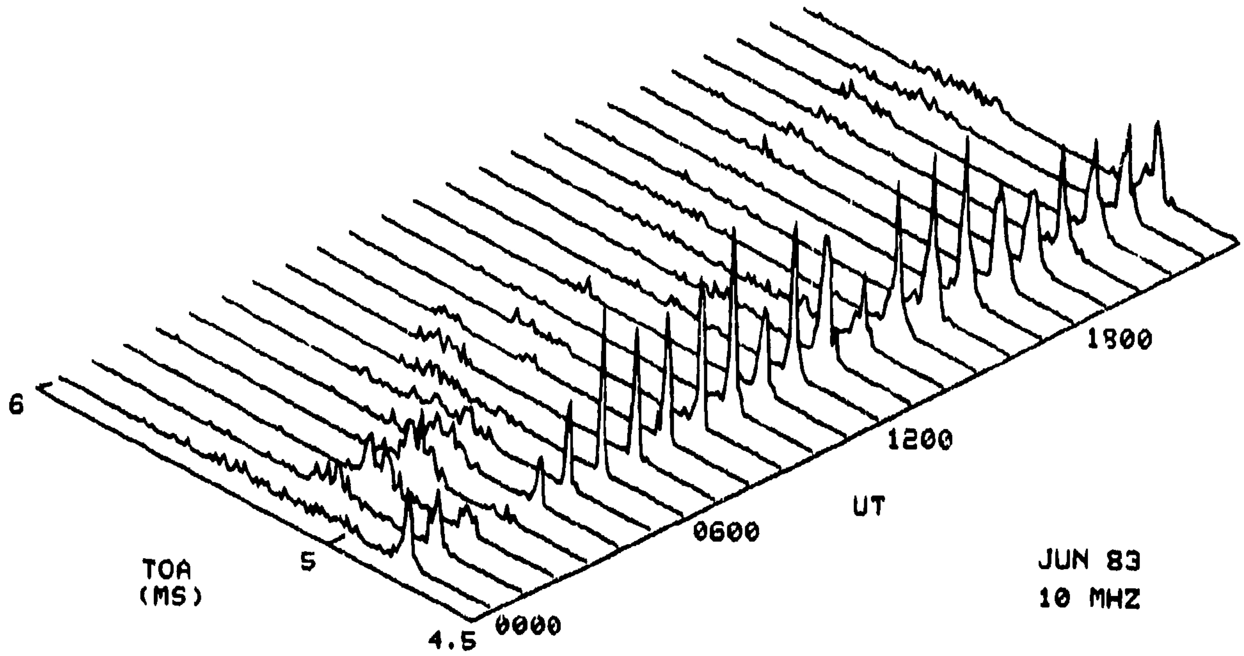


Figure 32. Hourly TOA averages Jun 1983 — WWV to NOSC.

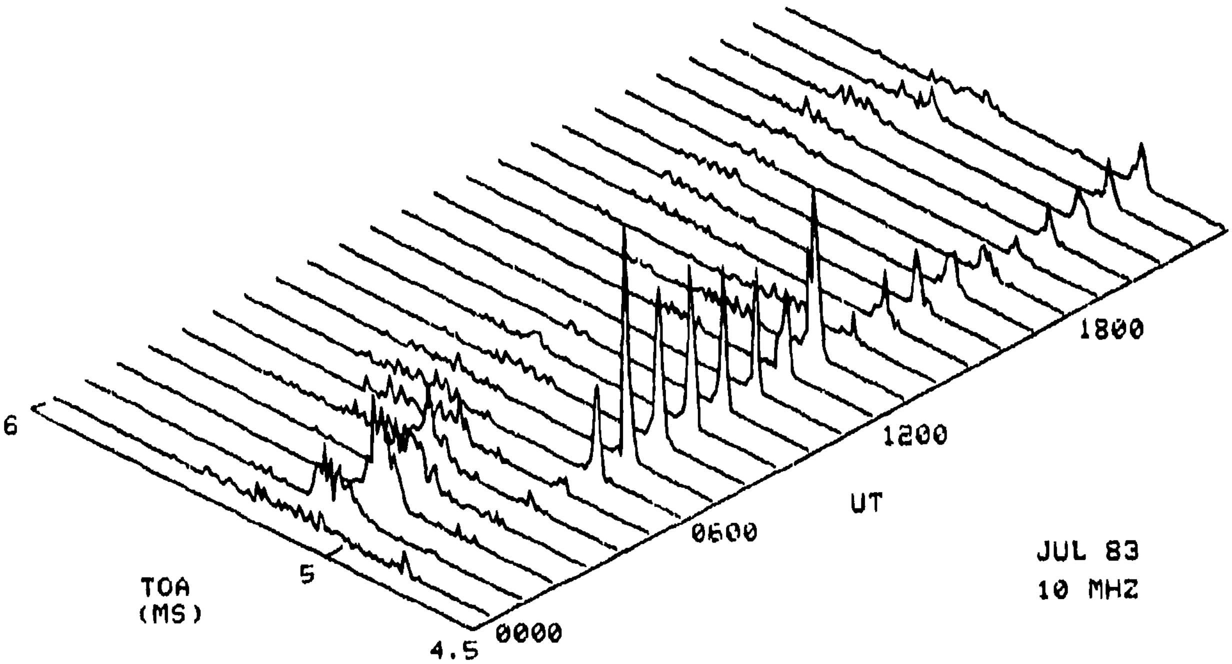


Figure 33. Hourly TOA averages Jul 1983 — WWV to NOSC.

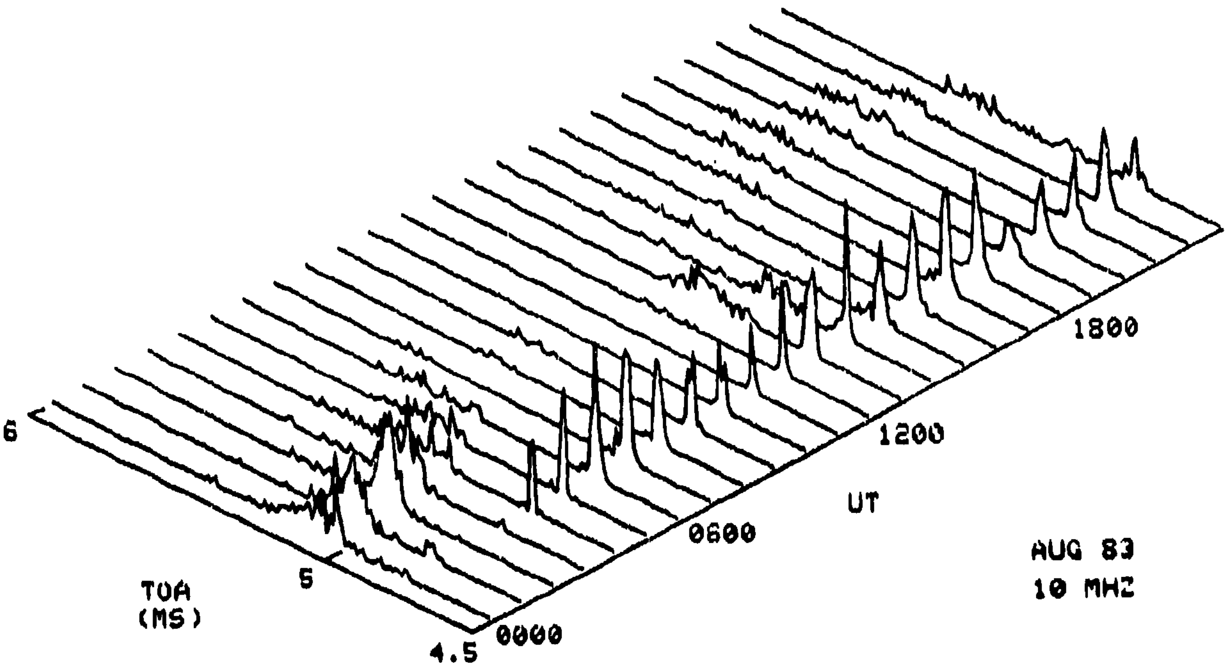


Figure 34. Hourly TOA averages Aug 1983 — WWV to NOSC.

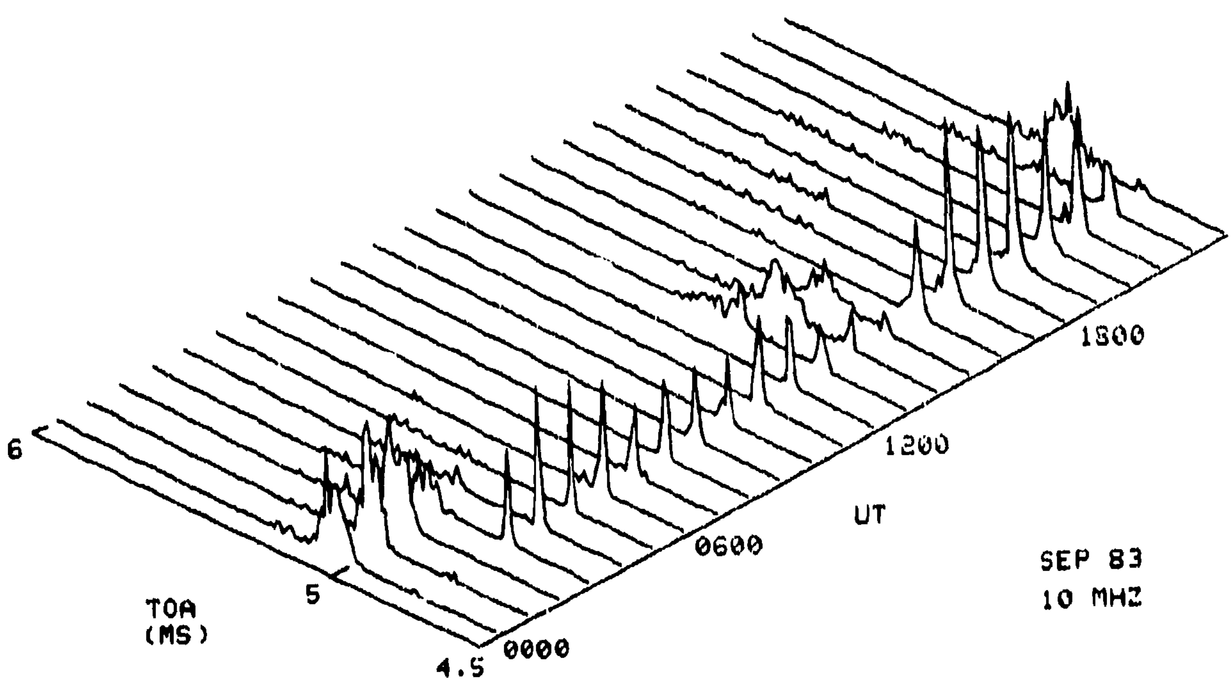


Figure 35. Hourly TOA averages Sep 1983 — WWV to NOSC.

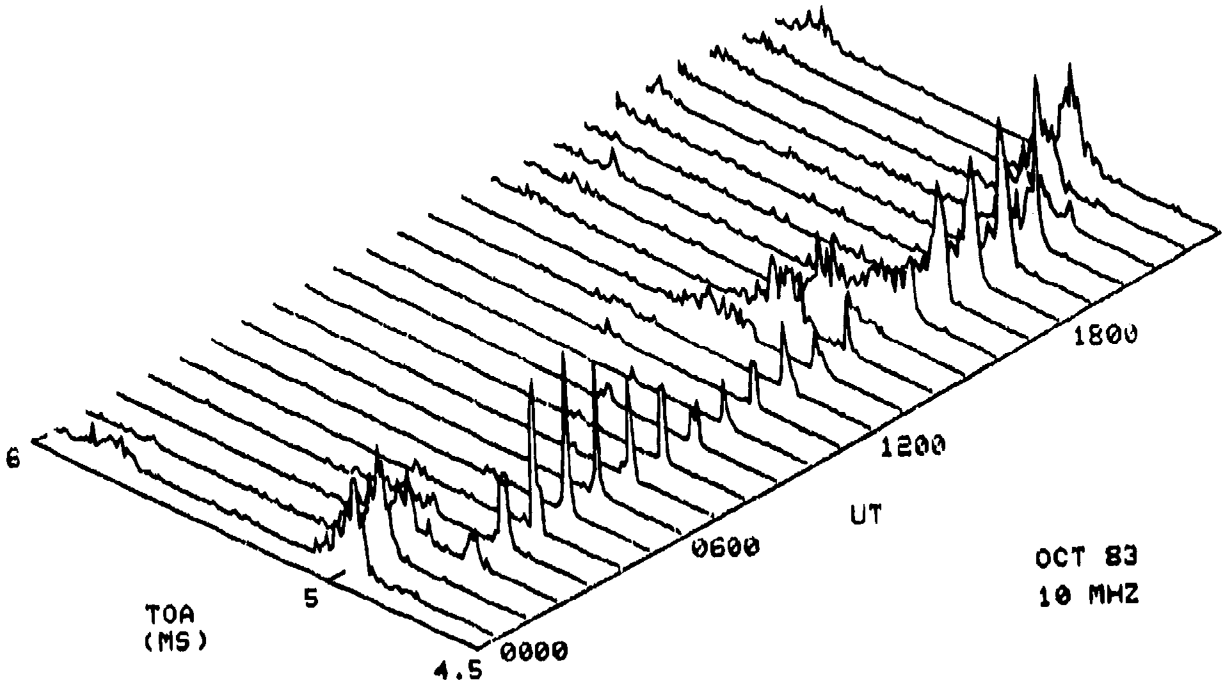


Figure 36. Hourly TOA averages Oct 1983 — WWV to NOSC.

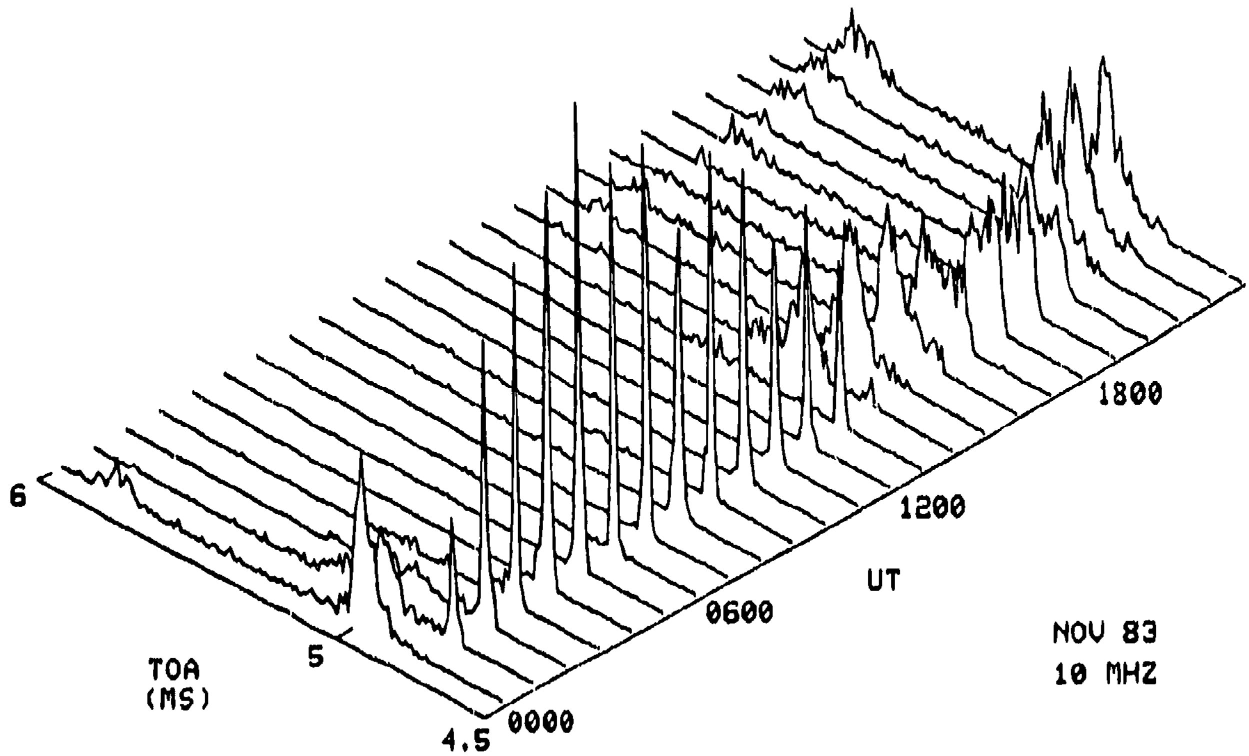


Figure 37. Hourly TOA averages Nov 1983 — WWV to NOSC.

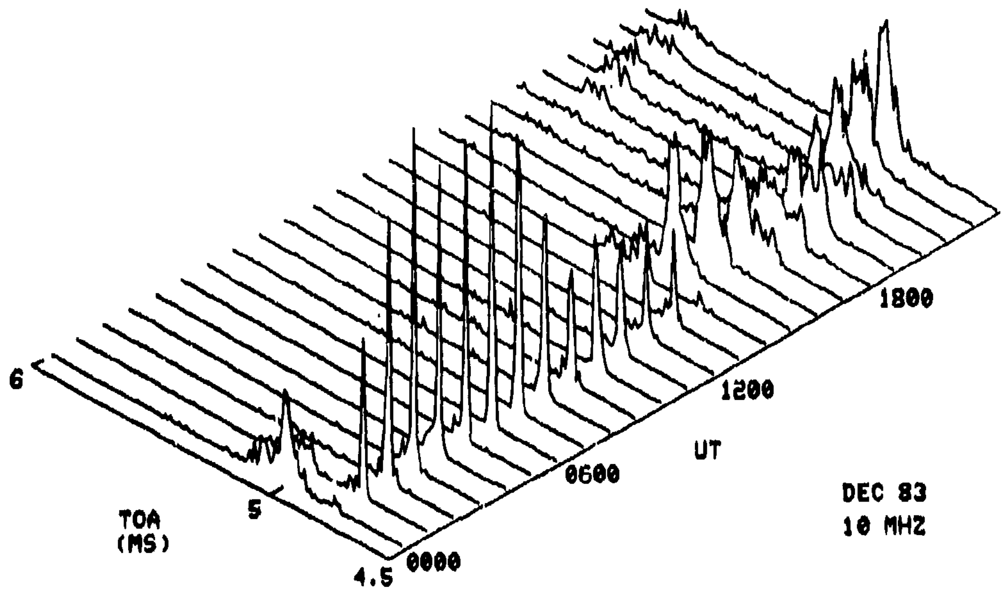


Figure 38. Hourly TOA averages Dec 1983 — WWV to NOSC.

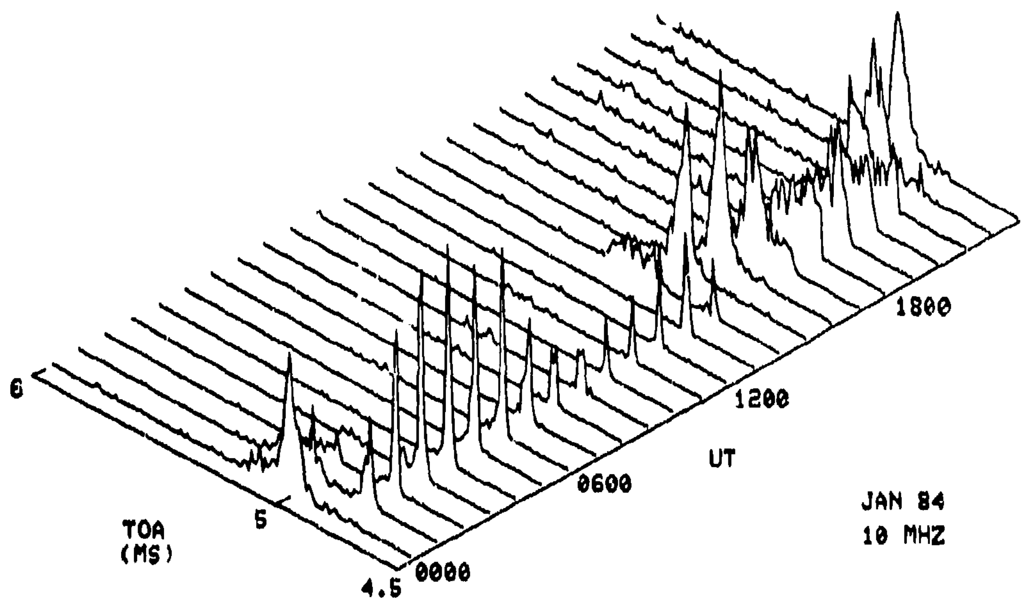


Figure 39. Hourly TOA averages Jan 1984 — WWV to NOSC.

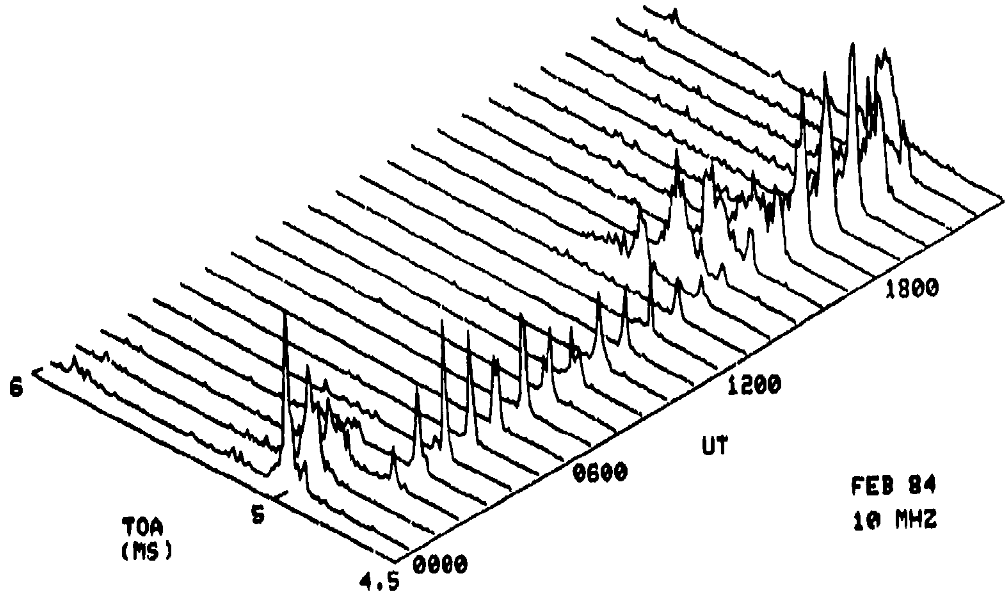


Figure 40. Hourly TOA averages Feb 1984 — WWV to NOSC.

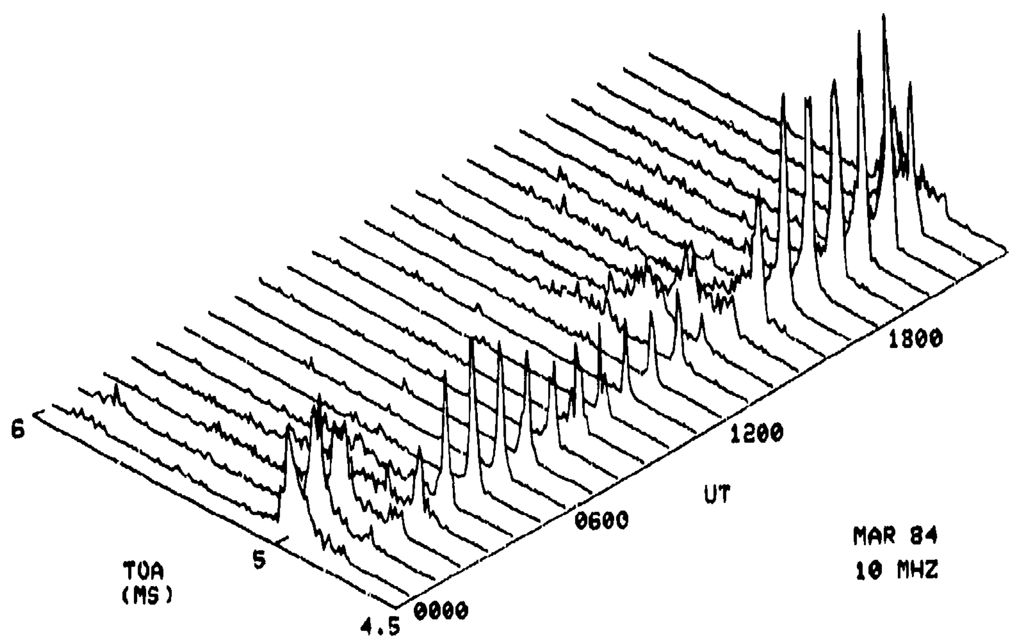


Figure 41. Hourly TOA averages Mar 1984 — WWV to NOSC.

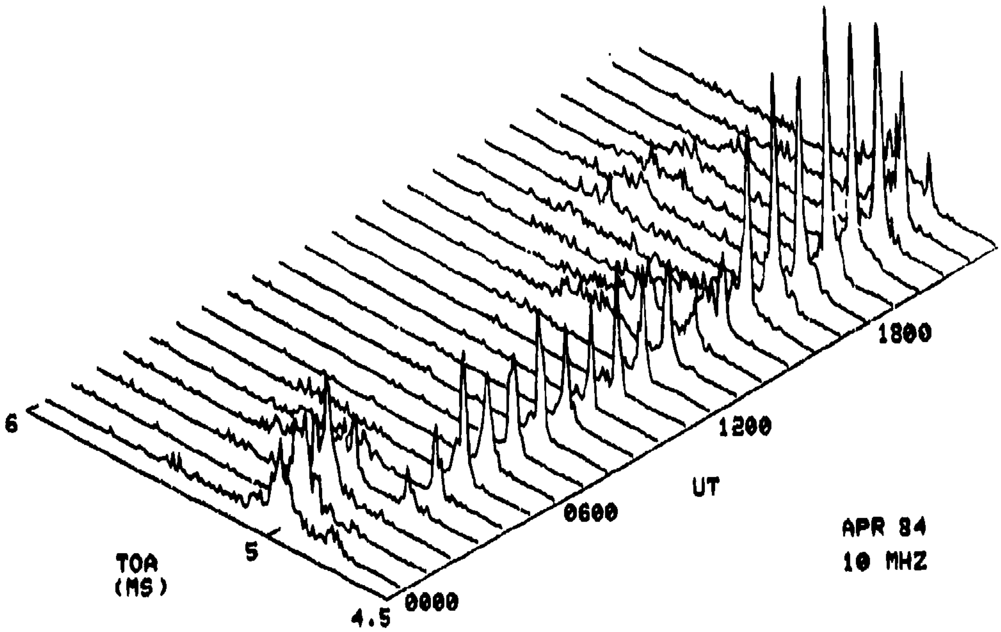


Figure 42. Hourly TOA averages Apr 1984 — WWV to NOSC.

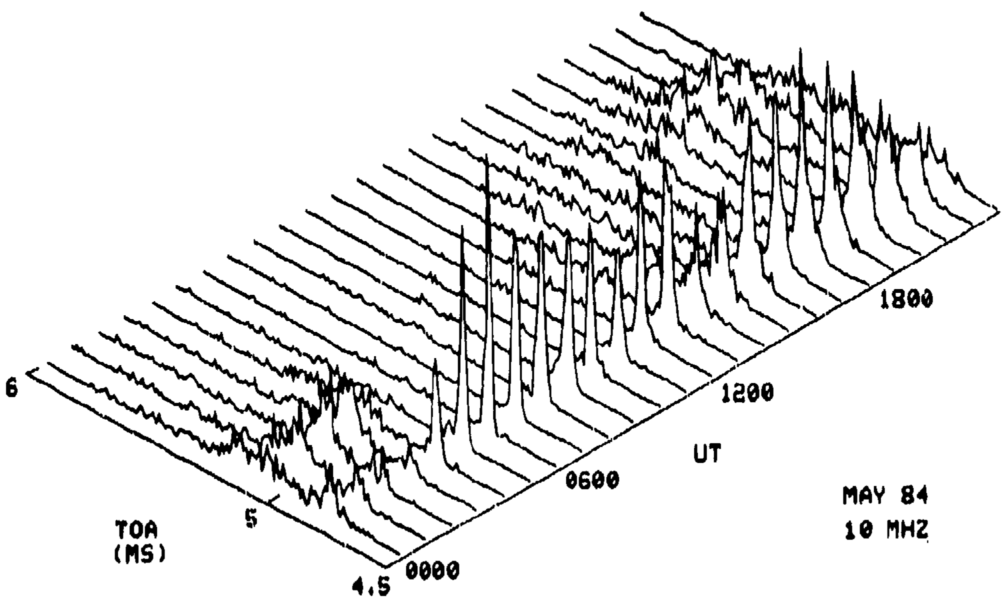


Figure 43. Hourly TOA averages May 1984 — WWV to NOSC.

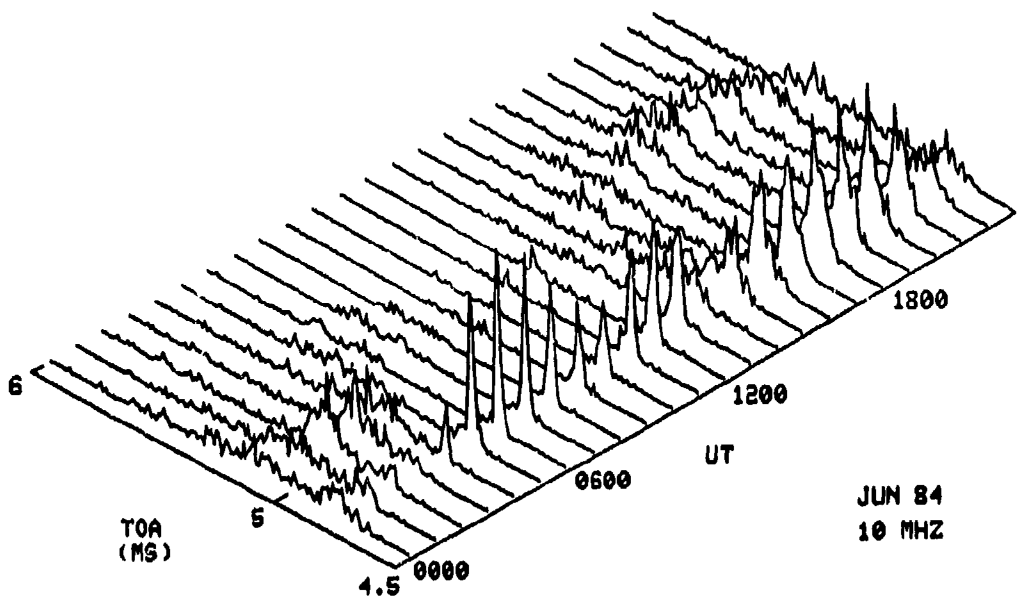


Figure 44. Hourly TOA averages Jun 1984 — WWV to NOSC.

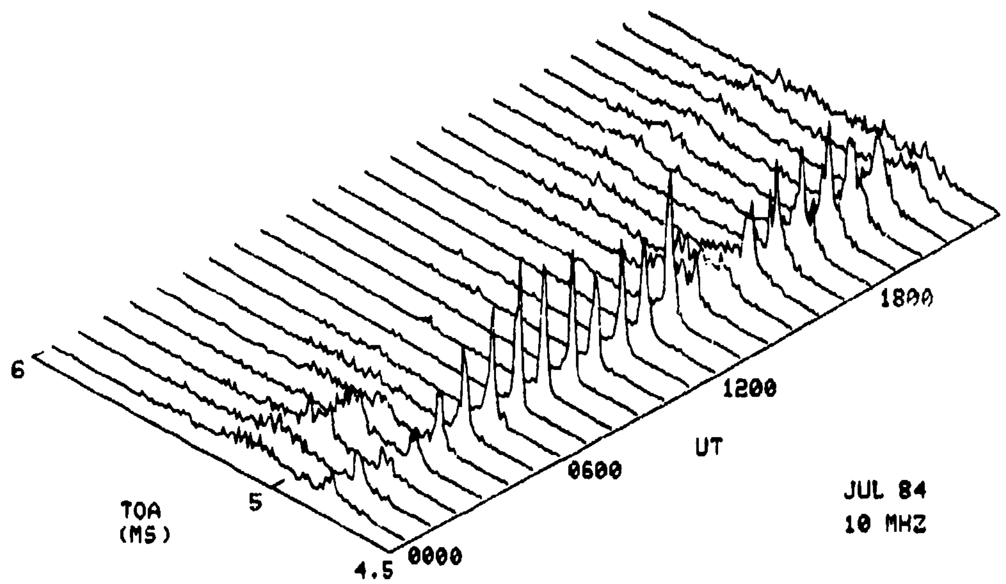


Figure 45. Hourly TOA averages Jul 1984 — WWV to NOSC.

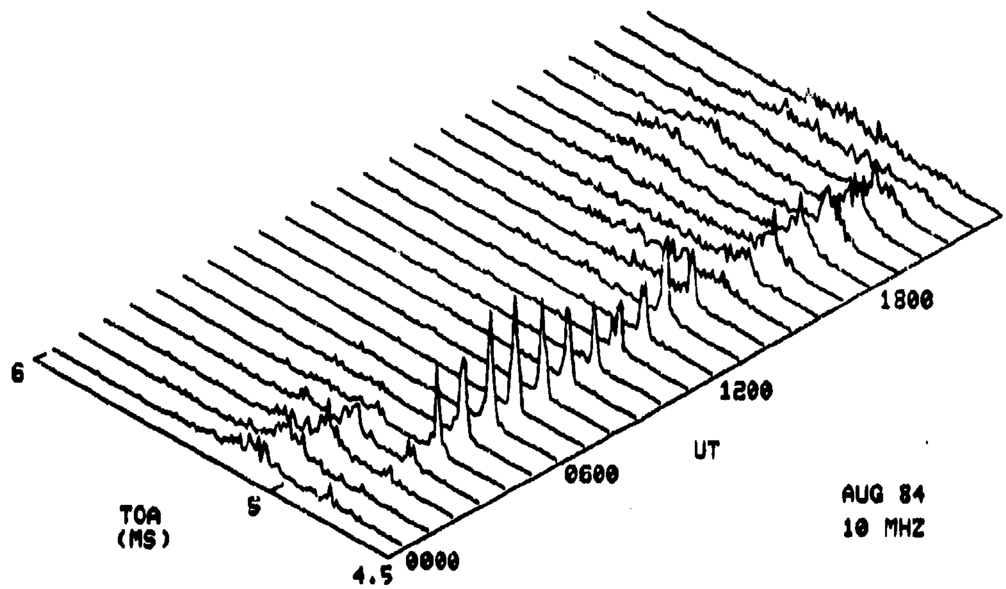


Figure 46. Hourly TOA averages Aug 1984 — WWV to NOSC.

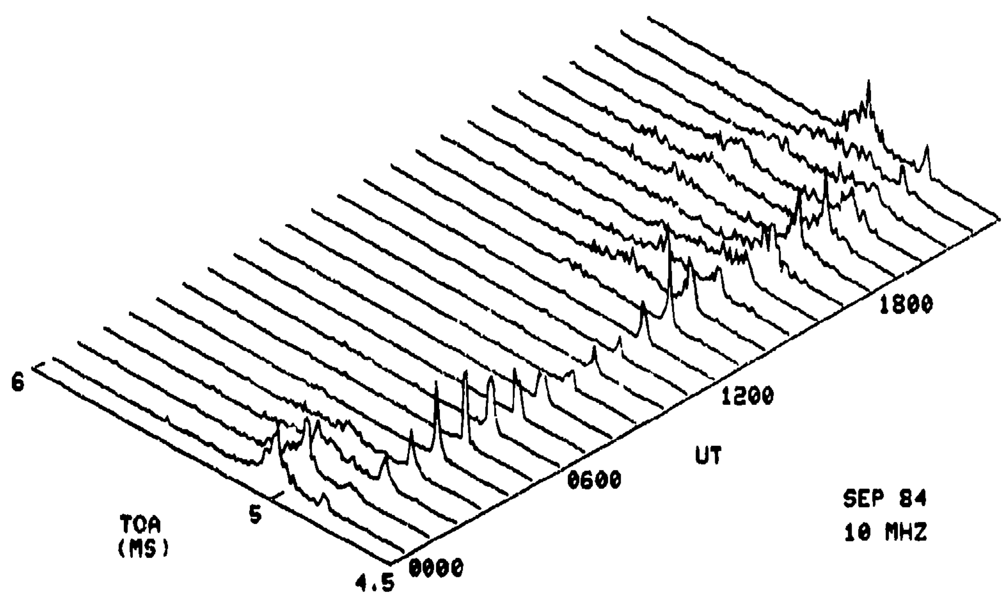


Figure 47. Hourly TOA averages Sep 1984 — WWV to NOSC.

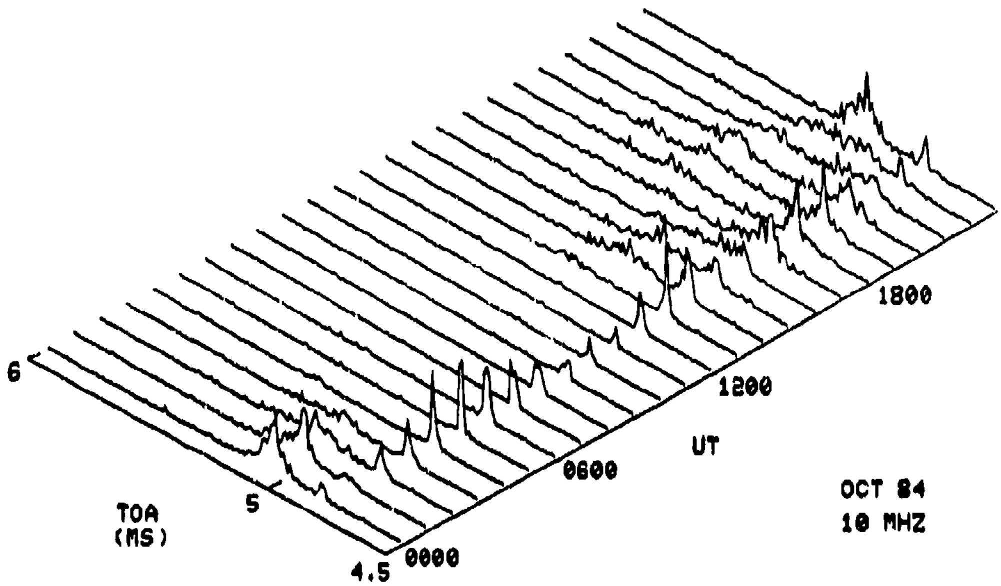


Figure 48. Hourly TOA averages Oct 1984 — WWV to NOSC.

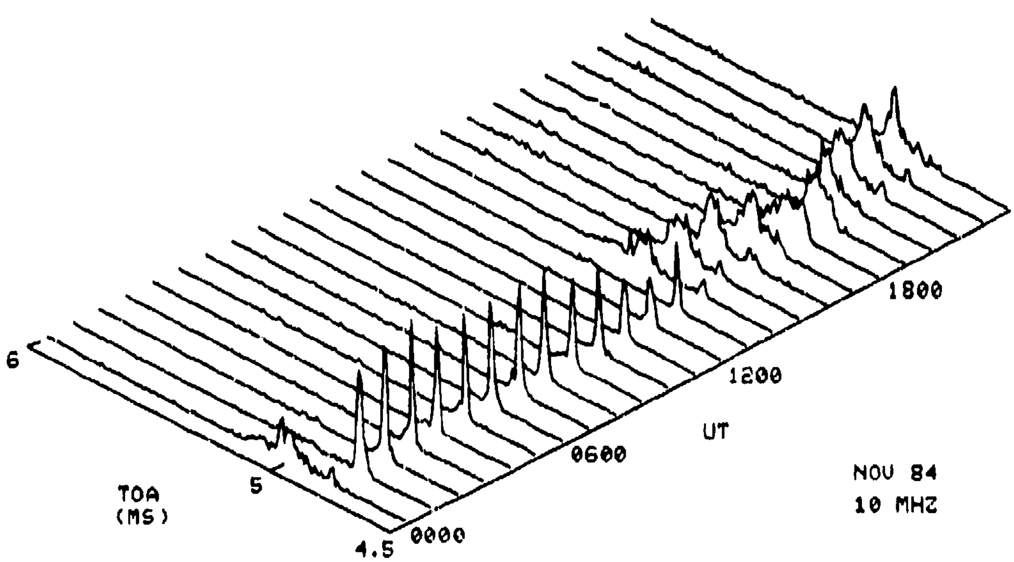


Figure 49. Hourly TOA averages Nov 1984 — WWV to NOSC.

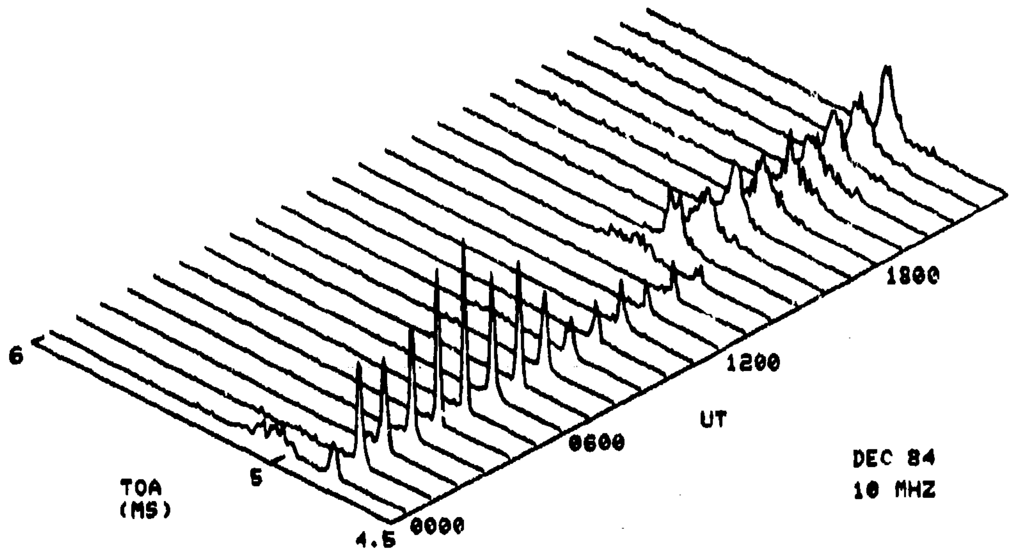


Figure 50. Hourly TOA averages Dec 1984 — WWV to NOSC.

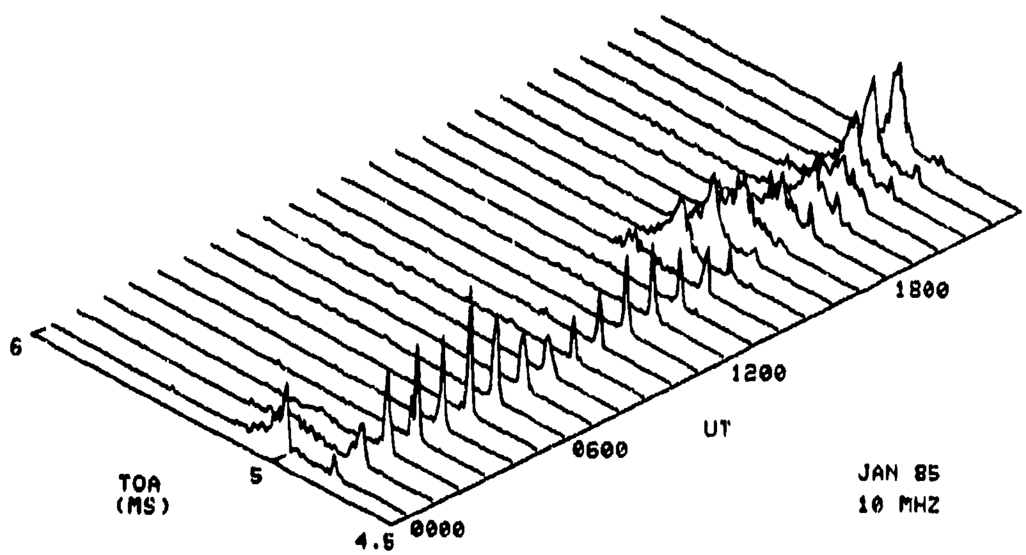


Figure 51. Hourly TOA averages Jan 1985 — WWV to NOSC.

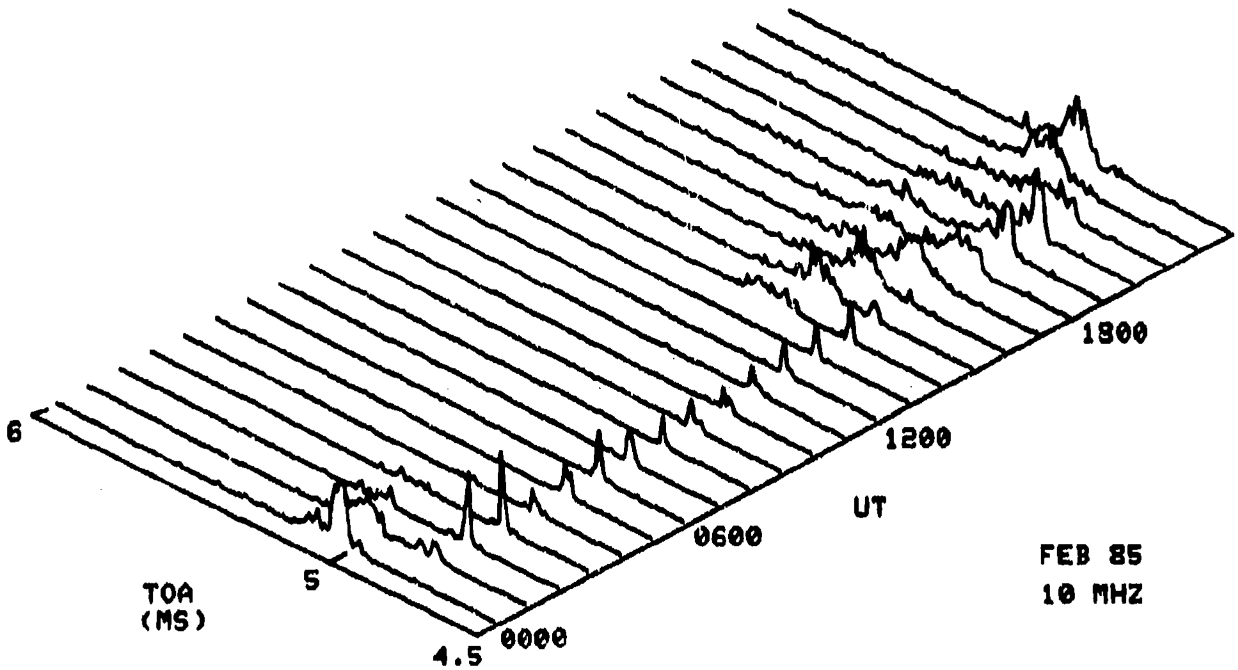


Figure 52. Hourly TOA averages Feb 1985 — WWV to NOSC.

