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Measurement Results from a Balloon Experiment Simulating Land Mobile Satellite Transmissions

MSAT-X

Mobile Satellite Experiment

An MSAT-X Contract Report by
The University of Texas at Austin

April 1984

NASA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

9950-1049

PREFACE

The work described in this report was jointly supported by the MSAT-X program and NASA Propagation Studies and Experiments program. Measurements were made in a moving vehicle during two high altitude balloon flights from the NASA Balloon Facility in Palestine, Texas; the first in October, 1983 and the second in January, 1984. Our experiment, which was under the direction of Dr. Wolfhard Vogel of the University of Texas at Austin consisted of an 869 MHz transmitter in the balloon package through which voice and CW could be transmitted. Antennas on the balloon and on the roof of our van were drooping dipole ones designed at JPL and were circularly polarized. The first flight produced a lot of data but due to incorrect estimates on the part of the Palestine meteorologist as to the direction the balloon would travel after it reached the stratosphere, our van headed off initially in the wrong direction with the result that the measurements were obtained at lower elevation angles (balloon as seen from the van) than had been hoped for ($6°$ to $35°$ instead of $20°$ to $60°$). Measurements were made as the van pursued the balloon across Texas and Louisiana. The balloon was moving at better than 50 MPH so the van never caught up to it before the balloon was cut down in the wee hours of the morning of October 11. The second balloon flight (January) was also a piggy-back one (our package was a guest on someone else's balloon) but this time it flew during daytime. The signal fading for both flights appears to be dominated by foliage attenuation (blockage) rather than ground multipath. This is a least partly attributable to the wooded and relatively level terrain of East Texas and Louisiana.

Our thinking in the experimental phase of the propagation work for the land mobile satellite program has gone through several phases. We considered using the video carrier of channel 68 (794-800 MHz) on Mt. Wilson (nearby JPL) as a signal source but the maximum elevation angle from a van turned out to be $14°$. We next looked at Yosemite Valley ($60°$ elevation angles), but decided that reflections off the canyon walls would kill us. We looked briefly at the NASA Ames Research Center fleet of planes through the good offices of Dr. Harry Jones and Brad Gibbs but they seemed a bit much for what we had in mind. Warren Flock of the University of Colorado had been working with me on the problem of formulating the experiment at the time, and, upon his return to the University proposed that I look into the stratospheric balloon facility at Palestine, Texas which had just been transferred from UCAR to NASA. Wolf Vogel, an able experimentalist, and longtime participant in the NASA Propagation program was game to get involved, and the current balloon program is the outcome. The present plans call for two dedicated balloon flights (at least one hopefully over mountainous terrain). Following that Dr. Julius Goldhirsh at Johns Hopkins Applied Physics Laboratory will be implementing a drone aircraft program in collaboration with Wolf Vogel.
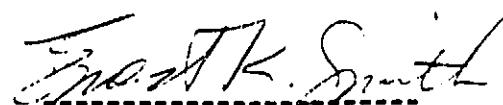
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29 October 1984

MEASUREMENT RESULTS FROM
A BALLOON EXPERIMENT
SIMULATING
LAND MOBILE
SATELLITE TRANSMISSIONS

by

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30 April 1984

Submitted to Jet Propulsion Laboratory under Contract 956520

Abstract

An experiment has been carried out in which a transmitter operating at
869.525 MHz was twice carried by a stratospheric balloon to an altitude of
about 40 km. A motor vehicle was driven within the line-of-sight from the
transmitter. Measurements of the received signal strength were made every 1/8
wavelength for an overall travelling distance of about seven hundred
kilometers. This scenario was to simulate a satellite system providing mobile
communications to rural areas.

The statistics of the sampled field, consisting of a combination of direct
wave, specular reflection and diffuse components, are presented as a function
of elevation angle. Parameters such as type of road driven (mostly 2 lane) or
type of landscape (rolling to flat) and vegetation (pine and mixed forest)
encountered are described where possible.

The power distribution function for all the data, at elevation angles from
10 to 35 degrees, is 1 dB below the free space mean at the 50% level, 7 dB
below at the 90% level, and 18 dB below at the 99% level. In the elevation
angle range of 30 to 35 degrees the corresponding values were found to be .5,
1.2, and 4.5 dB.

The conditional fade duration and level crossing rate distribution
functions are also presented. The former show some dependence on the
threshold level, the latter almost none.

1. INTRODUCTION

At the present time in areas of very high population density in the US mobile communication systems are being implemented, which can make any vehicle, even a moving one, a part of the switched telephone network. One can easily foresee a need for similar service in the less populated regions of the country for private, governmental, or emergency purposes. There, however, the ground based "cellular radio" approach used in the cities would probably be too expensive to implement because of the limited number of subscribers per cell.

In order to satisfy the need for access to the telephone network from moving vehicles in the rural environment, a satellite system operating at a frequency of about 900 Mhz has been proposed, but before one can be implemented one has to understand and quantify any mechanisms which might affect its performance.

As far as wave propagation is concerned, the most severe and also the theoretically most difficult to predict impairment to reliable communication occurs within the vicinity of the moving vehicle. This is due to the fact that the received signal is the sum of several time-varying components:

  -The direct wave from the satellite. It may have been shaded by natural or man-made obstacles.

  -One or more specularly reflected waves. Their polarization, phase and strength depends upon the nature and geometry of the reflecting surfaces. Their coupling into the receiver depends upon the antenna characteristics.

  -Diffusely scattered waves. All surfaces illuminated by the transmitter will scatter some energy towards the receiving antenna with random phase and amplitude.

The reciprocity theorem holds these statements valid also when the transmitter is on the vehicle.

This report describes an experiment which has been carried out to gain some information on signal level variations at 869 MHz in a reasonably realistic field simulation of a satellite - car link. A transmitter was borne by a stratospheric balloon launched from the National Scientific Balloon Facility (NSBF) in Palestine, Texas to an altitude of up to 44 km. A receiver and data acquisition system in a van sampled and recorded the received signal level every 1/8 of a wavelength over a total distance of about 700 km.

Similar experiments have been carried out by Huck, Butterworth, and Matt [1,2] in Canada using a transmitter carried by a helicopter.

Considering typical elevation angles to a geosynchronous satellite from the Continental United States, measurements were desired in the range of 20 to 60 degrees of elevation. Actual data were obtained for angles from about 10 to 35 degrees.

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Typical vegetation along the rolling two lane roads of East Texas were tall pine trees, mixed forest, and occasional grazing land. The path of the van led through a few towns and small cities. In Louisiana the trees gave way to open range land with fewer trees close to the roads.

After describing the experiment and the history of the two balloon flights which were carried out in October 1983 and January 1984, the results will be presented. They will be in the form of examples of time plots of the data and statistical evaluations of the power, fade duration, and level crossing rate distribution functions.

2. EXPERIMENT DESCRIPTION

2.1 Overview

The major hardware components of the experiment were the transmitter system borne by the balloon and the receiver system and data acquisition system carried in a converted standard size passenger van. A control program verified the proper operation of the equipment and stored the data. A calibration program produced conversion tables between the measured voltages and absolute power levels. These tables were used for the data analysis. The van was also equipped with audio recorders to produce a log of the van position and the environment being traversed.

2.2 Transmitter

A block diagram of the transmitter system is shown in Fig.1. It was housed in a .5m x .5m x .25m well insulated enclosure which was to provide protection both against the low temperatures of the stratosphere (-55C) and the impact of landing on a parachute. A commercially available 869 MHz communications transmitter was chosen mainly because it could be narrow band (up to 25 KHz deviation) FM modulated. At the start of the experiment it was thought to be a desirable to be able to make FM transmission tests, later this feature proved its value more as an aid in the operation of the experiment because it could be used for communication between the balloon base and the van.

The Karkar KR900 transmitter produced 4 watts of output power. Several modifications were made to it in order to improve its thermal characteristics in the near vacuum (5 mbar) of the cruising altitude of the balloon. For FM modulation the transmitter added the audio signal (300-2500 Hz) to the control voltage of a voltage controlled 869 MHz oscillator whose center frequency was locked to a stable reference signal. The response of the loop was low pass filtered to 40 Hz. Modifications in the manufacturer's loop design had to be made to reduce random frequency deviations of the transmitter which occurred at about a 40 Hz rate. This noise could not be totally eliminated, but was decreased to a level where it did not produce any significant amplitude modulation in the receiver.