15-MHz TOA (FIGURES 53-76)

Probably the most dramatic demonstration of the solar decline is on the 15-MHz channel. Initially, this frequency appears to be heavily influenced by E-region propagation during night hours. This characteristic seems to decline through the solar decline. Comparision of January 1984 (Figure 63) and January 1985 (Figure 75) shows a decline in E propagation at night and a reduction of one hop F during the day. F-region time delays appear to have a spread of uncertainty of 100-200 microseconds. The months of May through Septemper in both 1983 and 1984 show a very high occurrence of daytime E, almost completely negating the influence of F-region propagation. This trend was also seen in 1981 and 1982. Of all the frequencies under test, 15-MHz data produced the most clearly defined database. This is because only one-hop propagation could be sustained from the F-region most of the time. The predominant E-region mode was two hops.

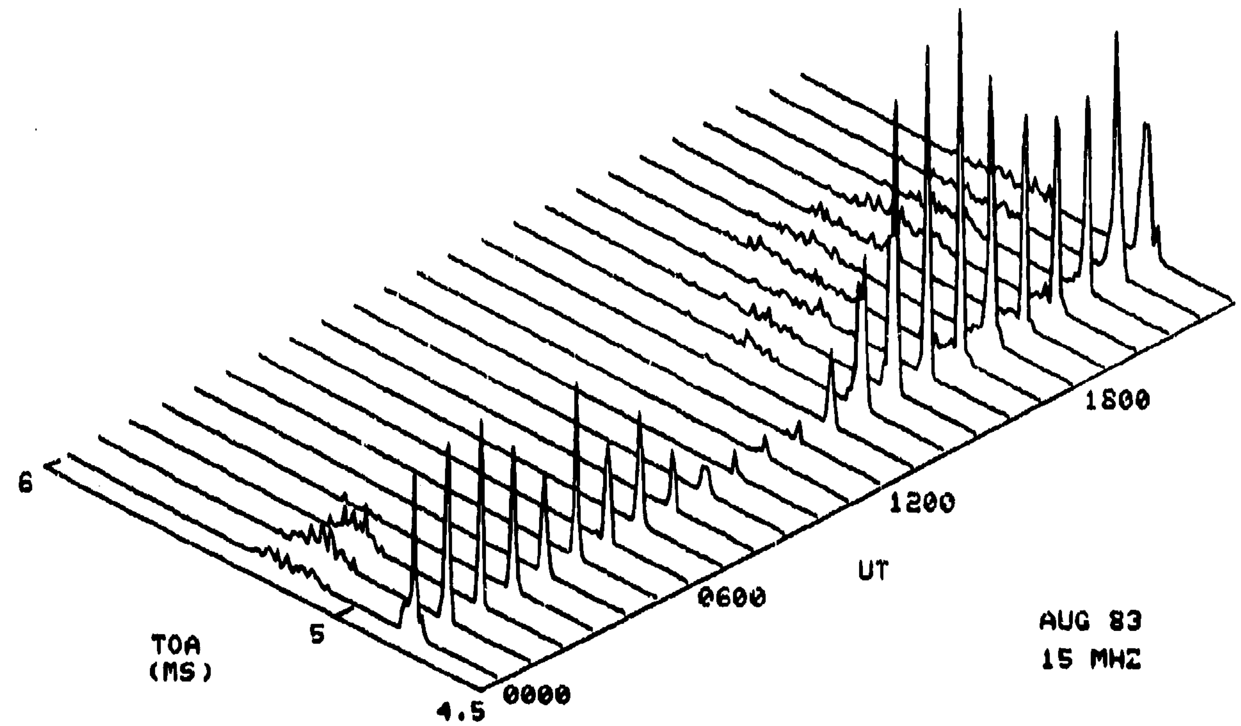


Figure 53. Hourly TOA averages Aug 1983 — WWV to NOSC.

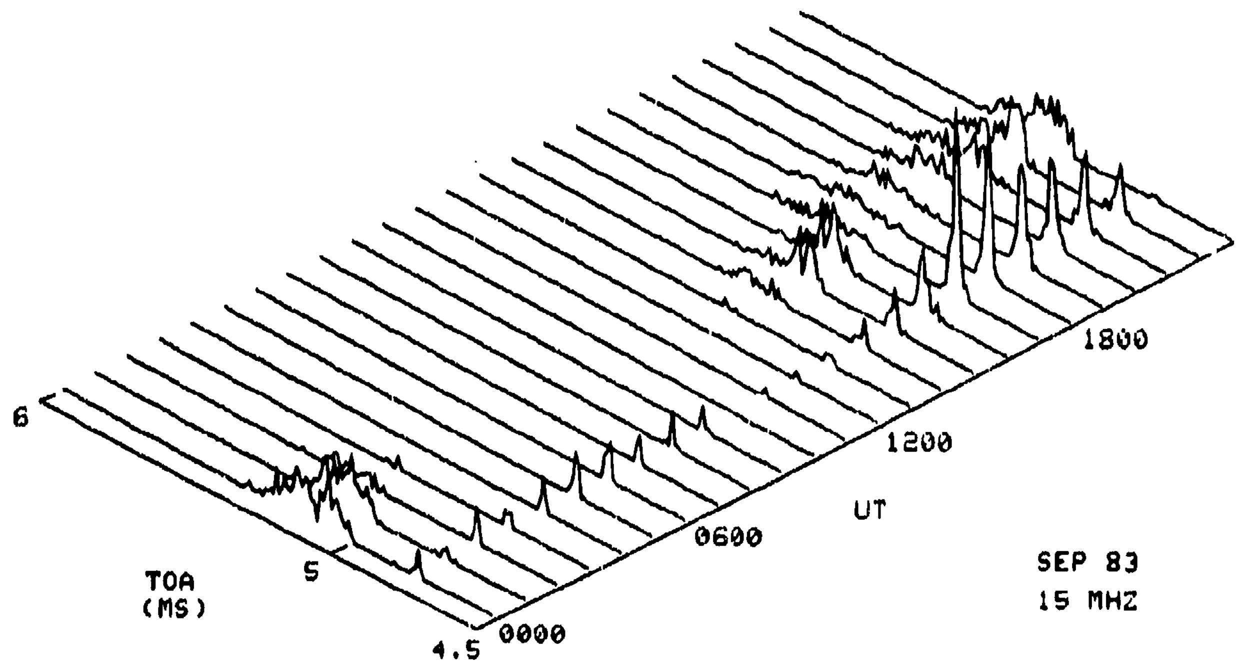


Figure 54. Hourly TOA averages Sep 1983 — WWV to NOSC.

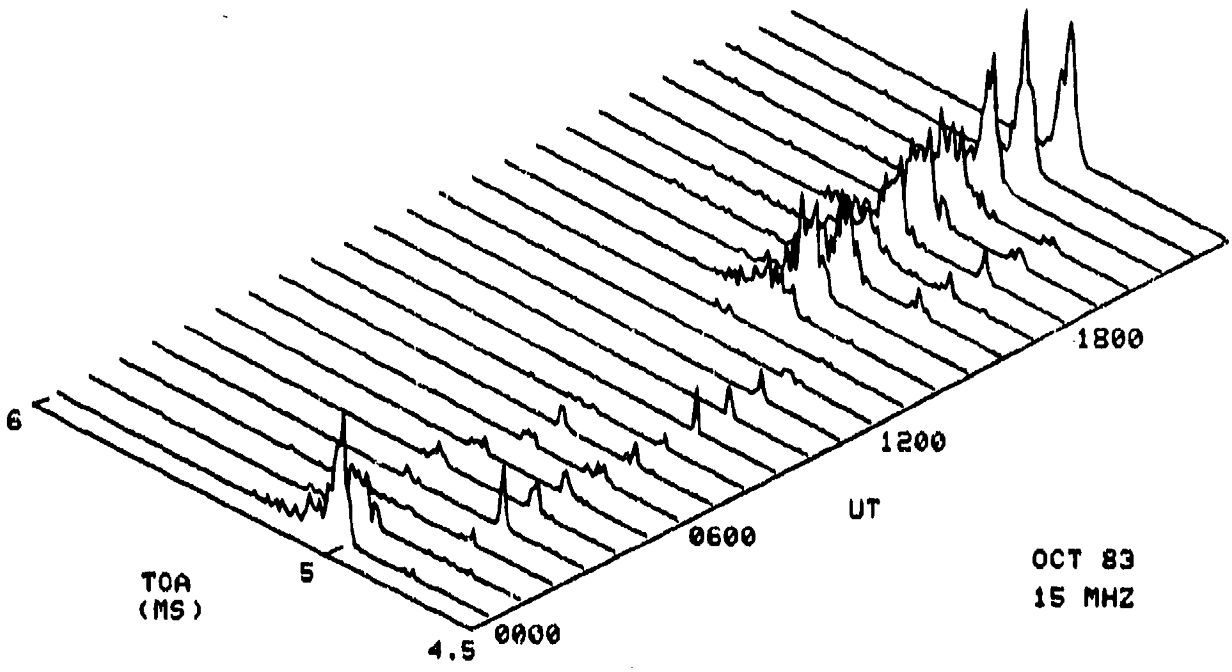


Figure 55. Hourly TOA averages Oct 1983 — WWV to NOSC.

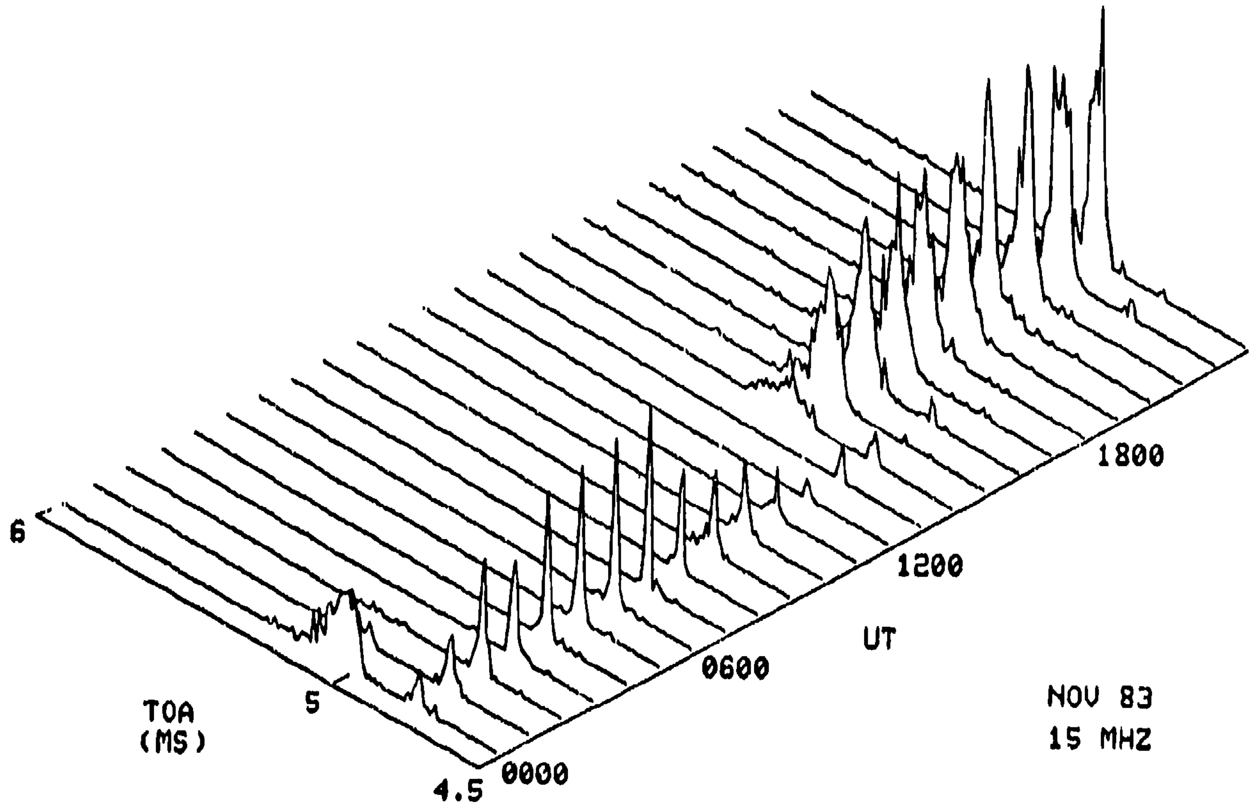


Figure 56. Hourly TOA averages Nov 1983 — WWV to NOSC.

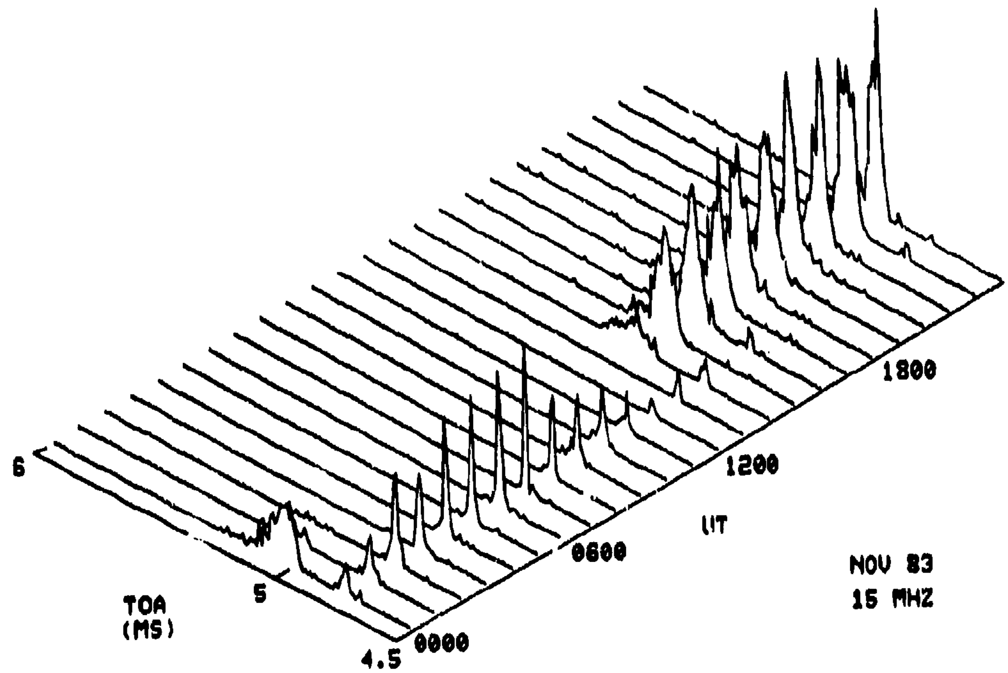


Figure 57. Hourly TOA averages Nov 1983 — WWV to NOSC.

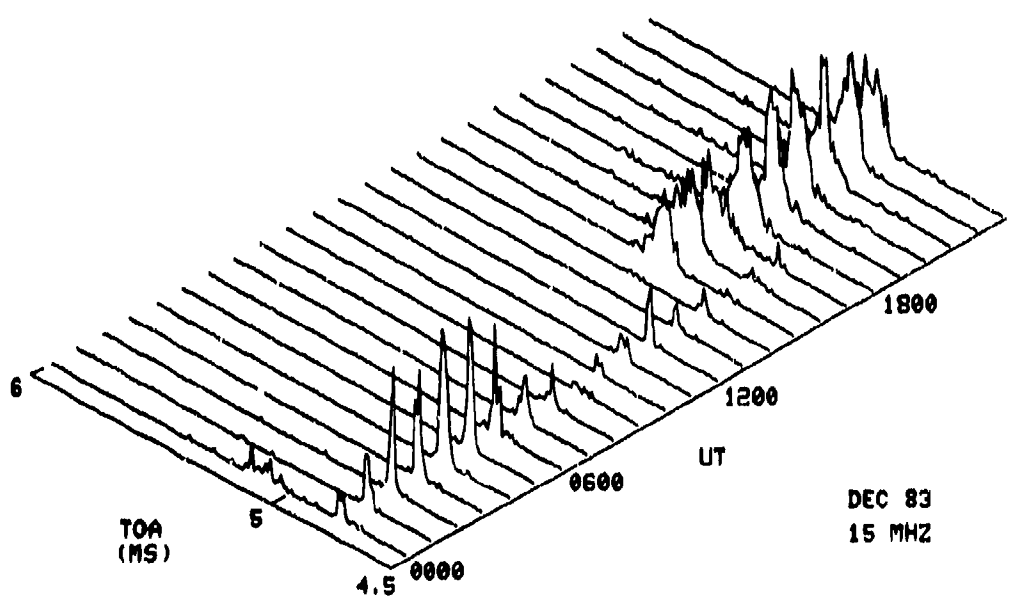


Figure 58. Hourly TOA averages Dec 1983 — WWV to NOSC.

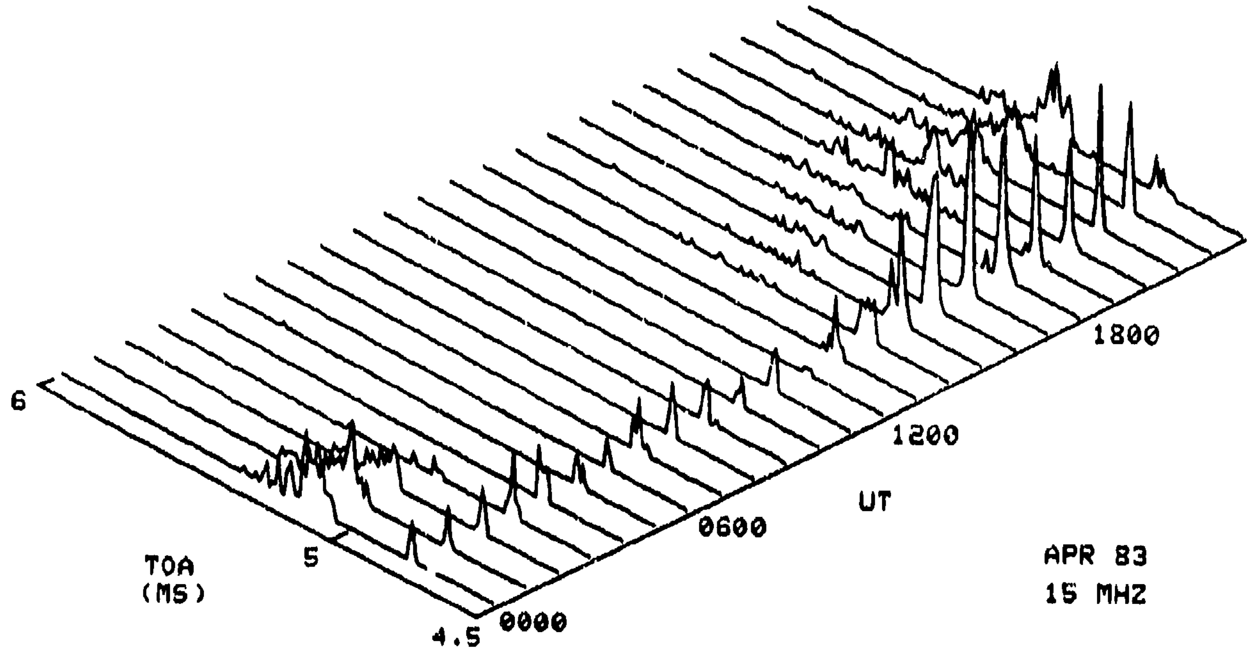


Figure 59. Hourly TOA averages Apr 1983 — WWV to NOSC.

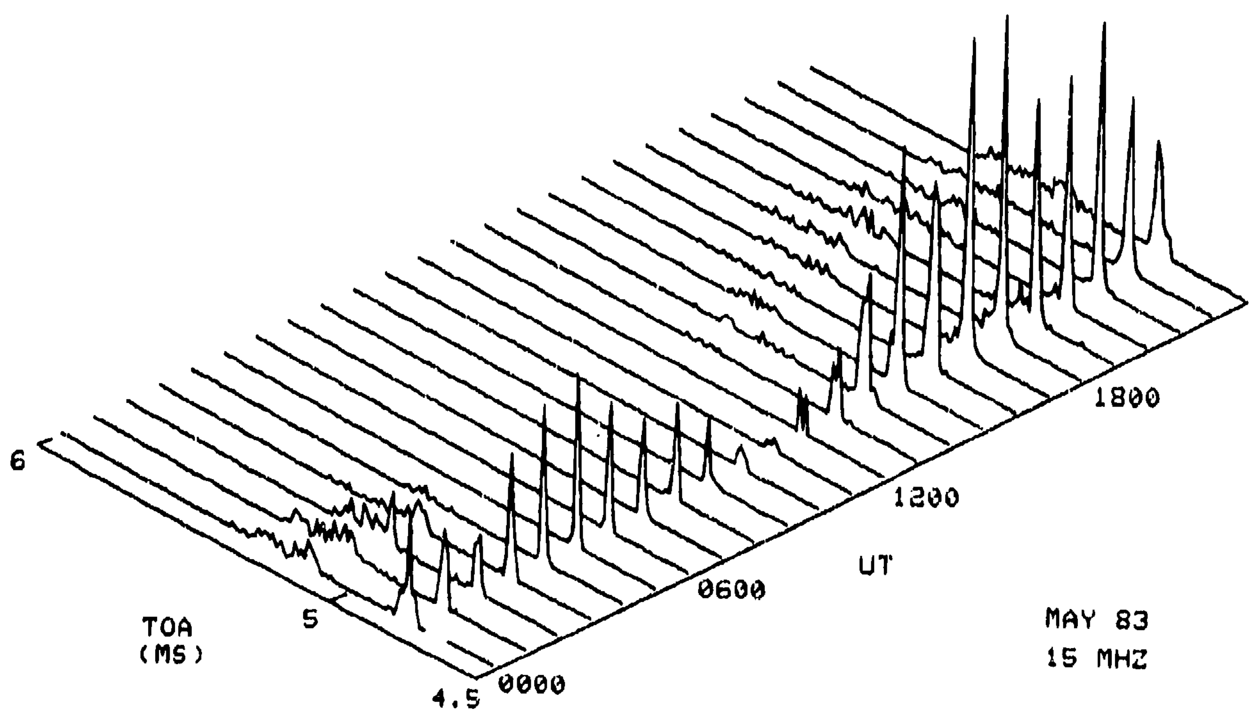


Figure 60. Hourly TOA averages May 1983 — WWV to NOSC.

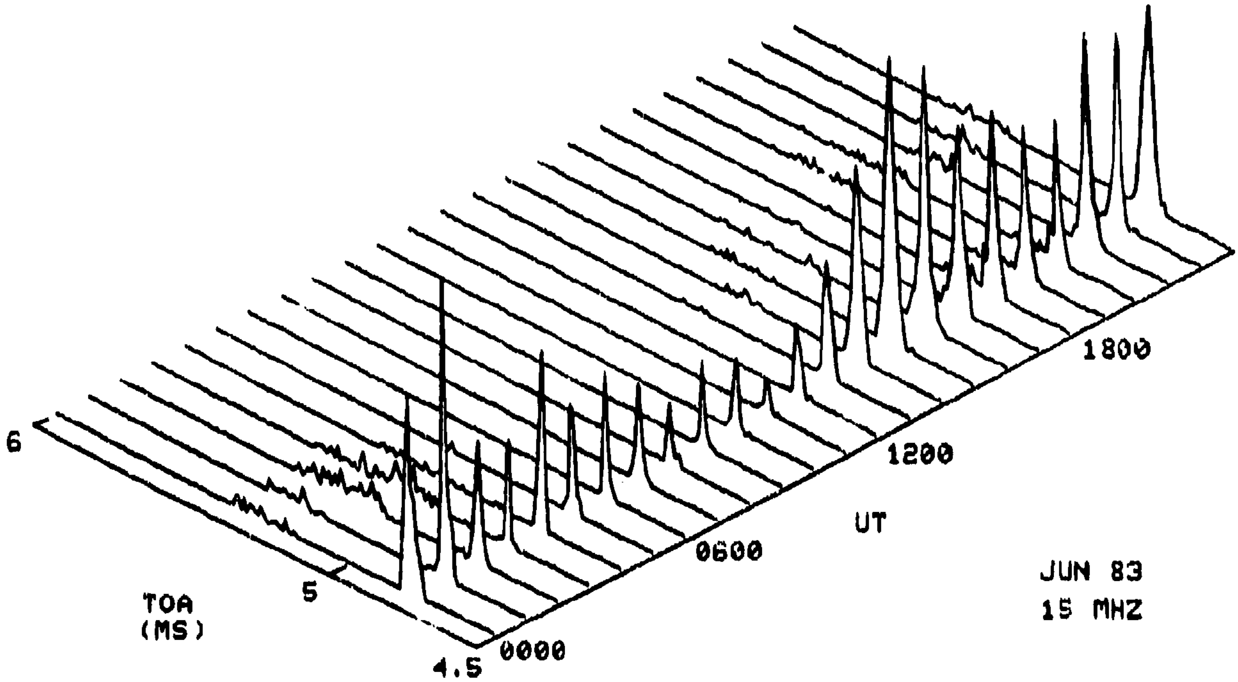


Figure 61. Hourly TOA averages Jun 1983 — WWV to NOSC.

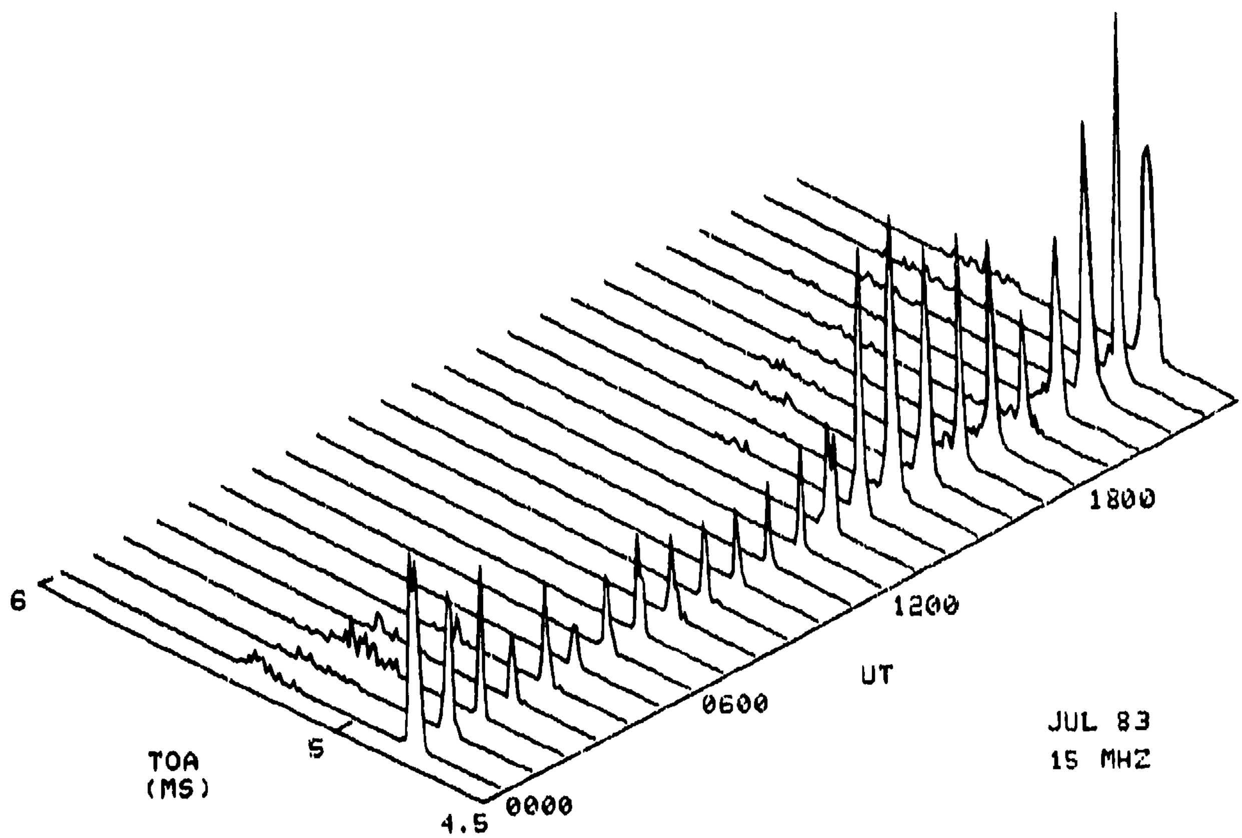


Figure 62. Hourly TOA averages Jul 1983 — WWV to NOSC.

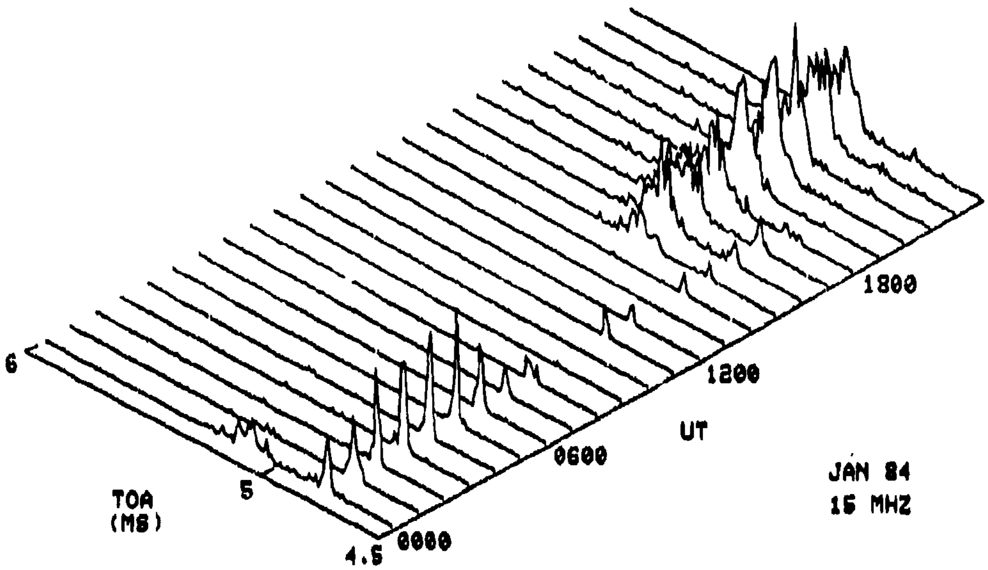


Figure 63. Hourly TOA averages Jan 1984 — WWV to NOSC.

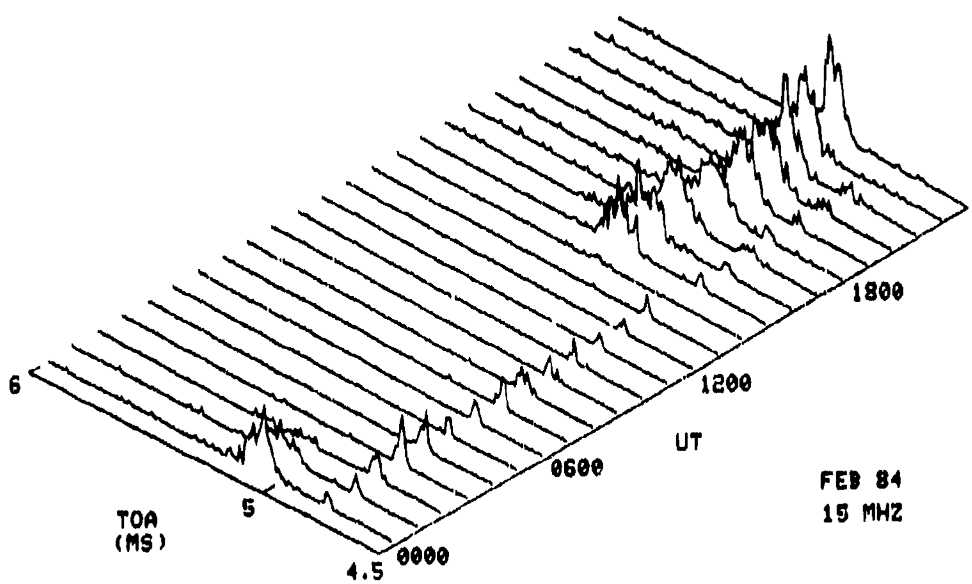


Figure 64. Hourly TOA averages Feb 1984 — WWV to NOSC.

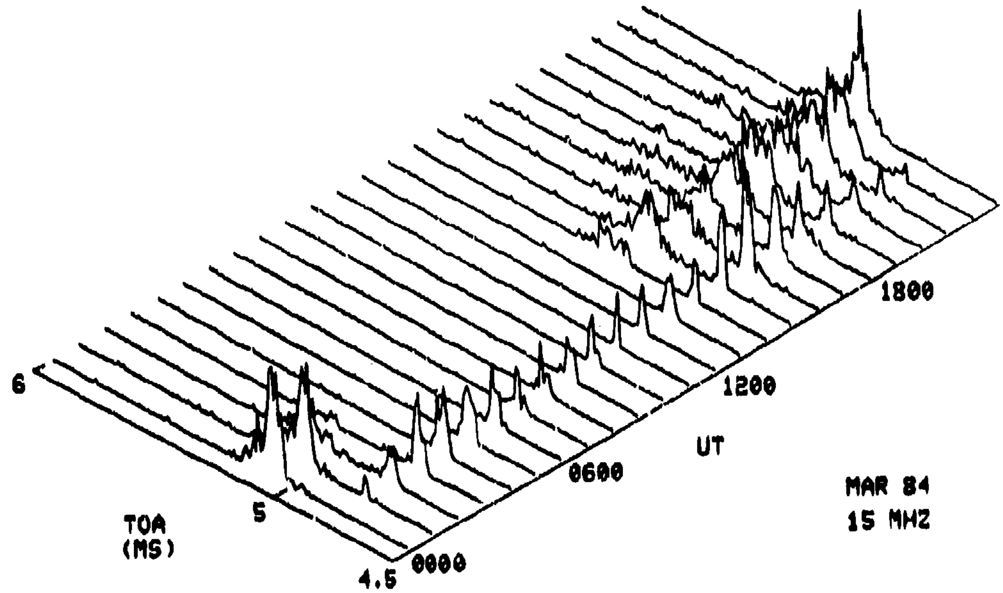


Figure 65. Hourly TOA averages Mar 1984 — WWV to NOSC.

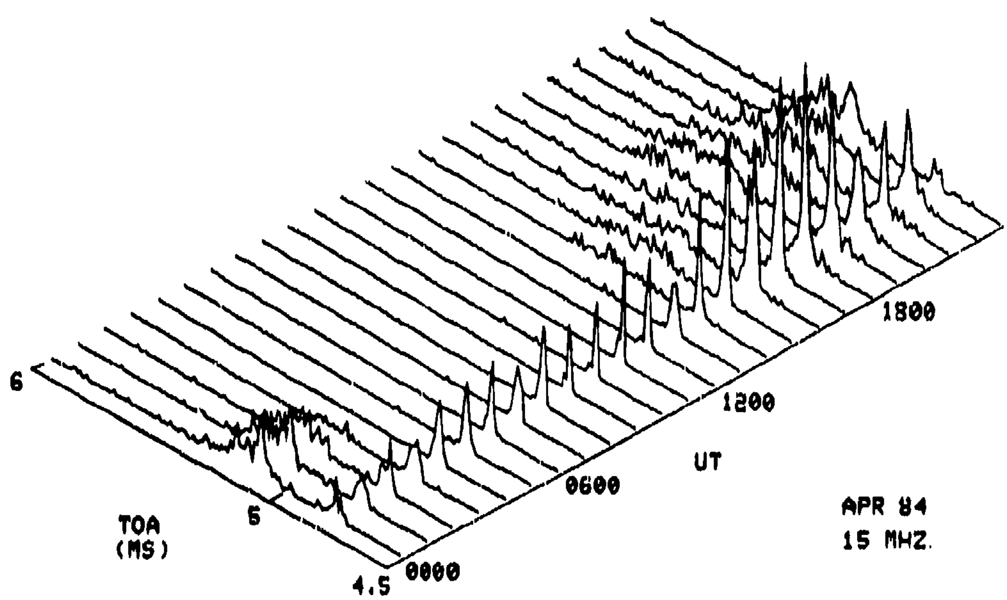


Figure 66. Hourly TOA averages Apr 1984 — WWV to NOSC.

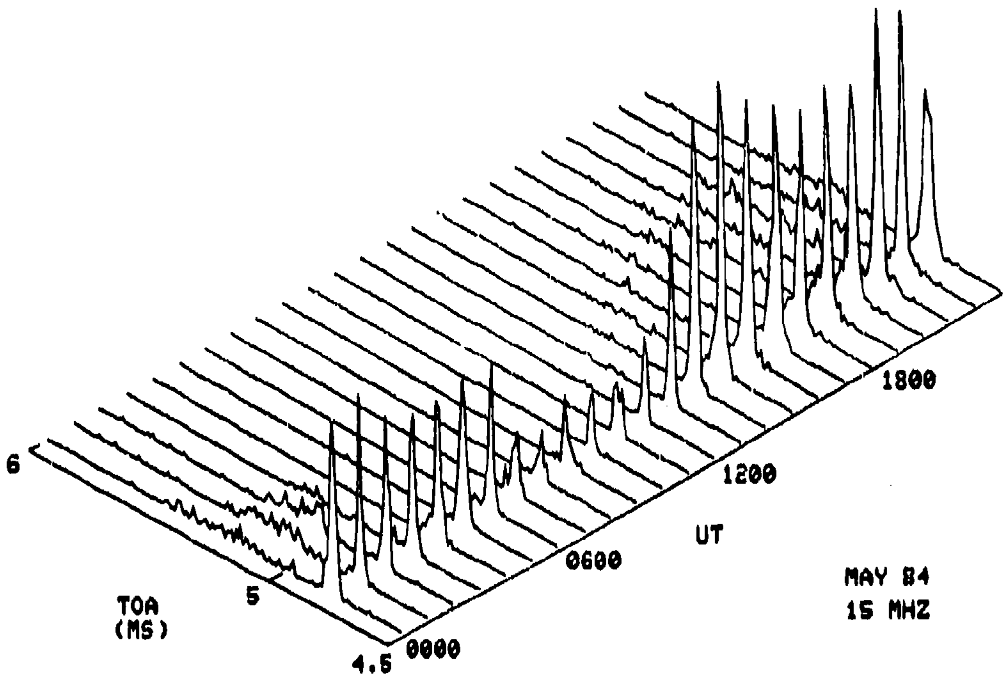


Figure 67. Hourly TOA averages May 1984 — WWV to NOSC.

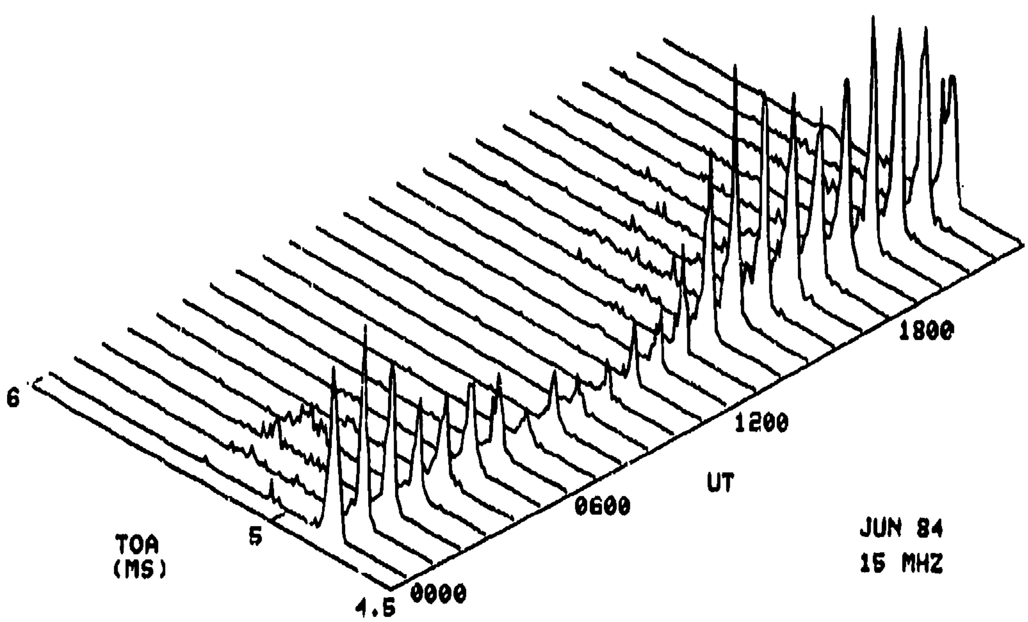


Figure 68. Hourly TOA averages Jun 1984 — WWV to NOSC.

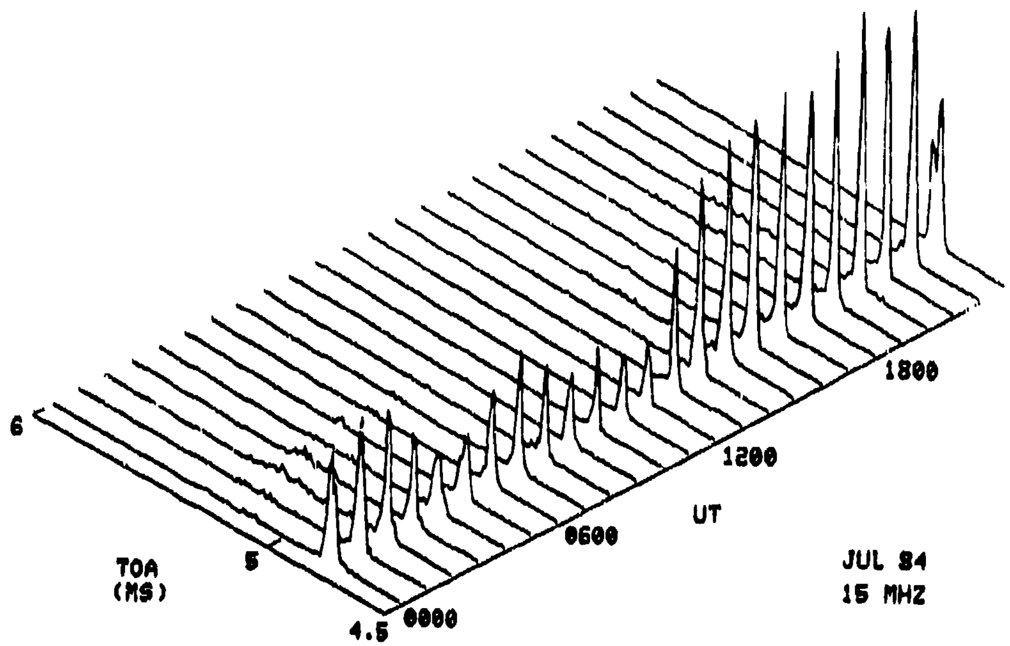


Figure 69. Hourly TOA averages Jul 1984 — WWV to NOSC.

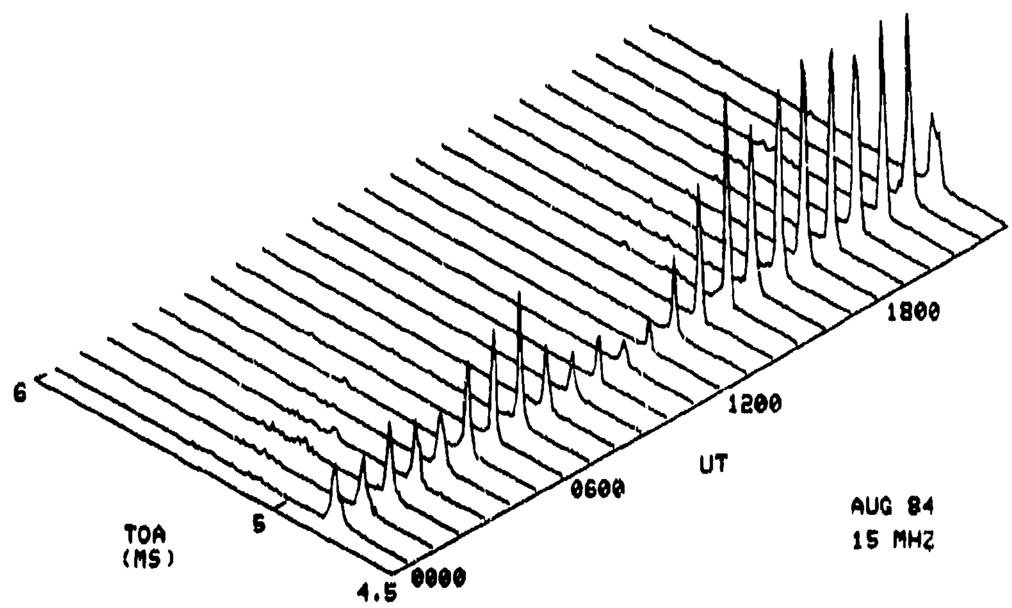


Figure 70. Hourly TOA averages.Aug 1984 — WWV to NOSC.

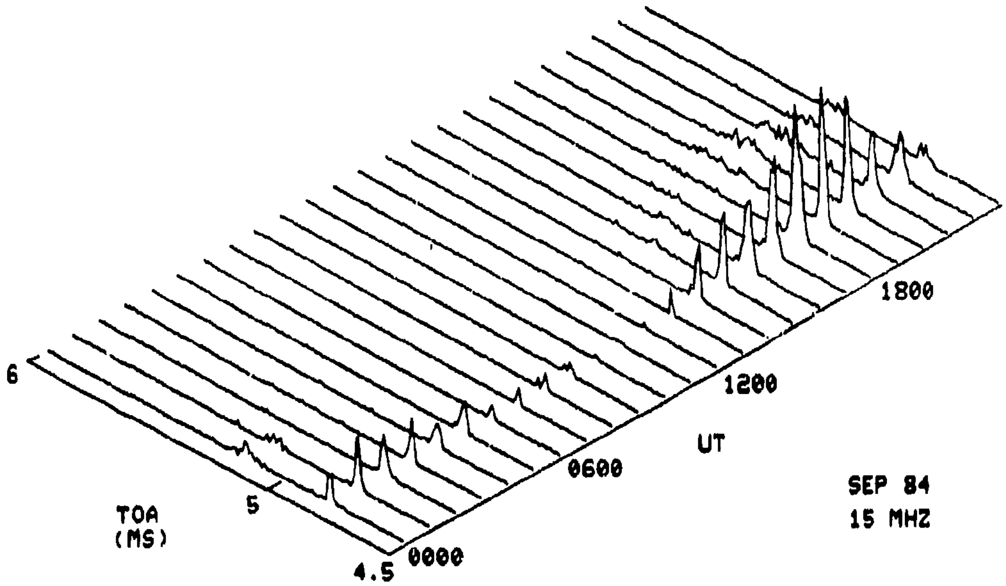


Figure 71. Hourly TOA averages Sep 1984 — WWV to NOSC.