The transmitter was powered by lithium batteries. It could be activated through the balloon control telemetry. The modulation signal could remotely be chosen to either repeat the balloon voice telemetry channel or to play back voice signals from a portable cassette recorder which was part of the transmitter package.

The antenna used was a drooping crossed dipole built after a design supplied by JPL (3). A sketch of this antenna is shown in Fig.2. It was mounted on a circular ground plane of 2.6 wavelengths diameter. It was very easily impedance matched to a return loss of better than 25 dB. The antenna assembly was mounted about 2.5 meters off the balloon axis and below the gondola in order to prevent any shading. The antenna pattern was not measured for this experiment, but assumed to be approximated by the theoretical pattern shown in Fig.3.

2.3 Receiver

The receiving antenna was identical to the transmitting antenna, except that it was mounted on a 4 by 8 foot ground plane which was supported above the roof of the Ford Econoline Van by luggage carriers. The 869.525 MHz signal was filtered and amplified by a low noise FET amplifier and converted to 29.525 MHz. The receiver backend consisted of a modified ICOM IC-R70 amateur radio communications receiver. The receiver was operated in the FM mode with a bandwidth of 14 KHz. The overall dynamic range exceeded 80 dB, the instantaneous dynamic range was better than 30 dB. The noise temperature of the receiver was 180 K, resulting in a signal to noise ratio of about 30 dB at a range of 130 km and 20 degrees of elevation.

2.4 Data Acquisition System

The data acquisition system consisted of an IBM personal computer with a Data Translation analog and digital input/output system board. The control program ran under DOS 2.0 and was written in Fortran, using the SuperSoft compiler.

Inputs to the program were the output voltage of the receiver, the discriminator voltage, and the speed of the van. The major program tasks were to:

- Control the rf gain of the receiver so that the peak signal voltage was in the range of the A/D converter.

- Measure the frequency of the received signal and insure that the receiver was tuned properly.

- Sample the signal at intervals of 1/8 wavelengths.

- Store the data together with pertinent system information on the
  floppy disks.

The signal was sampled in bursts of 1 second duration and then the
necessary calculations were performed and adjustments made to the receiver
before the next burst of sampling. The duty cycle of this was about 60
percent. Every 4 to 5 minutes the data were transferred from memory to floppy
disk. This process lasted about 20 seconds. No data were collected during
that process.

2.5 Calibration

In order to calibrate the receiver, an 869.525 MHz source was connected to
the input of the receiver front end and attenuated with a precision step
attenuator. The receiver was stepped through its gain settings and the output
voltages were measured for each input level. This procedure produced a
calibration table of voltages versus gain and power level which was used for
the data analysis.

2.6 Communication with the Balloon Base

In order for the van to follow the balloon, information about the
approximate position, speed , and direction of the balloon had to be
available in the van during the flight. This was accomplished by transmitting
from the van to the balloon at 150 MHz, using a portable radio. This signal
was relayed over the 1.5 GHz telemetry system to the balloon base. In the
other direction, the voice was transmitted from NSBF to the balloon at 150
MHz and relayed to the van over the 869.525 MHz link. The quality of this
signal was usually excellent because of the large signal to noise ratio in
the receiver.

3. HISTORY OF THE OCTOBER 1983 FLIGHT

The balloon was launched from the Palestine, Texas National Scientific
Balloon Facility (NSBF) at sunset on the 10th of October 1983. The resident
meteorologist had predicted that it would take a path in the ESE direction.
The van left the NSBF site at 18:19 CST, about 20 minutes before launch in
order to gain some distance on the balloon and have it eventually pass
overhead. As can be seen from Fig.4, the balloon trajectory went to the ENE
instead. This resulted in all the data being taken at elevation angles below
30 degrees. The signal from the transmitter was first acquired at 18:44 CST,
but the data presented exclude the initial period until at 19:29 CST the
elevation angle rose above 10 degrees.

Data were collected for some 8 hours, while the van travelled over a
distance of about 600 km. Local time at one hour intervals is indicated in
Fig.5.

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The path of the van led typically on two-lane farm-to-market roads through
rolling country with tall pine trees, mixed forest, and occasional grazing
land. A few small cities and towns were crossed. Only during the last hour,
from 2 am on, in Louisiana, trees gave way to shrubs.

4. HISTORY OF THE JANUARY 1984 FLIGHT

The transmitter package and antenna assembly had survived the landing on
October 11, 1983 without damage. The transmitter was outfitted with new
batteries to be ready for another flight opportunity which presented itself
on January 11, 1984. The balloon was launched at about 9 am. Full data
collection did not start until 11:49 CST. The delay was due to the breaking
of the van's speedometer cable on the way from Austin to Palestine early on
this day. After checking the operation of the transmitter at the launch site,
the van travelled along the direction of the balloon course trying to find a
replacement cable. One was located in Lufkin, Texas and installed by 11:49
CST. From there on data collection proceeded with the balloon visible at
about 30 degrees elevation.

The paths taken by the vehicles is shown in Fig.6. The van travelled
predominantly through East Texas pine forests on two lane roads. Shading by
tree tops occurred infrequently and could always be qualitatively correlated
to large variations of the signal strength.

Data were collected until 13:16 CST, when the transmitter started failing
intermittently. The failure was found to be due to a Plessey phase lock chip
not meeting its low temperature specification. This caused the transmitter to
repeatedly lose lock.

5. RESULTS OF THE MEASUREMENTS

5.1 Examples of the One Second Data Records

As explained previously, the data were collected in bursts of one second
at a time. Some typical timeplots of these data are shown in Figs. 7 to 10.
The first example was taken at 20:23:58 CST while the van was driving through
a pine forest on a two lane road with paved shoulders. The balloon elevation
was 19 degrees. The mean received power was -89.9 dBm. Most likely the large
signal variations were caused by shading. The variance, defined by:

$$var = 10 \log \frac{<(v-<v>)^2>}{<v>^2}$$

where v is the signal voltage and <> denotes taking the mean, was -8.9 dB. The power scale in these graphs, for the convenience of plotting, has been normalized so that the peak signal is at 0 dB. At the speed of 55.4 miles per hour the van travelled about 75 wavelengths in one second and about 600 samples were taken over this distance. If one assumes the van to be a probe sampling a standing wave field set up by interference between the direct wave and ground reflections, then the sampling rate was about twice the one required to resolve the fields. Field strength variations caused by shading are also assumed to be fully resolved with the sampling rate used.

The next one second record shown was taken at 23:59:59 CST while the van was crossing a long two lane causeway with steel guard rails over the Toledo Bend Reservoir at the Texas/Louisiana border. The elevation angle to the balloon was about 20 degrees and there was no shading at all. The specularly reflected component was either very small or effectively suppressed by the antenna pattern. The variance of this sample was only -35.3 dB.

The record from 12:10:47 CST clearly shows the effect of shading by trees. The van was driving on a two lane road through pine forests, and the balloon, at an elevation of 28 degrees, was visually observed to occasionally graze the tree tops. A few of the deep minima have been truncated by the instantaneous dynamic range limitation. These truncations occur infrequently enough to have very little effect on the overall statistics.

The next example was taken right after the previous one. The variations of the signal are probably due to multipath interference.

Finally, at 13:04:22 CST the van once again was crossing the causeway over the Toledo Bend Reservoir. This time the balloon was nearly straight ahead of the van at an elevation of 28 degrees. The signal observed is consistent with the one measured three months earlier.

5.2 Examples of the Five Minute Data Files

Successive one second data records were stored in a memory file until about 180 kbytes were accumulated and then copied to disk. With the van at cruising speed, these files represent about four to five minutes of data or equivalently, about 6.5 km of travel. Over 100 of these files were collected in the two balloon experiments.

The content of all these files have been plotted as a help in editing the data. Some examples are shown in Figs. 11 to 17. For each one second record the van speed (triangles), the mean signal level (circles), the +/- one standard deviation range (vertical line), and the minimum/maximum signal (x) are indicated. The 0 dB level in these plots has been set to the averaged mean level of the 16 one second records from this file with the lowest variance. This value will be called the file reference mean. Also given is the elevation angle to the balloon, calculated from the van position and the coordinates of the balloon supplied by the NSBF. The reference mean dB value will be discussed in the next section.