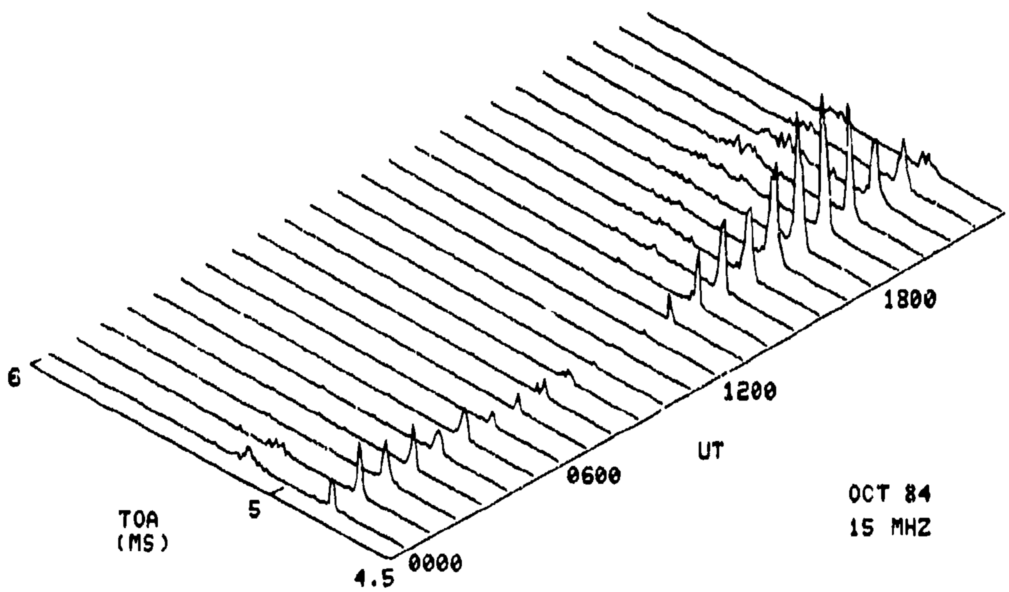


Figure 72. Hourly TOA averages Oct 1984 — WWV to NOSC.

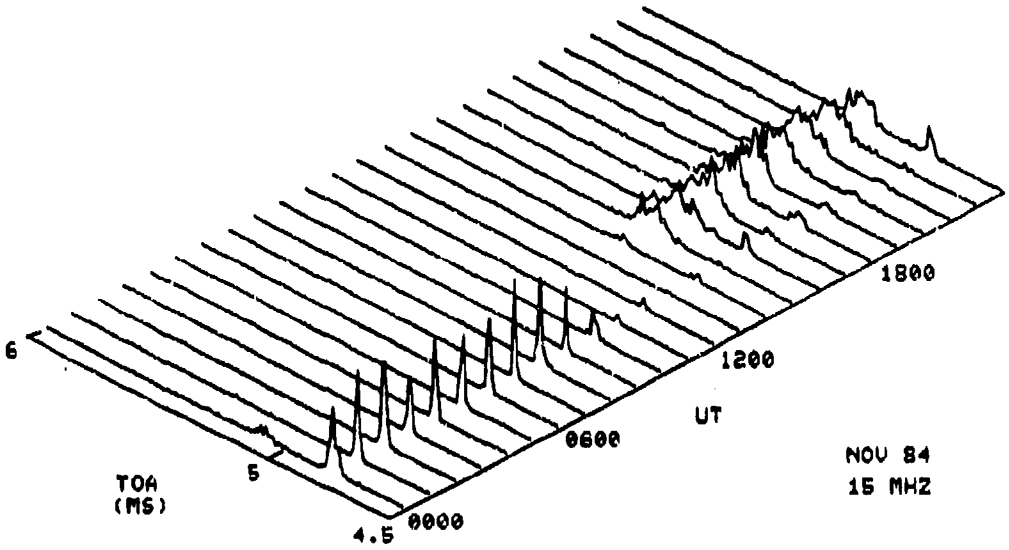


Figure 73. Hourly TOA averages Nov 1984 — WWV to NOSC.

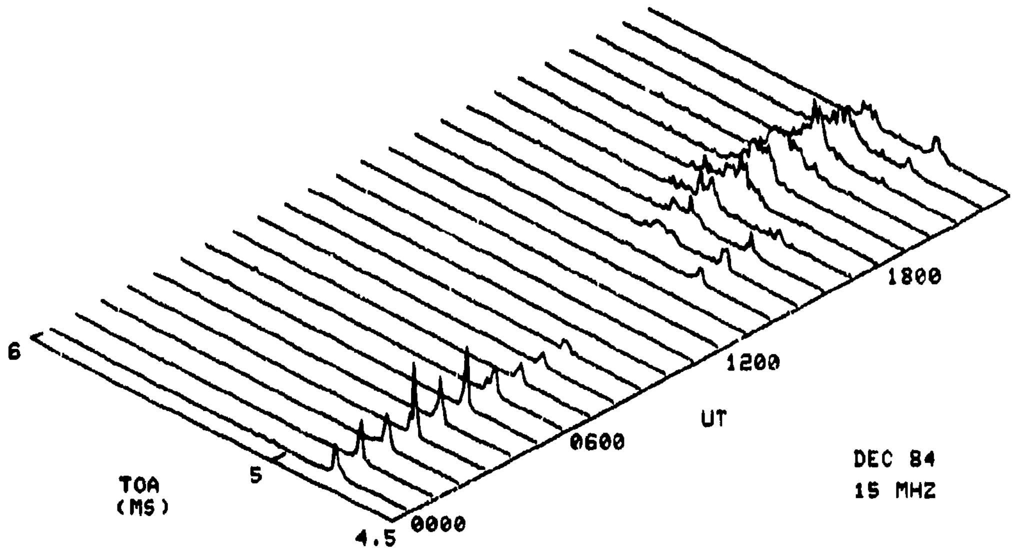


Figure 74. Hourly TOA averages Dec 1984 — WWV to NOSC.

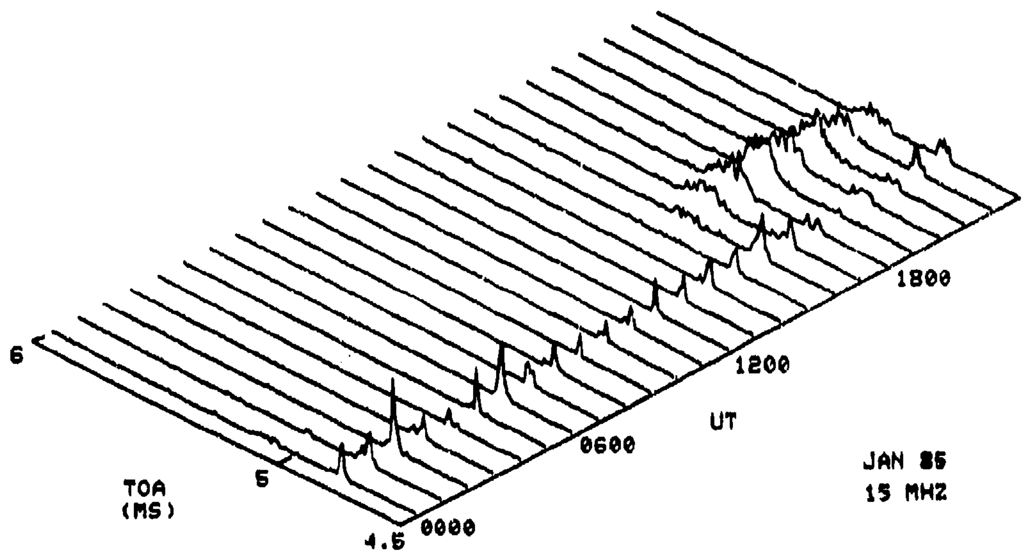


Figure 75. Hourly TOA averages Jan 1985 — WWV to NOSC.

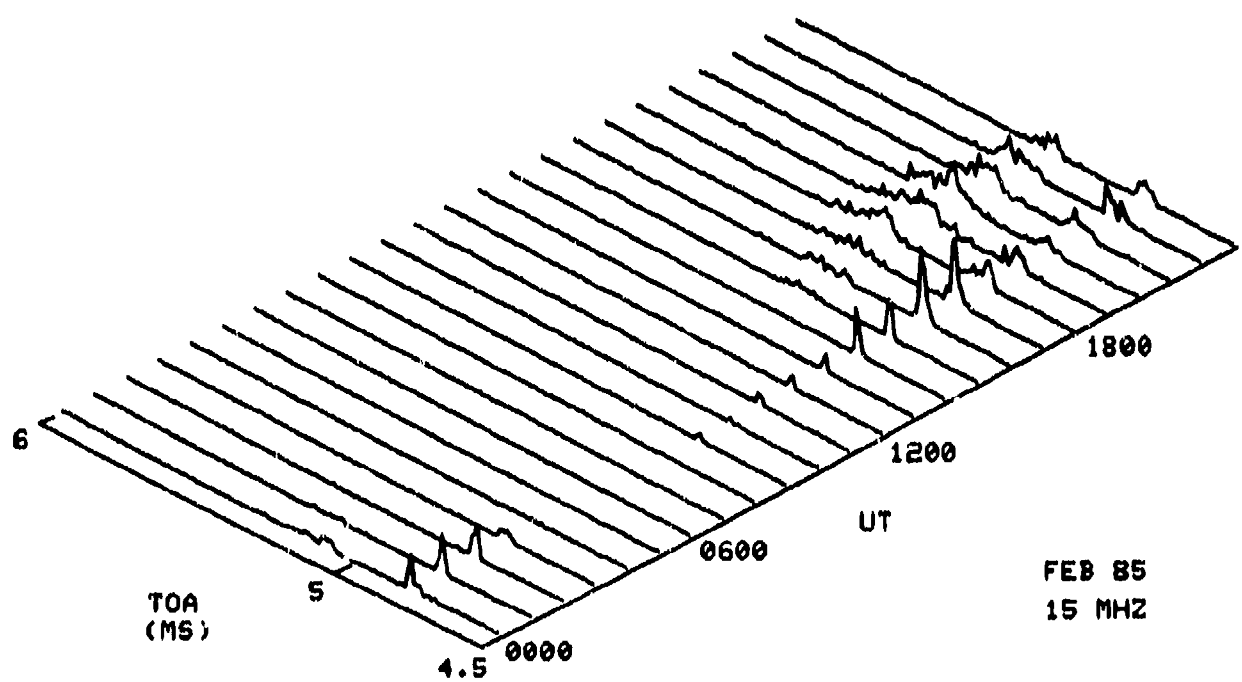


Figure 76. Hourly TOA averages Feb 1985 — WWV to NOSC.

5.0-MHz TOA (FIGURES 77-99)

While night E was not totally unexpected on 5 MHz, it was quite strong in the early part of the test in 1983 and slowly declined through 1984. This indicates that at solar maximum, the E-region is built up during the daylight hours and decays at a slower rate after sunset than first thought. Careful observation of the 1983 data shows the TOAs are from the same layer, are much stronger and building throughout daylight hours and decaying after sunset. From the data reviewed, it is hypothesized that the E layers' recombination is more similiar to the F-region decay than originally thought and has a much stronger dependence on the daily level of solar activity. The data from 5 and 15 MHz both strongly support this hypothesis.

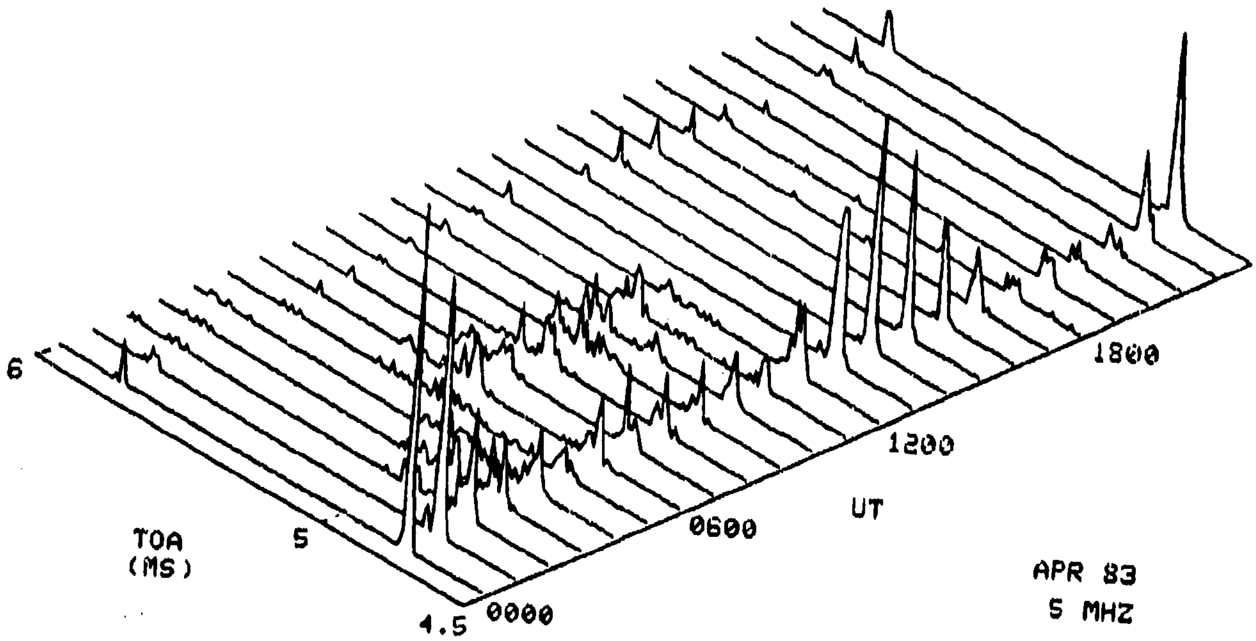


Figure 77. Hourly TOA averages Apr 1983 — WWV to NOSC.

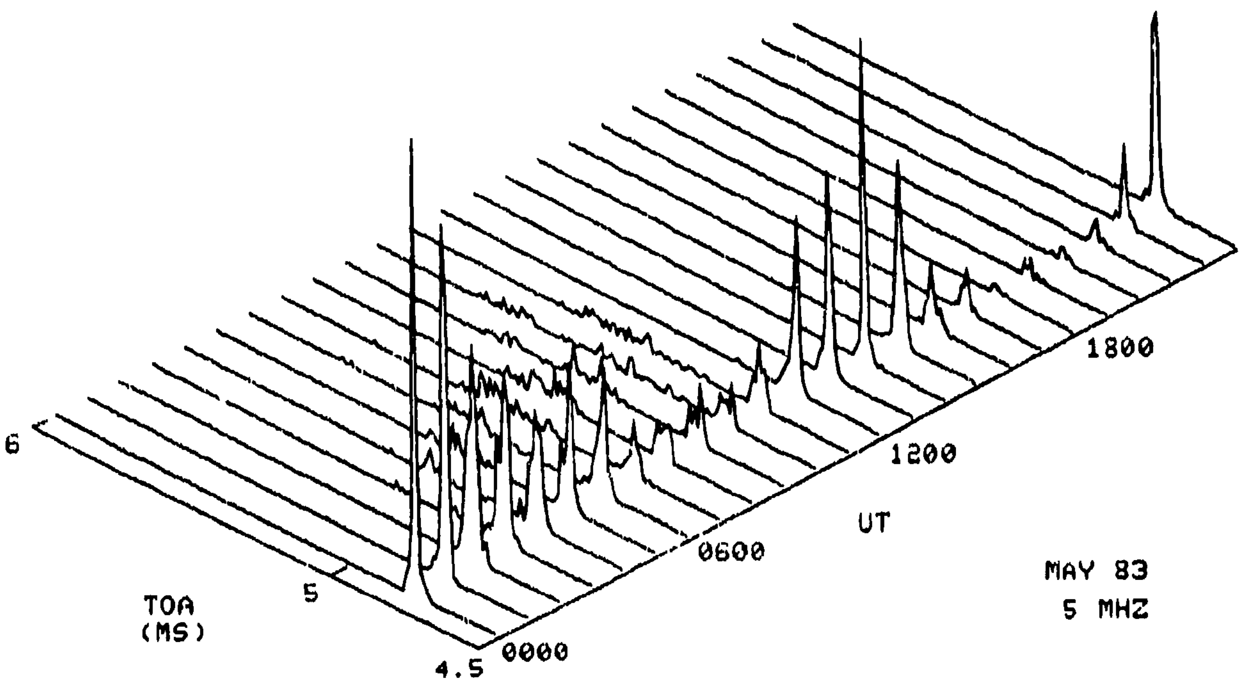


Figure 78. Hourly TOA averages May 1983 — WWV to NOSC.

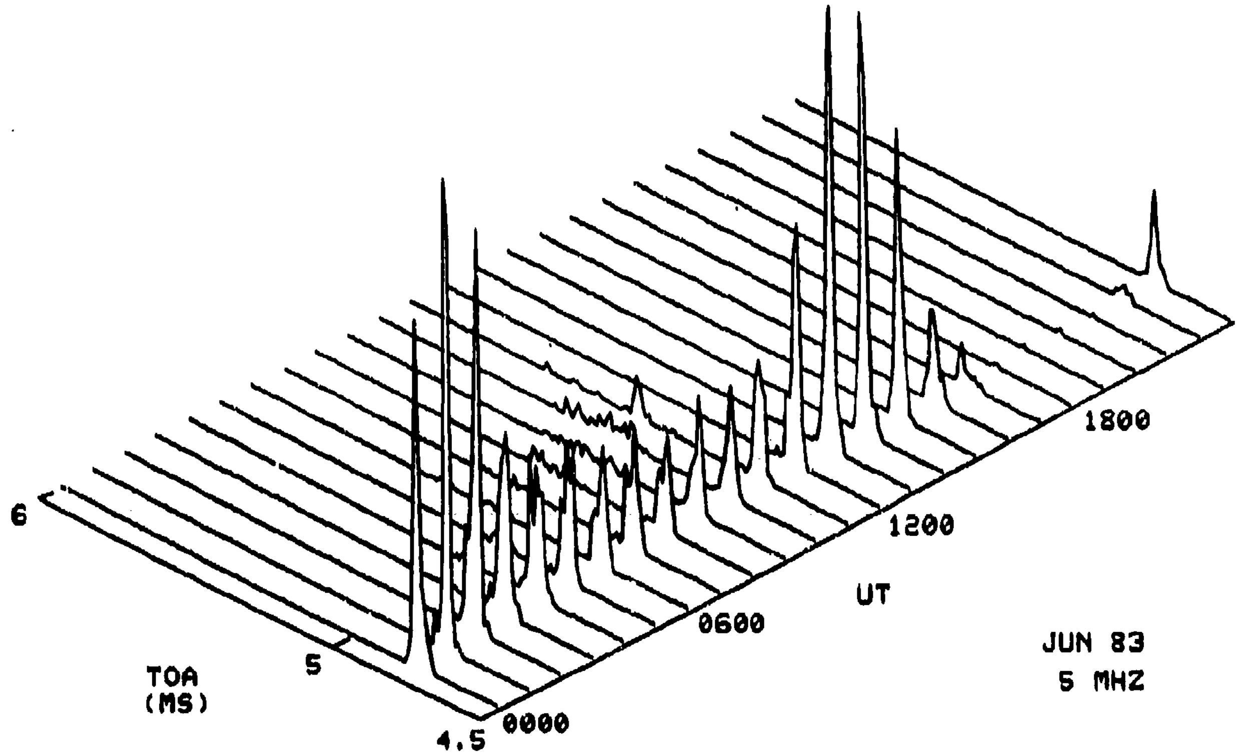


Figure 79. Hourly TOA averages Jun 1983 — WWV to NOSC.

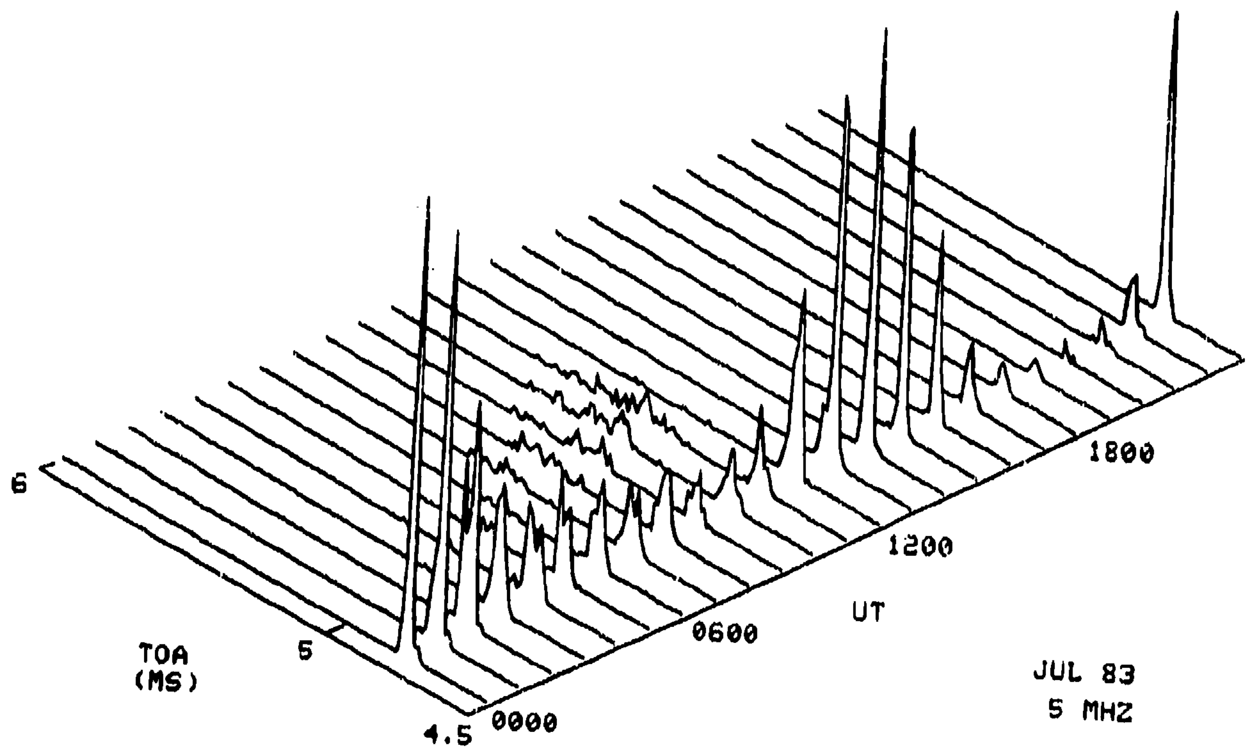


Figure 80. Hourly TOA averages Jul 1983 — WWV to NOSC.

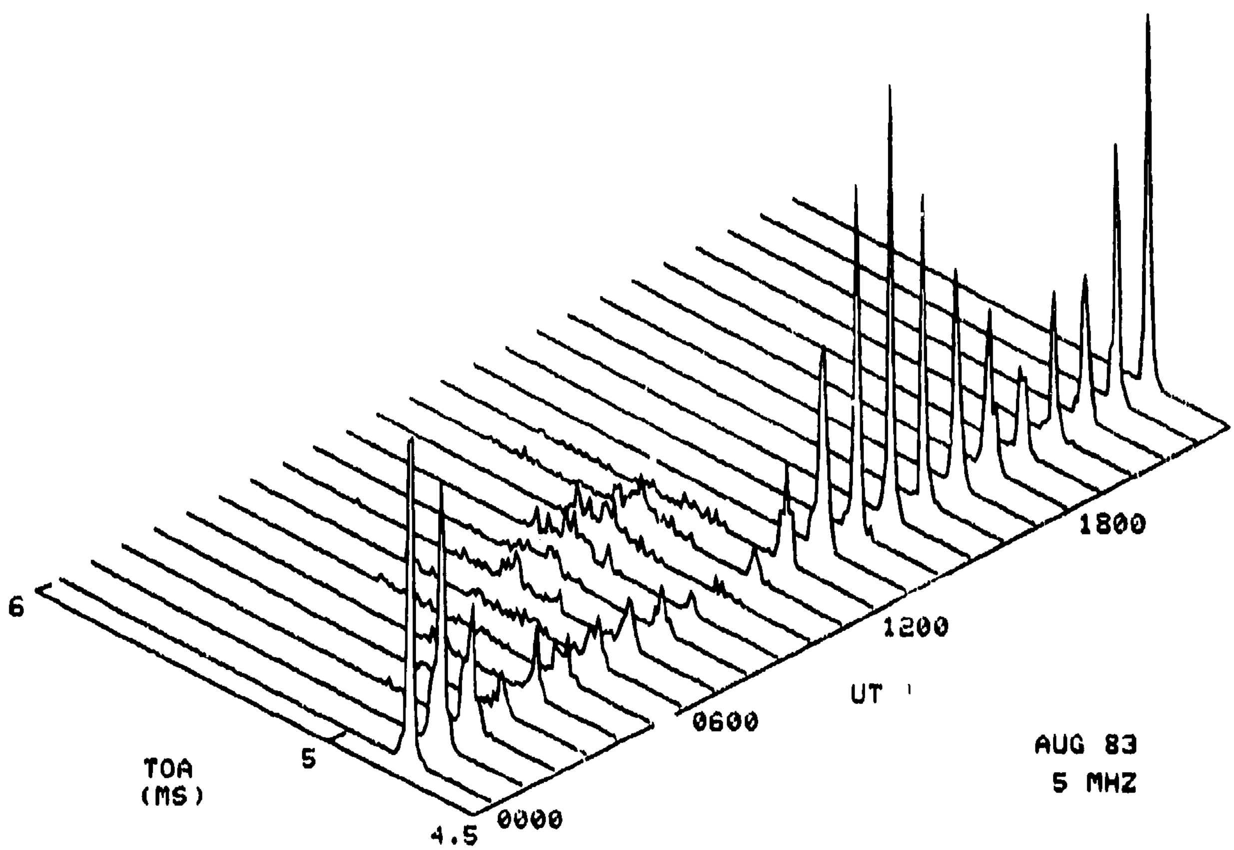


Figure 81. Hourly TOA averages Aug 1983 — WWV to NOSC.

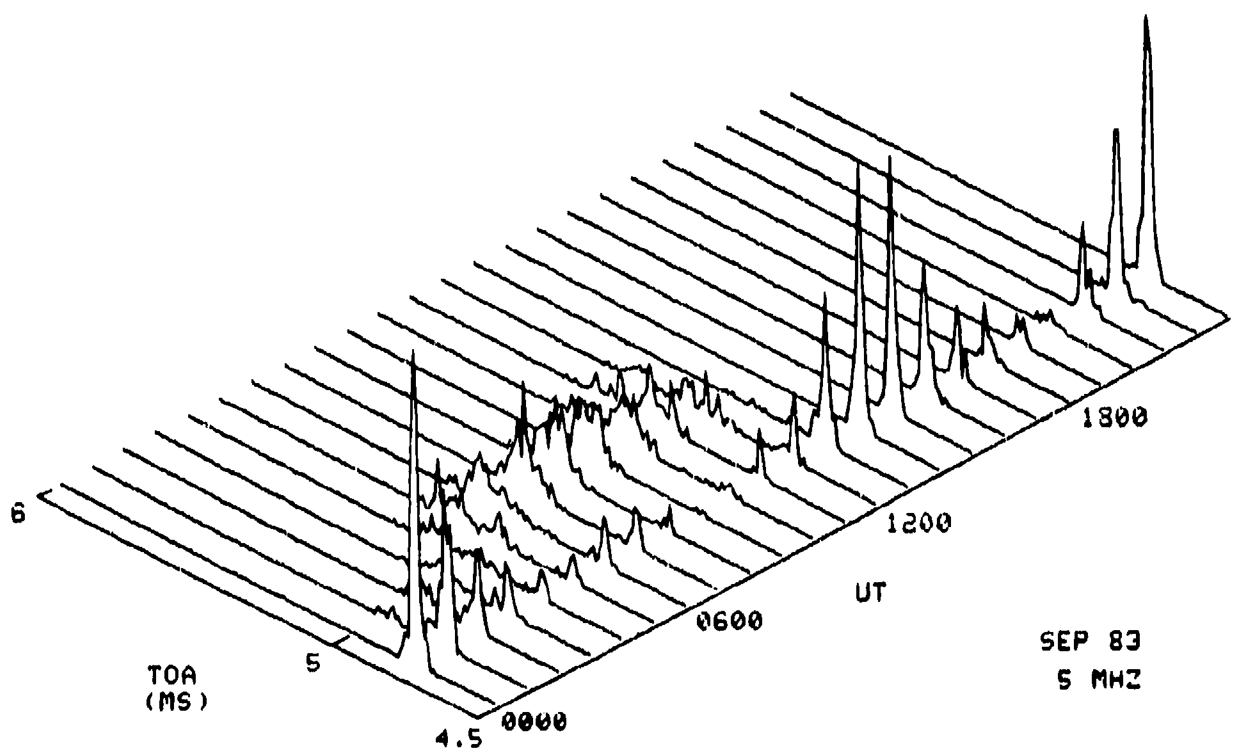


Figure 82. Hourly TOA averages Sep 1983 — WWV to NOSC.

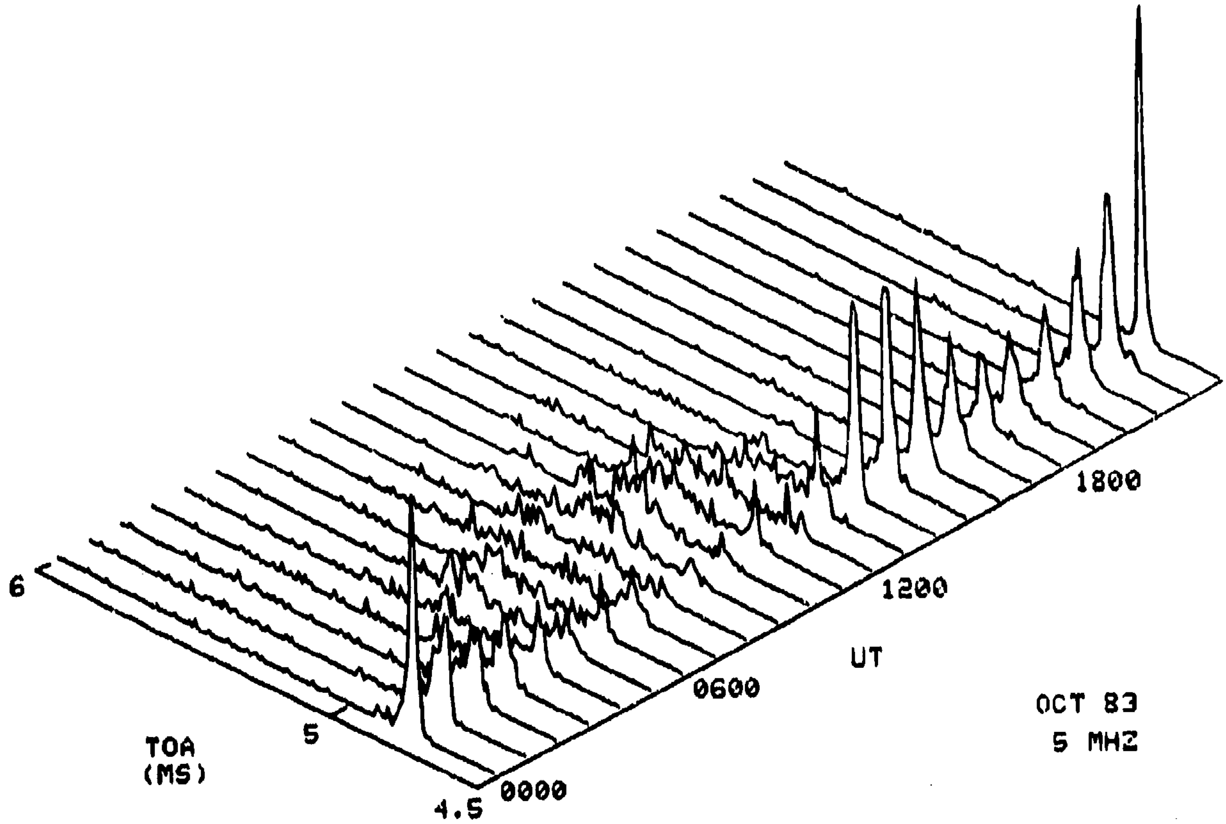


Figure 83. Hourly TOA averages Oct 1983 — WWV to NOSC.

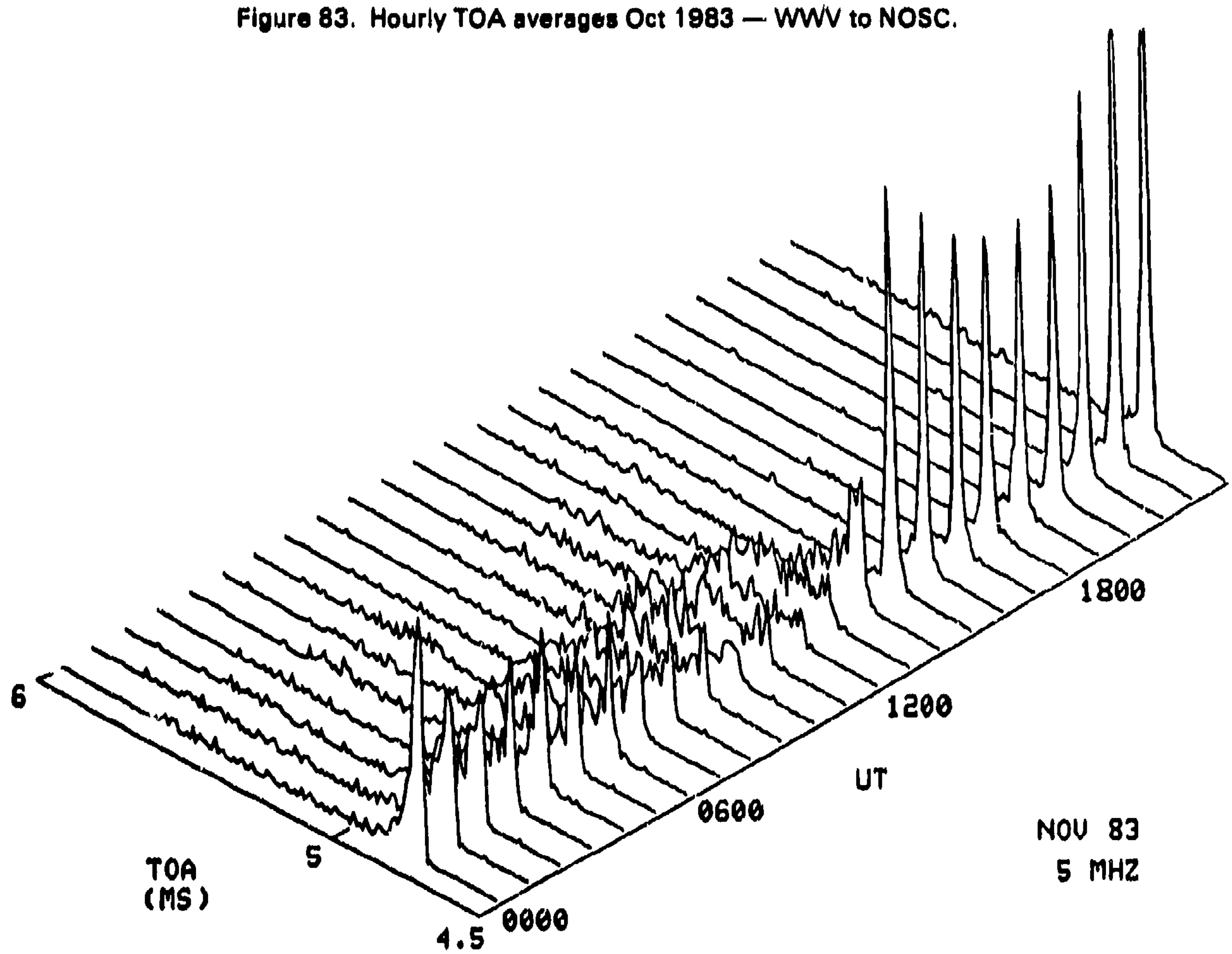


Figure 84. Hourly TOA averages Nov 1983 — WWV to NOSC.

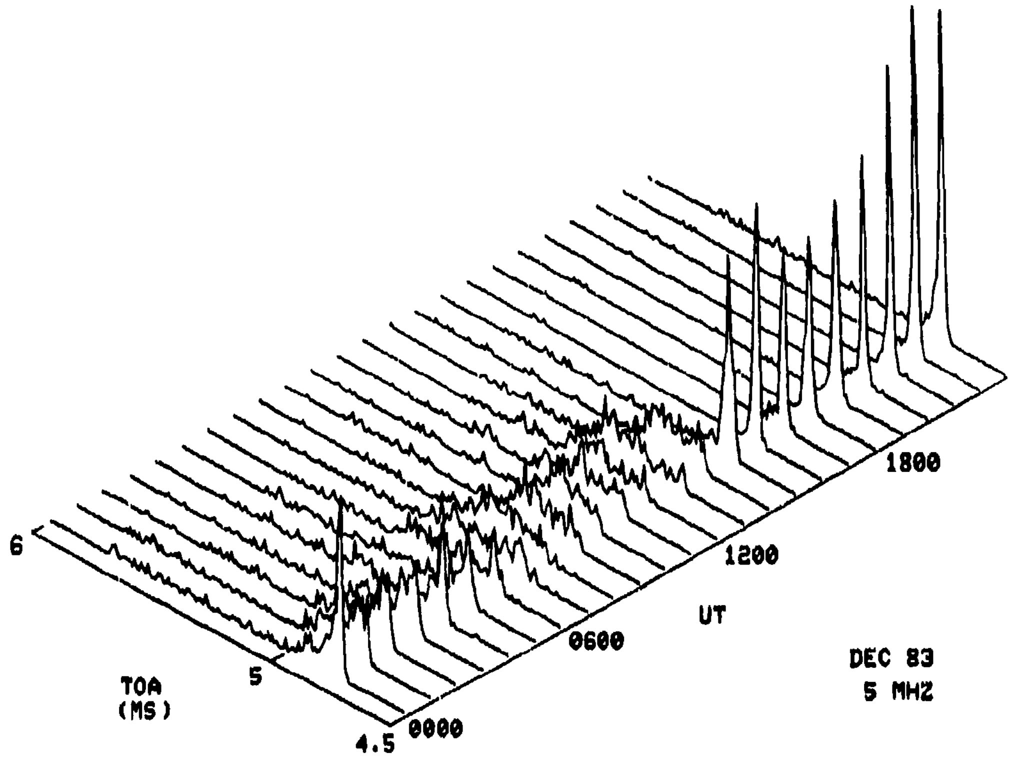


Figure 85. Hourly TOA averages Dec 1983 — WWV to NOSC.

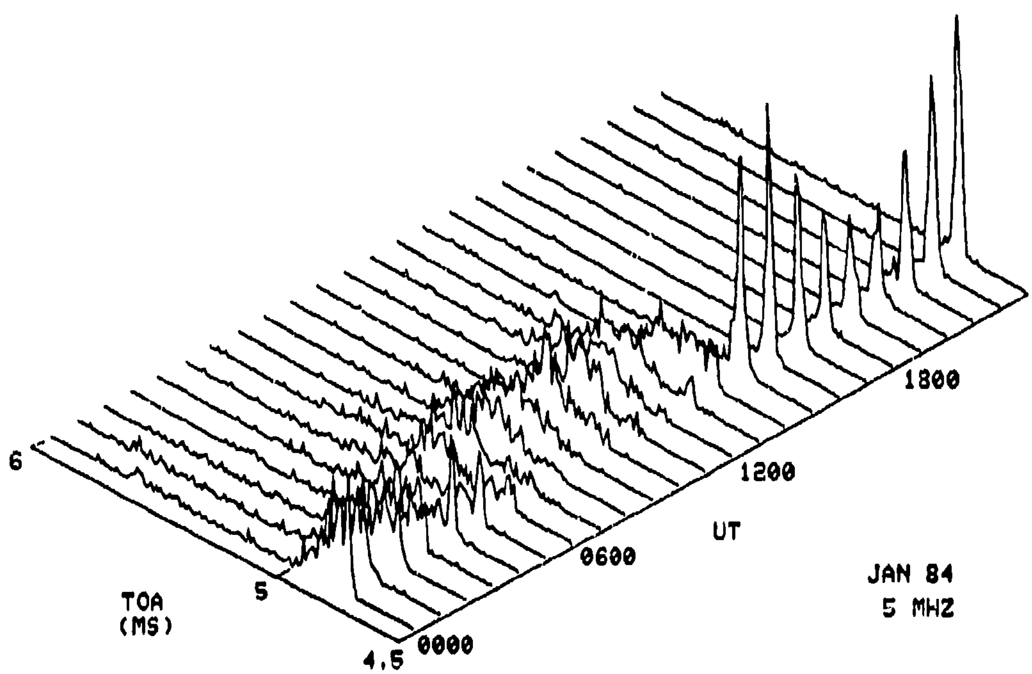


Figure 86. Hourly TOA averages Jan 1984 — WWV to NOSC.

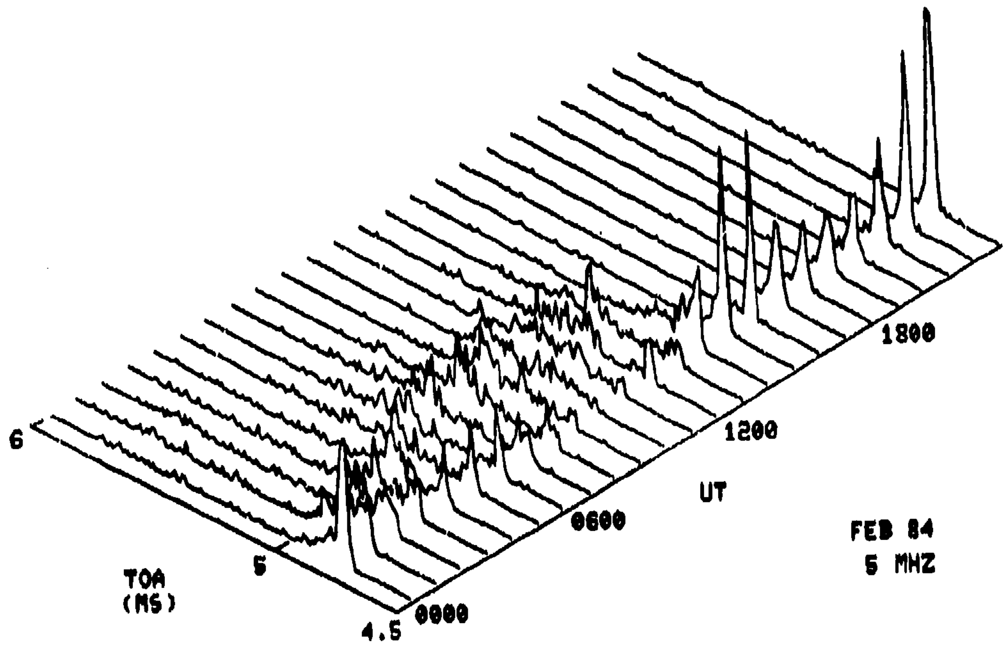


Figure 87. Hourly TOA averages Feb 1984 — WWV to NOSC.

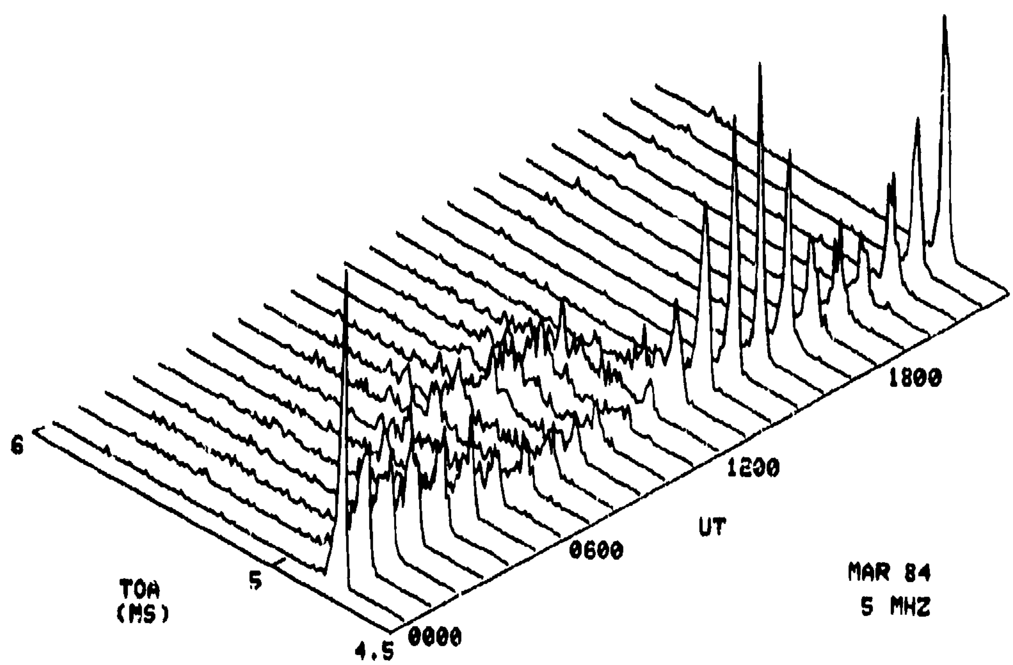


Figure 88. Hourly TOA averages Mar 1984 — WWV to NOSC.

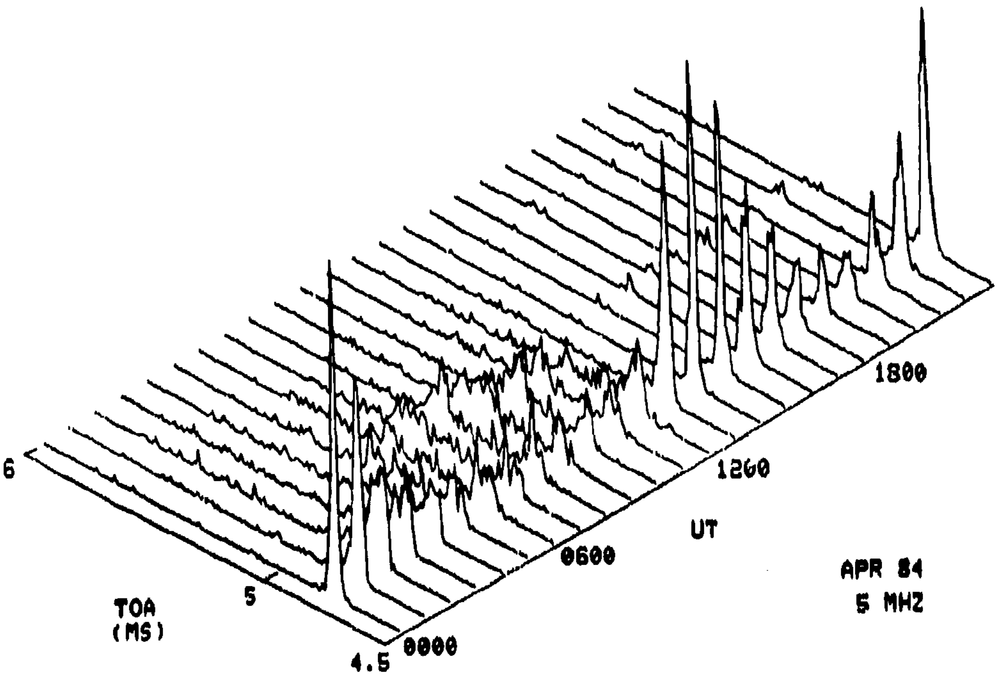


Figure 89. Hourly TOA averages Apr 1984 — WWV to NOSC.

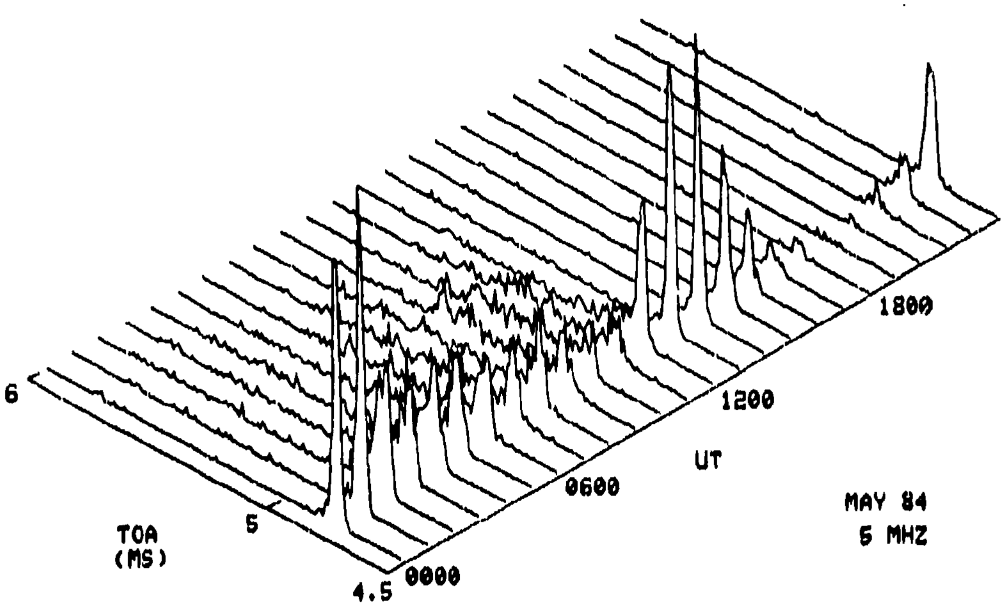


Figure 90. Hourly TOA averages May 1984 — WWV to NOSC.

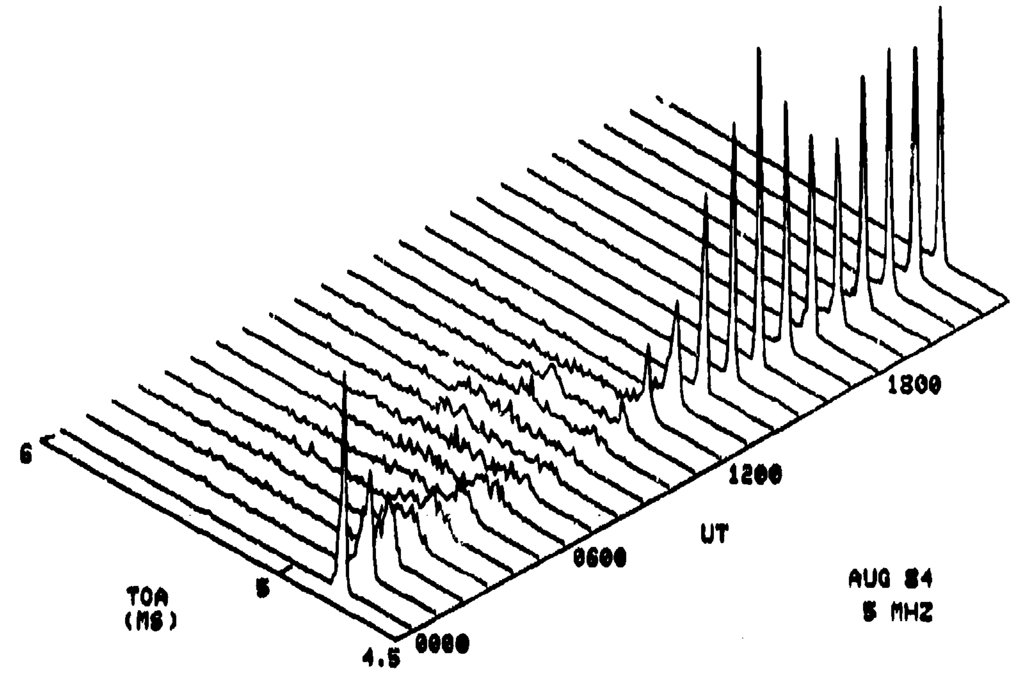


Figure 91. Hourly TOA averages Aug 1984 — WWV to NOSC.

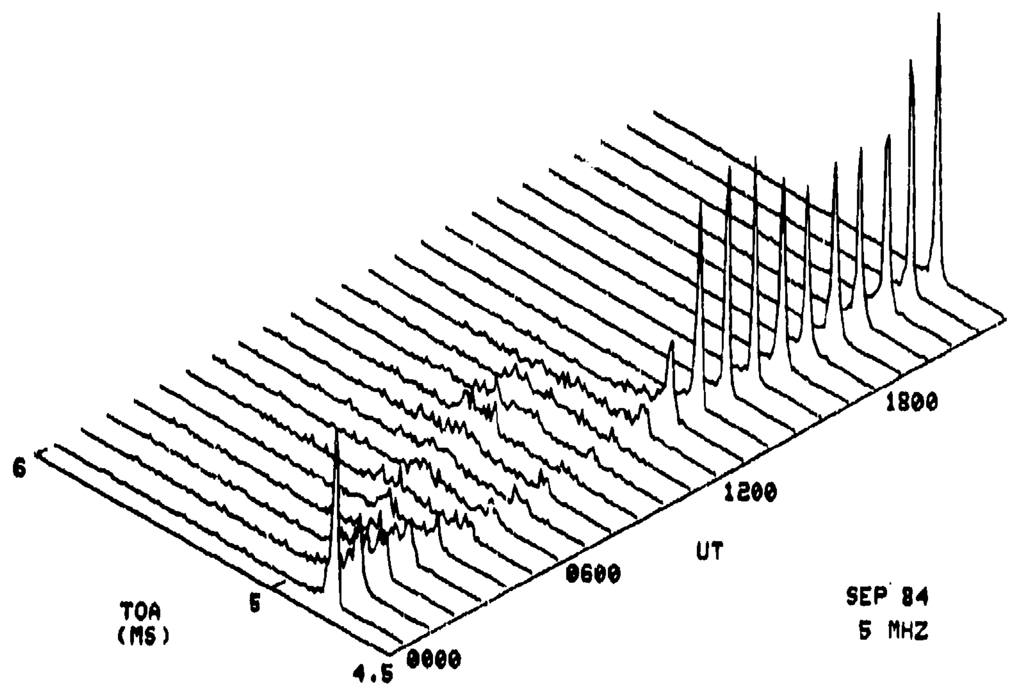


Figure 92. Hourly TOA averages Sep 1984 — WWV to NOSC.

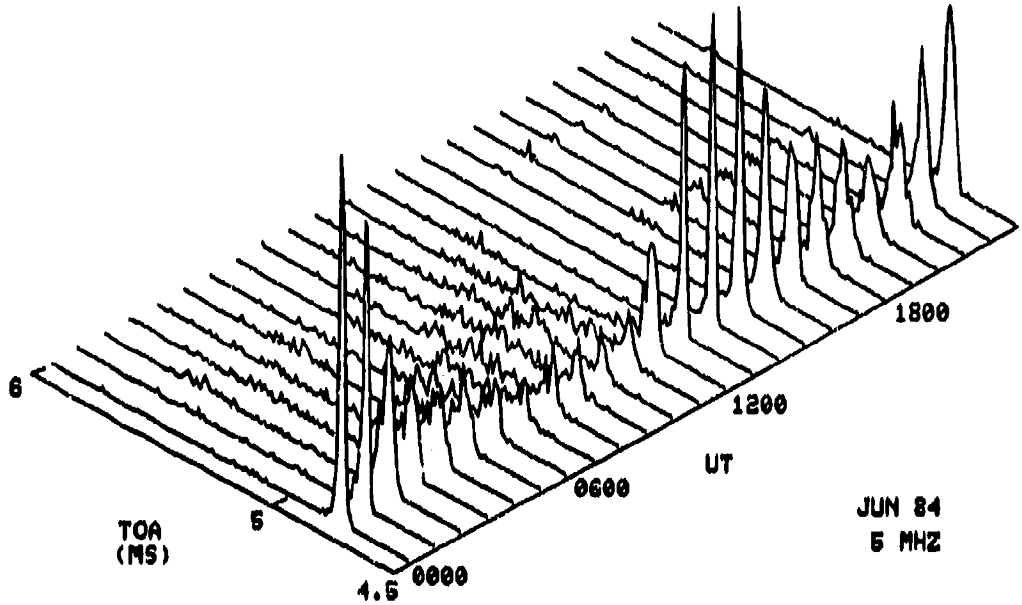


Figure 93. Hourly TOA averages Jun 1984 — WWV to NOSC.

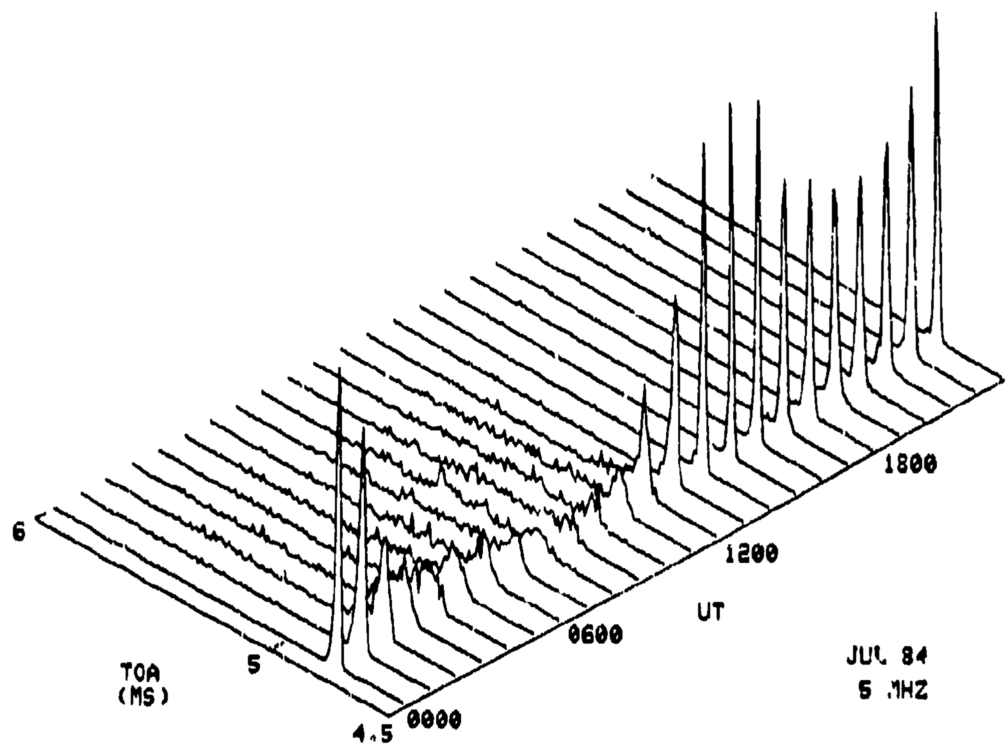


Figure 94. Hourly TOA averages Jul 1984 — WWV to NOSC.

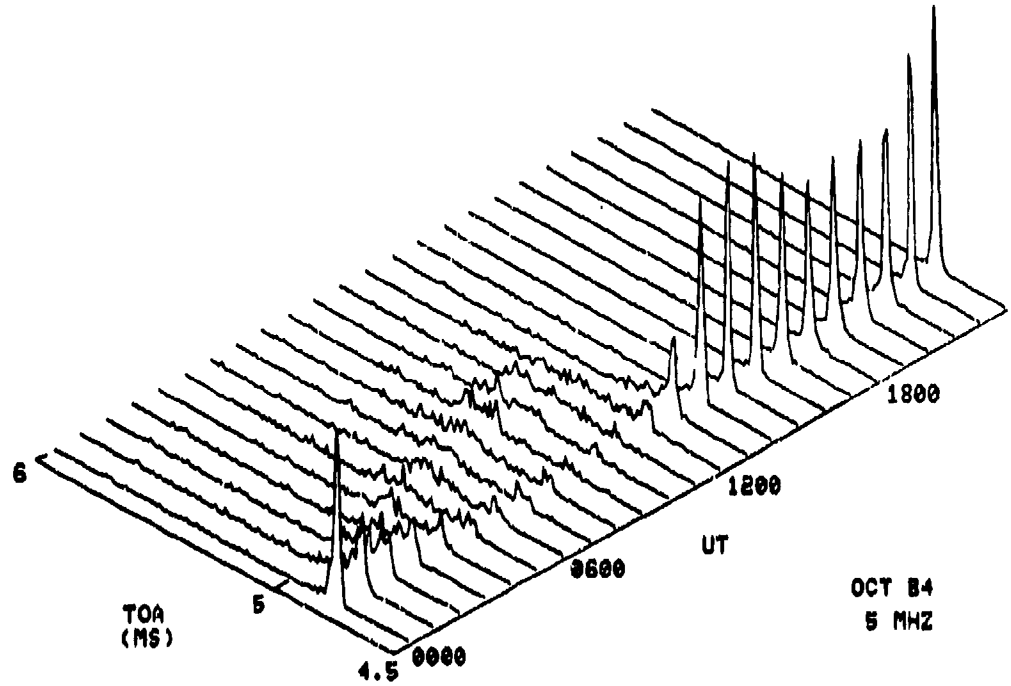


Figure 95. Hourly TOA averages Oct 1984 — WWV to NOSC.

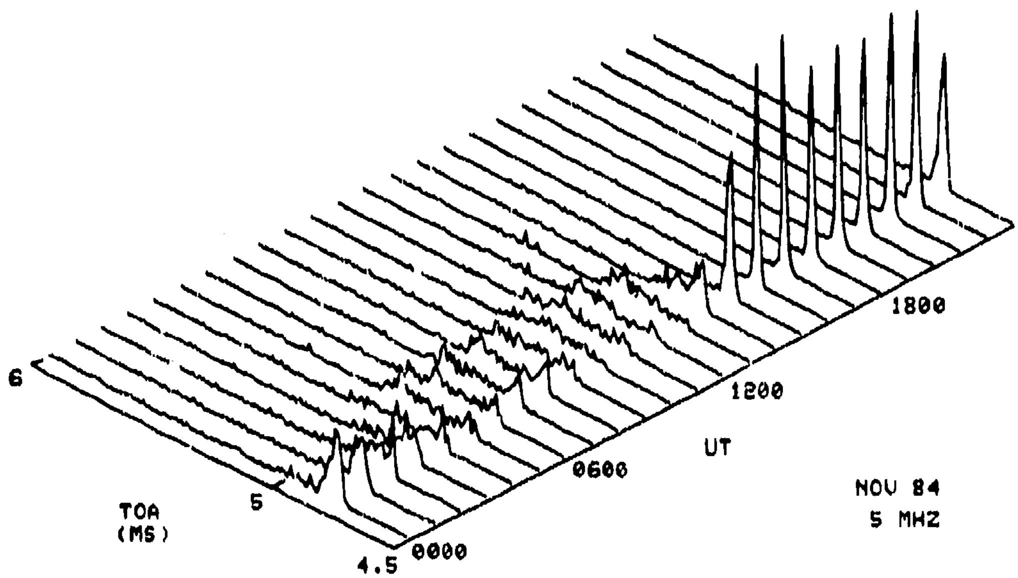


Figure 96. Hourly TOA averages Nov 1984 — WWV to NOSC.

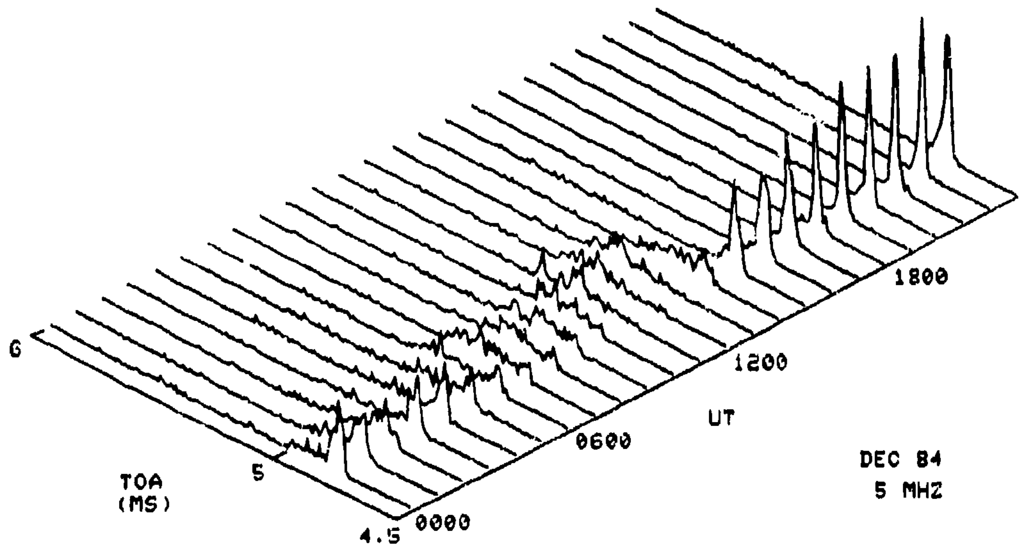


Figure 97. Hourly TOA averages Dec 1984 — WWV to NOSC.

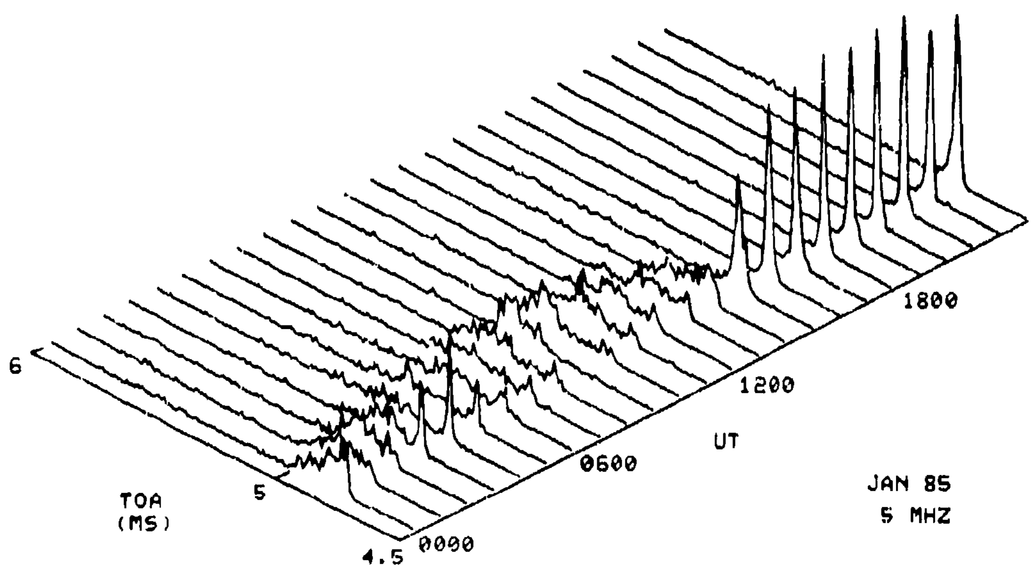


Figure 98. Hourly TOA averages Jan 1985 — WWV to NOSC.

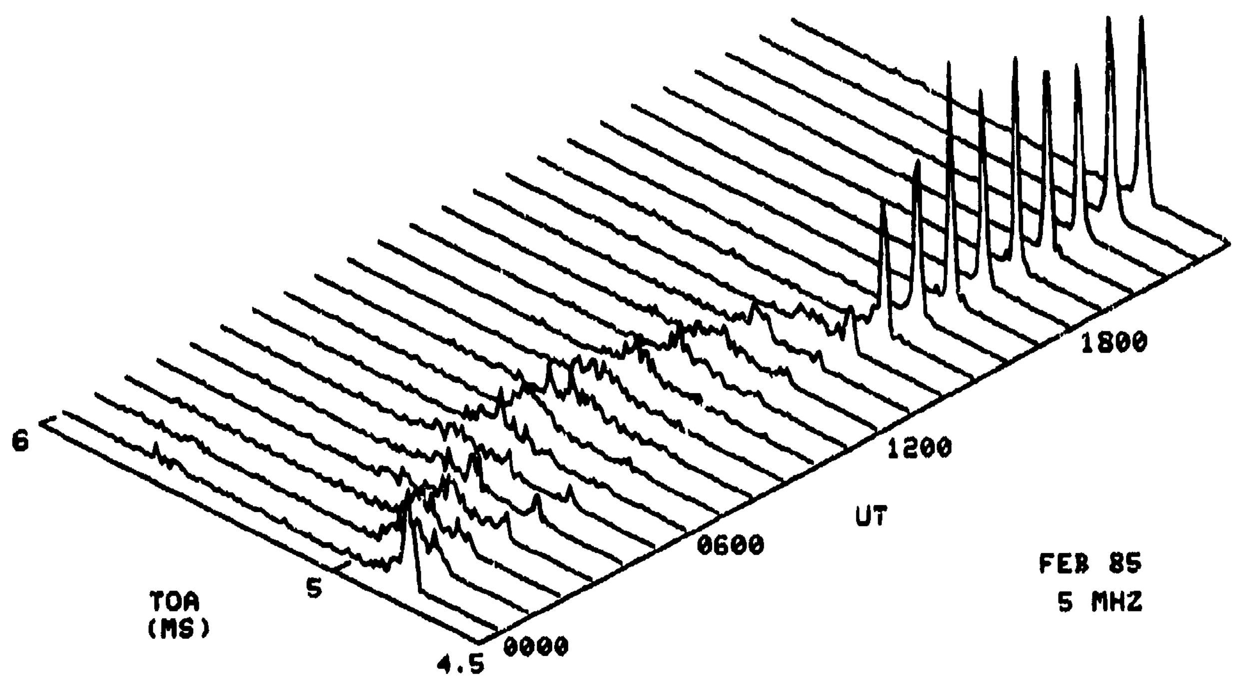


Figure 99. Hourly TOA averages Feb 1985 — WWV to NOSC.

The F-region propagation on 5 MHz is only seen at night and is very dispersed. In the winter and spring months where there are both F and E modes at nignt, TOAs can be spread over a half millisecond (500 microseconds).

2.5-MHz TOA (FIGURES 100-112)

In early 1984, 20-MHz signal reliability had declined so badly that it was replaced with signals from the 2.5-MHz WWV transmission. Because of absorption at these frequencies, the 20-MHz signal is a difficult frequency to use. However, in February 1984, the new TOA system started producing good measurement results. The 2.5 MHz signal is strictly a night frequency which simple physics will tell a user the results will primarily use the E-region. As can be seen from the Figures 102-114, the TOA data are primarily E but are spread out to approximately 100 microseconds.

The other observation from these data is that whatever steep incidence F-region propagation exists is badly scattered and diminishes through 1984. As would be expected, there is no daytime propagation on 2.5 MHz. Further, it is expected that time-sensitive systems operating in this part of the HF spectrum will have a severe signal-to-noise problem.

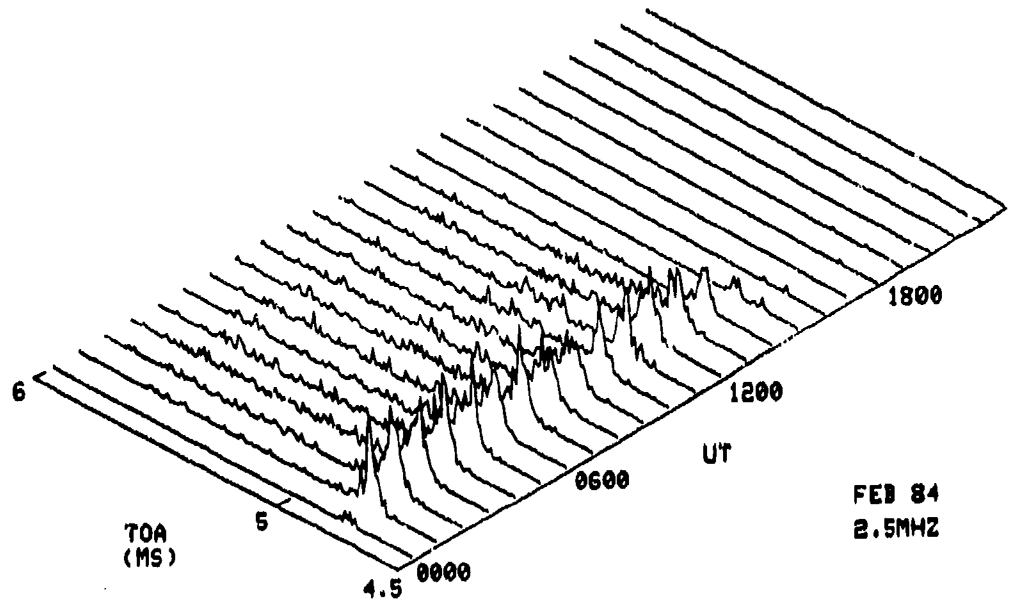


Figure 100. Hourly TOA averages Feb 1984 — WWV to NOSC.

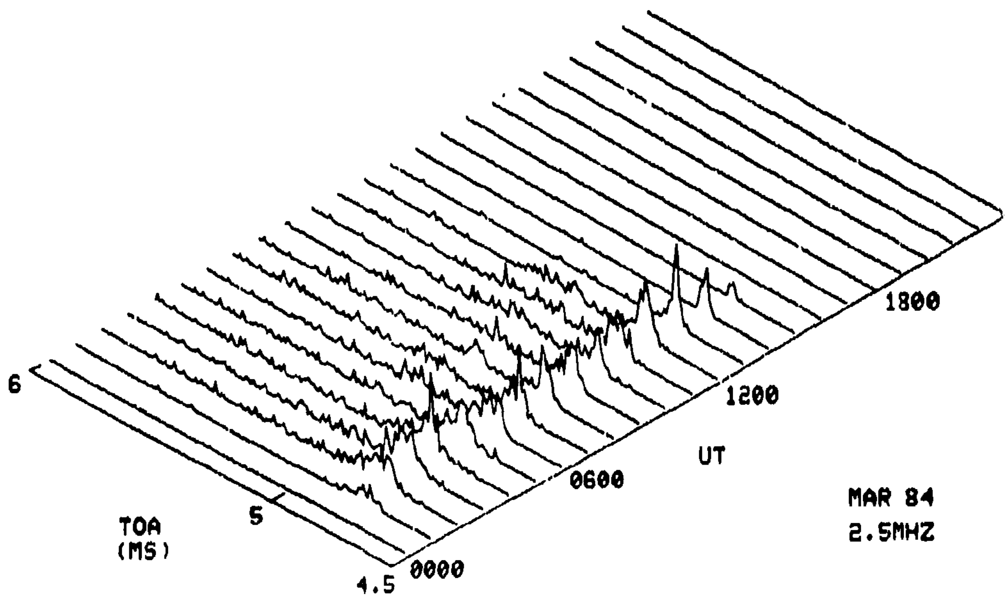


Figure 101. Hourly TOA averages Mar 1984 — WWV to NOSC.

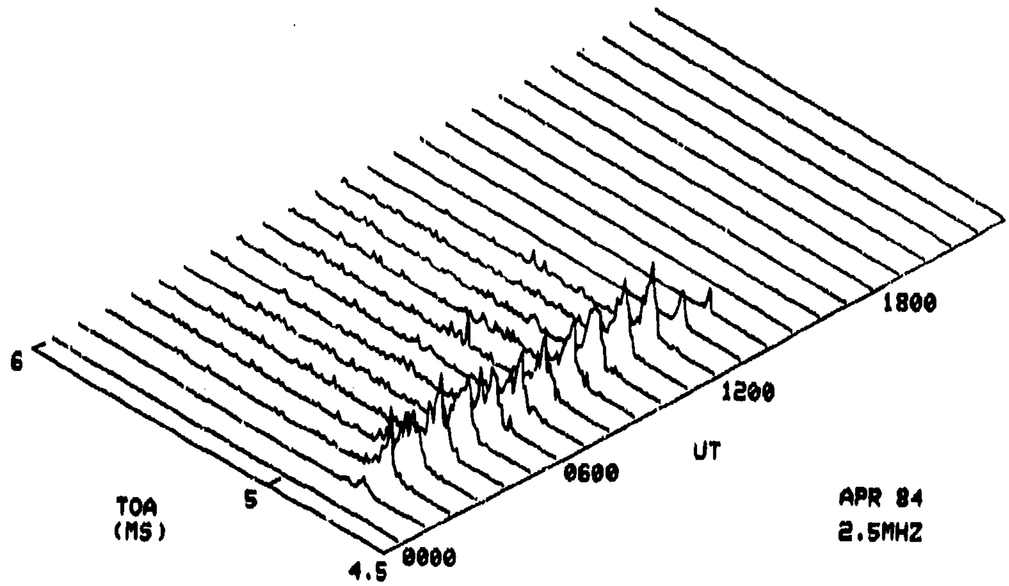


Figure 102. Hourly TOA averages Apr 1984 — WWV to NOSC.

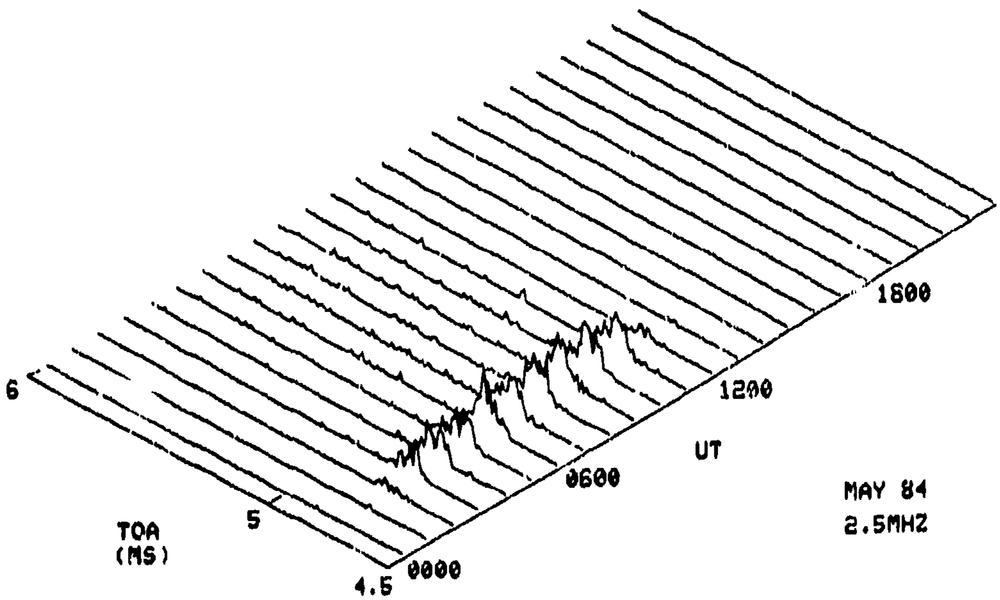


Figure 103. Hourly TOA averages May 1984 — WWV to NOSC.

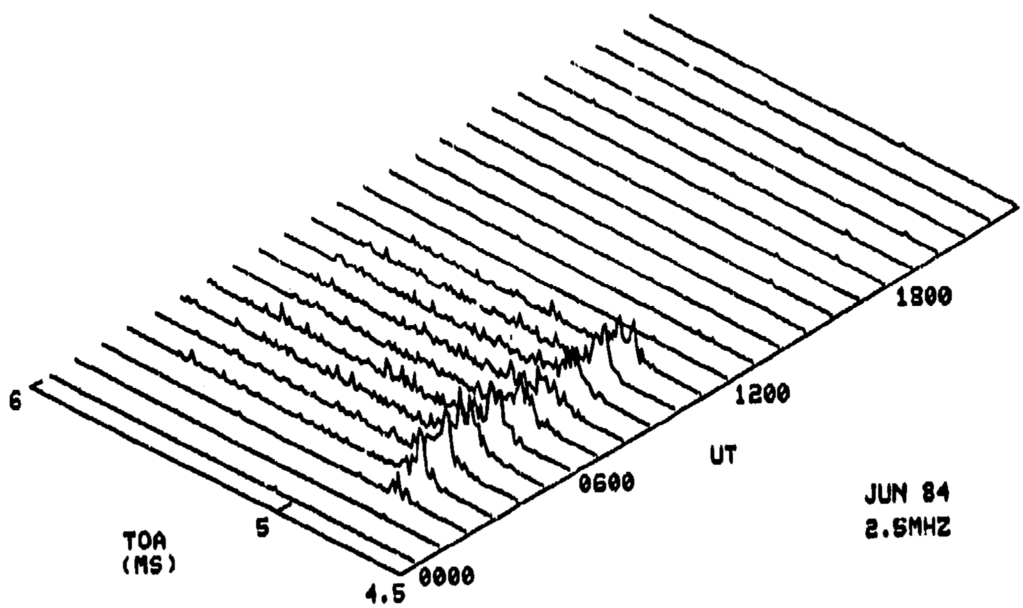


Figure 104. Hourly TOA averages Jun 1984 — WWV to NOSC.

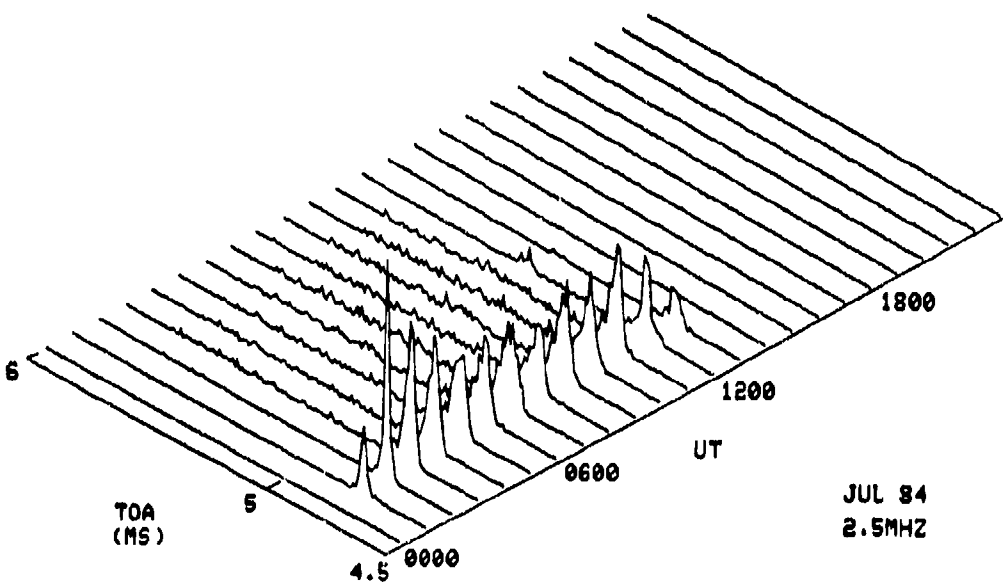


Figure 105. Hourly TOA averages Jul 1984 — WWV to NOSC.

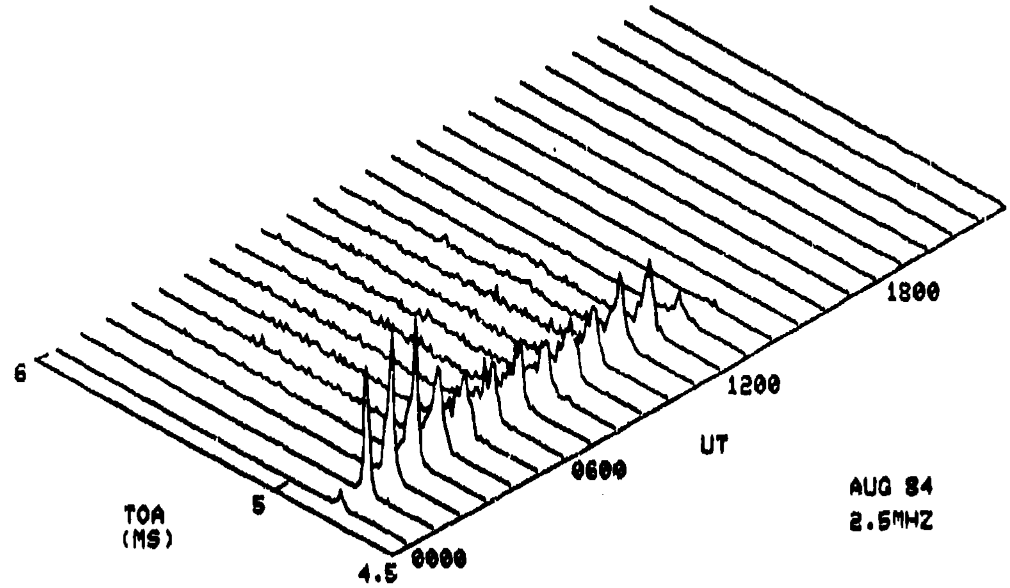


Figure 106. Hourly TOA averages Aug 1984 — WWV to NOSC.

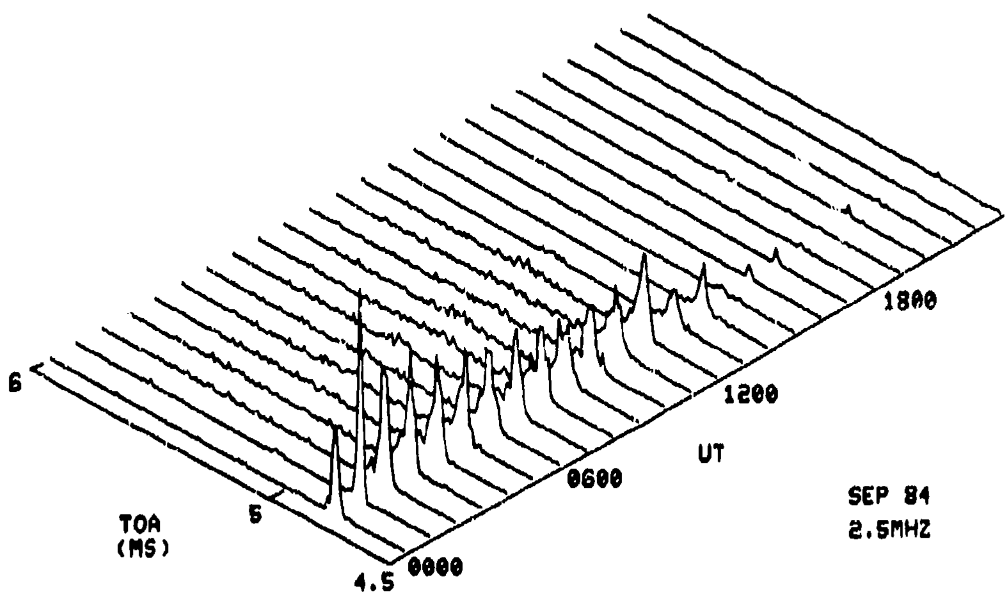


Figure 107. Hourly TOA averages Sep 1984 — WWV to NOSC.

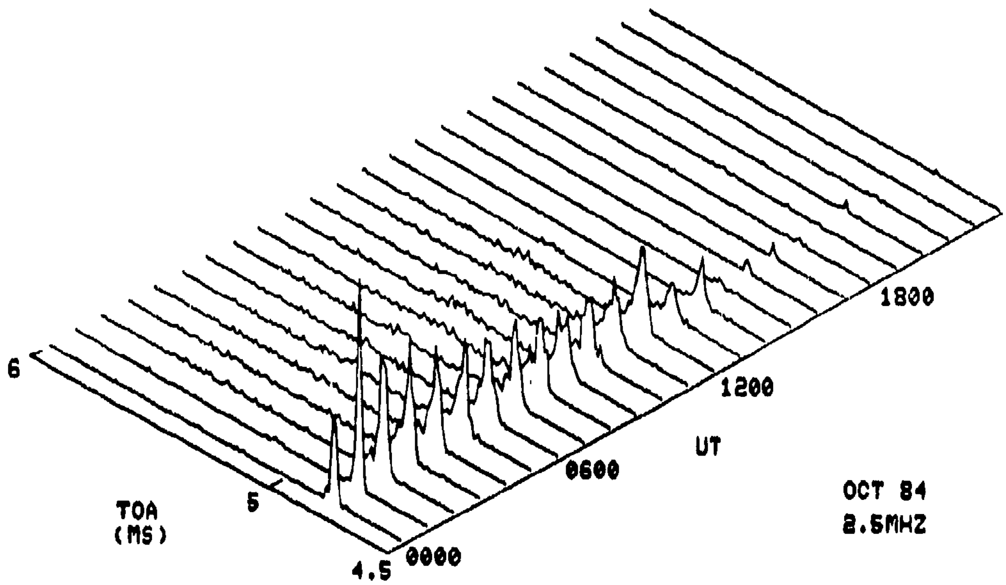


Figure 108. Hourly TOA averages Oct 1984 — WWV to NOSC.

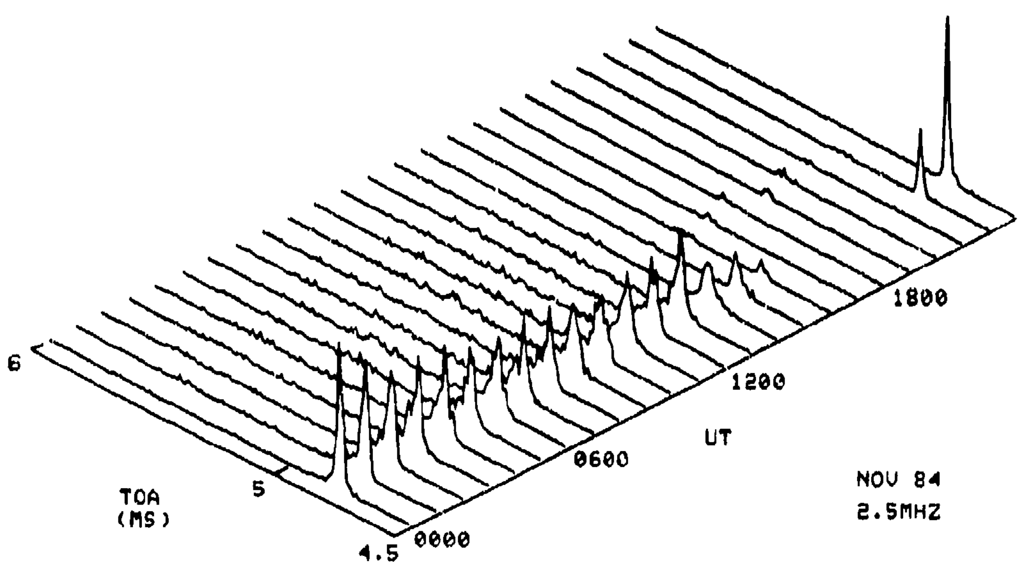


Figure 109. Hourly TOA averages Nov 1984 — WWV to NOSC.

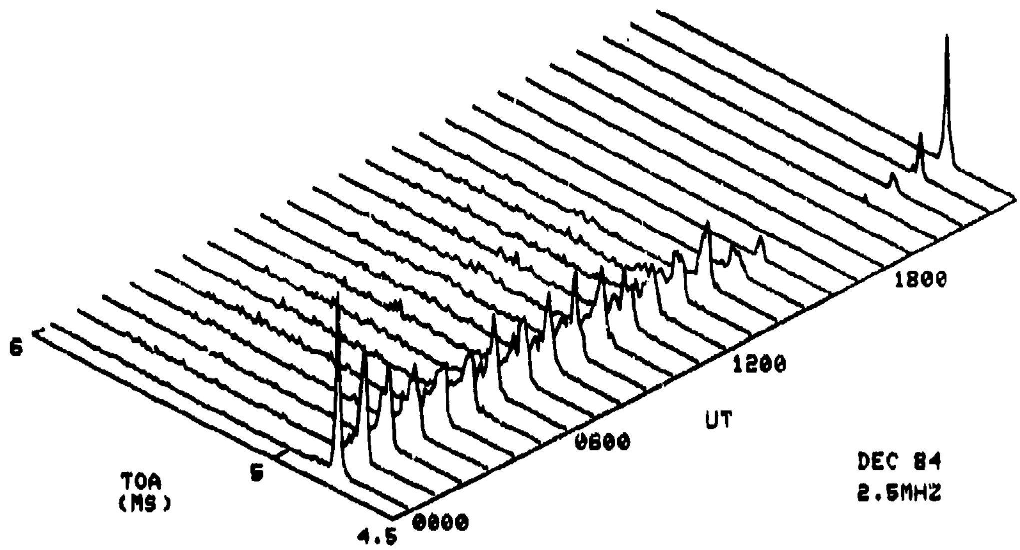


Figure 110. Hourly TOA averages Dec 1984 — WWV to NOSC.