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In the plot starting at 19:31:17 there is little attenuation due to shading, the next one from 21:50:28 was taken at a higher elevation angle and shows even less variations in the mean signal level , except for a 1 dB drop lasting about 20 seconds. At 22:09:15 alternating periods of shading and clear line of sight were produced while driving through dense pine forest. The average attenuation caused by the shading is about 6 to 7 dB. The figure with a starting time of 23:59:05 shows the change in the signal characteristics as the van finished crossing the Toledo Bend Reservoir causeway. On land at about 00:00:45 it made its way through some low density commercial and recreational development for about one minute followed by undeveloped surroundings with vegetation about 4 to 5 meters tall at each side of the two lane road without paved shoulders.

At 00:45:52 the van was entering the City of Natchitoches with commercial and urban development on both sides of the street. The mean signal level fluctuated over a range of about 10 dB. While driving through the Angelino National Forest at 12:28:33 the signal experienced repeated clipping by the tops of pine trees. The mean level was reduced by only about 3 to 4 dB. The standard deviation was increased by a factor of about 3. For some of the time the van was following a logging truck at 40 mph until it could pass as the road widened at the exit of the National Forest.

The last of these examples in Fig. 17 shows the signal as the van started to cross the causeway for the second time. The balloon was almost straight ahead at an elevation of 28 degrees. At about 13:04 the two lane road with pine trees on each side ended and the concrete causeway started out over water. Again, very little signal variations were observed in this situation.

5.3 The Free Space Correction Problem

In order to determine the received signal level relative to its reflectionless free space value a correction has to be applied to the measured absolute power levels for both the range dependence of the free space attenuation and the elevation angle variation of the transmitting and receiving antennas. To do this the positions of the van and the balloon have to be known. The van coordinates were determined after the experiments from the audio logs and road maps to an accuracy of about 1 mile. The balloon positions were supplied retroactively by the NSBF and were based both on partial radar measurements and an airborne LORAN receiver and pressure sensor. An accuracy of 1 to 2 miles in these data was expected. The move of a LORAN transmitter from Trinidad to Australia has had a negative impact on the balloon location instrumentation. During periods of non-optimal propagation conditions it becomes subject to significicant location errors. The data supplied, especially for the October 1983 flight, contain such errors.

The second source of error comes from using a calculated antenna pattern for the two antenna systems instead of measured ones. Finally, the transmitted power was not monitored. It probably varies with the temperature of the transmitter by a few dB.

Nevertheless, the range and pattern corrections were applied to the data. With none of the above errors present, the file reference mean should be close to 0 dB. The actual values found have been plotted in Figs. 18 and 19

against an arbitrary time axis of about 5 minutes per unit. For the October 1983 flight they range over about 25 dB and for the January 1984 flight over about 5 dB. In both cases they have been calculated relative to the crossing of the causeway, because the data obtained there had the lowest variance. Such large discrepancies deserve discussion in order to determine their probable impact on the interpretation of the data.

The January 1984 data, assuming the balloon position data valid, give a clue mainly on the temperature dependence of the transmitter power. Since all these data were taken at elevation angles between 26 and 30 degrees, only a constant pattern error might be expected. As the transmitter cooled off (to finally fail at the coldest) the power decreased by 4 to 5 dB. Laboratory measurements will be made in the future to confirm this hypothesis.

The data from October 1983 have been used to iteratively solve for a range and elevation angle to the balloon, assuming correct altitude, relying on the theoretical antenna patterns and disregarding power variations due to temperature effects. One possible derived range and elevation angle combination is shown in Figs. 20 and 21 to which the NSBF data have also been added. These results have to be regarded with caution, however, because the iteration is very sensitive to the assumed antenna pattern and temperature effects, especially at the higher elevation angles and is not always unique. The 25 dB excess power could be explained by the fact that (1) the transmitter was warmer then as compared to the time of the causeway crossing 4.5 hours later and (2) the relatively close distance to the balloon made for a large relative range error. Therefore, during this time the actual angle of elevation was probably higher than the one calculated from the NSBF data (and the range closer). The peak in elevation angle at time 30 is probably mainly due to the iteration errors. For some of these points convergence has been found with elevation angles around 40 degrees.

The errors in the free space correction could be qualitatively explained, but due to the large number of unknowns it seems unproductive to estimate a quantitative correction to find truer elevation angle and range data. The file reference mean seems to give a close estimate of the actual mean free space signal level, when judged by the consistency between files. The main impact on the results will be some uncertainty about the elevation angle dependence of the signal statistics.

5.4 Signal Level Distribution

A fading channel in which a direct wave combines with randomly reflected waves can be described by the Rician probability distribution, which can be expressed in terms of the received power as

$$P\{s\} = (1 + K) * \exp(-s(1 + K) - K) * I_o (2\sqrt{s(1 + K)\,K})$$

where K is the ratio of the direct power to the reflected power received. The resulting probability distribution functions for K from 0 to 25 have been plotted in Fig. 22 for comparison with the measured distribution functions. Without shading the fading on a satellite to mobile communications link is presumed to have Rician statistics.

The overall measurement results for elevation angles above 10 degrees are presented in Fig. 23. The plot is derived from 7.66 million samples taken at speeds greater than 10 mph during the two balloon flights. Similar graphs are given in Figs. 24 to 29 for elevation angle intervals of 10 to 15, 15 to 20, 20 to 25, 25 to 30, and 30 to 35 degrees, also obtained at speeds greater than 10 mph. The final figure in this series is based on the data at all elevation angles for which the vehicle speed was below 1 mph. In this case the sampling rate was fixed at 896 samples per second. There are only about 56000 of these samples available, even though the van was stopped more often, because the data collection program saved only every 10th of the one second records at slow speeds if the variance was below a threshold.

The most obvious difference between the measured and predicted distributions is the sharper turn towards lower power at probabilities above about 90 or 95 percent. The data show improving power levels with increasing elevation angle with the exception of the 20 to 25 degree data, which were subjected to the most shading. Table I summarizes these results:

Table I

Power Distribution vs. Elevation

Elevation	I	Signal Level in dB Relative To Mean for Probability of		
(degrees)	I	50%	90%	99%
10 <= elev < 35	I	-1	-7	-18
10 <= elev < 15	I	-1	-9	-20.5
15 <= elev < 20	I	-1	-8	-18.5
20 <= elev < 25	I	-1.5	-9.8	-20.3
25 <= elev < 30	I	-.8	-2.2	-8.2
30 <= elev < 35	I	-.5	-1.2	-4.5

5.5 Probability Distribution of the Fade Duration

The fade duration is defined as the number of wavelengths the signal is below a threshold. The measured durations for all the data and the data sorted in 5 degree elevation angle intervals are shown in Figs. 30 to 35. In these plots the conditional probability that the duration equals or exceeds the abscissa, given that the signal power s is less than S (see Figs. 23 to 29), has been plotted for signal levels S from -12 dB to +6 dB relative to the mean. All the graphs are remarkably similar as long as there are a sufficient number of samples available to produce a smooth curve. At the 50 percent level the deeper fades last about .5 wavelengths. The duration increases to about one wavelength for the higher signal levels. At the 1 percent level the duration exceeds 3 wavelengths at low signal level up to about 30 wavelengths at the higher ones. To find the absolute probabilities of duration, the conditional probability has to be multiplied by the probability derived from the power distribution curves.

5.6 Probability Distribution of the Level Crossing Rates

The level crossing rate is defined by how many times per wavelength an increasing signal crosses the threshold. The measurement results are shown in Figs. 36 to 41, again for all data and the series of 5 degree elevation angle intervals. Like the duration graphs the conditional crossing rates at the different elevation angles are quite consistent. The spread in the data with signal level threshold is quite small. The crossing rate at the 0 db threshold is usually the largest for a given probability. The rate at the 99 percent level is about .04 crossings , at the 50 percent level it is .6 crossings, and at the 1 percent level 3 to 4 crossings per wavelength. The highest thresholds have the lowest crossing rates. Again, the conditional probabilities have to be multiplied by the power probability density to obtain absolute values of the level crossing rate probabilities.