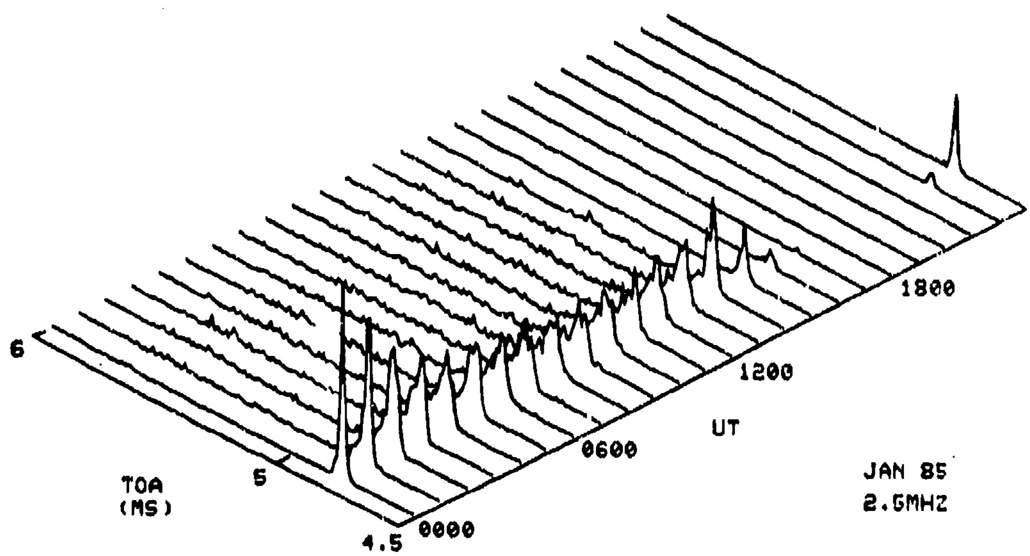


Figure 111. Hourly TOA averages Jan 1985 — WWV to NOSC.

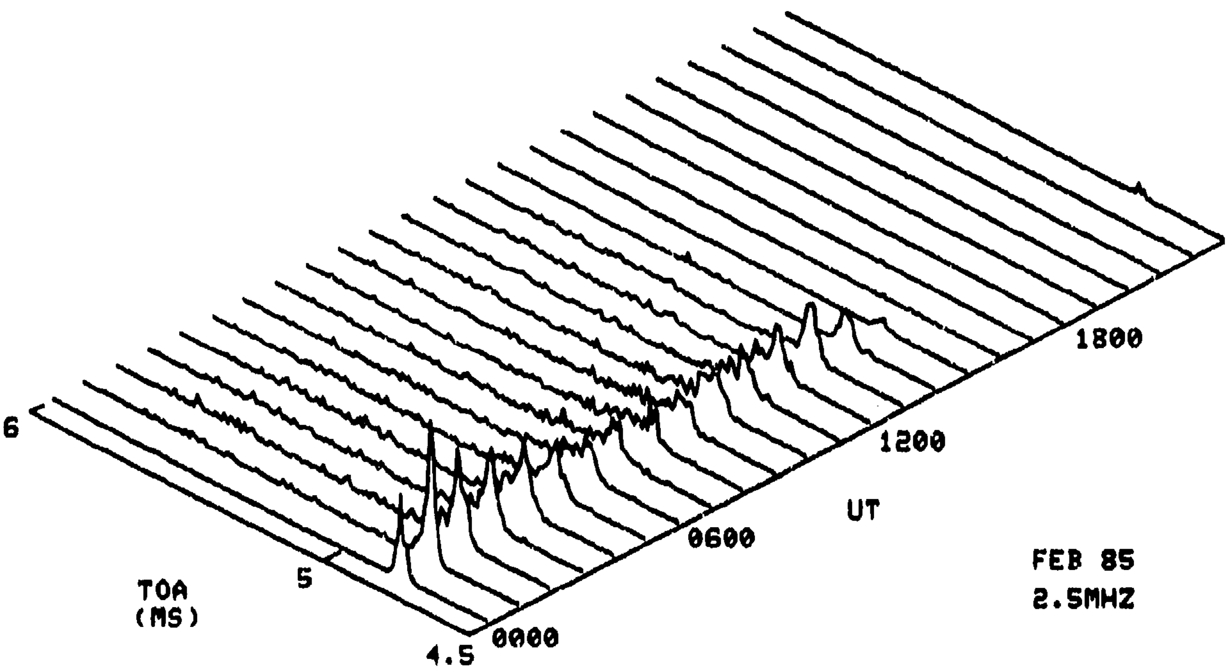


Figure 112. Hourly TOA averages Feb 1985 — WWV to NOSC.

20-MHz TOA (FIGURES 113-120)

The separate 20-MHz channel was in operation only between May and December 1983. This frequency is a bit high for the short path between Fort Collins and San Diego, and the solar decline eventually negated its usefulness. The only modes seen were daytime F and seasonal sporadic E. Of all the data reviewed so far, 20 MHz was the only one tc produce no surprises.

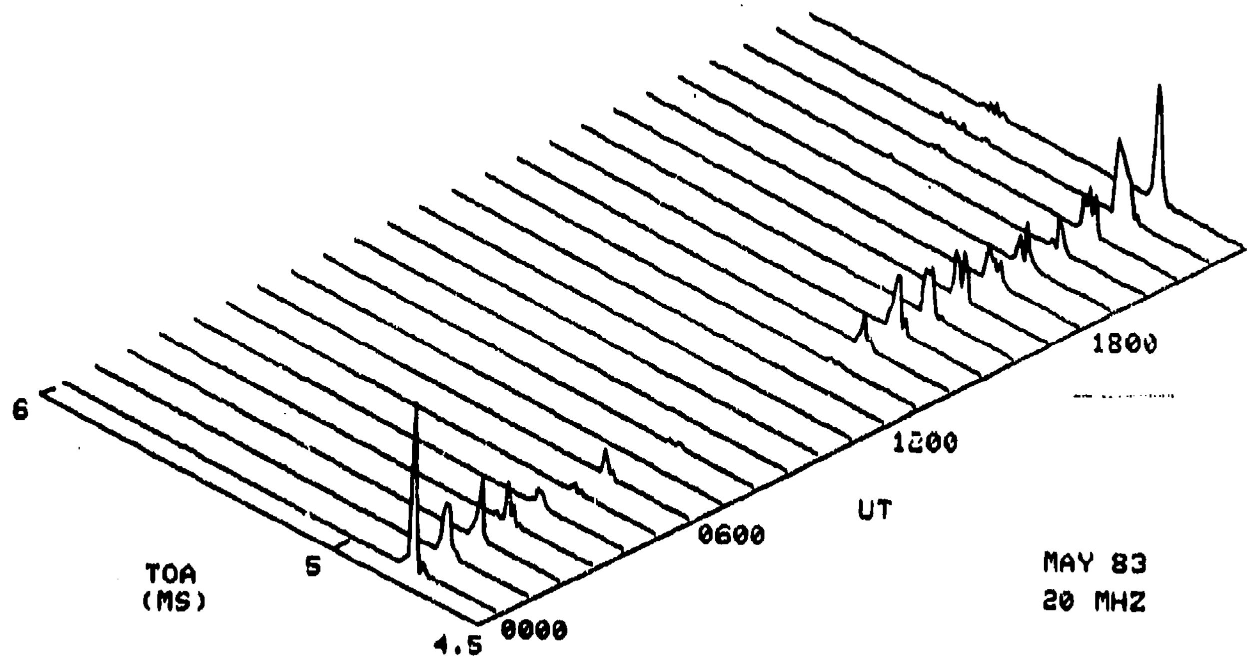


Figure 113. Hourly TOA averages May 1983 — WWV to NOSC.

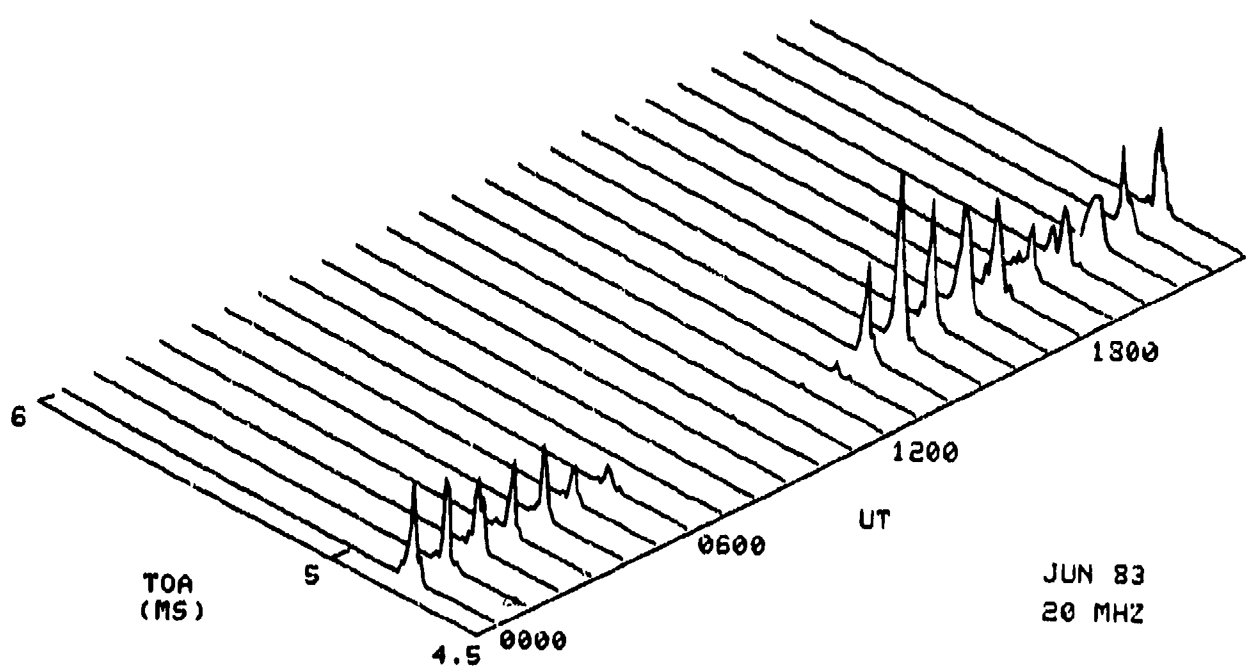


Figure 114. Hourly TOA averages Jun 1983 — WWV to NOSC.

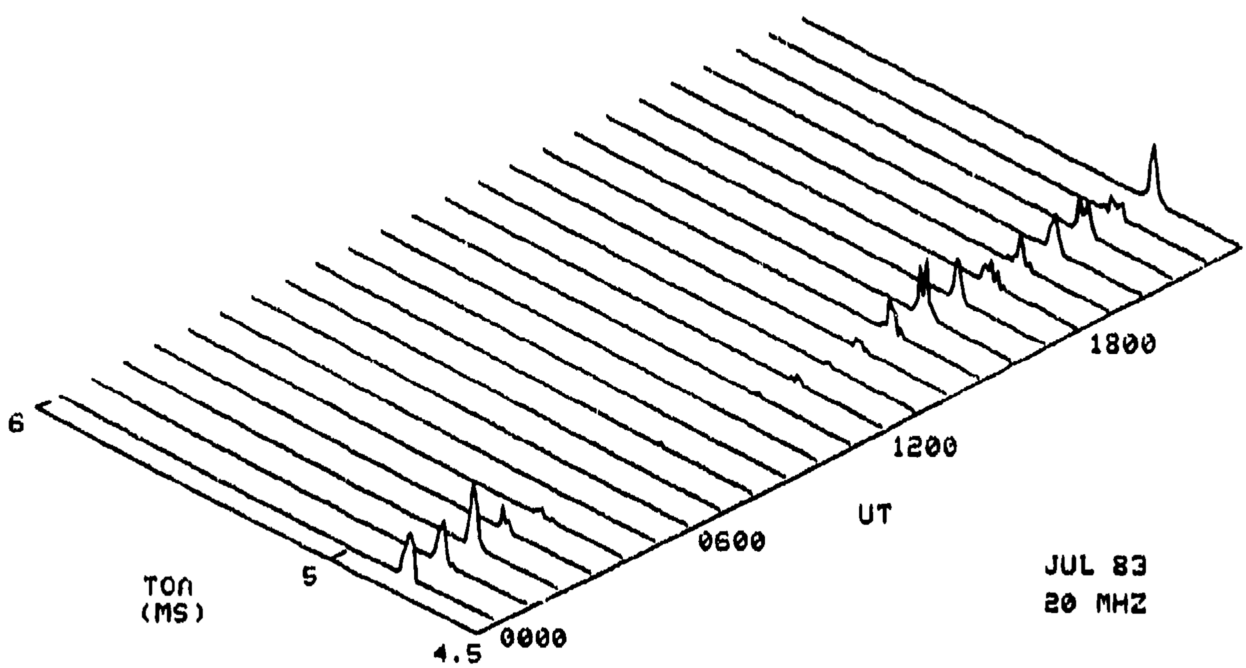


Figure 115. Hourly TOA averages Jul 1983 — WWV to NOSC.

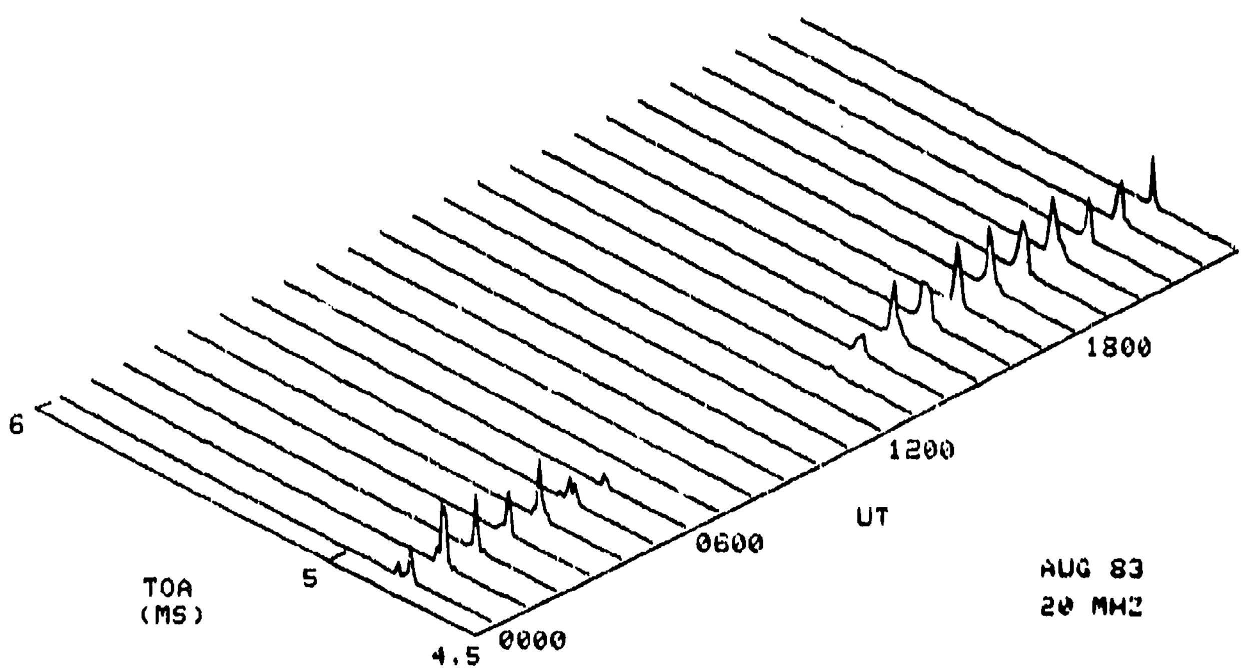


Figure 116. Hourly TOA averages Aug 1983 -- WWV to NOSC.

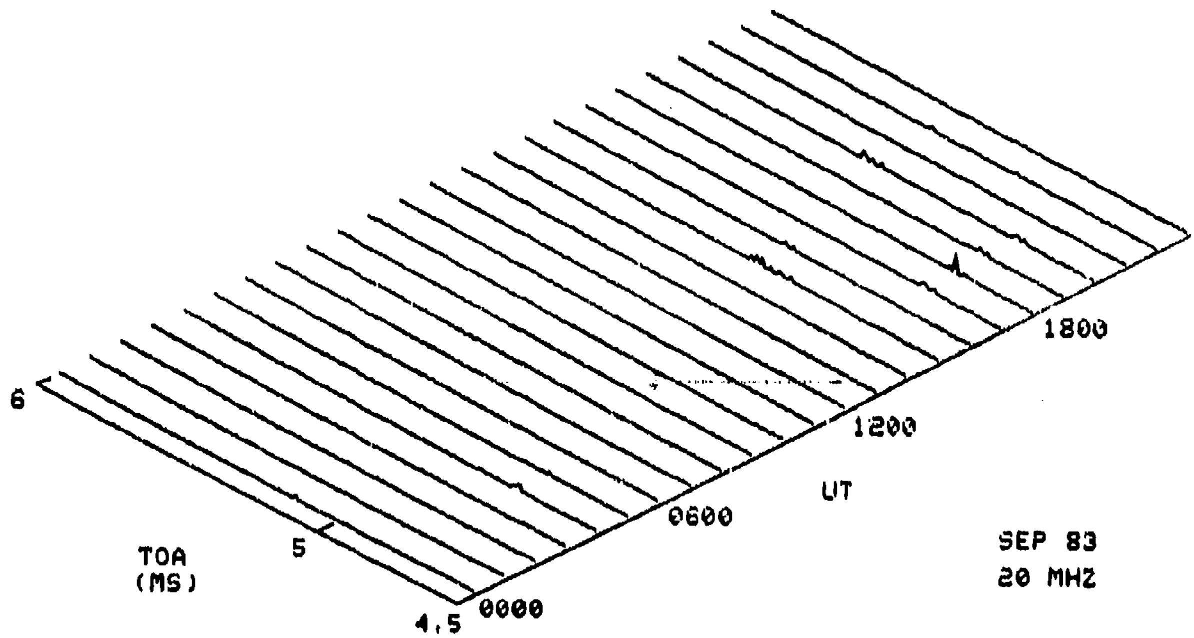


Figure 117. Hourly TOA averages Sep 1983 — WWV to NOSC.

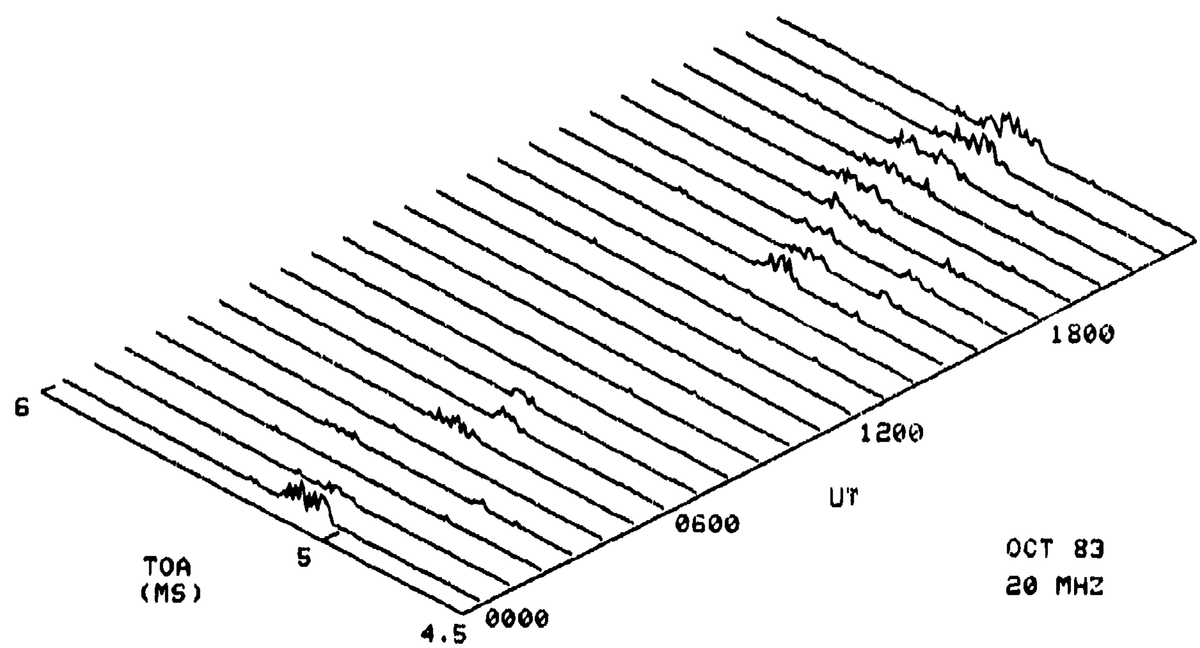


Figure 118. Hourly TOA averages Oct 1983 — WWV to NOSC.

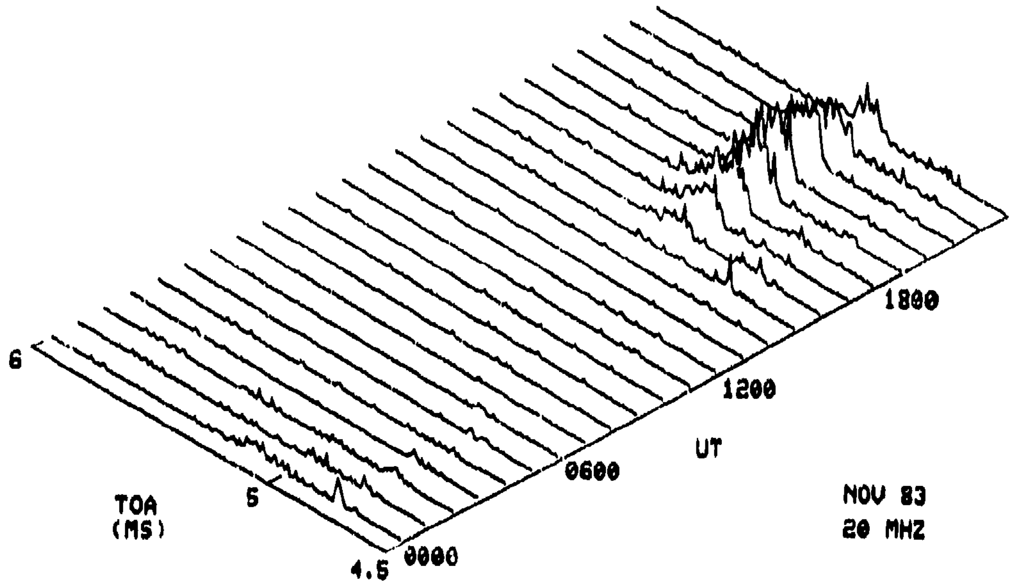


Figure 119. Hourly TOA averages Nov 1983 — WWV to NOSC.

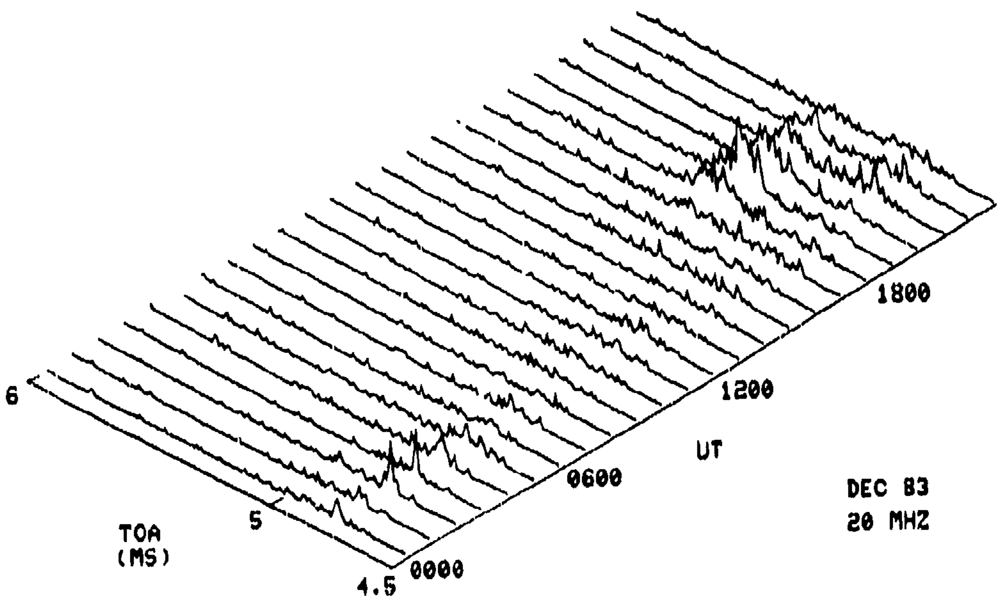


Figure 120. Hourly TOA averages Dec 1983 — WWV to NOSC.

GENERAL COMMENTS

It is not the intention of this report to exhaustively examine every figure presented. Its objective is to report certain trends and the ramifications of the findings. It is felt that others in the community will also scrutinize the data and reach other conclusions, further exploiting these data. To further this cause, Appendix A contains the hourly average TOA and its standard deviation for the years of 1983 and 1984. This should provide HF time-sensitive geolocation system engineers with the data needed to bound the potential accuracy of a proposed system. At best what we see is a best case uncertainty of approximately 25 microseconds, a nominal range of 75-100 microseconds, and the worst case showing 200- to 500-microsecond uncertainty. This is all seen on a supposedly well behaved, medium-range, mid-latitude, north-south path.

The most important result from this experiment is that the TOA sensor has proven to be a sensitive ionospheric sensor, especially with respect to ionospheric movement. The short range experiment has proven to provide extremely high resolution data and has shown the correlation time of a single ionospheric measurement at about 2 minutes. It has shown that the ionospheric medium is more stratified and volatile than traditionally thought.

LONG BASELINE TIME OF ARRIVAL (LBTOA) DATA

The NOSC Long Baseline Time of Arrival (LBTOA) experiment was installed at the Naval Security Group Activity, Wahiawa, Hawaii, on 4 October 1983. This experiment was designed to measure the TIC signals from WWV, Fort Collins, Colorado, and JJY Tokyo, Japan. Figure 121 shows the test configuration.

A extensive hearability study was conducted in November - December 1982. The current LBTOA design was based on these studies. The heart of the LBTOA system is the Kenwood R2000 receiver which is controlled by an 8086 microprocessor. The frequency to be monitored and the exact time window of the signal to be looked at is controlled by this microcomputer. The system is slaved to a cesium beam primary standard.

The LBTOA system uses two 16-degree beamwidth sectors form the FRD-10A CDAA antenna system. One is pointed at WWV and the other at JJY. Experience with this antenna has shown that it has more than enough rejection to eliminate co-channel interference. For example, both JJY and WWV can be monitored on 15 MHz without the signals interfering with one another.

The experiment consists of monitoring first WWV and then JJY in succession each second. The time gates for each are opened at preprogrammed times. This allows the desired signal to be measured and the unwanted time standard signals which have different and known TOAs to be rejected. The most troublesome interfering signals are BSF, Taipei, Formosa, and the RID and RIB Soviet Time Standard Stations on 10 and 15 MHz. Time-gating also eliminates noise from contaminating the experiment. In addition, a signal recognition module was built into the system. The system performed satisfactorily between October 1985 and August

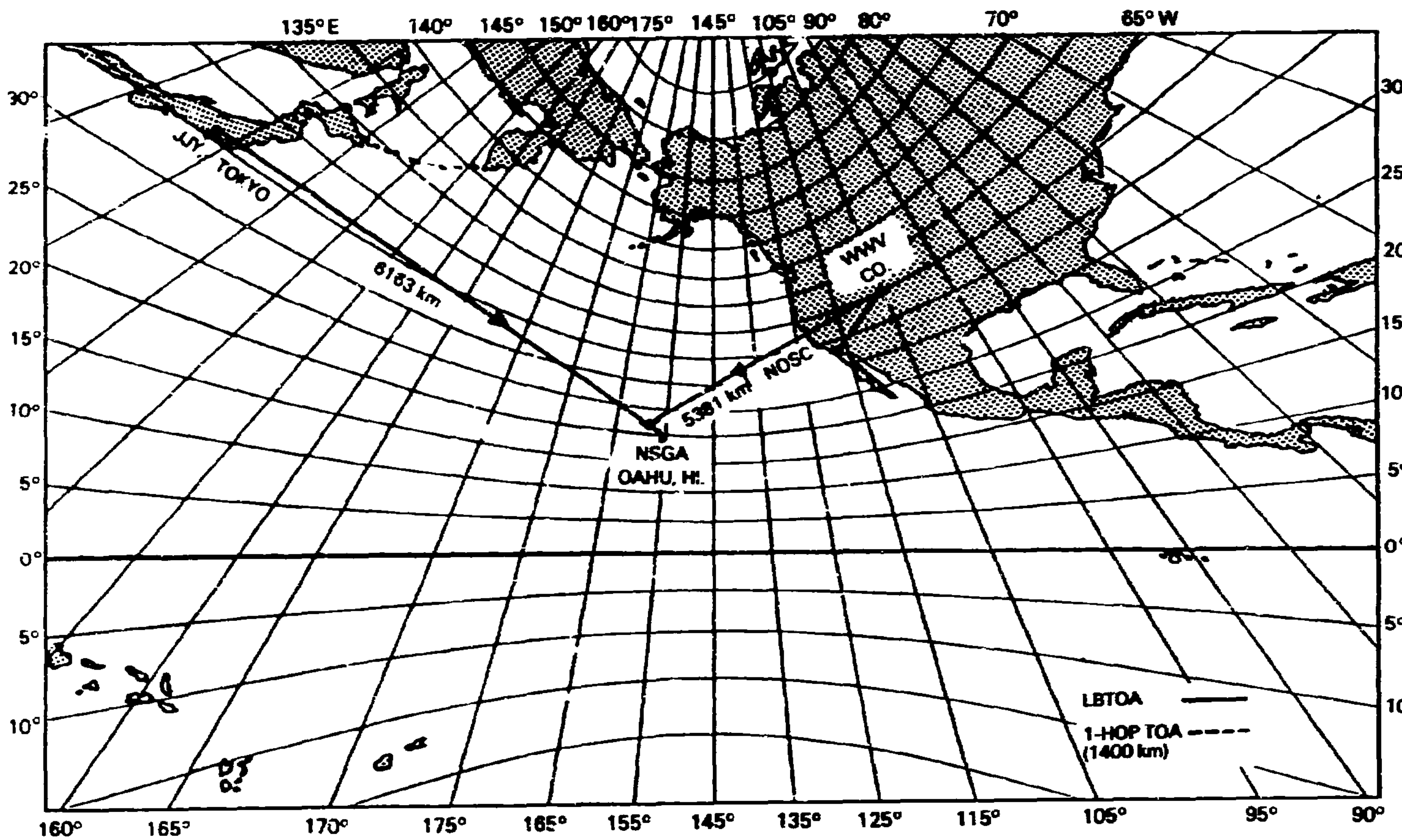


Figure 121. Configuration of NOSC Long Baseline Time of Arrival (LBTOA) experiment.

1985, when Hawaiian operations were discontinued. New priorities dictated the system's redeployment sometime in late 1985.

DISCUSSION OF THE DATA

Compared to the short range TOA data, the LBTOA sensor has produced some startling results. Reference 3 provided a discussion of some of the phenomena observed. Basically, that report showed ionospheric uncertainties are best described as range errors of 15-30 nautical miles at two-hop ranges. The modal structure described in that reference has persisted throughout the experiment. Progagation between Colorado and Hawaii is predominately two- and three-hop modes from the F-region. To insure continued measurements, the LBTOA sensor used split frequencies for day and night. These were

(a) Colorado to Hawaii, 20 MHz Day/10 MHz Night
(b) Japan to Hawaii, 15 MHz Day/8 MHz Night

The path between Japan and Hawaii has not produced the quality of data desired. The hearability tests conducted in 1983 indicated JJY signals to be very strong. However, by the time the LBTOA was deployed in 1984, JJY signals were not as consistent or strong. This was attributed to the solar decline because propagation in general in early 1984 showed strong solar mimimum tendencies. However, in September 1984, a hard crash was experienced in the cesium beam clock. While this was undergoing repair, the entire LBTOA was rehabilitated.

During this service cycle, a malfunctioning multicoupler was found in the 16-degree beam pointed at JJY. This was repaired and JJY signals significantly improved. By November 1984, the realignment was completed and strong JJY signals were monitored. For these reasons, the JJY data recorded prior to November 1984 are not of the same quality as those collected after that date.

The LBTOA data discussed in this report consist of the isometric monthly average plots listed in Table 2. The objective of these studies is to identify ionospheric variations that are not easily predictable nor mitigated. These are the primary accuracy constraints on geolocation systems. The subsequent discussions will first review results from WWV signal studies; then present analysis of JJY signals; and finally review coincident signals to do crude time-difference-of-arrival studies.

Table 2. LBTOA Listing

(Monthly Averages)

WWV To Hawaii	JJY To Hawaii
Mar 84	Mar 84
Apr 84	Apr 84
May 84	Jul 84
Jun 84	Aug 84
Jul 84	Oct 84
Aug 84	Nov 84
Sep 84	Dec 84
Oct 84	Jan 85
Nov 84	Feb 85
Dec 84	Mar 85
Jan 85	Apr 85
Feb 85	May 85
Mar 85	
Apr 85	
May 85	

Time Differences

JJY-WWV (Measured in Hawaii)

Nov 84	Mar 85
Dec 84	Apr 85
Jan 85	May 85
Feb 85	

33 Monthly Average Sets

Each hourly average represents approximately 54,000 TIC pulse samples. When a population of this size is plotted as a function of TOA, certain features appear. Each peak in occurrence represents a different propagation mode or a permutation of that mode. For the example shown in Figure 122, different configurations are shown for each mode. It is a basic fact that the more times a signal interacts with the ionosphere, the greater the amount of variation in the signal TOA. A two-hop mode has only two control points which interact with a lower part of the ionosphere. The three hop signal is steeper incidence, is refracted higher in the ionosphere, and therefore, is subject to a larger number of variations. The example shown in Figure 122 depicts two different multiple-hop configurations which can be due to variety of reasons Irrespective of the exact cause of each peak, the real concern is the amount of uncertainty introduced into the TOA measurement. The WWV LBTOA show a high level of variation in the model mix that can exist over paths that are longer than 4000 km. One fundamental question to be addressed was

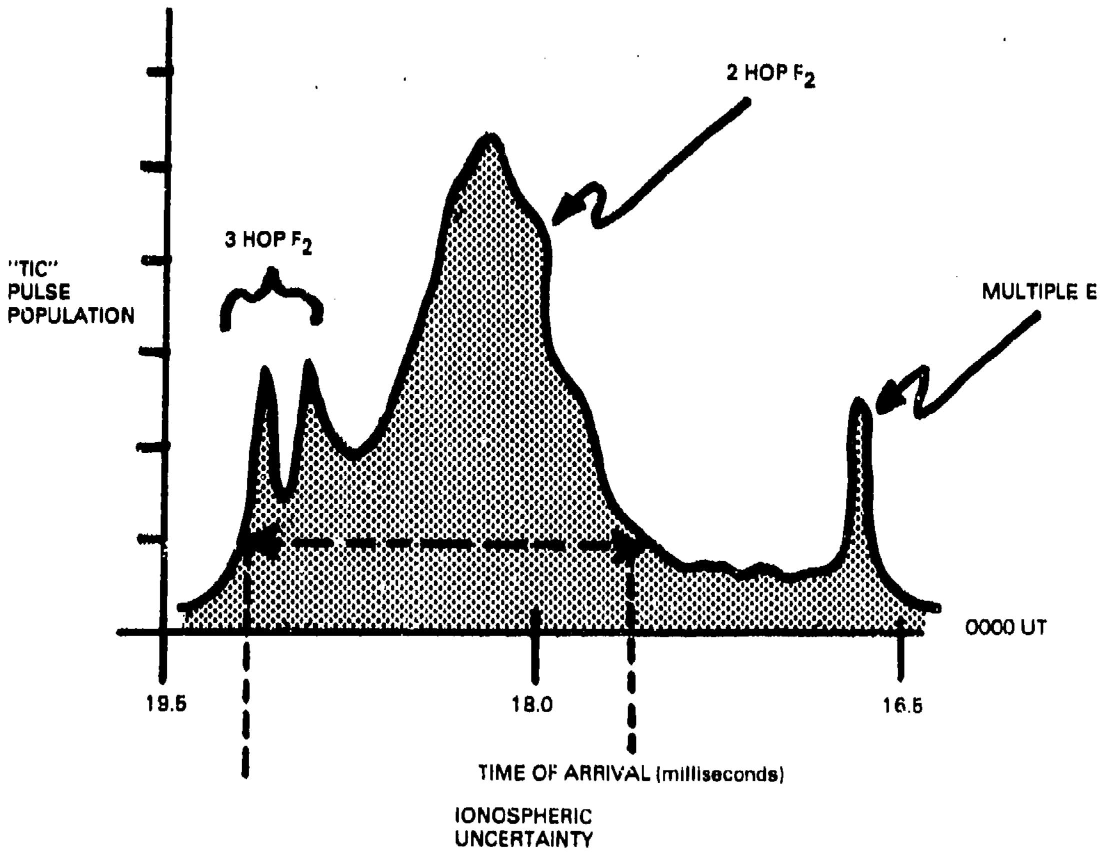


Figure 122. Explanation of hourly TOA averages.

whether TDOA systems were feasible over paths greater than one hop. Could ionospheric uncertainties be either predicted and/or mitigated sufficiently to perform HF geolocation at these ranges? In order to answer this question, the subsequent discussions will deal with how widely spread the TOA population is in each hourly average. It is to be remembered that each hourly average can consist of upwards of 54,000 samples.

WWV LBTOA DATA

There are 14 months of WWV LBTOA data. The month of September was lost due to system malfunction. The data for the month of August were badly degraded due to standard instability. Some October data were lost as the system was being brought back on line and calibrated. Figure 123 shows two typical days of LBTOA measurements from WWV transmissions. Each small dot is a 2-minute average. The rapidly and slowly varying components of the TOA are discussed in Reference 3.

The 10-MHz night frequency produced fewer discrete modal populations and a more singular widely spread distribution. Ten MHz at night, at high solar cycle, is somewhat like an HF wave guide which will support many different modes of propagation. As solar minimum approaches, the ionosphere weakens and fewer modes can be sustained. In March 1984 (Figure 124), a typical hourly TOA average spread (04UT) is 2 milliseconds with the major part of the population concentrated in 1 millisecond. This equates to an approximate 150-nautical-mile range uncertainty. Eleven months later, in February 1985, this spread appears to be about halved.

The use of 20 MHz as the daytime frequency for this test provided a situation where the two-hop mode was predominant. As solar decline continued, the TOA characteristics became more consistent. Some evidence of E region intervention is seen in March 1984 (the modes at 17.0 milliseconds starting at 17 UT). It is doubtful that these are pure multiple E but more likely M and N mode permutations. The primary mode is the two-hop F2 mode arriving at 18 milliseconds. Three-hop F2 mode can also exist on this path, although its probability of occurrence is less than the two-hop mode.

In cases where the daytime TOA populations have multiple peaks, then both the two and three-hop F2 modes exist. March 1984 (Figure 124) and July 1984 (Figure 128) are good examples of this. Here the TOA uncertainty is between 500 and 750 microseconds and in most cases, the probability of occurrence is about equal. As solar activity declined, the ionosphere became less ionized and not capable of sustaining the steeper incidence three-hop F2 mode. The results were a very consistent unimodal two-hop F2 mode TOA. November 1984 (Figure 131) and February 1985 (Figure 134) are good examples. In these cases the TOA uncertainty is 250 to 400 microseconds centered around 19 milliseconds. This is approximately a 38- to 60-nautical-mile range uncertainty. From the long baseline data reviewed thus far, the daylight hours (17- 02UT) of November 1984, December 1984, and February 1985 represent about the best TOA stability that could be expected on paths longer than one hop.

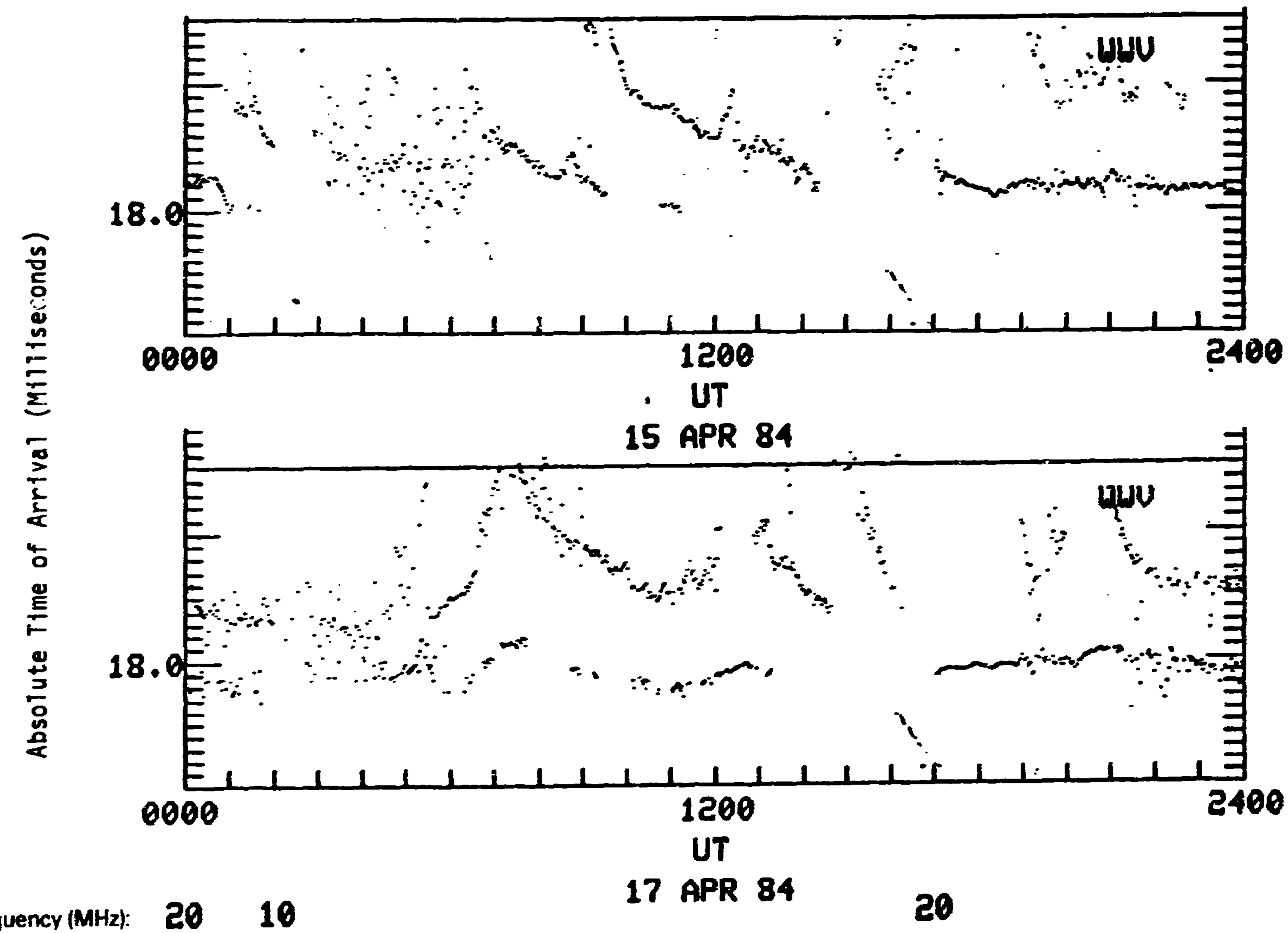


Figure 123. Long Baseline Time of Arrival Data (LBTOA), Colorado to Hawaii, April 1984.

JJY LBTOA DATA

Since the inception of the LBTOA, the JJY-to-Hawaii measurement has provided only "snapshots" of propagation and not the consistent hour-to-hour path hearability need to develop the monthly average plots. Reference 3 describes the results from studying the daily plots.

Until the renovation of the system in September and October 1984, very little useful data were collected on the 8-MHz nighttime frequency. The 15 MHz daytime (20-05 UT) frequency displayed a very erratic, multimode propagation path; three-, four-, and five-hop modes of propagation were spread from 750 to 1000 microsecond TOAs. This is best seen in November 1984, December 1984, January 1985, and February 1985, Figures 143, 144, 145, and 146 respectively. Although it takes another year of data on this path to develop meaningful monthly averages for this 6163-km path, the data characteristic appears typical of long path multimode propagation.

In November 1984, a repaired multicoupler allowed the system to start producing more meaningful data on the nighttime (05-18 UT) frequency. The result was multiple mode propagation spread across 1.5-millisecond TOAs. Each hourly average at 8 MHz displays several TOA population peaks although none are dominant. Also the apparent shift in TOA between December 1984 (Figure 144) and January 1985 (Figure 145) is an artifact of the cesium standard realignment.

DIFFERENTIAL TOA

Because this entire effort was motivated by questions arising on just how accurate a skywave TDOA system could be, a simple time difference comparison was performed on the JJY and WWV signals. Because at any instant, the precise mode of propagation was not known, it was not possible to calculate an actual TDOA line of position. This is an absolute requirement for an operational TDOA system. However, the plots shown in Figures 150 through 156 do represent the spread of TOA difference population a system designer would be faced with over long baselines. As was presented in Reference 3, multimodal conditions are difficult to deal with in that the propagation path switches between modes in an almost random manner. Therefore, the TDOA populations shown in Figures 150-156, do show how much uncertainty does exist over long baselines. The daylight hours between 19UT and 24UT show the only real peaks in the population distribution. The population spread at 21UT varies between 750 microseconds in January 1985 to 1300 microseconds in November 1984. Nighttime values range between 1200-1500 microseconds. The data in Figures 150-156 depict the range of variability that must be mitigated in long baseline TDOA systems.

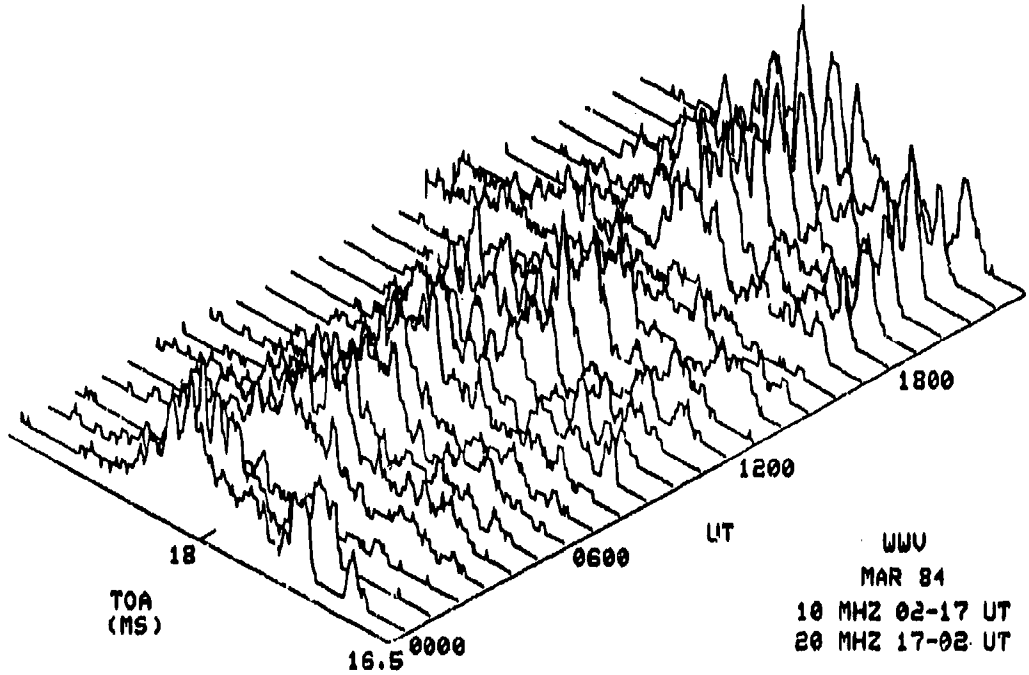


Figure 124. Hourly TOA averages Mar 1984 — WWV to Hawaii.