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ACKNOWLEDGEMENT

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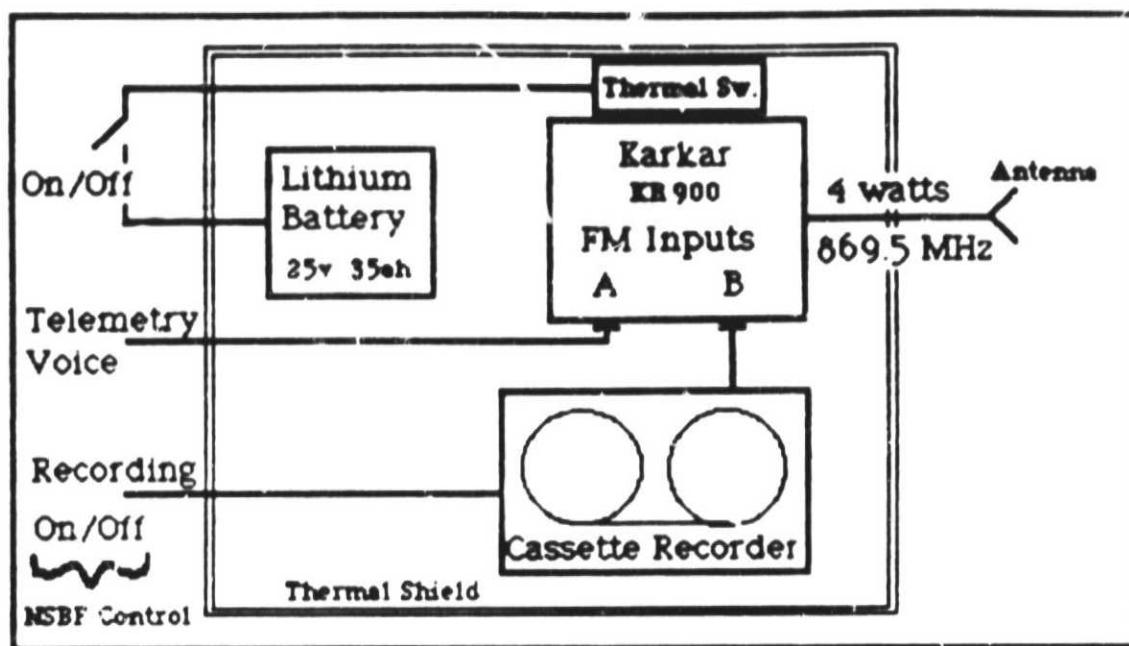
Fig. 1   A block diagram of the balloon transmitter system.
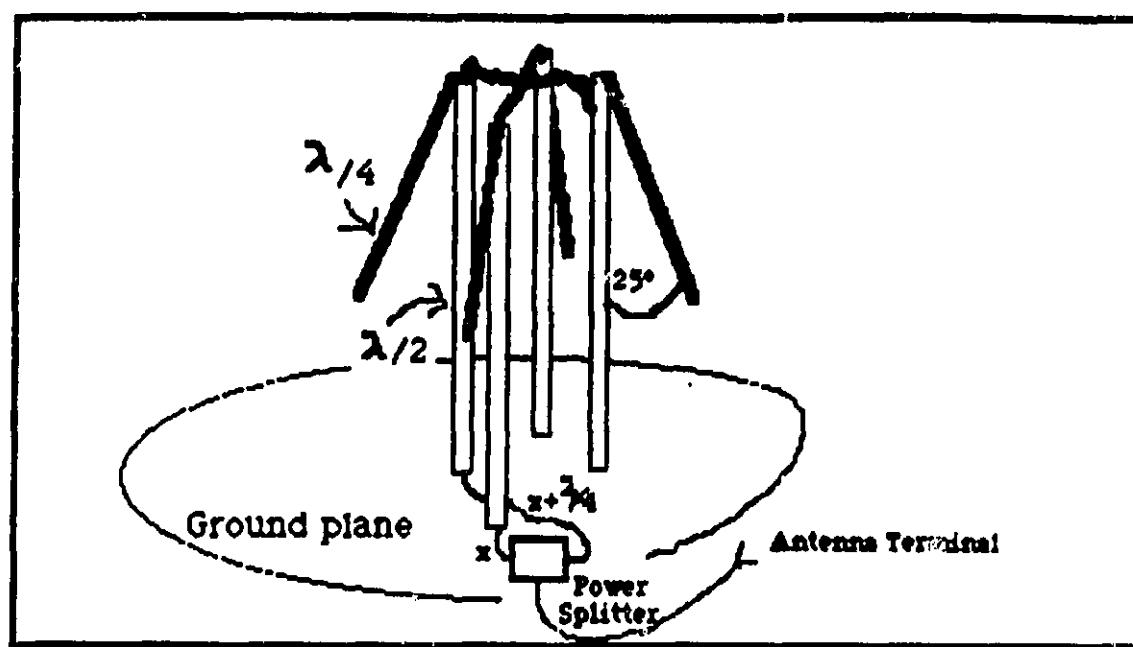
Fig.2   Sketch of the drooping dipole antenna used for both the transmitter and receiver.
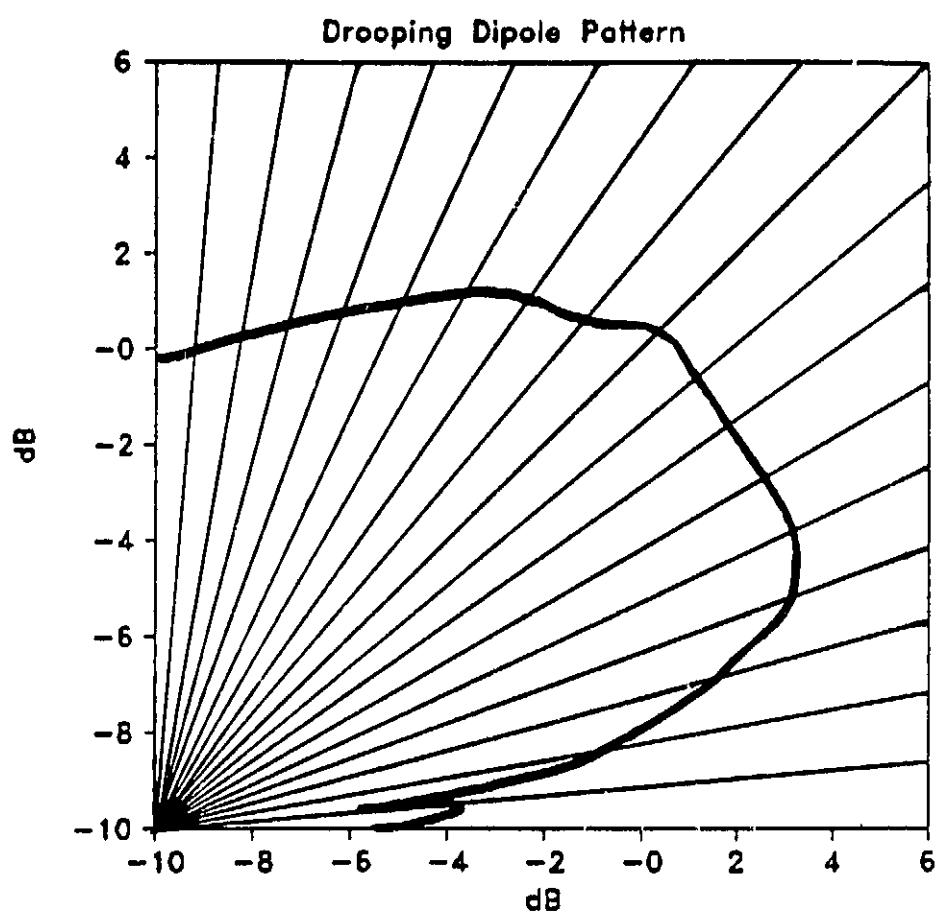
Fig.3   The estimated theoretical antenna patterns used for the data reduction.
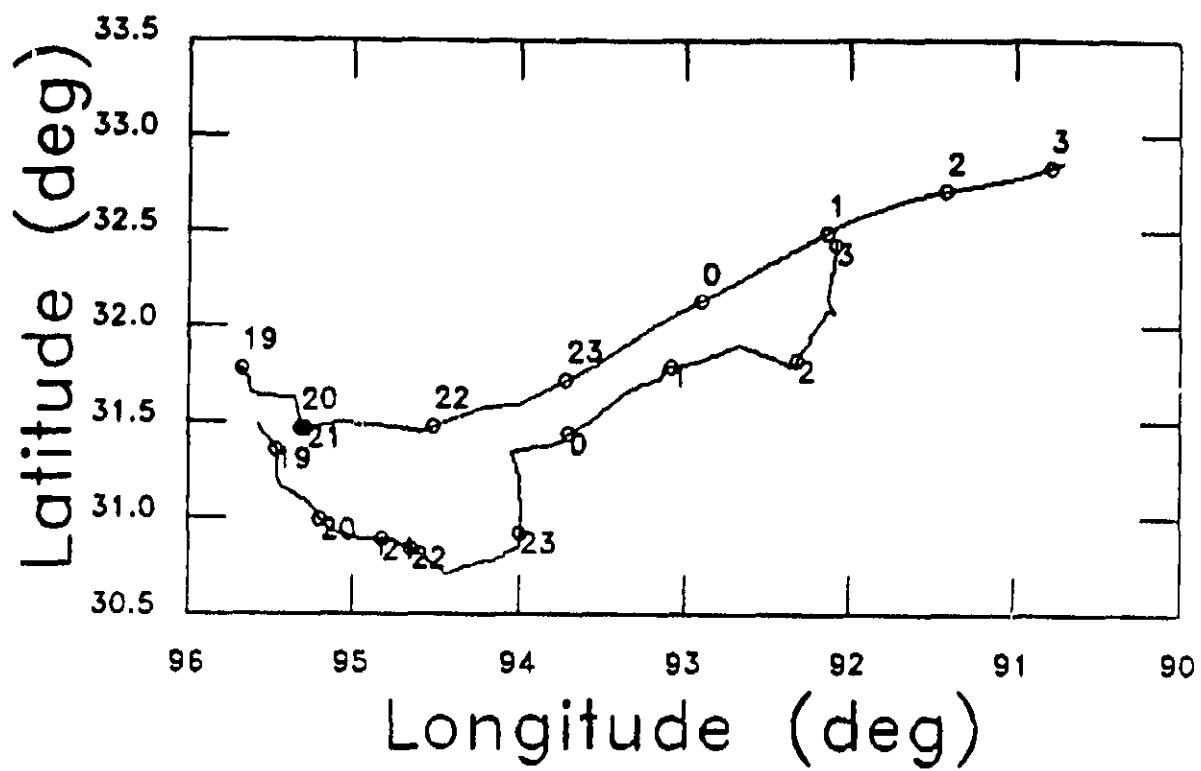
Fig.4   The path of the balloon (on top) and the van (the lower one) for the flight on October 10 and 11, 1983. Central Standard Time is indicated at intervalls of one hour.
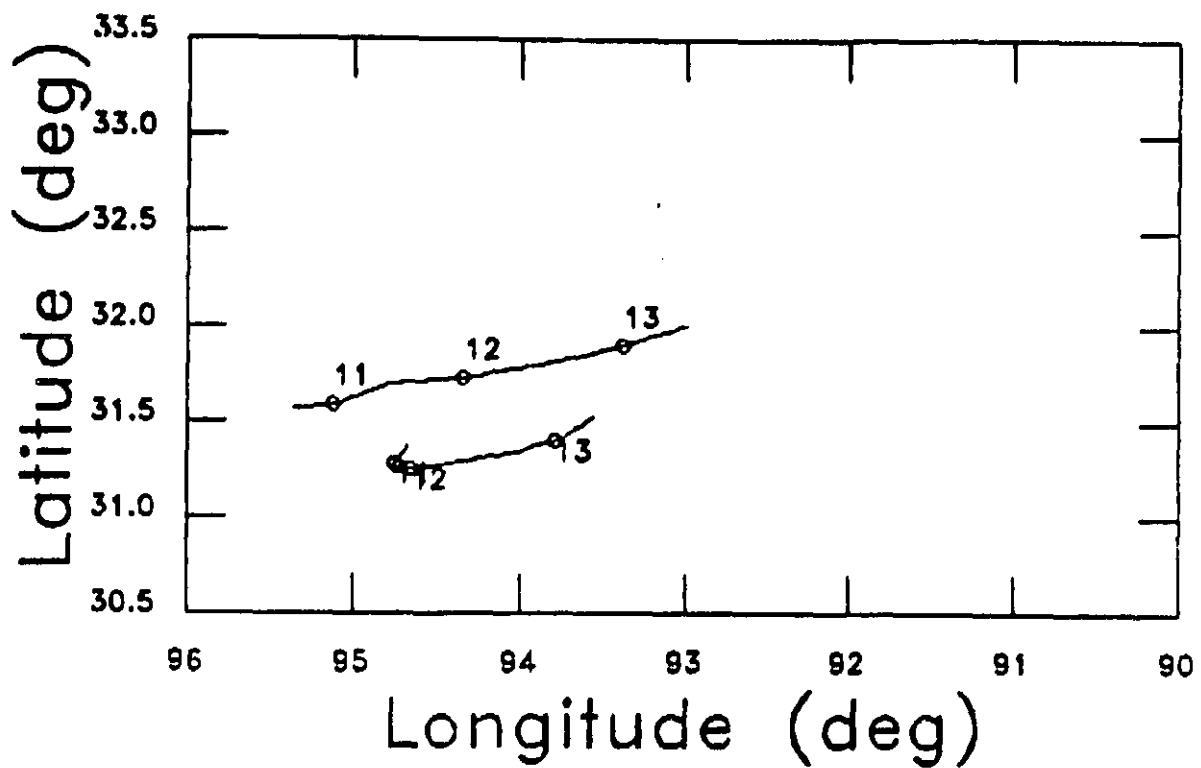
Fig.5   The path of the balloon (on top) and the van (the lower
one) for the flight on January 11, 1984.Central Standard
Time is indicated at intervalls of one hour.