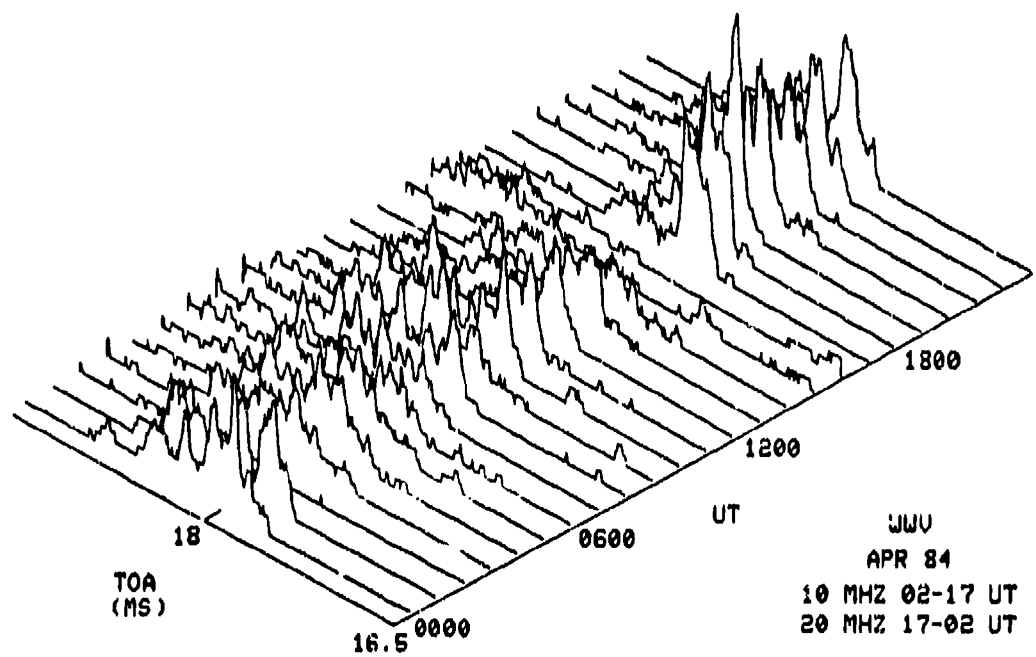


Figure 125. Hourly TOA averages Apr 1984 — WWV to Hawaii.

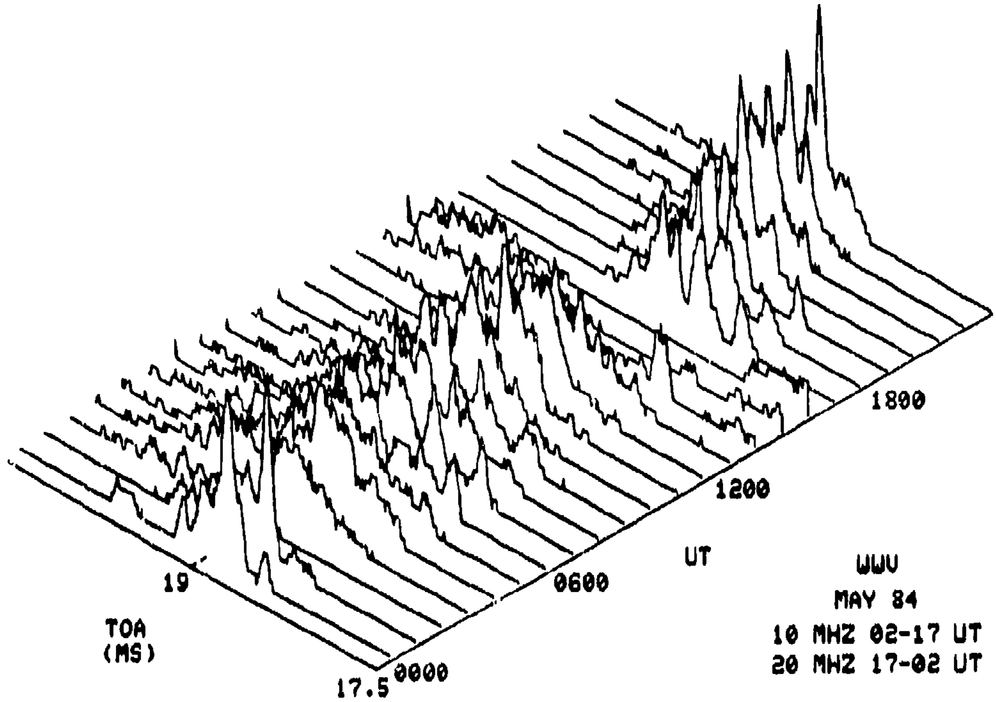


Figure 126. Hourly TOA averages May 1984 — WWV to Hawaii.

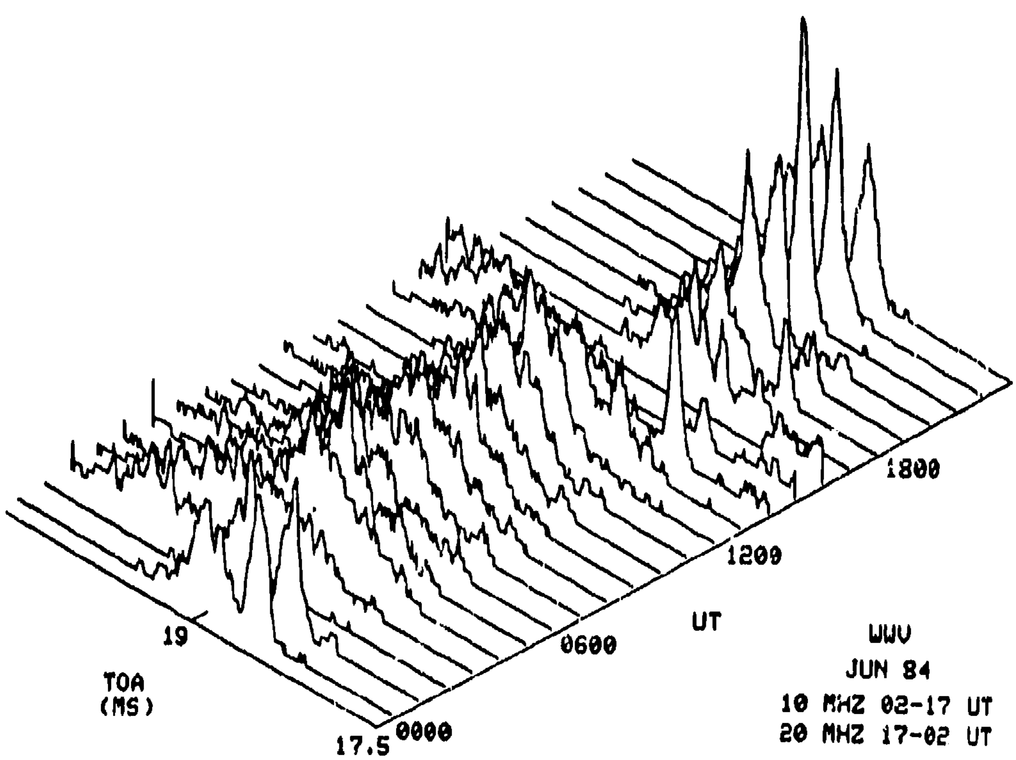


Figure 127. Hourly TOA averages Jun 1984 — WWV to Hawaii

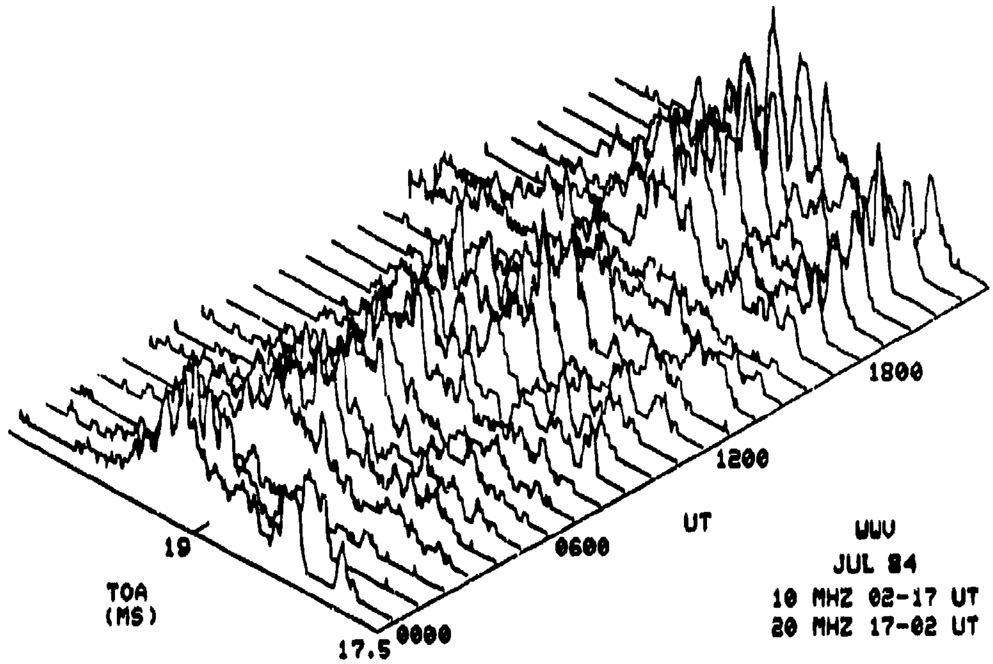


Figure 128. Hourly TOA averages Jul 1984 — WWV to Hawaii.

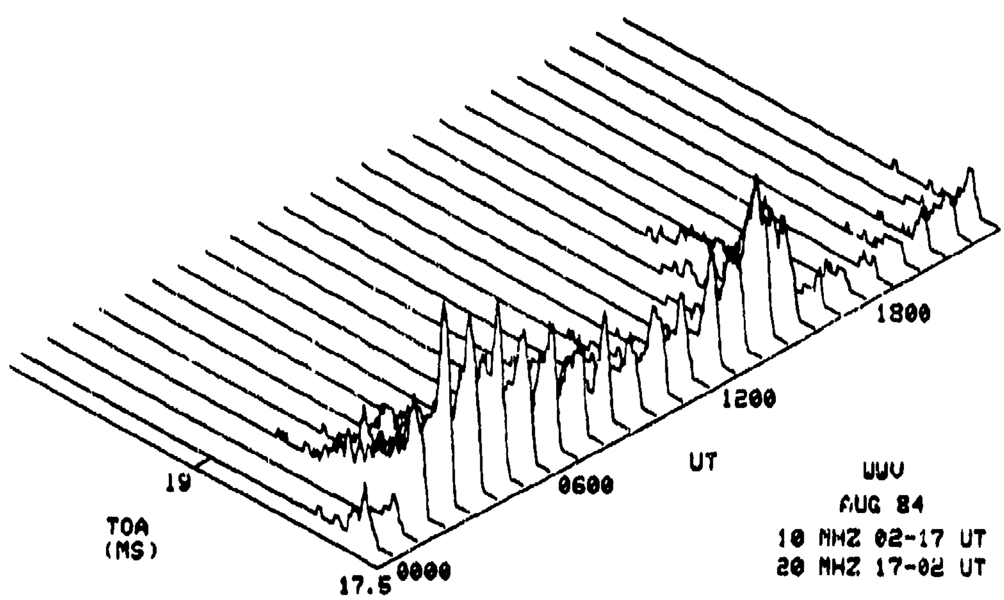


Figure 129. Hourly TOA averages Aug 1984 — WWV to Hawaii.

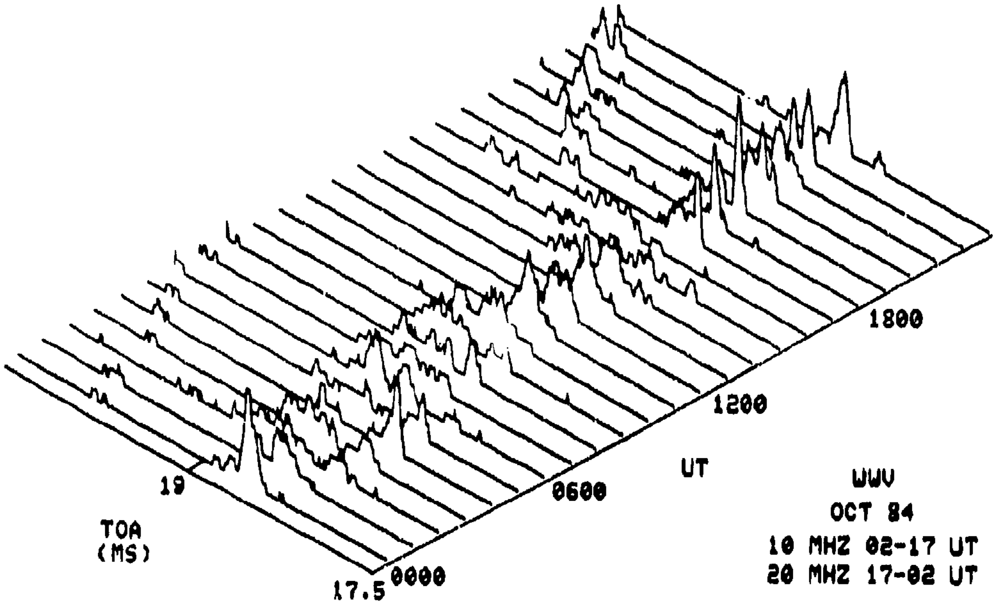


Figure 130. Hourly TOA averages Oct 1984 — WWV to Hawaii.

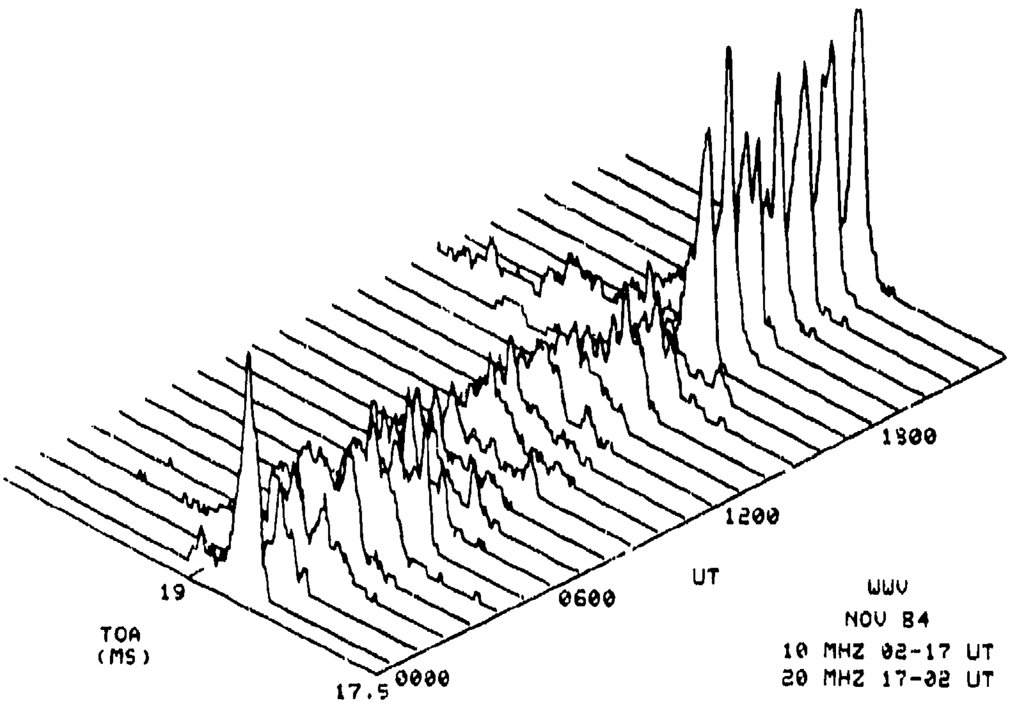


Figure 131. Hourly TOA averages Nov 1984 — WWV to Hawaii.

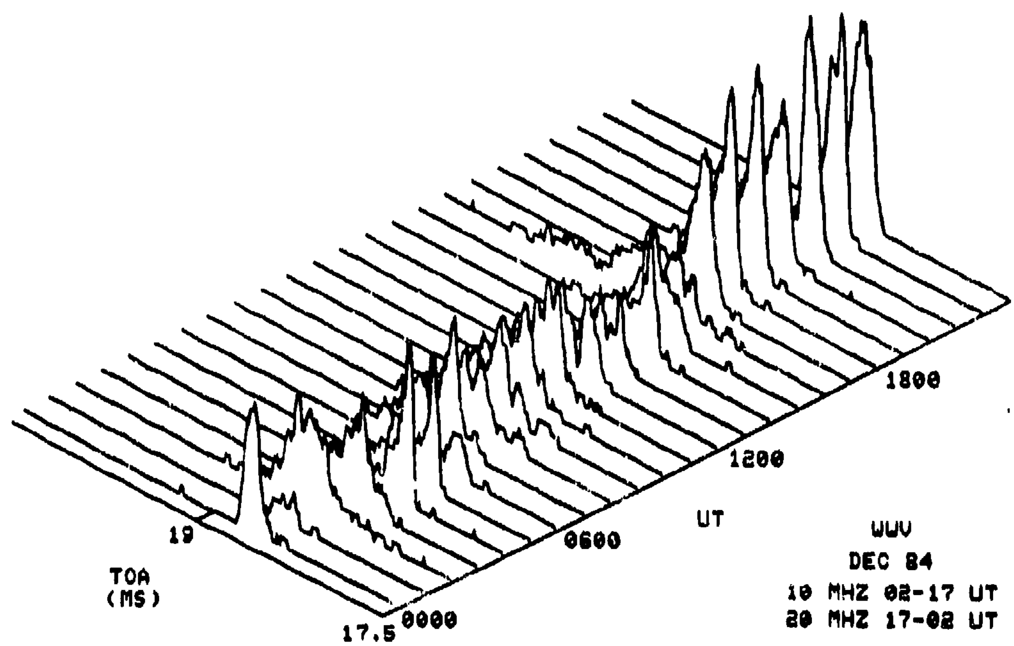


Figure 132. Hourly TOA averages Dec 1984 — WWV to Hawaii.

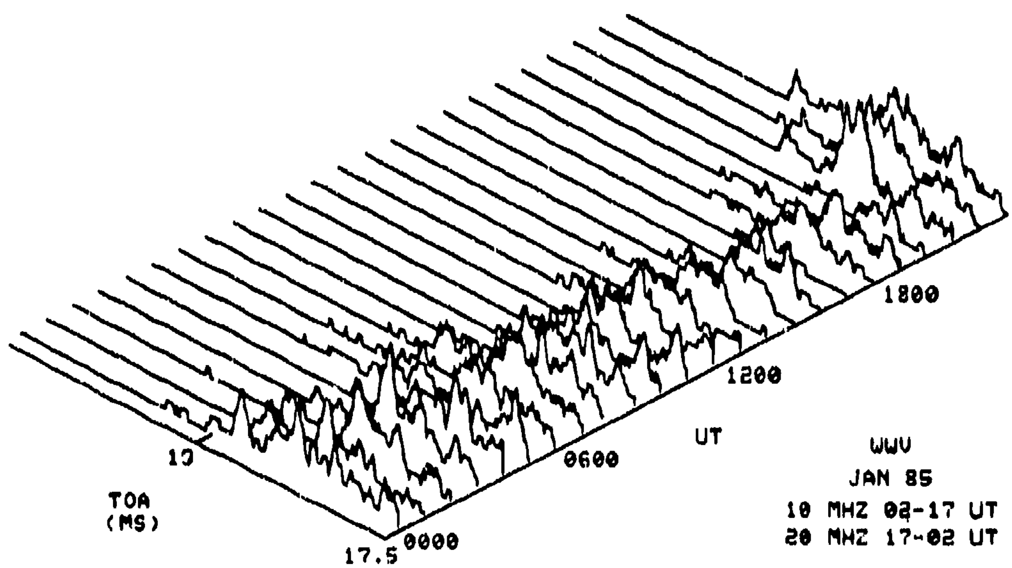


Figure 133. Hourly TOA averages Jan 1985 — WWV to Hawaii.

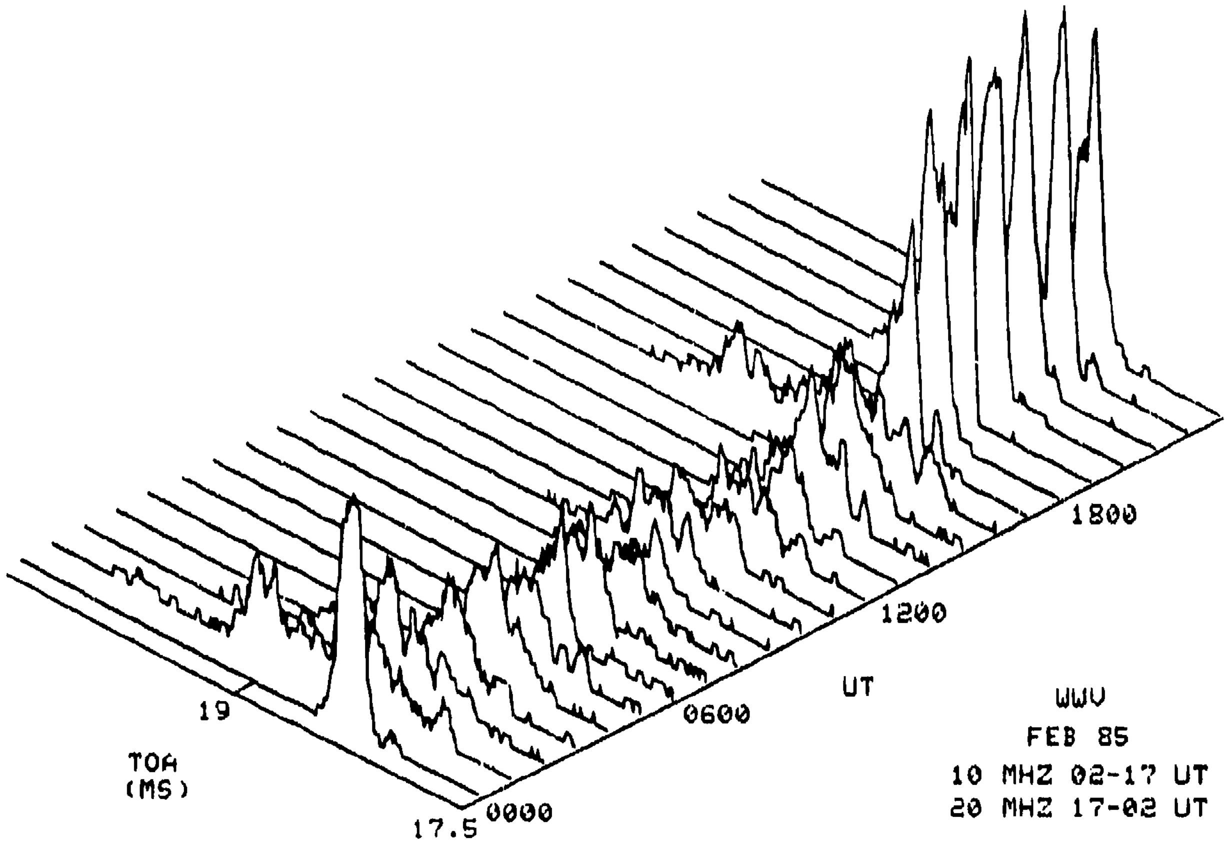


Figure 134. Hourly TOA averages Feb 1985 — WWV to Hawaii.

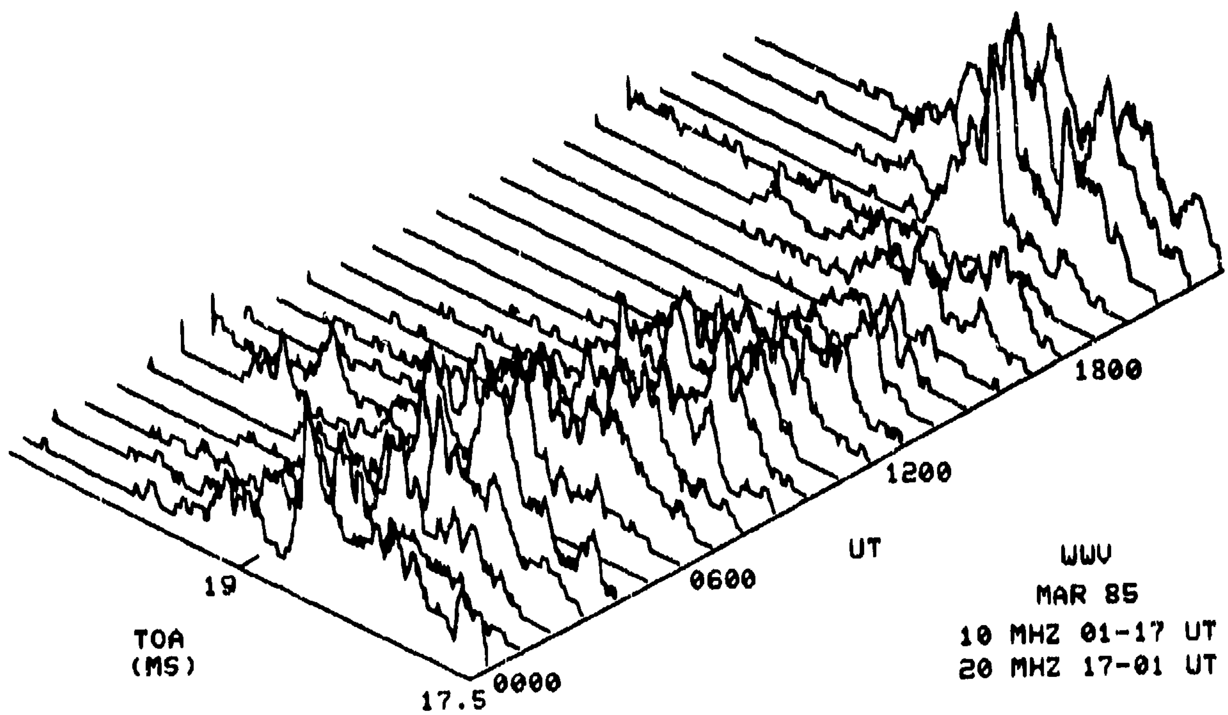


Figure 135 Hourly TOA averages Mar 1985 — WWV to Hawaii.

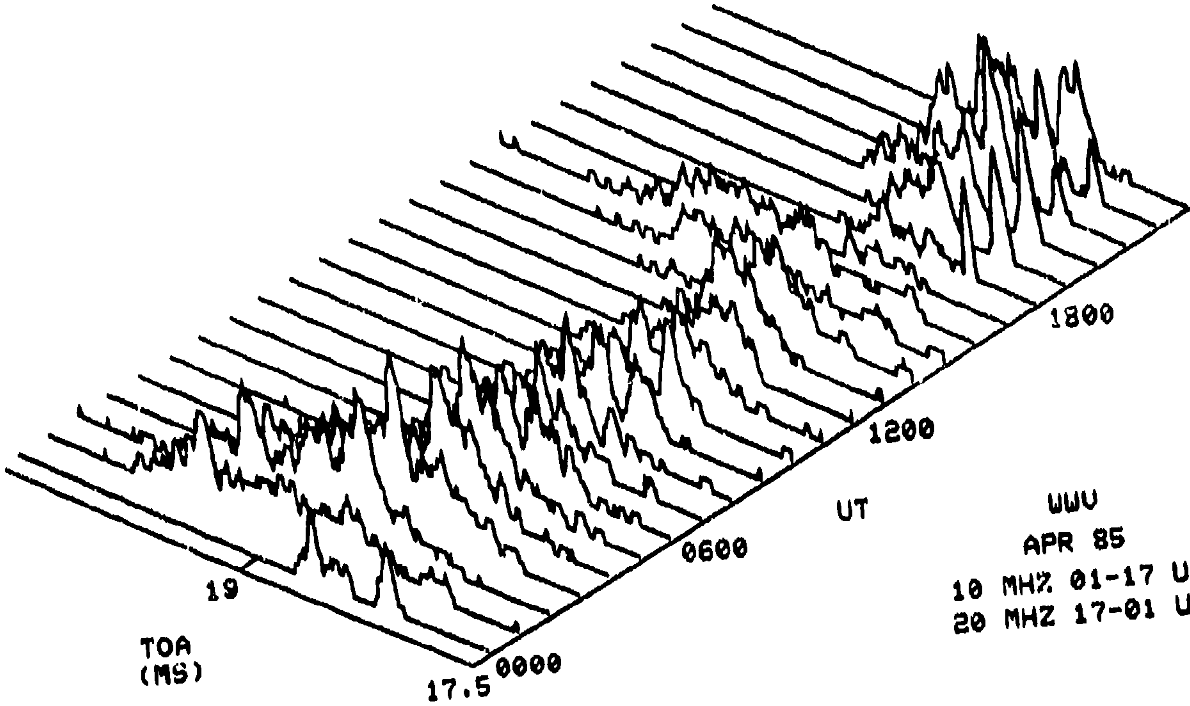


Figure 136. Hourly TOA averages Apr 1985 — WWV to Hawaii.

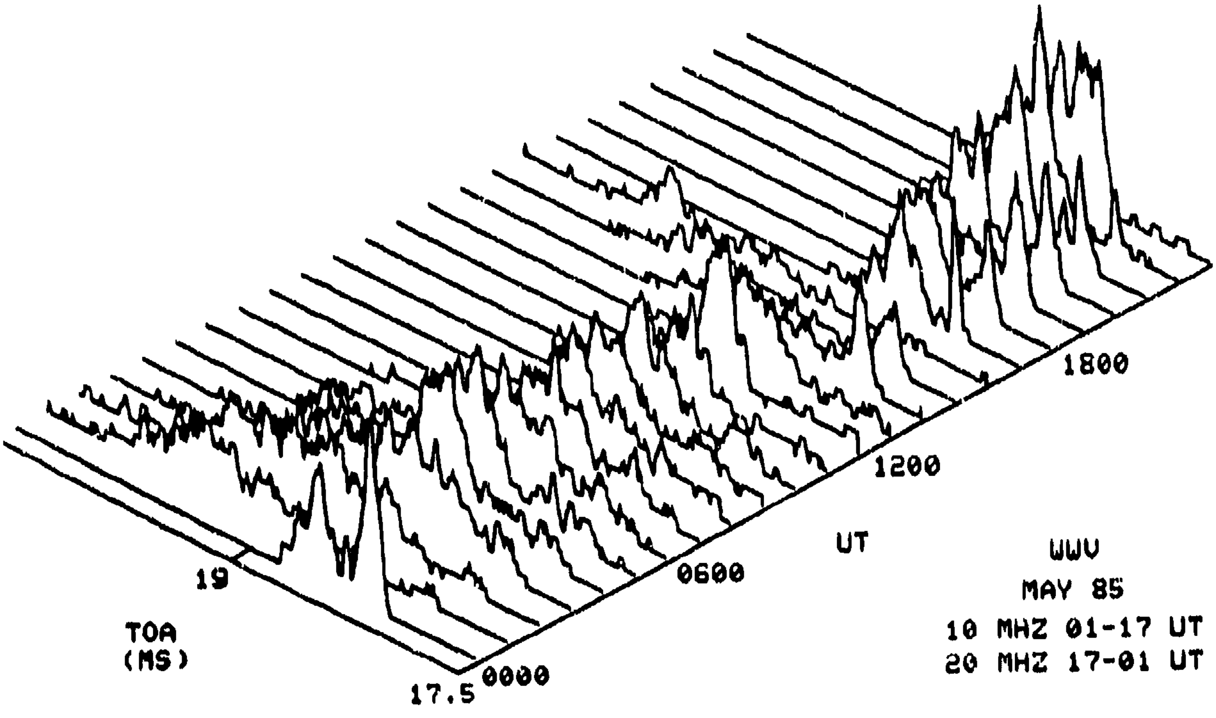


Figure 137. Hourly TOA averages May 1985 — WWV to Hawaii.

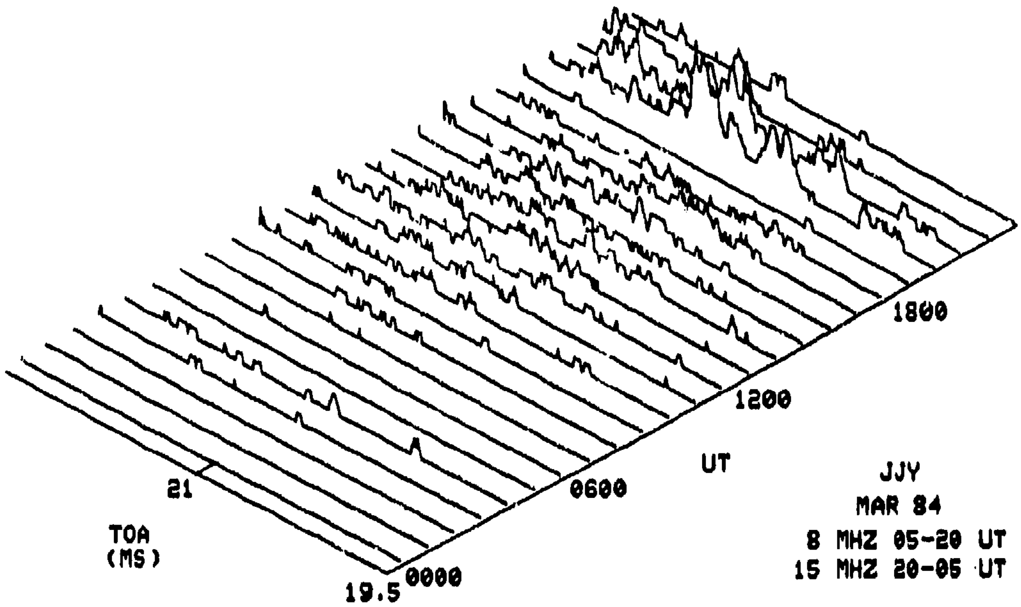


Figure 138. Hourly LBTOA averages Mar 1984 — Japan to Hawaii.

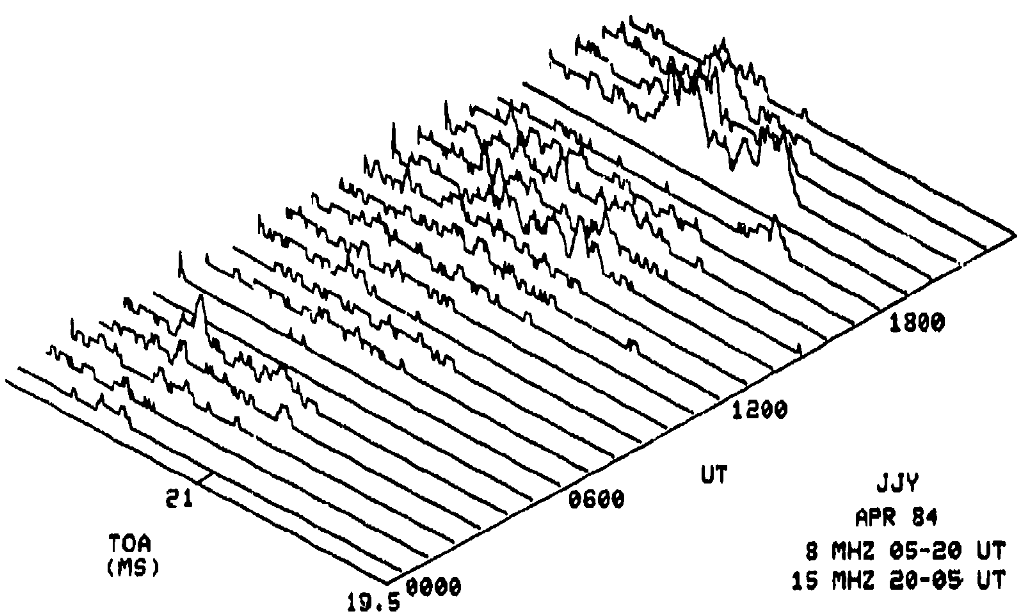


Figure 139. Hourly LBTOA averages Apr 1984 — Japan to Hawaii.

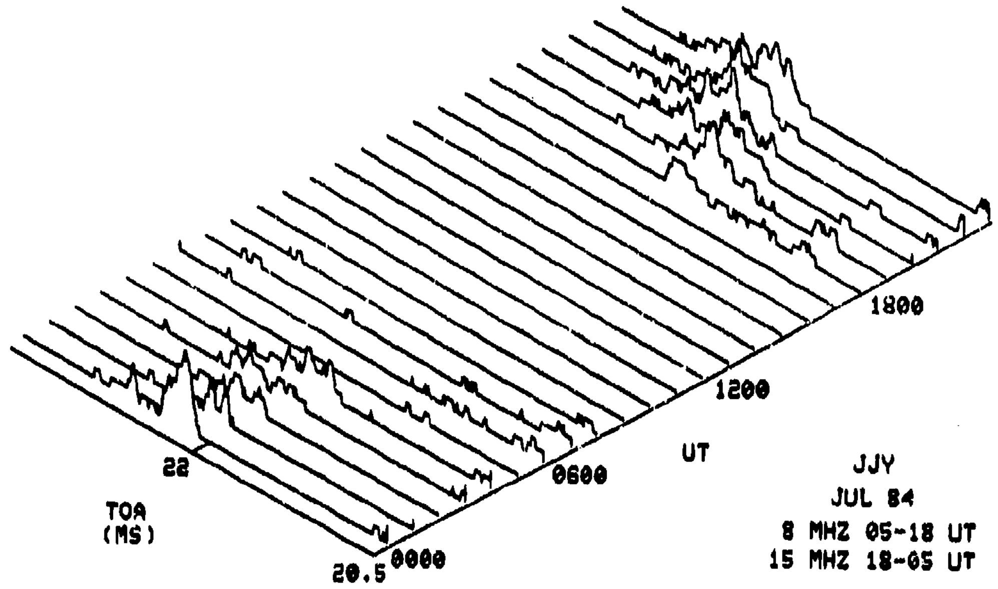


Figure 140. Hourly LBTOA averages Jul 1984 — Japan to Hawaii.

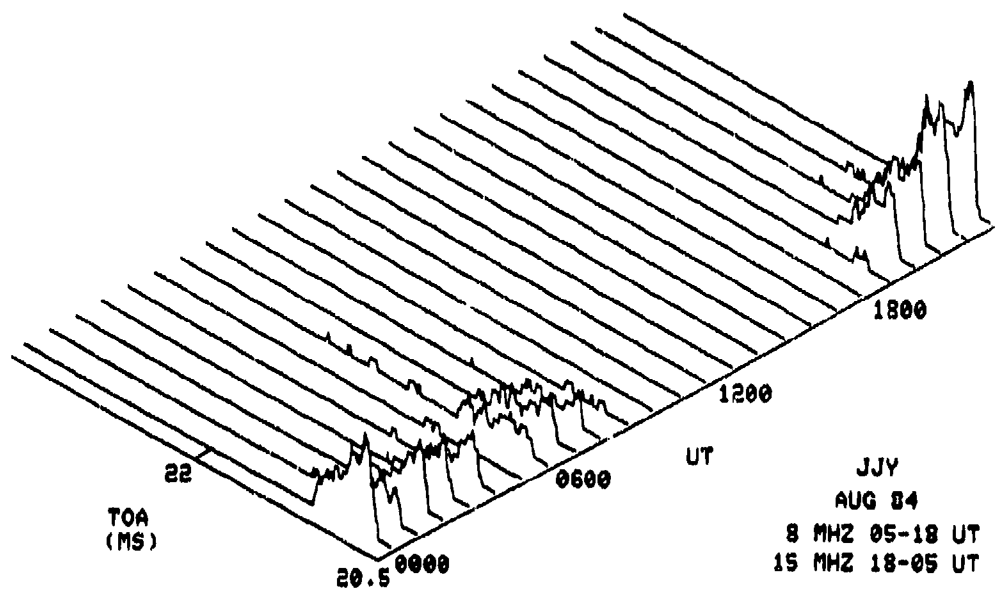


Figure 141. Hourly LBTOA averages Aug 1984 — Japan to Hawaii.

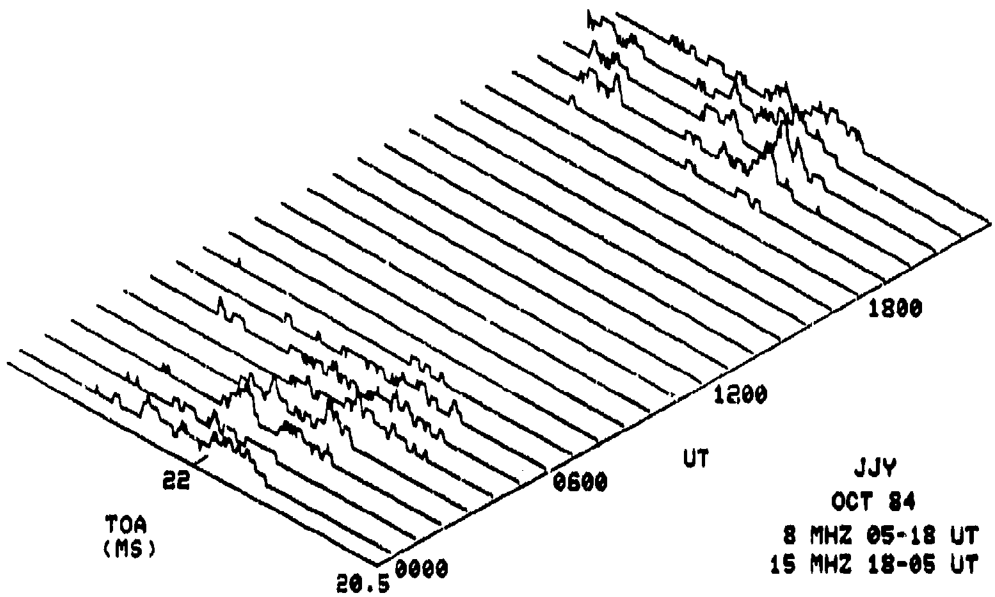


Figure 142. Hourly LBTOA averages Oct 1984 — Japan to Hawaii.

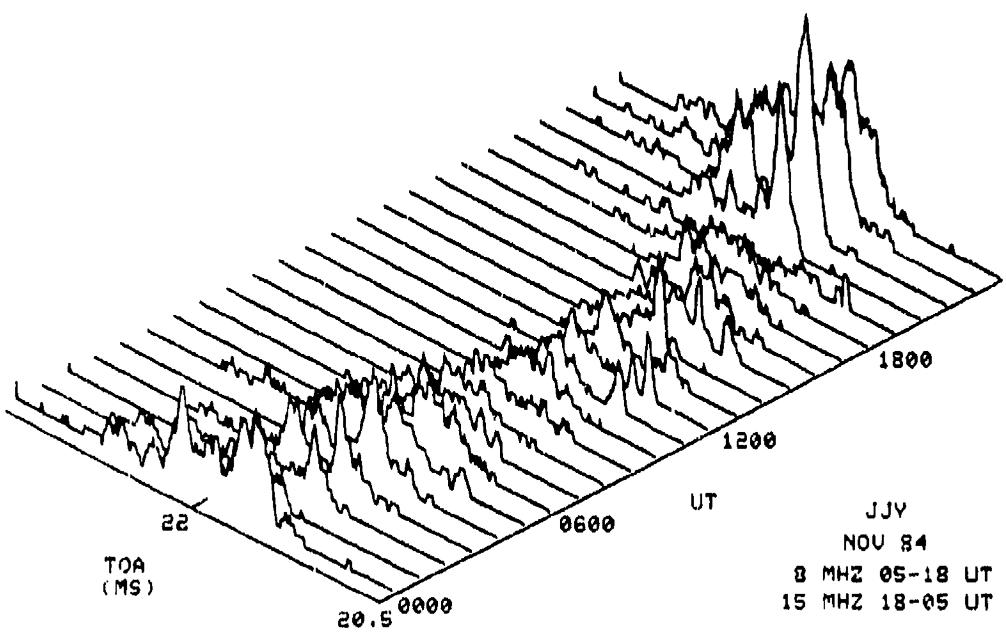


Figure 143. Hourly LBTOA averages Nov 1984 — Japan to Hawaii.

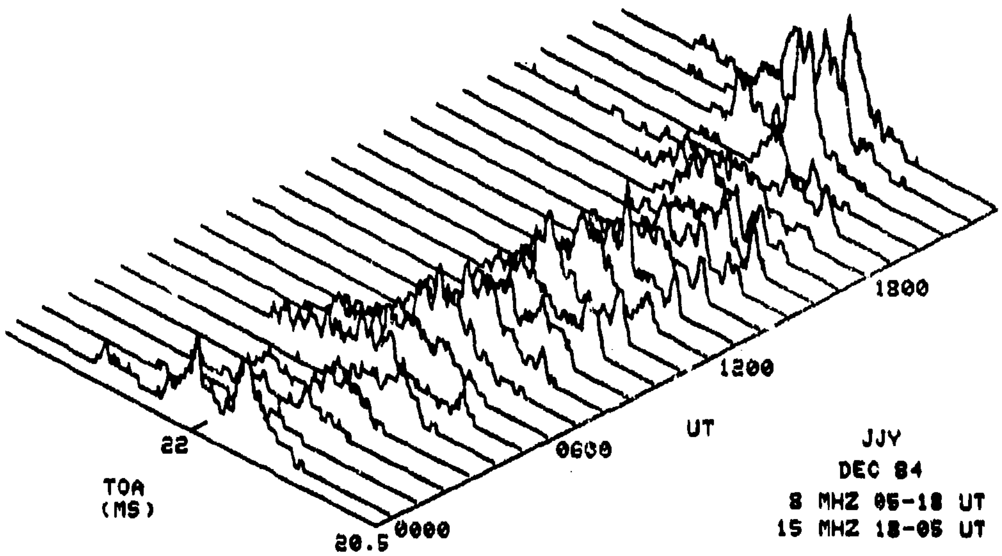


Figure 144. Hourly LBTOA averages Dec 1984 — Japan to Hawaii.

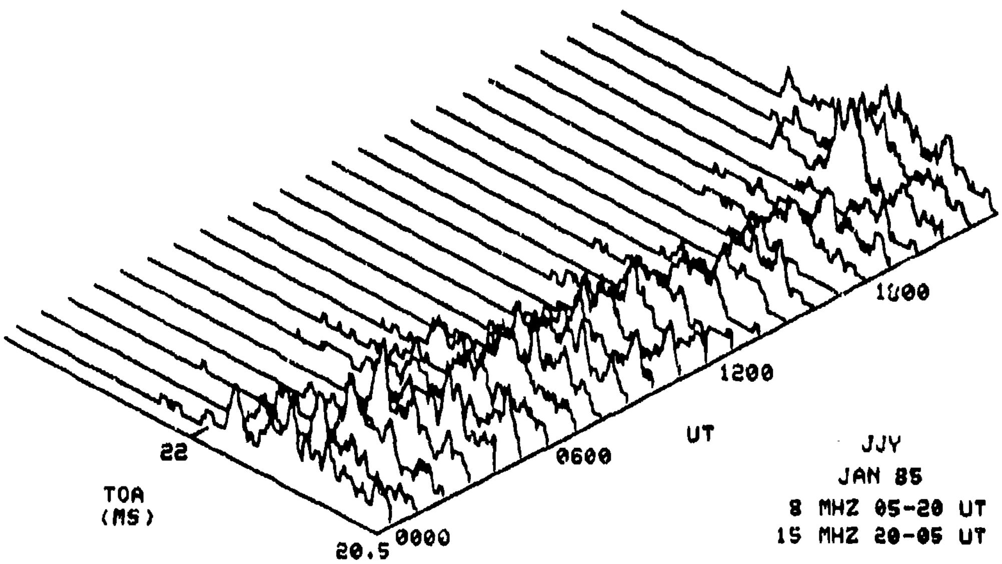


Figure 145. Hourly LBTOA averages Jan 1985 — Japan to Hawaii.

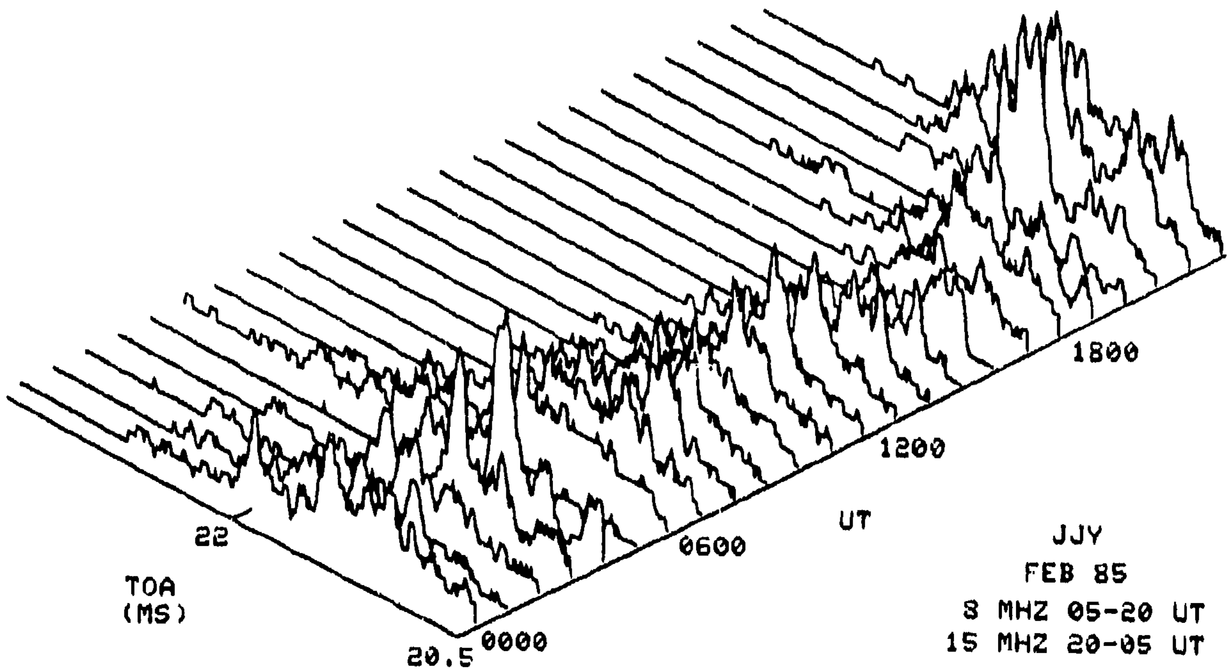


Figure 146. Hourly LBTOA averages Feb 1985 — Japan to Hawaii.

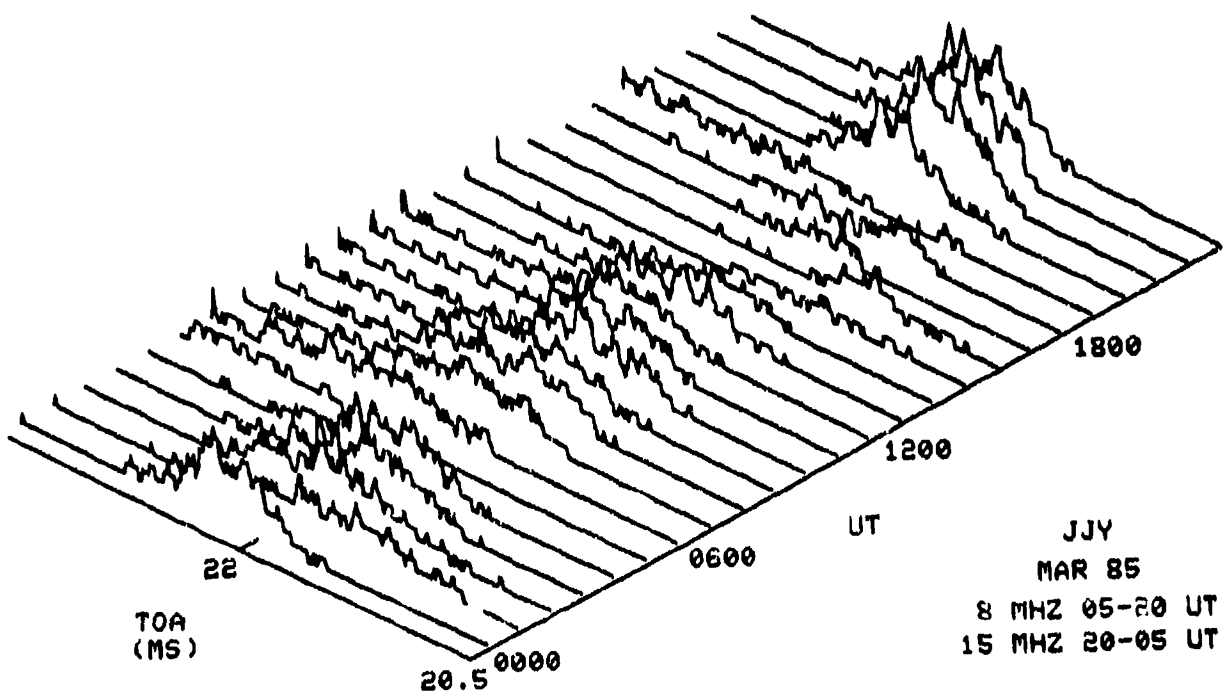


Figure 147. Hourly LBTOA averages Mar 1985 — Japan to Hawaii.

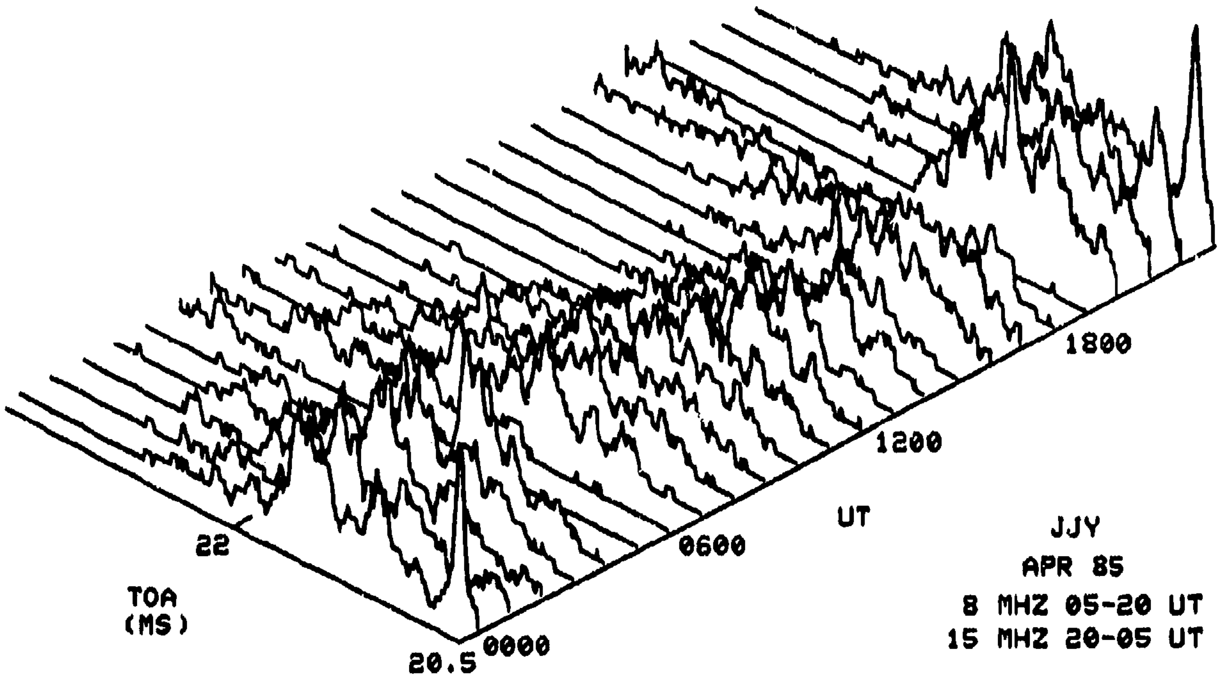


Figure 148. Hourly LBTOA averages Apr 1985 — Japan to Hawaii.

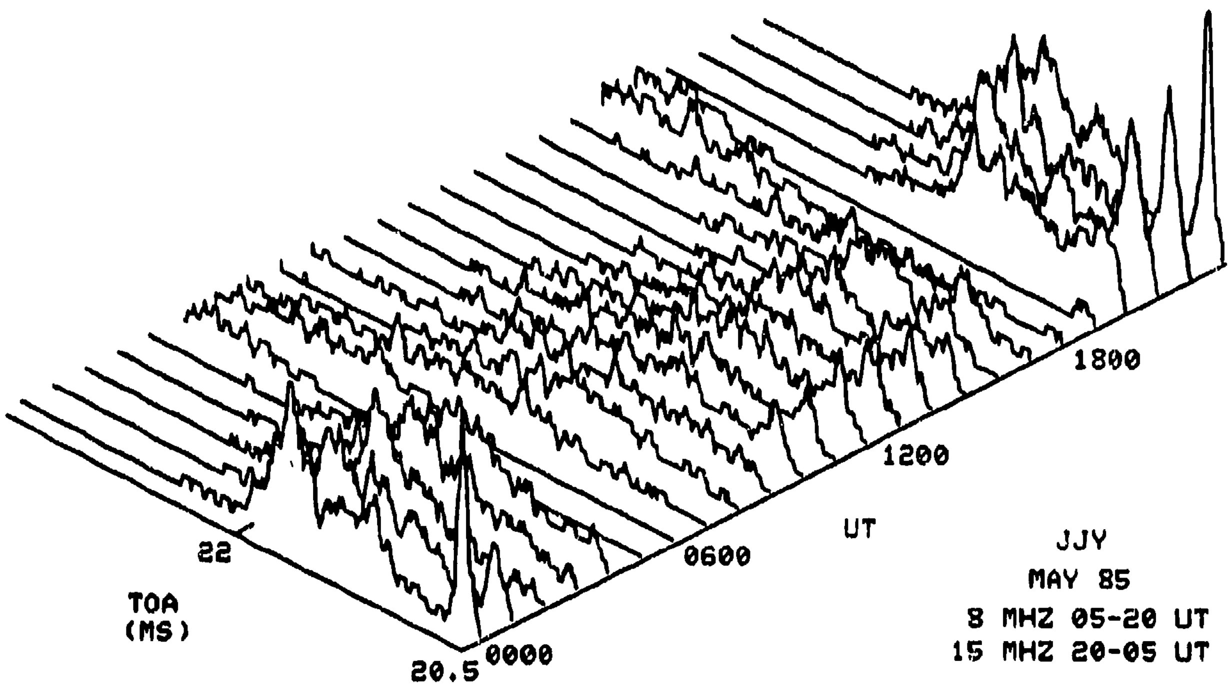


Figure 149. Hourly LBTOA averages May 1985 — Japan to Hawaii.

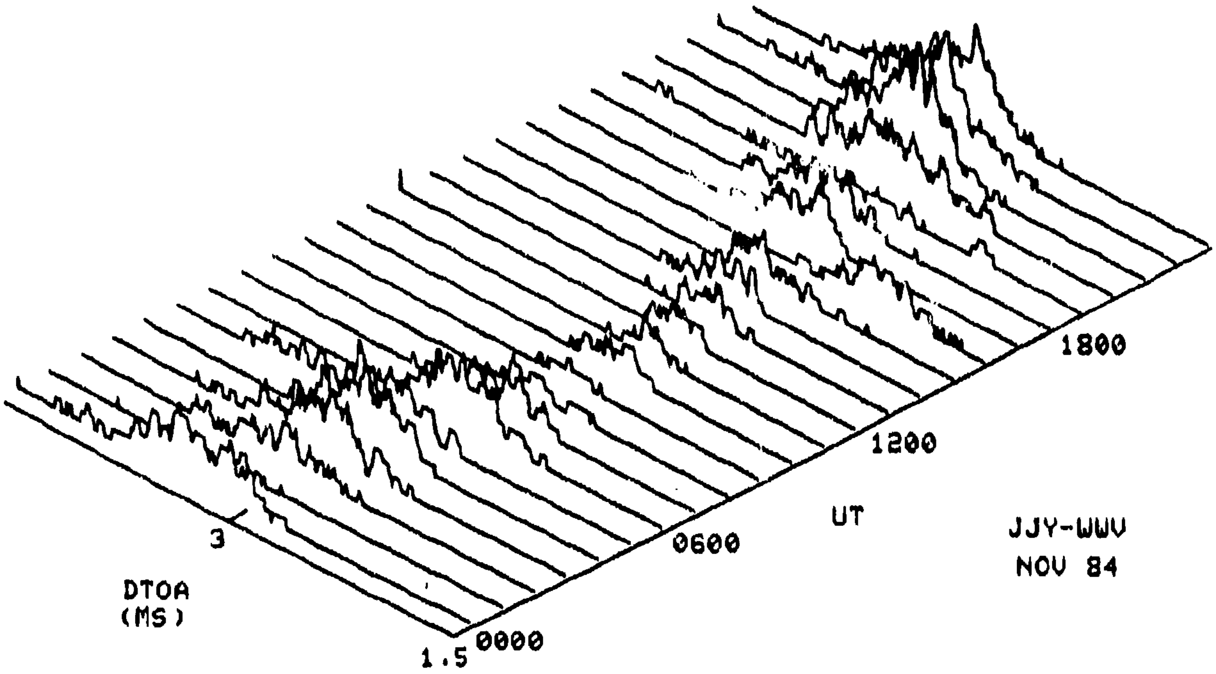


Figure 150. Hourly TOA averages Nov 1984.

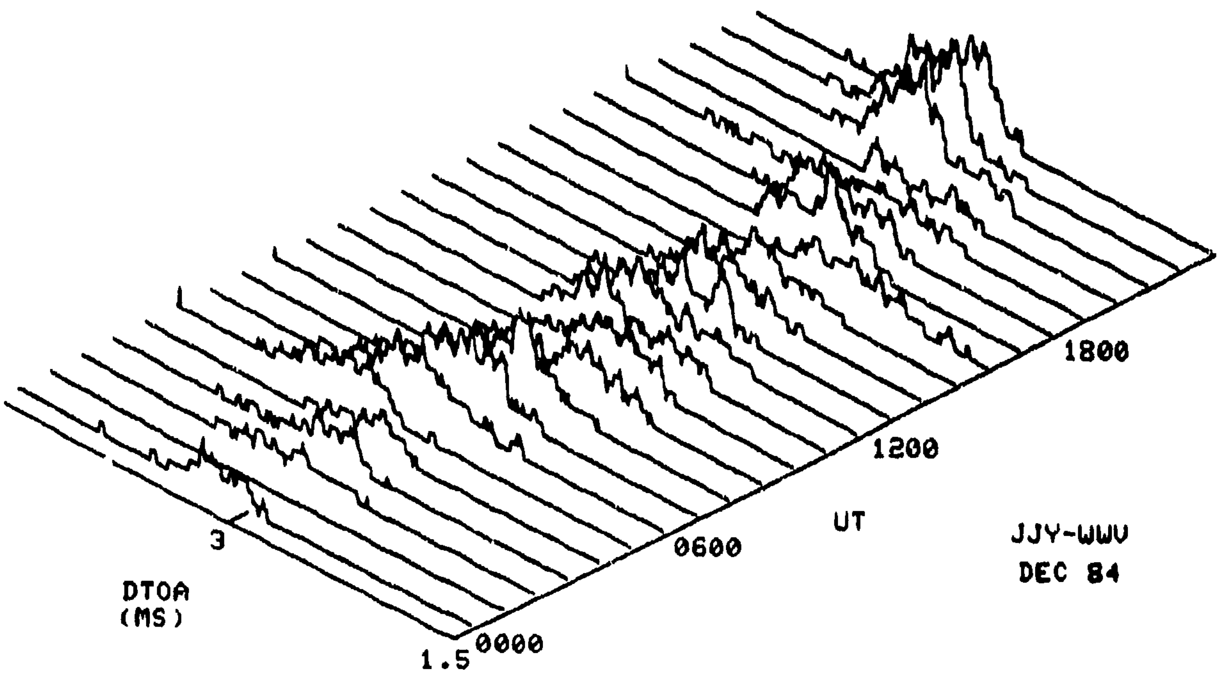


Figure 151. Hourly TOA averages Dec 1984.

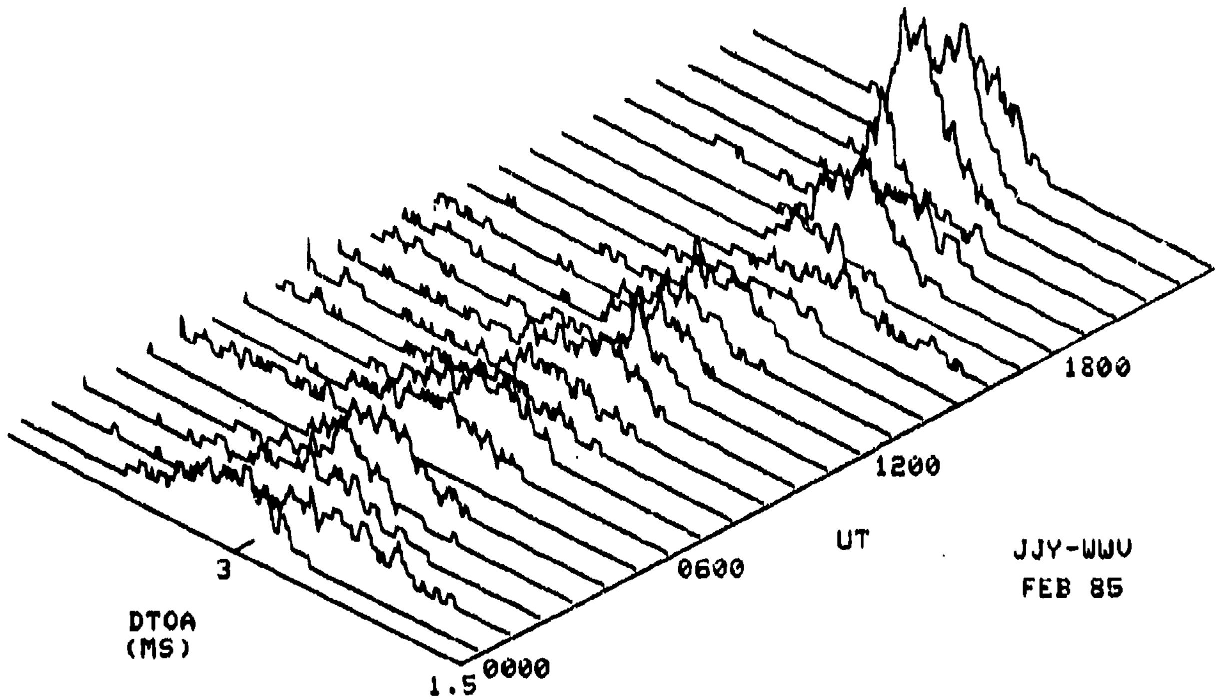


Figure 152. Hourly TOA averages Feb 1985.

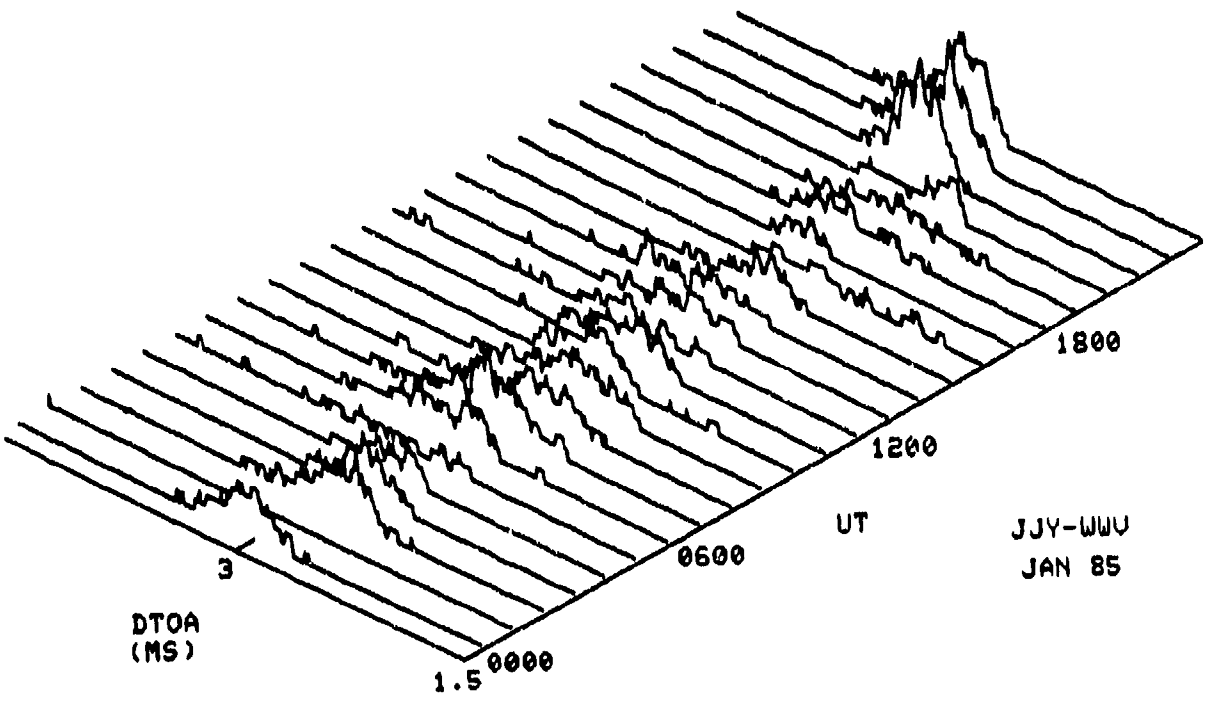


Figure 153. Hourly TOA averages Jan 1985.

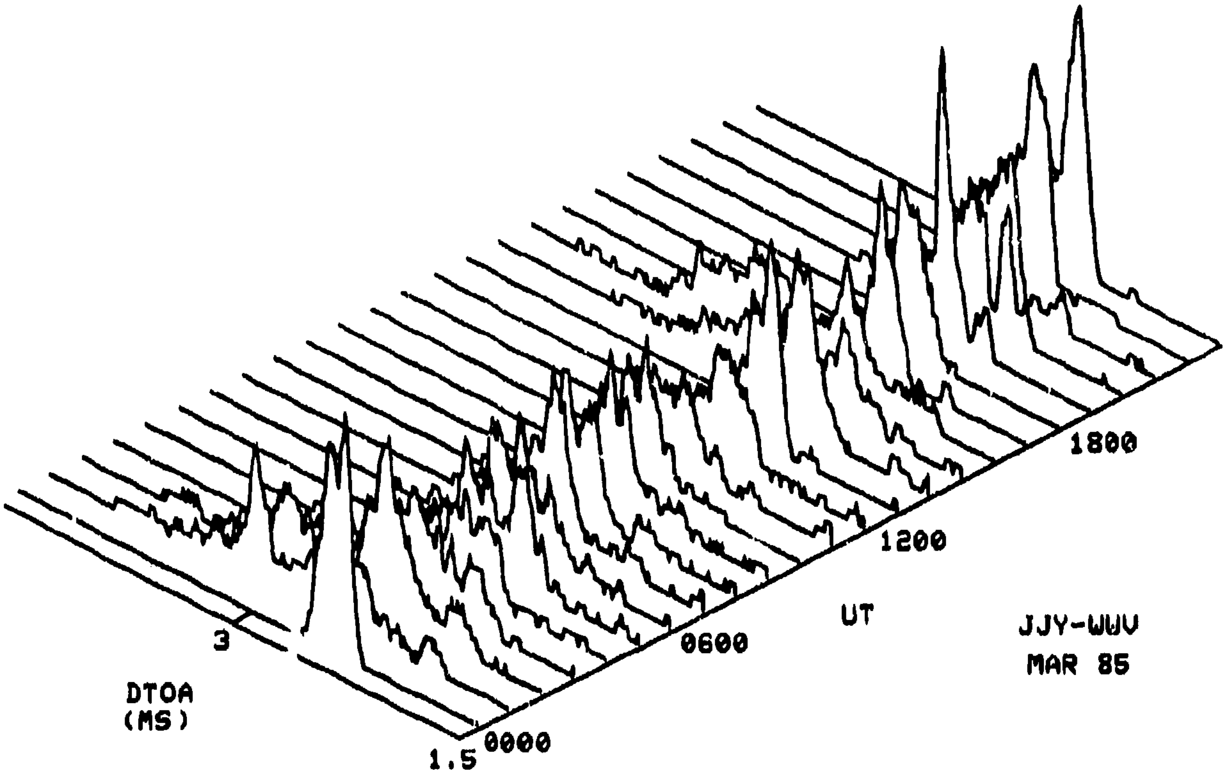


Figure 154. Hourly TOA averages Mar 1985.

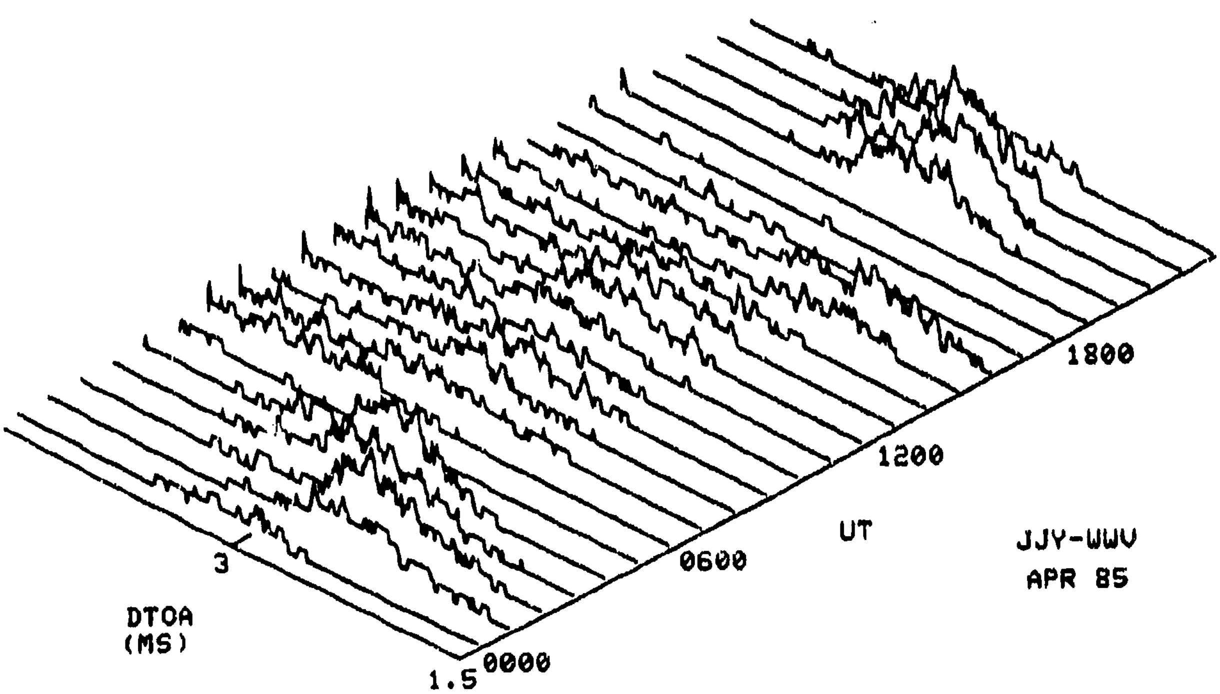


Figure 155. Hourly TOA averages Apr 1985.

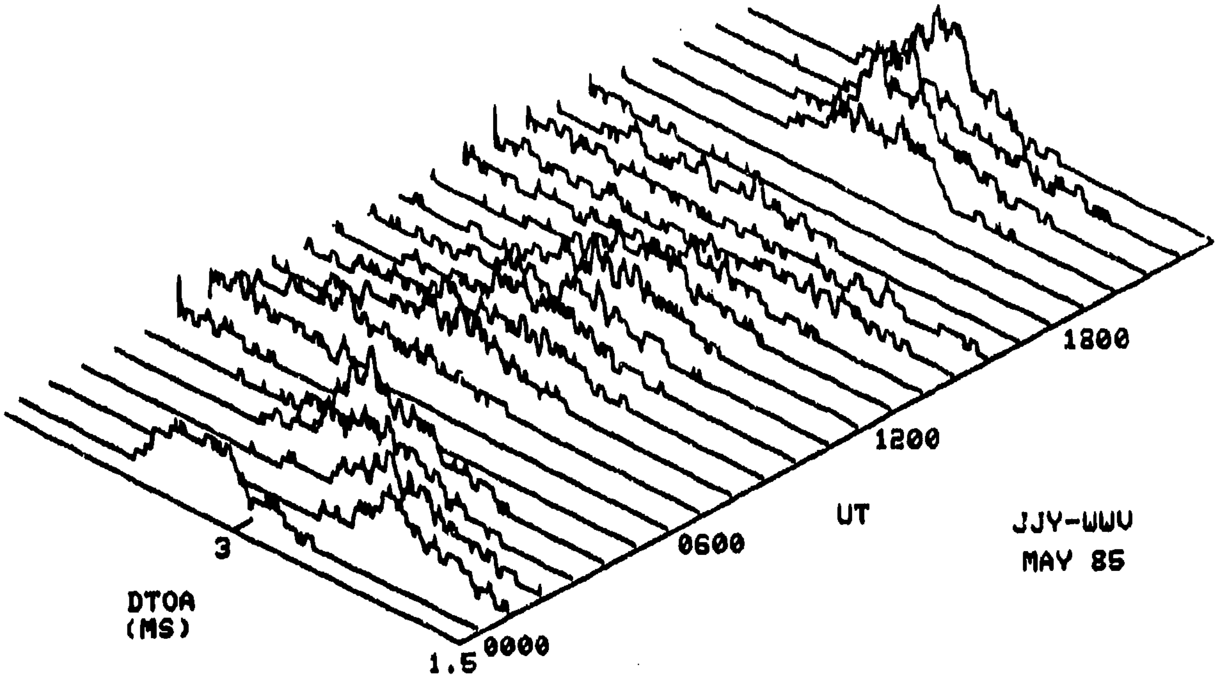


Figure 156. Hourly TOA averages May 1985.

CONCLUSION

It was the intention of this report to present a substantial amount of skywave HF TOA data for review by the HF propagation research community. The sensitivity and durability of the sensing hardware exceeded the expectations of the developers and data analysts. The cost of hardware was extremely cost effective with both the TOA and LBTOA systems costing less than $25k to construct, deploy, and operate. The technical objective of quantifying the range of ionospheric uncertainty that could be expected on a skywave time sensitive system is continuing to be met as new analysis is performed. Thus far this has been a successful experiment.

This conclusion section is not meant to be exhaustive because analysis is still underway. It will highlight those areas where some judgment has been made and present new concepts based on observations. It is expected that the subsequent comment will "trigger" new ideas, approaches, ways to interpret the data, and even controversy. This is acceptable and even desirable if the subsequent dialogue moves ionospheric sciences forward.

The most significant observation made during the analysis thus far is that the ionosphere is much more volatile with respect to time sensitive systems than first thought. This is the consensus of NOSC scientists after viewing both the TOA and LBTOA results. It is generally concluded that the ionospheric layer is

a. more stratified as evidence by the simultaneous multifrequency measurements.

b. constantly moving in all directions and these movements are not necessarily correlated. Further, traditional approaches to ionospheric predictions do not account for the amount of observed variability.

There is a higher incidence of night E than thought earlier. It is also tightly related to solar cycle activity. Current prediction systems do not account for this during dark hours.

In cases where there are multiple modes of propagation, the receiving sensor has an almost equal probability of seeing one or the other or both. This switching between modes appears to be almost random and is a very common occurrence.

After much experimentation in averaging or time integrating the "TIC" pulse data it was determined that 2-minute averages produced the greatest resolution in interpeting TOA data. It was also learned that the correlation between one 2-minute average to the next was very poor. Based on previous 2-minute averages, it was virtually impossible to tell which direction the next 2-minute average would move and by how much. This puts into question tables of coefficients which are based on single hourly Vertical Ionosonde Sounder (VIS) measurements which are used to typify that hour. These tables of coefficients are the basis of most traditional HF prediction programs. It is obvious now that a single measurement made once an hour does not provide a valid representation of the entire 60-minute period.

Because of the amount of data collected and presented, it is difficult to reduce the aggregate into a few simple conclusions. Tables 3 and 4 provide estimates for the short and long baseline testing. Range uncertainties are based on 1.5 nautical miles for each 10 microseconds of error. This is an optimistic estimate based on tests conducted during the CLASSIC NABLA TDOA program in 1976.

These numbers provide a first estimate of the level of uncertainty introduced into a skywave time measurement. It indicates that TDOA is only realistic at ranges inside one hop and on frequencies that will sustain only one or two modes of propagation. Further the user must be able to positively identify which mode the TDOA measurement was made on.

The results thus far on the short range system are consistent with real world TDOA data collected during Classic Toad, Reference 4.

RECOMMENDATIONS

1. Continue both TOA and LBTOA sensors operations. Further investigate new path configurations for the LBTOA.

2. Provide additional support in the analysis and dissemination of the data.

Table 3. Short Range TOA/Range Uncertainties

Level	Typical TOA (msec) Population	Range Uncertainty (nmi)
Best Observed	25	4
Nominal	75-100	12-15
Worst	200-500	30-75

Table 4. Long Baseline TOA/Range Uncertainties

Path	Typical TOA Population	Range Uncertainty (nmi)
JJY (8 MHz) NITE	1500	225
JJY (15 MHz) DAY	750	100
WWV (10 MHz) NITE	1000	150
WWV (20 MHz) DAY	250	38

REFERENCES

1. LaBahn, R.W. and Rose, R.B., "*Time delay variations in HF propagation,*" Radio Science, Vol 17, No. 5, pg 1285-1299, Sept-Oct 1982.

2. LaBahn R.W. and Paul, A.K., "*HF Propagation Modes for 5 and 15 MHz over a 1400km Mid latitude Path,*" NOSC Technical Document TD 658, October 1983.

3. Rose, R.B., "*Long Baseline Time of Arrival (LBTOA) Experiment,*" NOSC Technical Document TD 693, April 1984.

4. Rose, R.B., "*Cross fix by Single HFDF Line of Bearing vs Single TDOA Line of Position,*" NOSC Technical Report TR 834.

Appendix A

F and E Region Mean Time of Arrivals and Standard Deviations

1983 and 1984

All Times are in Microseconds

1983 5 & 15 MHZ

HR	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
	E		F		E		F		E		F		E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	4757	29	5074	63	0	0	5063	24	0	0	5048	37												
1	0	0	5168	90	0	0	5119	68	0	0	5053	48												
2	4764	15	5115	35	0	0	5170	0	4784	7	5120	94												
3	4800	0	5030	129	0	0	5462	163	0	0	5464	92												
4	0	0	5184	133	0	0	5756	122	0	0	5375	129												
5	0	0	5203	106	0	0	5670	162	0	0	5577	21												
6	0	0	5276	145	0	0	5910	56	0	0	5730	0												
7	0	0	5229	84	0	0	5808	83	0	0	5640	0												
8	0	0	5220	170	0	0	5767	102	0	0	0	0												
9	0	0	5233	110	0	0	5850	123	0	0	5554	225												
10	0	0	5247	60	0	0	5650	15	0	0	5704	25												
11	0	0	5245	119	0	0	5715	21	0	0	5653	21												
12	4780	0	5207	65	0	0	5675	16	0	0	5493	210												
13	0	0	5170	95	0	0	0	0	0	0	0	0												
14	0	0	5138	55	0	0	0	0	0	0	0	0												
15	0	0	5049	54	0	0	5060	45	4795	7	5074	59												
16	0	0	5035	26	0	0	5093	35	4782	17	5074	75												
17	0	0	5043	33	0	0	5096	49	4773	12	5092	91												
18	0	0	5027	50	4780	0	5126	59	4782	15	5085	117												
19	4790	0	5024	71	4790	0	5094	88	4786	15	5105	116												
20	4790	0	5017	66	4790	0	5067	83	4787	13	5105	88												
21	4790	0	5036	44	4790	0	5087	79	4787	11	5108	100												
22	4760	0	5042	35	0	0	5093	36	4787	8	5088	56												
23	0	0	5022	30	0	0	5075	20	4795	7	5068	27												

1984 2.5 MHZ

HR	JANUARY				FEBRUARY				MARCH			
	E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0					4767	19	0	0	0	0	0	0
1					4771	22	5364	324	4768	25	4949	260
2					4774	25	5083	313	4772	31	5020	242
3					4773	25	5123	310	4766	36	5022	242
4					4776	21	5099	299	4762	43	5048	297
5					4772	22	5051	279	4767	37	5097	298
6					4779	19	5083	293	4770	21	5085	241
7					4776	25	5111	251	4777	21	5194	318
8					4766	29	5102	296	4780	18	5209	301
9					4771	27	5090	287	4770	18	5121	263
10					4774	24	5143	267	4774	27	5101	207
11					4769	30	5095	228	4776	23	5085	231
12					4775	23	5074	268	4782	19	5061	238
13					4771	25	5033	236	4786	13	4993	293
14					4778	15	4988	250	4770	15	5290	0
15					4736	51	0	0	4765	14	0	0
16					4690	52	0	0	0	0	0	0
17					0	0	0	0	0	0	0	0
18					4650	0	0	0	0	0	0	0
19					4720	99	0	0	0	0	0	0
20					0	0	0	0	0	0	0	0
21					0	0	0	0	0	0	0	0
22					0	0	0	0	0	0	0	0
23					0	0	0	0	0	0	0	0

HR	APRIL				MAY				JUNE			
	E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	0	0	0	0	0	0	4560	0	0	0	5070	0
1	4765	18	4840	10	0	0	0	0	4730	0	0	0
2	4765	25	5031	294	0	0	0	0	4770	26	5006	287
3	4764	28	5006	304	4769	24	4895	104	4776	23	5085	342
4	4765	24	5040	291	4767	36	4900	245	4773	30	5010	263
5	4771	21	5114	316	4770	22	4898	194	4766	34	5081	293
6	4766	25	5072	273	4773	26	4993	289	4770	32	5086	295
7	4763	30	5063	292	4773	27	5027	309	4764	35	5065	257
8	4769	25	5153	309	4777	21	4983	270	4754	37	5097	273
9	4769	27	5099	308	4773	31	4993	273	4769	29	5096	302
10	4775	23	5105	342	4777	31	4958	206	4779	18	5097	289
11	4773	21	5106	341	4763	43	4999	233	4769	22	5025	259
12	4770	24	5041	220	4750	0	0	0	4800	0	0	0
13	4758	15	0	0	0	0	0	0	4695	35	5460	0
14	4756	10	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	4750	0	0	0
17	0	0	0	0	0	0	0	0	0	0	4830	0
18	0	0	0	0	0	0	0	0	4690	0	0	0
19	0	0	0	0	0	0	0	0	4760	0	5505	403
20	0	0	0	0	0	0	0	0	4530	0	0	0
21	0	0	0	0	0	0	0	0	0	0	5160	0
22	0	0	0	0	0	0	4820	0	0	0	5410	0
23	0	0	0	0	0	0	0	0	0	0	4960	0

HR	JULY				AUGUST				SEPTEMBER			
	E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	0	0	0	0	4777	13	4820	14	4787	12	4975	262
1	4765	19	4927	29	4781	13	4814	5	4790	8	4910	210
2	4777	12	4951	312	4782	13	4886	222	4785	13	4953	267
3	4784	13	5050	329	4789	10	4959	266	4786	25	5007	294
4	4787	12	5043	305	4789	13	5015	284	4788	12	5041	275
5	4785	13	5014	267	4785	18	5047	278	4783	17	5065	265
6	4786	15	5053	295	4784	19	5069	296	4784	15	5023	259
7	4785	14	5071	289	4785	14	5089	283	4785	14	5081	280
8	4784	16	5083	276	4778	24	5128	300	4786	13	5060	262
9	4785	13	5098	297	4782	21	5093	292	4785	15	5046	257
10	4786	15	5098	286	4790	11	5077	279	4786	17	5030	252
11	4787	16	5073	278	4786	19	5049	265	4782	25	5046	270
12	4778	19	5068	237	4785	14	5015	243	4790	13	5015	269
13	4770	20	5002	232	4769	22	5069	314	4778	22	4972	219
14	4730	0	0	0	4761	20	4810	0	4770	26	4826	20
15	0	0	0	0	0	0	0	0	4774	30	4818	10
16	0	0	0	0	0	0	0	0	4798	5	4810	0
17	0	0	0	0	0	0	0	0	4795	7	4810	0
18	0	0	0	0	0	0	0	0	4790	14	5088	298
19	0	0	0	0	0	0	0	0	0	0	5125	181
20	0	0	0	0	0	0	0	0	4760	0	4861	116
21	0	0	0	0	0	0	0	0	4796	17	4823	15
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	4770	0	0	0

HR	OCTOBER				NOVEMBER				DECEMBER			
	E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	4765	18	5132	160	4783	14	4898	223	4787	10	5067	362
1	4782	13	4944	268	4787	10	4936	224	4789	12	5052	338
2	4784	12	4921	247	4785	13	4980	280	4791	11	4942	243
3	4784	12	4993	283	4785	13	5007	294	4791	9	5017	298
4	4778	15	5142	312	4782	15	5054	309	4788	10	5085	316
5	4777	18	5092	250	4784	18	5059	277	4785	18	5073	291
6	4779	18	5070	230	4781	16	5066	269	4791	11	5074	291
7	4780	16	5090	290	4782	17	5079	279	4786	13	5070	278
8	4780	16	5064	285	4781	17	5077	288	4783	18	5101	286
9	4780	15	5083	299	4783	17	5080	277	4785	14	5098	286
10	4781	18	5114	297	4781	16	5066	271	4785	14	5089	289
11	4781	18	5072	267	4781	17	5076	279	4780	20	5070	283
12	4782	17	5049	278	4784	15	5065	282	4787	16	5091	294
13	4778	18	5063	288	4782	16	5053	269	4786	16	5086	292
14	4750	21	5270	0	4769	28	4994	261	4786	12	5030	277
15	4743	22	4823	15	4770	22	5061	163	4779	17	4924	208
16	4795	7	5140	185	4773	17	5085	93	4789	7	4810	0
17	4792	7	5151	168	0	0	5112	24	4768	22	0	0
18	4790	8	5055	194	0	0	5143	29	0	0	0	0
19	4775	44	5080	184	0	0	5086	11	0	0	0	0
20	4795	8	5079	181	0	0	5124	24	4790	0	4810	0
21	4787	15	5173	127	4780	0	5138	16	4784	10	0	0
22	4720	0	4994	184	4777	13	5100	27	4782	7	4810	0
23	4750	21	5140	105	4778	15	4825	24	4781	11	4810	0

1983 5 MHZ

HR UT	JANUARY E MEAN	SIG	F MEAN	SIG	FEBRUARY E MEAN	SIG	F MEAN	SIG	MARCH E MEAN	SIG	F MEAN	SIG	APRIL E MEAN	SIG	F MEAN	SIG	MAY E MEAN	SIG	F MEAN	SIG	JUNE E MEAN	SIG	F MEAN	SIG
0													4763	7	5771	8	4769	11	0	0	4765	14	0	0
1													4768	10	5356	494	4777	10	4817	7	4776	11	4817	5
2													4778	11	5022	323	4785	13	4822	26	4783	11	4820	11
3													4779	14	5009	257	4787	12	4874	100	4787	12	4823	22
4													4776	15	5084	262	4788	12	4931	152	4786	13	4858	78
5													4783	16	5178	218	4786	10	4998	172	4789	10	4877	103
6													4788	12	5197	220	4784	12	5097	224	4785	11	4905	167
7													4783	12	5188	250	4783	13	5182	177	4787	10	4911	162
8													4784	13	5188	190	4785	11	5125	161	4785	10	4992	188
9													4783	11	5195	163	4784	11	5180	185	4786	10	5013	182
10													4784	10	5237	197	4787	10	5181	253	4786	10	5139	166
11													4788	9	5236	190	4789	11	5131	213	4790	10	5025	231
12													4784	13	5131	323	4783	10	4828	40	4782	11	4818	10
13													4772	12	4827	6	4776	11	4812	4	4775	12	4813	7
14													4765	10	5582	432	4767	11	0	0	4766	14	0	0
15													4757	10	5767	11	4759	14	4810	0	4758	14	0	0
16													4752	10	5761	6	4754	18	0	0	4748	17	0	0
17													4749	14	5592	271	4754	16	0	0	4750	22	0	0
18													4714	64	5579	278	4757	15	0	0	4755	7	0	0
19													4737	15	5720	0	4751	18	0	0	4770	0	0	0
20													4744	14	0	0	4749	19	0	0	4755	7	0	0
21													4732	21	5743	12	4745	18	0	0	4750	0	0	0
22													4745	12	5753	12	4758	13	0	0	4755	16	0	0
23													4756	13	5763	7	4763	13	0	0	4758	16	0	0