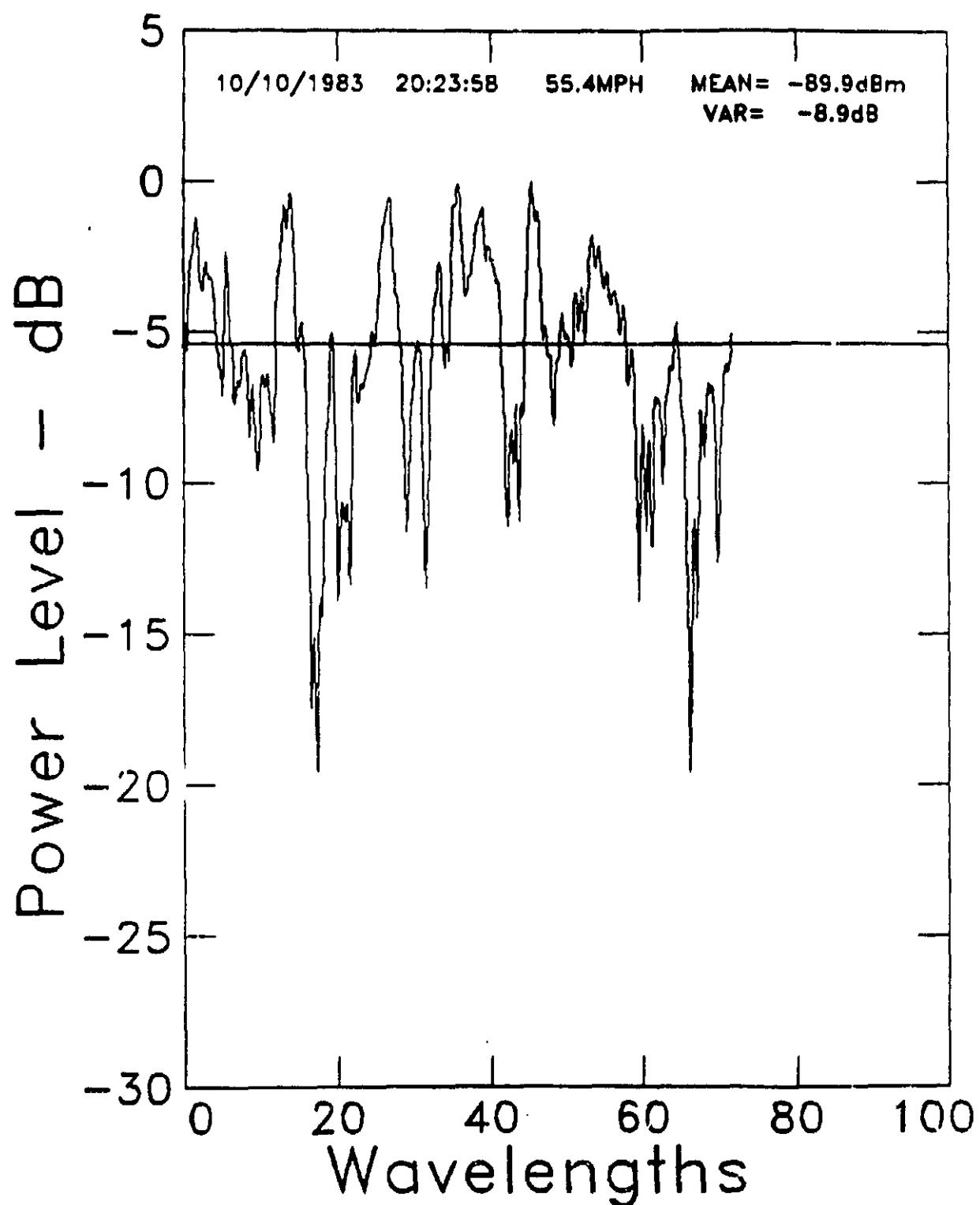
Fig.6 A timeplot of the received signal power for the duration
of one second starting at 20:23:58 CST.
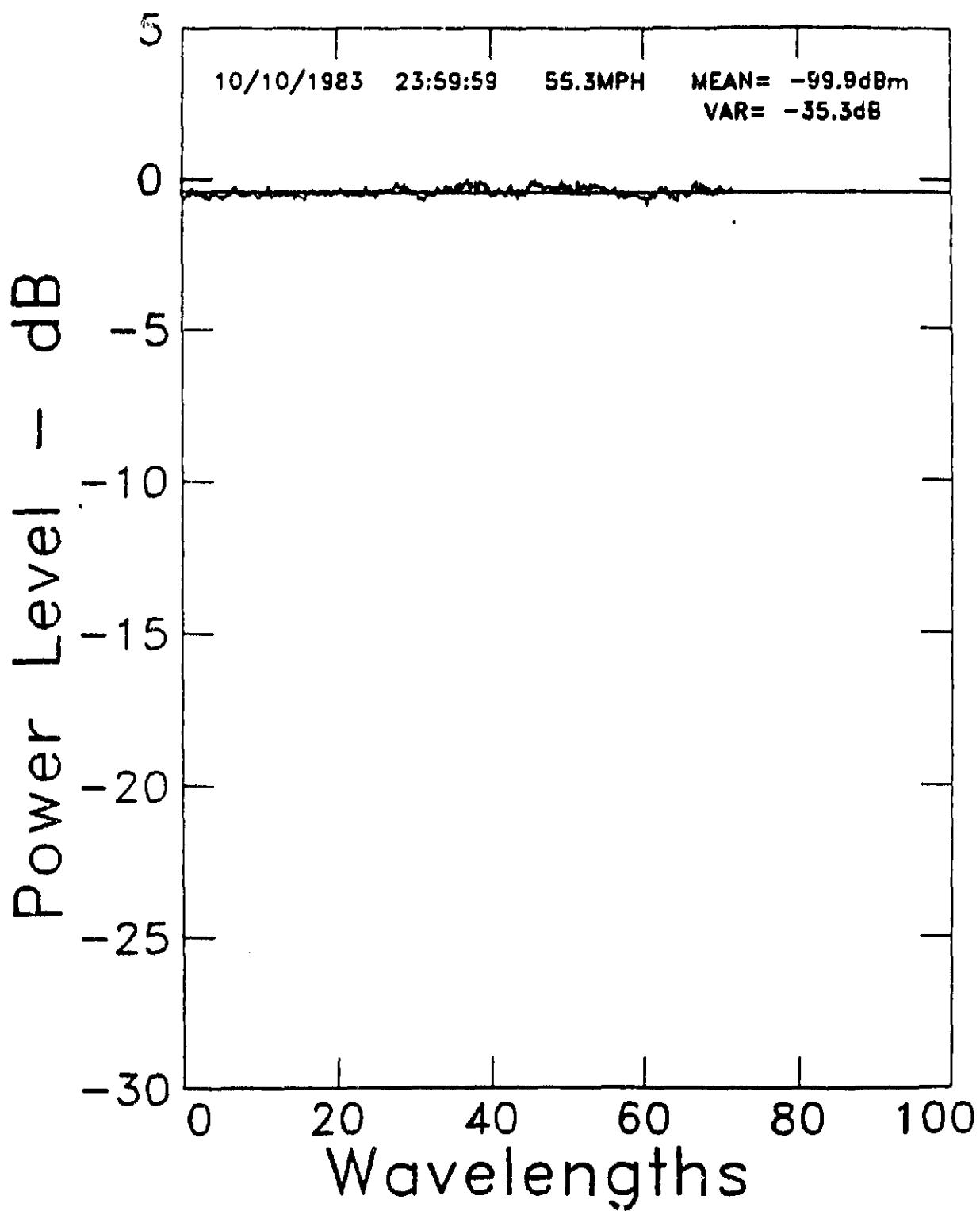
Fig.7   A timeplot of the received signal power for the duration
of one second starting at 23:59:59 CST.
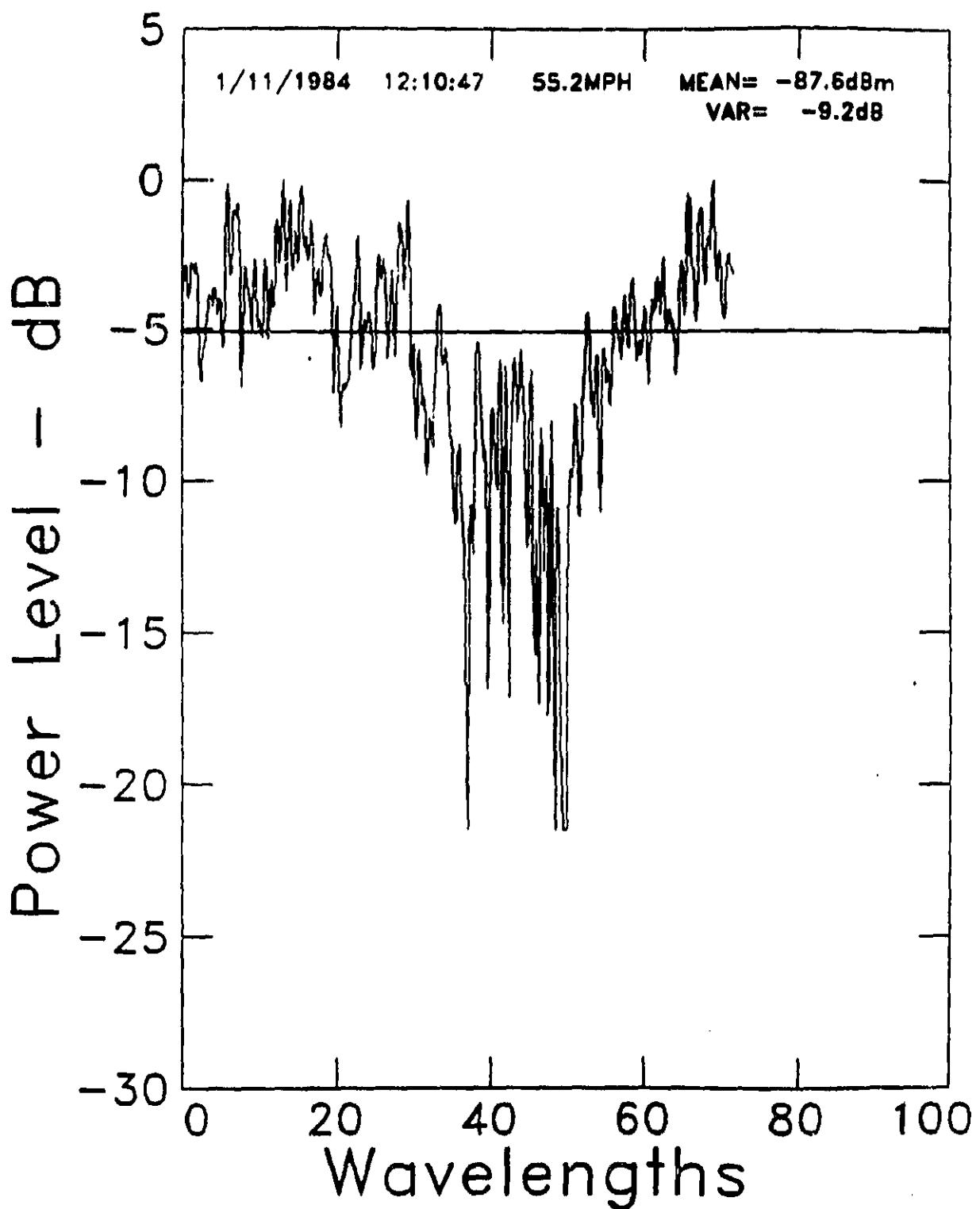
Fig. 8   A timeplot of the received signal power for the duration of one second starting at 12:10:47 CST.
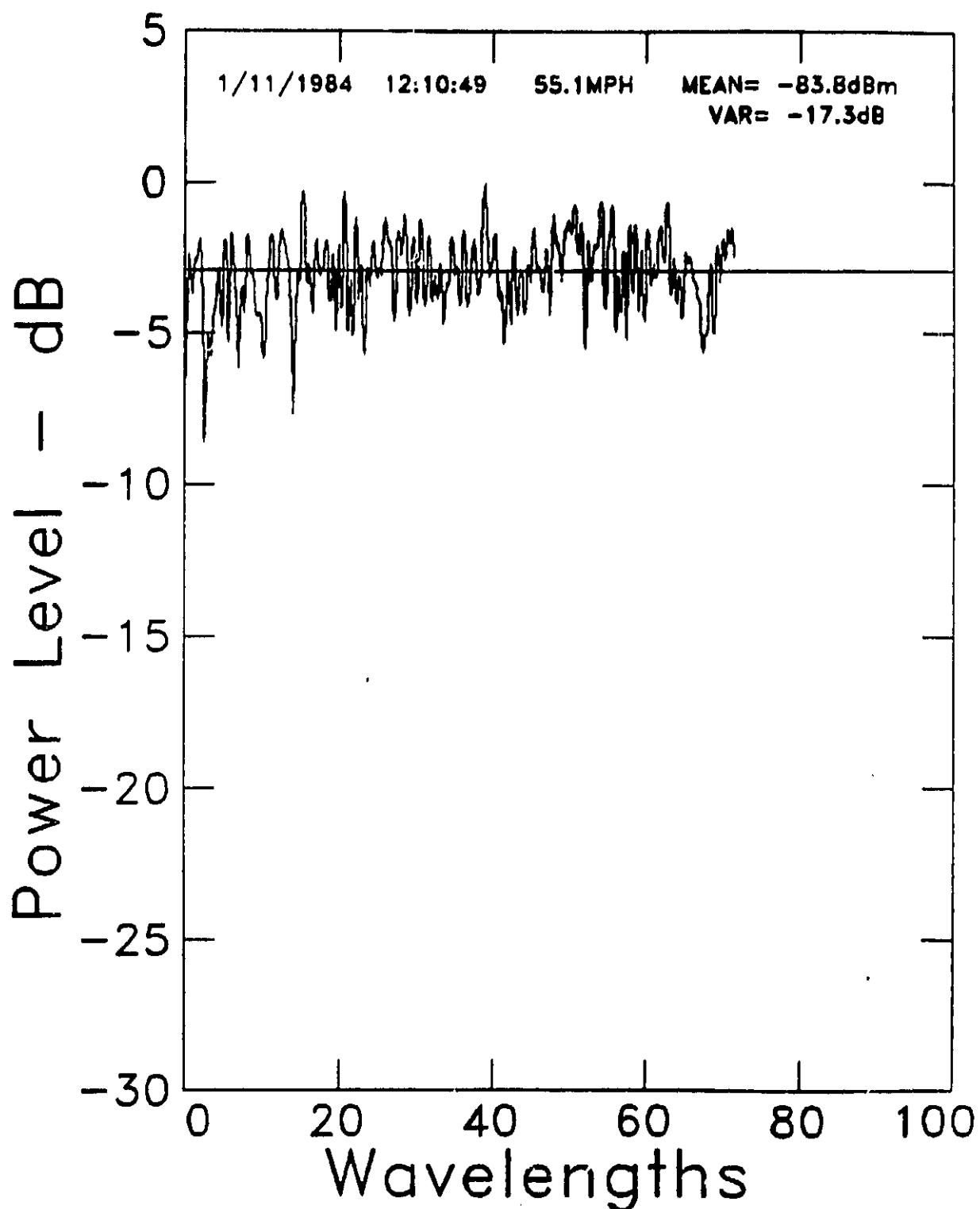
Fig.9   A timeplot of the received signal power for the duration
        of one second starting at 12:10:47 CST.
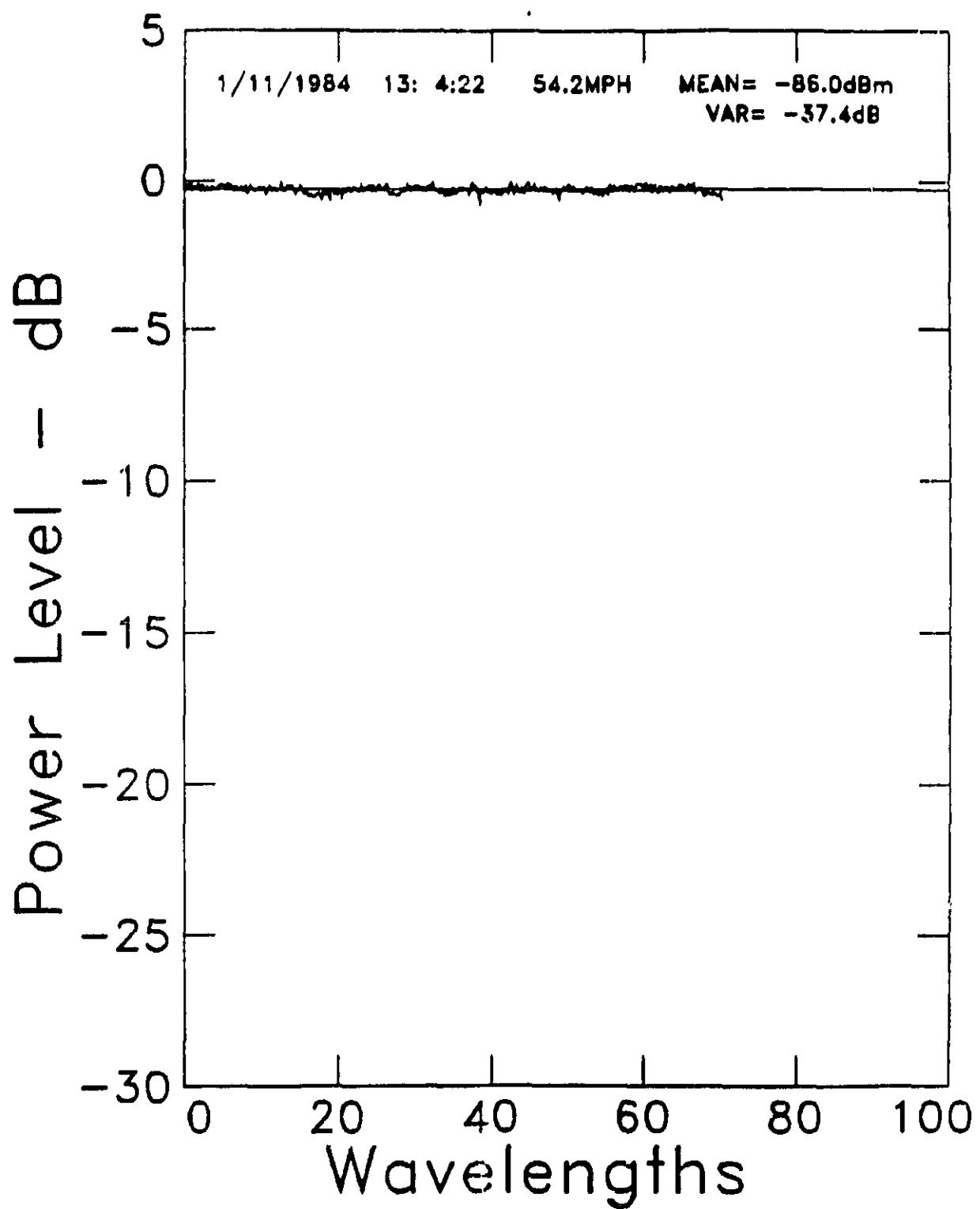
Fig.10   A timeplot of the received signal power for the duration
of one second starting at 13:04:22 CST.
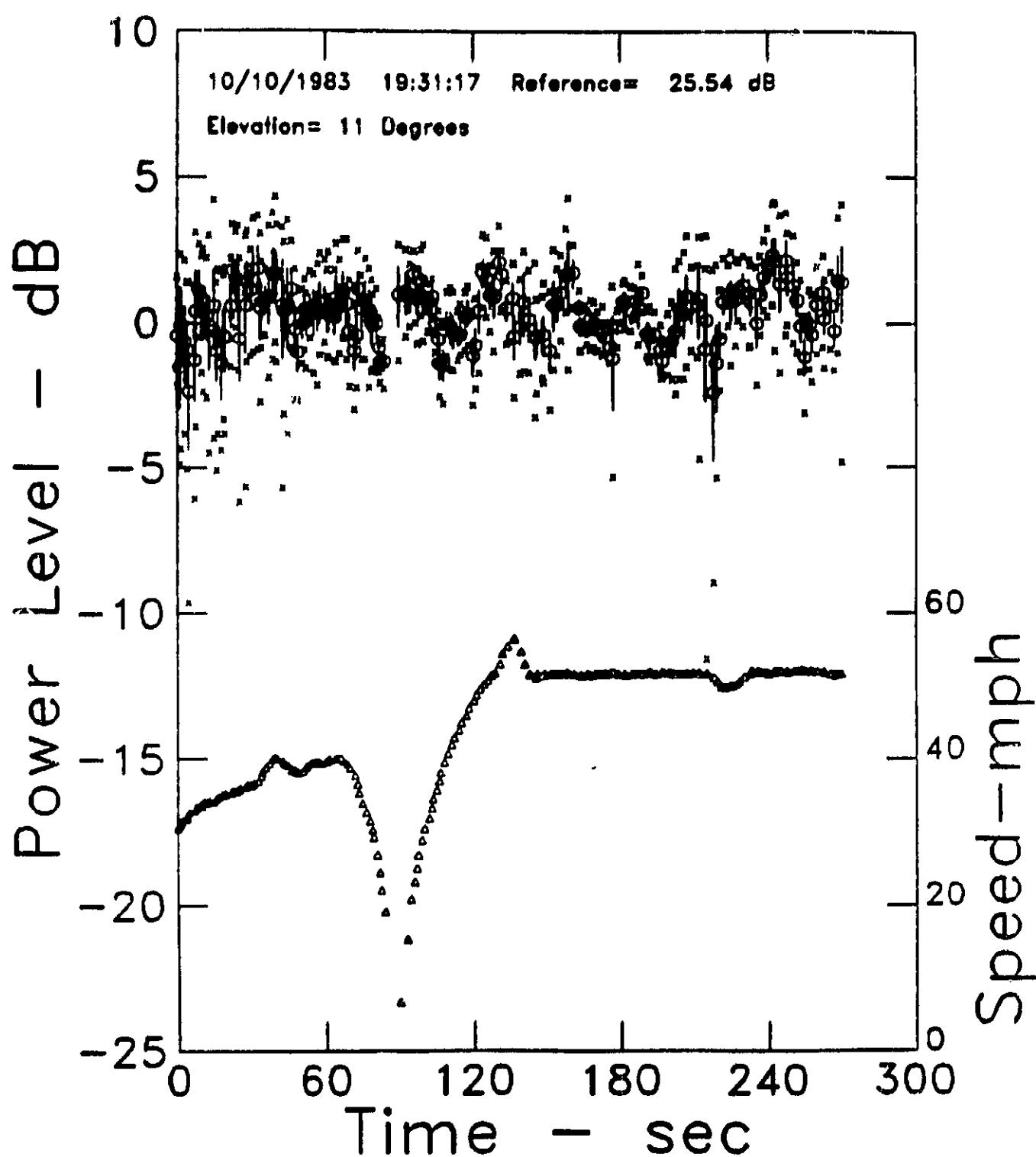
Fig.11   The speed of the van (triangles), the mean signal level