HR UT	JULY E MEAN	SIG	F MEAN	SIG	AUGUST E MEAN	SIG	F MEAN	SIG	SEPTEMBER E MEAN	SIG	F MEAN	SIG	OCTOBER E MEAN	SIG	F MEAN	SIG	NOVEMBER E MEAN	SIG	F MEAN	SIG	DECEMBER E MEAN	SIG	F MEAN	SIG
0	4777	11	4810	0	4775	12	4813	5	4769	15	4813	5	4778	15	5056	321	4774	15	5052	281	4778	12	5067	299
1	4783	10	4816	9	4779	13	4817	8	4774	15	4885	69	4775	16	5022	305	4776	18	5036	283	4782	14	5029	279
2	4786	10	4821	11	4781	16	4842	73	4776	13	4939	69	4774	19	5006	274	4777	19	5013	251	4789	10	4980	200
3	4790	11	4826	35	4787	12	4961	109	4776	16	4983	84	4775	19	5022	225	4780	13	4972	193	4783	13	4975	192
4	4783	13	4843	79	4782	11	5018	130	4776	11	5059	104	4773	17	5095	203	4780	19	5069	240	4774	25	5068	211
5	4789	11	4896	110	4782	14	5033	214	4773	12	5133	101	4778	19	5093	159	4778	20	5075	217	4776	16	5077	228
6	4788	11	4930	154	4784	12	5055	205	4775	12	5155	92	4774	15	5106	175	4772	22	5091	244	4774	21	5056	182
7	4785	13	5048	224	4785	11	5130	168	4777	11	5155	57	4771	20	5163	217	4781	14	5010	182	4768	33	5060	190
8	4786	12	5081	198	4781	14	5180	127	4774	10	5165	62	4779	14	5146	186	4781	20	4992	140	4767	37	5014	158
9	4788	12	5113	198	4794	7	5204	91	4773	15	5169	57	4779	22	5147	167	4773	24	5033	169	4779	16	5042	235
10	4787	13	5192	192	4782	24	5195	102	4780	15	5165	99	4783	20	5129	144	4774	27	5075	190	4787	10	5002	191
11	4789	12	5142	222	4791	13	5207	157	4786	9	5179	97	4784	16	5114	164	4778	19	5071	194	4789	10	5023	178
12	4790	10	4841	98	4792	9	5063	234	4781	11	5129	146	4765	25	5119	177	4773	18	5078	187	4788	15	5057	159
13	4784	10	4818	8	4782	12	4818	8	4776	14	4886	100	4779	20	4993	177	4779	19	5036	196	4768	17	5068	180
14	4776	11	4810	0	4777	12	4814	5	4772	14	4810	0	4771	14	5110	252	4781	15	5015	279	4787	14	4991	203
15	4772	10	4820	0	4772	10	4810	0	4770	13	4810	0	4766	17	5000	214	4778	13	5272	377	4779	13	5049	306
16	4768	11	0	0	4767	11	0	0	4762	19	4810	0	4764	18	5137	214	4773	14	4962	220	4774	12	4990	369
17	4762	14	0	0	4764	13	0	0	4765	17	0	0	4761	23	5133	253	4767	15	5140	274	4771	13	4887	245
18	4759	14	0	0	4761	15	0	0	4768	18	0	0	4761	27	4830	26	4766	16	5140	572	4771	15	5201	451
19	4761	11	0	0	4759	14	0	0	4776	15	0	0	4767	26	4880	114	4766	16	5188	391	4769	13	4919	166
20	4761	13	0	0	4762	14	0	0	4772	22	4820	0	4760	27	4977	246	4763	13	4970	242	4764	13	4938	325
21	4751	19	0	0	4764	13	0	0	4765	17	0	0	4761	21	5004	203	4766	13	4960	216	4764	12	5293	472
22	4765	14	0	0	4768	11	0	0	4765	18	4820	0	4760	23	4977	197	4767	12	5118	447	4766	12	5120	445
23	4770	11	0	0	4771	10	0	0	4769	14	4815	7	4764	12	5335	294	4768	12	5210	320	4768	14	5167	334

1954 5 MHZ

HR UT	JANUARY F MEAN	JANUARY F SIG	JANUARY F MEAN	JANUARY F SIG	FEBRUARY F MEAN	FEBRUARY F SIG	FEBRUARY F MEAN	FEBRUARY F SIG	MARCH F MEAN	MARCH F SIG	MARCH F MEAN	MARCH F SIG
0	4777	16	5003	273	4775	15	5069	330	4773	13	4960	301
1	4778	33	5012	262	4783	16	5049	295	4781	14	4965	262
2	4781	14	5006	221	4785	13	5066	265	4784	14	4998	265
3	4781	26	4990	161	4788	9	5053	238	4795	12	4952	206
4	4774	18	5041	164	4781	13	5066	198	4783	14	5022	238
5	4770	18	5085	196	4773	16	5133	194	4780	14	5049	204
6	4762	24	5127	194	4767	24	5153	177	4774	28	5089	199
7	4765	34	5087	146	4763	26	5186	183	4767	30	5182	193
8	4783	16	5066	138	4764	28	5147	157	4762	24	5168	205
9	4775	44	5086	138	4773	34	5114	142	4775	16	5155	202
10	4784	28	5034	117	4789	14	5106	154	4781	22	5156	185
11	4791	16	5045	126	4783	10	5106	145	4774	33	5173	168
12	4782	16	5109	157	4774	15	5147	172	4787	12	5166	196
13	4772	25	5100	134	4772	17	5129	153	4787	13	4963	175
14	4788	10	4978	154	4762	10	4936	165	4782	14	4918	221
15	4783	13	4960	237	4784	11	4949	248	4777	14	4993	353
16	4778	13	4869	201	4780	12	4987	342	4772	13	5053	430
17	4773	14	4938	317	4777	15	4901	249	4769	21	5225	459
18	4772	16	4819	9	4775	16	4907	190	4769	21	5170	459
19	4775	16	4949	340	4777	16	4834	57	4768	25	5132	434
20	4775	17	4873	153	4778	17	4917	259	4771	25	5192	446
21	4772	16	4979	342	4773	17	4996	340	4773	21	5184	428
22	4770	16	5002	316	4774	15	5051	406	4771	16	5078	421
23	4773	14	5209	376	4770	16	5130	335	4773	14	5216	461

HR UT	APRIL F MEAN	APRIL F SIG	APRIL F MEAN	APRIL F SIG	MAY F MEAN	MAY F SIG	MAY F MEAN	MAY F SIG	JUNE F MEAN	JUNE F SIG	JUNE F MEAN	JUNE F SIG
0	4769	13	5217	365	4780	13	5085	443	4777	11	4994	266
1	4776	15	4979	240	4778	12	5005	312	4785	10	4928	230
2	4781	14	4977	248	4786	12	5019	256	4789	11	4982	282
3	4782	13	5006	236	4787	12	5028	245	4790	10	4994	251
4	4780	15	5036	211	4788	11	5084	291	4789	11	4996	236
5	4780	18	5056	190	4787	13	5026	226	4787	14	5036	247
6	4766	27	5142	226	4786	23	5023	213	4787	15	5043	202
7	4768	27	5118	189	4778	34	5116	247	4773	27	5071	202
8	4778	32	5104	172	4779	24	5113	268	4773	22	5106	225
9	4776	26	5126	184	4780	21	5114	198	4778	25	5155	229
10	4779	22	5071	158	4782	9	5158	213	4779	23	5147	198
11	4773	26	5094	175	4768	25	5174	200	4779	24	5116	229
12	4771	33	5038	225	4785	12	4999	239	4789	11	4978	260
13	4780	13	4998	254	4779	11	4911	169	4785	8	4941	234
14	4772	14	5173	363	4774	16	4965	365	4776	10	4870	111
15	4766	14	5220	331	4773	17	4830	14	4772	14	5094	371
16	4767	18	5160	250	4784	14	4970	331	4772	18	5166	367
17	4769	17	5263	388	4780	20	4817	9	4772	18	5060	318
18	4774	16	5059	298	4780	21	5052	245	4769	24	5066	301
19	4773	14	5280	247	4766	26	4845	35	4770	23	5075	343
20	4775	16	5196	309	4787	6	0	0	4771	23	4975	230
21	4773	19	5404	319	4789	10	4880	150	4767	24	5088	323
22	4771	18	5215	300	4783	17	4826	15	4772	20	4940	247
23	4767	15	5188	383	4779	17	5012	370	4773	17	5031	343

HR UT	JULY F MEAN	JULY F SIG	JULY F MEAN	JULY F SIG	AUGUST F MEAN	AUGUST F SIG	AUGUST F MEAN	AUGUST F SIG	SEPTEMBER F MEAN	SEPTEMBER F SIG	SEPTEMBER F MEAN	SEPTEMBER F SIG
0	4784	9	4813	4	4788	9	4842	123	4793	8	4925	240
1	4789	9	4944	257	4789	10	4909	201	4792	10	4962	222
2	4791	10	4978	254	4790	10	4992	260	4796	6	4981	217
3	4793	10	4995	235	4784	15	5011	256	4782	19	5003	233
4	4789	11	5021	230	4784	11	5032	241	4792	12	5022	162
5	4790	13	5022	225	4778	30	5042	215	4776	21	5122	226
6	4786	16	5040	212	4765	36	5077	214	4774	22	5139	209
7	4786	13	5093	221	4772	21	5096	193	4769	35	5168	184
8	4766	34	5127	216	4770	28	5136	195	4776	29	5196	191
9	4774	19	5101	210	4787	19	5138	180	4755	53	5195	175
10	4775	27	5135	222	4762	29	5121	213	4763	47	5188	175
11	4783	17	5108	240	4783	20	5096	190	4734	43	5141	185
12	4788	15	4939	198	4792	10	4975	177	4774	41	5089	207
13	4789	9	4917	228	4794	8	4920	224	4794	11	4931	187
14	4783	8	4869	139	4791	7	4827	66	4795	7	4919	237
15	4776	8	5275	658	4785	8	4811	4	4792	7	4821	45
16	4774	9	5130	459	4780	8	5190	0	4785	9	4819	14
17	4774	11	5276	461	4780	10	5235	438	4781	15	4895	180
18	4772	13	5024	357	4778	10	4817	16	4773	16	4879	141
19	4774	14	4979	334	4778	11	4870	169	4775	14	4819	22
20	4774	13	4965	327	4778	11	4825	14	4781	12	4867	129
21	4774	12	5017	387	4780	10	4921	322	4784	13	4889	160
22	4775	11	4906	282	4781	10	4814	9	4786	8	4817	10
23	4778	9	4976	390	4784	8	4816	11	4790	9	4895	245

HR UT	OCTOBER F MEAN	OCTOBER F SIG	OCTOBER F MEAN	OCTOBER F SIG	NOVEMBER F MEAN	NOVEMBER F SIG	NOVEMBER F MEAN	NOVEMBER F SIG	DECEMBER F MEAN	DECEMBER F SIG	DECEMBER F MEAN	DECEMBER F SIG
0	4789	11	4939	233	4786	12	4974	234	4785	11	5018	267
1	4790	10	4982	258	4786	14	4983	228	4789	12	4954	207
2	4788	11	5000	246	4783	9	4957	170	4785	12	4939	149
3	4786	19	4991	201	4789	11	4967	181	4787	17	4959	166
4	4783	15	5056	212	4784	21	5028	185	4789	10	5005	206
5	4777	31	5059	221	4782	18	5051	165	4780	27	5019	193
6	4777	27	5048	199	4788	10	5018	157	4787	13	5023	169
7	4759	40	5078	178	4793	13	5025	170	4783	11	4981	124
8	4773	26	5078	155	4792	10	5013	178	4778	26	5005	162
9	4787	22	5066	155	4789	11	5022	183	4783	23	4995	155
10	4785	11	5071	188	4785	11	5021	143	4799	4	4991	121
11	4781	26	5063	187	4787	16	5026	140	4777	14	5032	140
12	4786	17	5034	163	4784	17	5074	156	4765	26	5083	162
13	4789	14	4980	176	4776	16	5029	168	4774	31	5066	117
14	4795	7	4923	233	4796	6	4925	158	4787	13	4975	190
15	4793	8	4872	198	4792	8	4996	302	4783	13	5113	322
16	4787	9	4841	109	4790	8	4892	180	4778	14	5046	295
17	4782	12	4836	84	4786	10	4978	236	4779	16	4951	215
18	4777	14	4870	159	4783	11	4815	12	4776	19	5124	272
19	4778	13	4847	124	4780	12	4916	215	4777	15	4904	157
20	4779	14	4908	191	4782	10	4813	7	4775	17	4957	217
21	4782	10	4868	124	4783	10	4811	4	4775	14	4885	113
22	4786	8	4869	126	4783	10	5036	342	4774	14	5087	288
23	4788	10	4912	222	4785	10	4962	232	4778	13	5116	337

1983 10 MHZ

HR	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
	F		F		F		F		F		F		F		F		F		F		F		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	0	0	4999	34	0	0	5024	27					4777	6	5082	120	4779	12	5061	155	4778	13	5166	221
1	0	0	5033	62	0	0	5014	45					4790	0	5074	199	4787	13	5080	203	4786	14	5036	153
2	4777	16	5064	85	0	0	5033	58					4760	0	5084	101	4786	13	5047	81	4787	12	5075	102
3	4781	16	5070	129	0	0	5076	60					0	0	5121	107	4787	9	5091	152	4760	13	5092	101
4	4778	19	4816	7	0	0	0	0					4770	12	5266	141	4786	7	5131	146	4778	9	5126	90
5	4780	19	4817	5	0	0	0	0					4773	11	5313	223	4778	11	5240	155	4784	8	5221	114
6	4787	15	4822	8	0	0	0	0					4781	11	4815	6	4776	8	5433	133	4782	7	5287	114
7	4787	13	4833	15	0	0	0	0					4778	15	4810	0	4776	13	5378	228	4779	9	5420	106
8	4790	12	4823	10	0	0	0	0					4781	15	0	0	4773	11	5365	154	4780	9	5319	276
9	4788	14	4813	5	4776	13	0	0					4785	8	0	0	4776	11	5299	81	4776	9	5276	174
10	4780	15	4820	0	4770	9	0	0					4777	8	5230	34	4778	11	5218	171	4778	11	5151	358
11	4777	17	4829	9	4779	5	4320	0					4780	8	0	0	4779	12	4810	0	4781	12	5199	288
12	4777	16	4836	13	4778	13	4815	7					4780	10	5068	158	4789	8	4899	136	4791	10	5072	200
13	4768	24	4815	7	4776	18	4820	0					4789	12	5058	176	4789	9	4985	199	4786	13	5008	179
14	4766	23	5069	87	0	0	5071	80					4781	10	5069	185	4776	11	5003	103	4775	15	5115	229
15	0	0	4958	38	0	0	4961	36					4764	12	5116	288	4771	15	5088	285	4769	17	5321	321
16	0	0	4946	30	0	0	4920	23					4757	14	5333	216	4765	15	5345	360	4763	17	5221	381
17	4766	18	4924	23	4770	0	5089	382					4756	21	5600	43	4759	15	5514	227	4759	19	5269	383
18	4766	22	5390	622	4740	0	0	0					4752	17	5753	96	4756	17	5527	63	4750	19	5561	64
19	4763	17	5021	346	4770	28	5360	735					4751	16	5603	215	4758	16	5534	49	4752	20	5603	108
20	4755	10	4914	40	4769	14	5900	0					4752	20	5554	91	4758	16	5637	185	4753	18	5454	250
21	4780	0	4898	37	4765	15	4900	0					4759	14	5533	34	4760	17	5546	113	4762	20	5523	179
22	0	0	4947	40	0	0	4951	36					4762	14	5200	261	4763	15	5351	197	4765	16	5457	175
23	0	0	4980	104	4796	0	4973	24					4769	11	5061	231	4773	14	5122	281	4770	16	5285	279

HR	JULY				AUGUST				SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER			
	F		F		F		F		F		F		F		F		F		F		F		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	4781	14	5155	168	4785	6	5090	105	4775	7	5057	52	4778	18	5193	354	4775	21	5118	313	4784	10	5023	89
1	4795	7	5133	80	4791	11	5074	84	4763	15	5037	46	4770	0	5647	174	4776	12	5065	126	4780	8	5035	96
2	4780	17	5075	52	0	0	5084	82	[illegible]	0	5073	68	4774	19	5050	91	4777	11	5068	123	4781	13	5021	177
3	4792	11	5087	78	4783	6	5134	82	4790	8	5142	108	4778	15	5131	139	4779	9	4994	194	4781	9	4840	64
4	4767	20	5194	132	4784	6	5198	123	4777	8	5171	103	4780	10	5057	150	4783	9	4816	10	4782	8	4822	11
5	4789	9	5235	120	4786	10	5236	103	4780	6	5244	107	4782	8	4996	67	4780	8	4813	5	4780	10	4822	9
6	4783	11	5322	179	4783	11	5269	181	4778	10	4983	246	4780	8	4950	104	4777	5	5010	238	4780	8	0	0
7	4788	9	5344	169	4790	11	5069	335	4775	13	4840	26	4777	9	4918	85	4777	8	4820	0	4777	9	5256	113
8	4784	11	5152	214	4793	11	5246	224	4779	8	0	0	4775	6	5046	32	4775	12	5238	313	4776	11	5095	213
9	4786	10	5199	248	4778	11	5334	46	4781	10	4810	0	4770	11	5069	12	4775	11	5338	210	4772	13	5085	209
10	4784	8	5075	250	4781	11	4810	0	4782	10	4813	5	4776	10	5088	5	4773	10	5045	332	4774	12	5206	123
11	4783	7	4810	0	4788	7	0	0	4783	12	0	0	4784	6	5222	156	4774	10	4970	226	4790	11	4924	111
12	4791	8	4983	175	4790	6	5150	141	4783	8	5060	354	4780	14	5356	97	4778	9	5260	14	4778	12	4837	24
13	4793	8	4958	175	4794	6	5054	166	4784	11	5110	81	4780	16	5131	86	4778	8	5178	143	4777	11	4911	270
14	4777	15	5048	162	4789	7	5054	161	4797	5	5040	91	4786	8	5097	257	4783	10	5059	162	4773	19	5069	65
15	4778	15	5320	295	4780	14	5247	309	[illegible]	8	4974	68	4790	12	5055	278	4785	17	5043	251	0	0	5010	122
16	4776	14	5498	186	4778	16	5333	260	4780	12	5048	288	4783	21	5039	324	4781	14	5053	288	4790	0	4986	165
17	4773	17	5480	261	4776	12	5318	323	4777	12	5239	289	4784	13	5032	339	4785	21	5010	271	4788	13	4994	210
18	4761	23	5480	251	4774	15	5506	234	4773	13	5352	254	4783	13	5120	430	4787	11	4961	239	4778	25	5052	283
19	4763	21	5548	61	4773	17	5578	165	[illegible]	14	5319	359	4782	16	5255	454	4785	13	5030	315	4788	21	5043	316
20	4766	17	5547	133	4771	15	5528	71	4773	14	5517	208	4781	16	5022	307	4788	13	4945	203	4787	13	5117	346
21	4770	15	5533	60	4773	13	5488	129	4777	12	5247	258	4781	11	5044	312	4786	15	5042	289	4786	12	5079	292
22	4777	12	5381	183	4776	12	5458	74	4776	12	5047	157	4783	10	5075	289	4772	16	5107	328	4793	6	5097	307
23	4782	11	5316	196	4777	16	5165	198	4779	12	5041	71	4640	14	5200	376	4782	13	5190	375	4777	40	5072	273

1984 10 MHZ

HR UT	JANUARY E MEAN	JANUARY E SIG	JANUARY F MEAN	JANUARY F SIG	FEBRUARY E MEAN	FEBRUARY E SIG	FEBRUARY F MEAN	FEBRUARY F SIG	MARCH E MEAN	MARCH E SIG	MARCH F MEAN	MARCH F SIG	APRIL E MEAN	APRIL E SIG	APRIL F MEAN	APRIL F SIG	MAY E MEAN	MAY E SIG	MAY F MEAN	MAY F SIG	JUNE E MEAN	JUNE E SIG	JUNE F MEAN	JUNE F SIG
0	4747	15	5030	104	4715	92	5100	273	4784	14	5050	236	4770	27	5047	161	4766	46	5169	217	4755	43	5149	230
1	4782	13	5050	107	0	0	5064	189	4773	21	5103	273	4786	15	5034	120	4776	34	5170	237	4764	38	5129	205
2	4785	12	5051	128	4773	17	5057	133	4771	21	5075	184	4784	23	5071	144	4784	12	5155	269	4777	32	5121	219
3	4781	11	4936	136	4776	13	5113	116	4772	25	5158	217	4770	32	5150	167	4771	20	5119	179	4768	33	5097	213
4	4779	10	4925	167	4775	10	5064	187	4777	14	5140	203	4770	27	5224	161	4778	19	5230	173	4778	23	5147	199
5	4779	12	4820	11	4776	10	5117	266	4772	15	5124	188	4773	16	5231	220	4781	12	5166	296	4779	18	5227	228
6	4776	10	5071	249	4780	13	0	0	4769	14	5285	277	4777	19	4949	258	4780	11	5168	295	4783	12	5313	274
7	4777	14	4818	5	4773	9	4623	15	4771	14	5138	209	4782	14	5119	413	4781	11	4961	198	4779	14	5333	211
8	4780	11	5134	165	4777	18	4980	333	4776	15	5298	426	4777	14	5031	284	4773	14	4960	219	4779	15	5252	231
9	4775	13	5169	117	4774	19	4918	10	4772	16	5151	276	4777	15	4994	250	4777	12	5016	209	4773	19	5167	181
10	4782	8	5450	551	4777	20	4961	223	4796	14	5470	292	4783	9	4948	183	4778	17	5166	261	4775	24	5098	257
11	4752	7	5170	154	4779	16	0	0	4785	9	5461	267	4779	10	4995	220	4771	31	5132	231	4775	20	5120	232
12	4776	22	5200	244	4780	11	4630	14	4786	10	5154	241	4779	13	5146	202	4783	18	5062	248	4784	17	5031	219
13	4777	8	4895	79	4781	8	5093	159	4781	26	5188	165	4781	21	5106	140	4784	16	4993	213	4783	26	5056	229
14	4776	10	5094	92	4755	12	5074	81	4781	27	5054	134	4775	26	5038	142	4773	21	5122	278	4755	51	5039	198
15	4730	70	5020	70	4772	63	4977	56	4771	35	4992	155	4772	20	5031	217	4771	30	5130	298	4767	29	5100	258
16	4790	8	4986	119	4786	29	4953	99	4773	22	5053	274	4770	25	5115	276	4771	25	5218	297	4763	34	5185	314
17	4787	12	4954	141	4796	13	4950	174	4775	16	5091	314	4763	26	5267	266	4762	27	5334	289	4763	30	5252	305
18	4786	11	4945	177	4784	11	4942	195	4773	17	5078	276	4757	27	5355	240	4765	23	5356	335	4757	31	5341	292
19	4787	13	4977	246	4785	11	4922	179	4770	20	5097	282	4757	22	5375	233	4758	25	5423	265	4756	30	5308	286
20	4788	12	4964	222	4796	10	4952	210	4772	15	5068	320	4759	24	5283	257	4744	27	5484	198	4757	33	5326	277
21	4790	9	4974	202	4797	12	4942	197	4774	14	5018	282	4765	23	5186	240	4728	35	5453	133	4750	31	5345	271
22	4762	21	5018	195	4788	13	4969	176	4781	12	4911	163	4776	19	5009	217	4736	35	5384	202	4745	37	5244	261
23	4795	6	5023	191	4755	42	5025	182	4773	27	4960	108	4774	24	5014	195	4742	39	5261	215	4747	40	5205	227

HR UT	JULY E MEAN	JULY E SIG	JULY F MEAN	JULY F SIG	AUGUST E MEAN	AUGUST E SIG	AUGUST F MEAN	AUGUST F SIG	SEPTEMBER E MEAN	SEPTEMBER E SIG	SEPTEMBER F MEAN	SEPTEMBER F SIG	OCTOBER E MEAN	OCTOBER E SIG	OCTOBER F MEAN	OCTOBER F SIG	NOVEMBER E MEAN	NOVEMBER E SIG	NOVEMBER F MEAN	NOVEMBER F SIG	DECEMBER E MEAN	DECEMBER E SIG	DECEMBER F MEAN	DECEMBER F SIG
0	4749	45	5124	208	4733	45	5134	159	4745	62	5042	111	4779	3	5044	161	4791	18	5003	103	4790	8	5043	166
1	4770	36	5132	191	4748	48	5125	134	4795	6	5047	113	4780	32	5050	139	4789	11	4932	129	4790	11	4970	149
2	4764	32	5121	182	4760	38	5095	142	4786	24	5075	139	4788	15	5003	127	4792	9	4930	162	4794	7	4839	30
3	4777	21	5102	166	4776	30	5113	147	4788	16	5079	162	4788	14	4905	136	4795	10	4883	132	4793	8	4843	102
4	4781	20	5145	181	4789	13	5130	172	4792	12	5087	268	4792	10	4828	41	4796	5	4821	19	4793	7	4860	134
5	4794	23	5147	220	4795	13	5093	229	4790	11	5148	315	4792	9	4828	28	4794	13	5014	297	4790	7	4900	178
6	4781	15	5109	264	4784	14	4981	220	4787	11	5062	276	4790	9	4870	136	4792	10	5076	313	4787	10	4946	264
7	4785	13	4924	196	4786	10	4847	116	4782	11	0	0	4790	8	4866	43	4789	11	5077	289	4784	8	5065	162
8	4784	11	5015	223	4784	13	5038	236	4786	12	4931	321	4788	10	4810	0	4788	9	5042	258	4786	10	5041	229
9	4781	13	4941	213	4782	17	5053	246	4783	12	4867	111	4789	10	4810	0	4785	9	4930	116	4785	13	4995	140
10	4782	16	5031	258	4783	12	5075	248	4788	9	4920	152	4786	12	4877	147	4787	9	4911	118	4786	16	4896	135
11	4785	12	5047	258	4783	18	4946	217	4792	8	5015	220	4788	10	4860	134	4788	11	4820	10	4785	17	4820	11
12	4795	21	4947	185	4783	27	4952	249	4794	8	4922	236	4788	9	4810	0	4788	10	4881	136	4793	9	4836	27
13	4792	12	4950	202	4793	16	4964	193	4793	18	5047	185	4791	8	5083	105	4788	9	5119	124	4788	7	4934	178
14	4783	29	4998	193	4779	43	4983	166	4782	47	5012	154	4792	8	5031	116	4789	12	5068	85	4791	8	5063	97
15	4767	29	5050	216	4761	37	5093	182	4763	50	5039	174	4788	20	4996	126	4725	92	5028	185	0	0	5000	41
16	4770	33	5087	267	4765	40	5071	219	4788	17	5019	191	4753	54	5005	201	4764	49	5046	245	4800	0	4994	118
17	4770	30	5129	311	4768	31	5128	268	4772	34	5042	244	4784	24	5020	235	4778	33	4985	220	0	0	4988	97
18	4768	28	5193	332	4765	33	5202	290	4764	42	5117	247	4782	29	4995	237	4794	7	4946	195	4743	98	5015	220
19	4767	29	5208	341	4758	33	5256	282	4771	32	5183	245	4791	11	4984	229	4757	19	4922	165	4795	7	4979	178
20	4768	30	5172	308	4755	35	5218	273	4768	30	5173	240	4790	13	4973	199	4790	24	4960	161	4786	12	4988	149
21	4766	32	5181	315	4751	37	5162	258	4767	38	5057	181	4787	9	4995	170	4773	65	4998	168	4783	29	5053	237
22	4750	39	5190	279	4734	40	5149	201	4776	30	5055	146	4774	40	5033	136	4800	0	4990	108	4750	87	5010	163
23	4752	44	5121	221	4734	44	5141	159	4780	36	5053	126	4787	10	5023	153	1793	5	5034	194	4775	32	5004	123

1983 15 MHZ

HR	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
	E		F		E		F		E		F		E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0													4783	6	5149	68	4786	11	5122	171	4781	16	5122	246
1													4769	6	5163	76	4782	11	5167	84	4775	12	5245	149
2													4761	9	5131	65	4778	10	5126	82	4770	12	5196	119
3													4770	10	5081	100	4776	8	5139	97	4775	8	5168	117
4													4778	12	0	0	4776	[illegible]	5080	38	4774	9	5171	119
5													4765	14	5780	0	4776	[illegible]	0	0	4774	10	5200	17
6													4776	5	0	0	4773	[illegible]	0	0	4769	9	0	0
7													4781	15	0	0	4770	[illegible]	0	0	4766	12	0	0
8													4780	7	0	0	4769	9	0	0	4766	12	0	0
9													4774	12	0	0	4765	12	0	0	4765	11	0	0
10													4767	9	0	0	4766	10	0	0	4764	11	0	0
11													4768	8	0	0	4774	12	0	0	4765	12	0	0
12													4760	10	0	0	4780	10	0	0	4770	12	0	0
13													4777	14	4820	0	4780	13	5228	40	4776	12	5120	209
14													4778	16	5132	216	4786	12	4978	198	4782	13	4945	179
15													4777	13	5025	248	4786	9	5049	230	4779	15	4958	229
16													4780	13	5108	192	4782	11	5081	291	4771	16	4997	236
17													4770	10	5258	109	4776	11	5173	255	4768	17	4989	251
18													4764	12	5260	192	4771	12	5183	289	4762	15	4883	109
19													4766	13	5285	103	4769	18	5185	270	4758	16	5247	297
20													4762	11	5264	113	4772	9	5277	188	4764	15	5209	256
21													4770	6	5277	103	4774	10	5264	125	4767	14	5223	158
22													4780	7	5220	80	4785	10	5206	196	4774	14	5184	239
23													4781	19	5168	93	4789	12	5114	185	4779	15	5097	271

HR	JULY				AUGUST				SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER			
	E		F		E		F		E		F		E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	4785	12	5147	236	4785	12	5092	196	4761	9	5134	83	4770	17	5043	61	4764	24	5047	68	4763	24	5095	82
1	4780	11	5165	154	4794	8	5217	55	4767	14	5128	65	4720	46	5075	59	4772	17	5077	82	4770	14	5145	225
2	4781	7	5194	76	4778	6	5211	44	4778	7	5213	63	4775	8	5144	111	4772	20	5048	152	4775	12	5008	243
3	4778	10	5191	56	4777	7	5302	49	4780	9	5174	19	4780	8	5103	18	4775	21	4915	7	4771	22	4820	0
4	4776	11	5086	30	4779	8	0	0	4770	7	0	0	4775	17	5096	78	4772	22	4813	6	4771	18	4813	6
5	4786	9	0	0	4780	7	0	0	4769	11	0	0	4772	21	5060	77	4771	19	4825	21	4774	12	4825	21
6	4792	10	4810	0	4750	8	4820	0	4768	9	0	0	4768	14	4978	85	4767	18	4825	7	4771	21	4823	6
7	4782	9	0	0	4778	9	0	0	4773	6	0	0	4762	22	5013	10	4765	16	0	0	4766	16	4820	0
8	4775	13	0	0	4778	7	0	0	4769	9	0	0	4776	9	5082	80	4768	11	0	0	4762	18	4810	0
9	4776	12	0	0	4772	11	0	0	4768	8	0	0	4771	3	0	0	4766	15	4820	12	4746	29	0	0
10	4776	3	0	0	4776	7	0	0	0	0	0	0	4766	5	0	0	4768	15	4813	5	4782	9	0	0
11	4777	7	0	0	4790	6	4810	0	4780	0	0	0	4772	8	0	0	4773	14	4810	0	4783	14	4823	15
12	4777	7	0	0	4782	4	4820	0	4777	6	0	0	4777	20	0	0	4774	7	0	0	4781	10	0	0
13	4783	11	4814	5	4780	9	5210	0	4777	11	5127	23	4767	15	5114	24	4775	7	0	0	4774	22	4810	0
14	4789	10	4965	201	4786	11	5013	184	4778	13	5148	55	4790	0	5080	68	4776	10	5077	55	4775	23	5062	24
15	4786	12	4847	111	4785	10	5131	223	4777	14	5117	64	0	0	5060	55	4750	52	5058	57	4774	21	5058	45
16	4781	12	5029	257	4781	7	5182	141	4781	19	5108	81	4776	15	5078	107	4792	15	5048	81	4772	27	5080	70
17	4778	12	5048	261	4778	9	5244	247	4784	11	5150	175	4765	45	5111	114	4740	30	5066	77	4785	13	5068	109
18	4777	11	5013	259	4779	11	5278	252	4782	12	5229	171	4770	11	5116	71	4775	21	5070	95	4780	0	5071	107
19	4775	15	5097	259	4776	8	5254	239	4777	14	5226	128	4769	17	5104	56	4790	0	5055	65	4690	0	5036	68
20	4776	12	5123	321	4776	8	5249	198	4780	13	5205	110	4767	17	5122	109	4750	0	5056	60	4760	24	5049	91
21	4776	14	5252	305	4779	10	5208	175	4781	15	5192	126	0	0	5107	74	0	0	5045	53	4753	52	5057	75
22	4782	12	5190	320	4786	10	5107	230	4774	14	5175	78	0	0	5080	44	4785	5	5034	56	0	0	5064	60
23	4785	13	5042	266	4787	14	5050	221	4760	10	5162	74	0	0	5041	27	4793	6	5037	77	4773	21	5059	62

1984	15 MHZ																							
	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
HR	E		F		E		F		E		F		E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	4780	15	5091	105	4784	9	5086	111	[illegible]	0	5082	76	4773	17	5166	159	4789	24	5032	273	4790	11	4850	93
1	4775	16	5055	176	4778	10	5121	106	4783	14	5089	102	4780	16	5144	119	4787	14	5107	234	4788	12	4961	197
2	4784	9	4967	275	4762	14	5098	156	4777	15	5108	119	4776	14	5129	140	4787	9	5140	279	4785	12	5087	208
3	4781	15	4928	174	4782	11	4946	220	4775	17	5012	159	4774	22	5067	130	4779	12	5038	233	4782	16	5145	177
4	4778	10	4972	247	4784	14	4818	11	4778	17	4881	141	4780	13	4812	4	4782	12	4817	5	4781	17	4945	171
5	4775	11	4315	7	4794	7	4830	0	4777	17	4814	5	4780	12	4888	123	4794	12	4866	156	4781	17	4925	191
6	4776	19	0	0	4785	10	4810	0	4777	15	4820	17	4783	10	4810	0	4783	13	4849	33	4783	13	4847	110
7	4792	10	0	0	4779	10	4860	100	4783	15	4822	12	4786	10	4846	95	4785	13	4828	16	4776	18	4890	186
8	4783	16	5010	0	4784	16	4839	68	4786	15	4822	11	4788	8	4839	70	4786	11	4832	28	4777	19	4844	80
9	4780	0	0	0	4784	19	4810	0	4783	14	4823	10	4786	7	4810	0	4789	16	4818	15	4782	16	4833	28
10	0	0	0	0	4786	16	4810	0	4791	11	4811	3	4785	6	4912	160	4793	8	0	0	4778	15	4950	247
11	4786	9	0	0	4790	6	4810	0	4800	0	4812	4	4784	8	4810	0	4780	0	4810	0	4779	10	4944	190
12	4786	7	0	0	4790	6	4810	0	4797	5	4813	6	4781	8	4813	6	4786	8	0	0	4787	10	4879	103
13	0	0	0	0	4797	5	4368	109	[illegible]	9	4847	129	4783	11	4973	149	4790	8	4877	102	4793	8	4872	103
14	4783	6	5030	0	0	0	5138	58	4795	5	5140	116	4784	15	5161	150	4793	9	4821	35	4794	9	4883	134
15	4792	7	5075	70	4784	12	5133	57	4790	19	5089	135	4784	12	5139	177	4795	8	4841	70	4790	15	4914	182
16	4794	9	5097	83	4778	14	5157	116	4780	27	5101	182	4779	20	5133	222	4790	11	4845	140	4790	14	4909	168
17	4782	13	5124	93	4771	24	5133	143	4777	19	5160	196	4781	15	5171	226	4787	12	4848	85	4784	15	4908	169
18	4762	29	5136	128	4750	72	5091	142	[illegible]	29	5140	159	4772	27	5296	209	4786	13	4840	31	4783	19	4913	188
19	4730	0	5093	105	4787	9	5057	111	[illegible]	28	5102	122	4768	30	5288	211	4787	12	4892	164	4786	12	4923	198
20	4780	14	5084	125	4792	11	5067	142	4767	28	5105	125	4766	31	5251	281	4789	11	4849	72	4786	12	4903	178
21	4762	24	5105	93	4767	31	5098	148	4761	30	5119	153	4764	38	5244	200	4792	9	4666	123	4788	13	4924	198
22	4716	72	5092	92	4723	59	[illegible]	141	4774	41	5112	146	4773	28	5183	165	4794	8	4843	96	4787	15	4921	184
23	4762	39	5094	62	4748	56	5087	116	0	0	5109	78	4760	41	5198	122	4791	21	4911	208	4789	10	4914	179

	JULY				AUGUST				SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER			
HR	E		F		E		F		E		F		E		F		E		F		E		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	4783	19	4860	124	4781	24	4918	177	4793	14	5053	159	4780	18	5080	100	4784	17	5019	134	4787	14	4985	143
1	4783	15	4949	191	4782	19	5040	216	[illegible]	7	5057	169	4782	16	5021	172	4791	7	4907	190	4792	8	4820	10
2	4781	14	5131	177	4784	15	5135	157	[illegible]	13	4881	161	4789	14	4968	170	4792	9	4818	19	4793	8	4821	14
3	4782	13	5129	176	4783	16	5097	177	4790	8	4977	225	4796	5	4815	11	4794	6	4839	95	[illegible]	6	4812	4
4	4783	15	4975	209	4734	14	4918	204	4788	11	4901	172	4795	7	4810	0	4796	5	4813	8	4791	7	4891	273
5	4782	13	4953	224	4788	11	4955	222	4790	9	4815	8	4793	6	4822	20	4792	7	4810	0	4791	6	4934	346
6	4784	11	4975	228	4788	9	4961	265	[illegible]	8	4830	0	4793	7	4816	9	4792	6	4815	6	4787	8	4957	349
7	4782	12	5002	235	4786	9	4905	184	4783	5	0	0	4789	12	4840	37	4791	7	4815	7	4786	9	4820	10
8	4781	13	4900	172	4783	15	4828	29	[illegible]	6	4810	0	4791	10	4810	0	4788	10	4810	0	4798	5	4813	5
9	4784	15	4810	0	4785	15	4815	10	4784	9	4813	5	4786	12	4820	20	4790	6	0	0	4793	10	4814	5
10	4782	10	4815	8	4786	7	4810	0	4787	6	0	0	4786	11	4813	6	4782	10	4810	0	4800	0	0	0
11	4786	11	4820	14	4788	13	4813	6	4790	10	4815	7	4787	9	4814	5	4791	7	4850	0	0	0	4810	0
12	4787	10	4814	12	4792	7	4818	10	[illegible]	0	0	0	4791	8	4813	5	4790	9	4830	0	0	0	0	0
13	4790	8	4823	14	4796	7	4816	10	[illegible]	5	5170	0	4792	11	4825	21	4787	15	0	0	4800	0	0	0
14	4792	10	4833	82	4795	8	4813	9	4793	7	4922	147	4792	11	5014	125	4784	5	5079	87	4794	6	5006	294
15	4792	10	4864	123	4794	8	4876	121	[illegible]	9	4952	162	4793	9	5018	137	4783	21	5079	57	4794	6	5025	140
16	4792	8	4832	92	4792	9	4865	132	[illegible]	11	4947	165	4791	11	5087	109	4791	11	5068	77	4794	10	5059	124
17	4790	9	4864	160	4793	8	4850	132	[illegible]	9	4878	141	4788	20	5108	138	4787	13	5074	84	4778	34	5099	100
18	4788	9	4889	194	4793	8	4836	100	[illegible]	8	4881	160	4783	22	5134	143	4788	11	5087	101	4762	53	5094	80
19	4782	11	5017	256	4793	7	4828	80	4793	10	4946	211	4785	21	5108	135	4780	16	5110	82	4800	0	5108	82
20	4787	14	5014	258	4793	11	4852	147	4795	11	4989	214	4784	15	5098	135	4764	41	5100	79	0	0	5099	94
21	4791	8	4892	185	4793	12	4904	185	[illegible]	12	4993	187	4781	14	5108	146	4773	20	5103	72	4798	5	5074	57
22	4791	8	4821	43	4793	9	4838	97	4790	23	4983	191	4770	20	5104	99	4783	15	5088	64	4788	15	5066	87
23	4785	11	4630	73	4785	15	4853	151	4789	10	5025	184	4784	9	5094	76	4789	13	5065	83	4784	17	5053	89

1983 20 MHZ	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
HR	F		F		F		F		F		F		F		F		F		F		F		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0													0	0	0	0	4781	10	4813	6	4777	15	4815	5
1													0	0	5238	35	4778	14	4810	0	4774	13	4813	6
2													4780	0	0	0	4777	11	4810	0	4776	13	4815	10
3													4775	7	5770	0	4785	13	4830	0	4775	10	4832	23
4													4788	13	4810	0	4789	10	4815	7	4776	11	4815	7
5													4790	17	0	0	4778	13	0	0	4783	11	4820	0
6													0	0	0	0	4782	12	0	0	4774	13	4810	0
7													0	0	0	0	0	0	0	0	0	0	0	0
8													0	0	0	0	4767	21	0	0	0	0	0	0
9													0	0	0	0	0	0	0	0	0	0	0	0
10													0	0	0	0	0	0	0	0	4790	0	0	0
11													0	0	0	0	0	0	0	0	0	0	0	0
12													0	0	0	0	0	0	0	0	4780	0	0	0
13													0	0	0	0	4787	15	0	0	4764	19	0	0
14													0	0	0	0	4785	12	4810	0	4780	15	4810	0
15													4790	0	4810	0	4785	12	4814	5	4780	13	4813	5
16													4773	19	4813	5	4788	11	4810	0	4783	12	4819	10
17													4785	11	4920	229	4785	12	4812	4	4780	14	4814	6
18													4789	9	4979	343	4781	15	4814	5	4779	15	4816	5
19													4782	12	4825	7	4785	10	4815	7	4776	12	4823	11
20													4776	12	0	0	4782	9	4953	278	4773	13	4817	7
21													4779	11	0	0	4789	10	4901	193	4776	16	4813	5
22													4780	0	5395	7	4786	13	4922	218	4786	15	4812	4
23													0	0	5290	0	4785	11	5184	259	4785	13	4820	0

	JULY				AUGUST				SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER			
HR	F		F		F		F		F		F		F		F		F		F		F		F	
UT	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG	MEAN	SIG
0	4795	11	4812	4	4781	5	4820	0	0	0	5140	6	0	0	5116	59	4759	24	5129	170	4761	44	5082	282
1	4786	11	4813	6	4779	12	0	0	0	0	0	9	0	0	5125	50	4749	25	5168	317	4765	42	5070	303
2	4788	10	4810	0	4778	9	0	0	0	0	0	0	0	0	5145	431	4744	28	5287	314	4768	27	5034	172
3	4791	11	4810	0	4780	9	4810	0	0	0	0	0	4700	0	5145	244	4749	42	5553	249	4760	36	5012	276
4	4778	23	0	0	4777	12	0	0	4785	10	0	0	0	0	5250	0	4735	30	5232	313	4758	36	5147	306
5	0	0	0	0	4782	12	4820	0	4780	0	0	0	0	0	5140	45	4734	30	4890	0	4735	48	5142	284
6	0	0	0	0	4776	5	0	0	0	0	0	0	0	0	5066	26	4780	0	4847	23	4760	40	5129	330
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5125	21	0	0	4950	0	4757	40	5002	216
8	0	0	4810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5013	114	4741	42	5070	246
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4960	0	4730	0	5185	267	4753	50	5063	242
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4840	0	4720	0	5214	307	4715	45	5071	235
11	0	0	4810	0	0	0	0	0	0	0	0	0	0	0	0	0	4746	28	5030	212	4749	47	5068	280
12	4787	6	4810	0	0	0	0	0	0	0	0	0	0	0	4900	0	4745	7	5052	327	4750	48	5056	276
13	4795	7	0	0	4775	7	0	0	0	0	0	0	4740	0	5270	368	4690	0	5215	474	4740	46	5038	216
14	4790	12	4810	0	4787	9	4810	0	0	0	0	0	0	0	5135	64	4734	61	5068	242	4711	42	5094	282
15	4792	11	4813	7	4778	14	4815	7	0	0	5116	47	0	0	5067	84	4767	33	5109	282	4739	36	5124	262
16	4788	10	4813	6	4783	15	4813	5	0	0	5145	21	4770	0	5067	171	4752	35	5108	195	4734	44	5076	203
17	4791	9	4813	5	4788	8	0	0	4763	21	0	0	4770	0	5043	167	4764	26	5125	142	4739	49	5127	229
18	4783	14	4814	5	4782	12	4813	6	4769	15	0	0	4785	21	5144	146	4756	58	5133	110	4728	49	5152	203
19	4792	10	4820	12	4784	12	4813	5	4787	15	0	0	4720	28	5266	88	4725	32	5136	101	4748	44	5118	123
20	4790	16	4813	5	4784	13	4810	0	4767	15	5300	26	0	0	5227	73	4738	33	5166	78	4743	49	5121	132
21	4790	9	4819	7	4780	9	0	0	0	0	0	0	0	0	5222	113	4733	52	5152	100	4757	38	5098	206
22	4788	8	4822	14	4785	10	0	0	0	0	5300	0	0	0	5170	64	4729	44	5129	113	4754	35	5084	188
23	4786	12	4813	6	4779	5	0	0	0	0	0	0	0	0	5144	75	4751	33	5113	144	4753	40	5070	241