        (circles), the +/- 1 standard deviation limits (vertical
        line), and the extreme values (x) for each one second
        record of the five minute file starting at 19:31:17 CST.
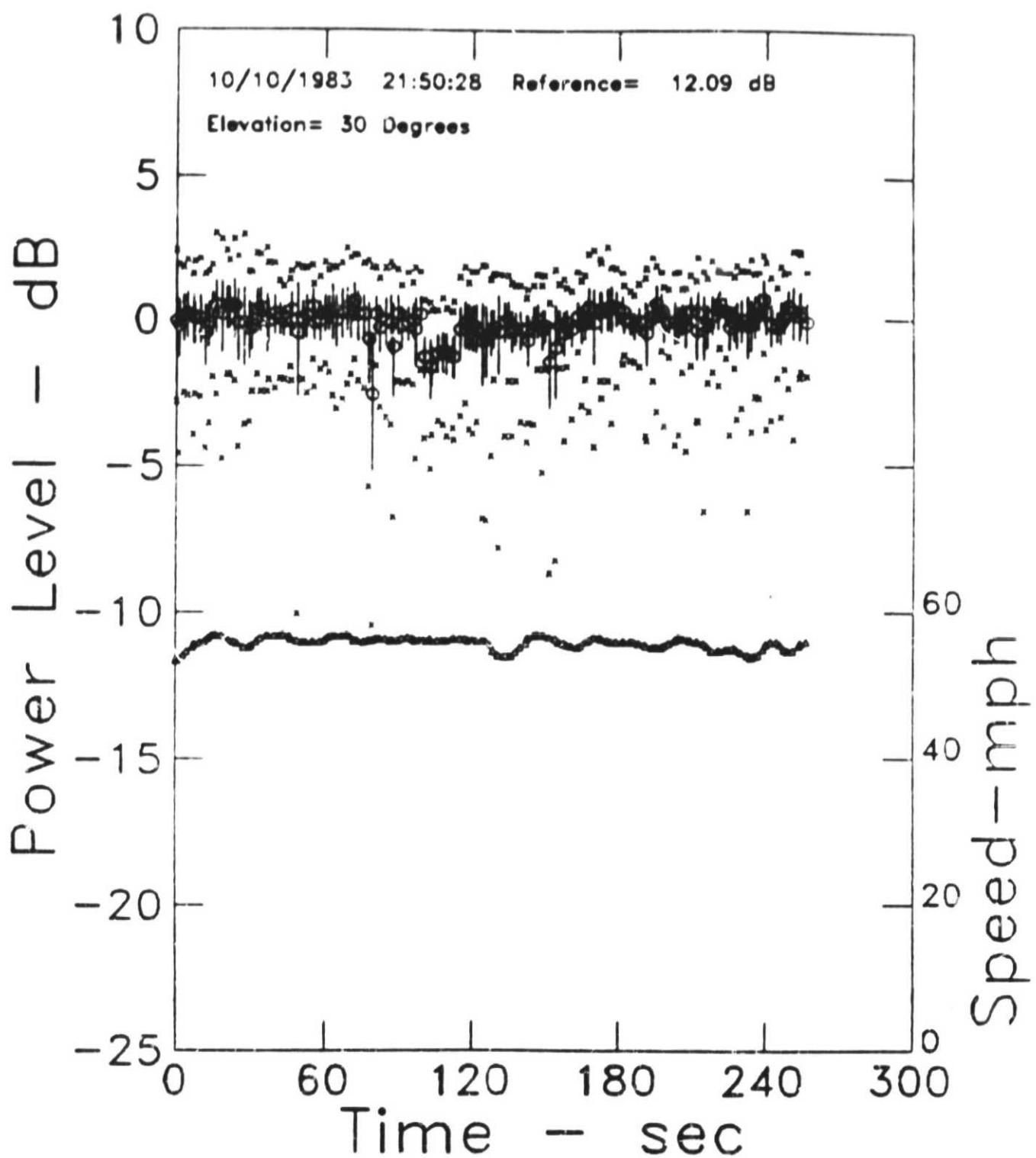
Fig.12 The speed of the van (triangles), the mean signal level (circles), the +/- 1 standard deviation limits (vertical line), and the extreme values (x) for each one second record of the five minute file starting at 21:50:28 CST.
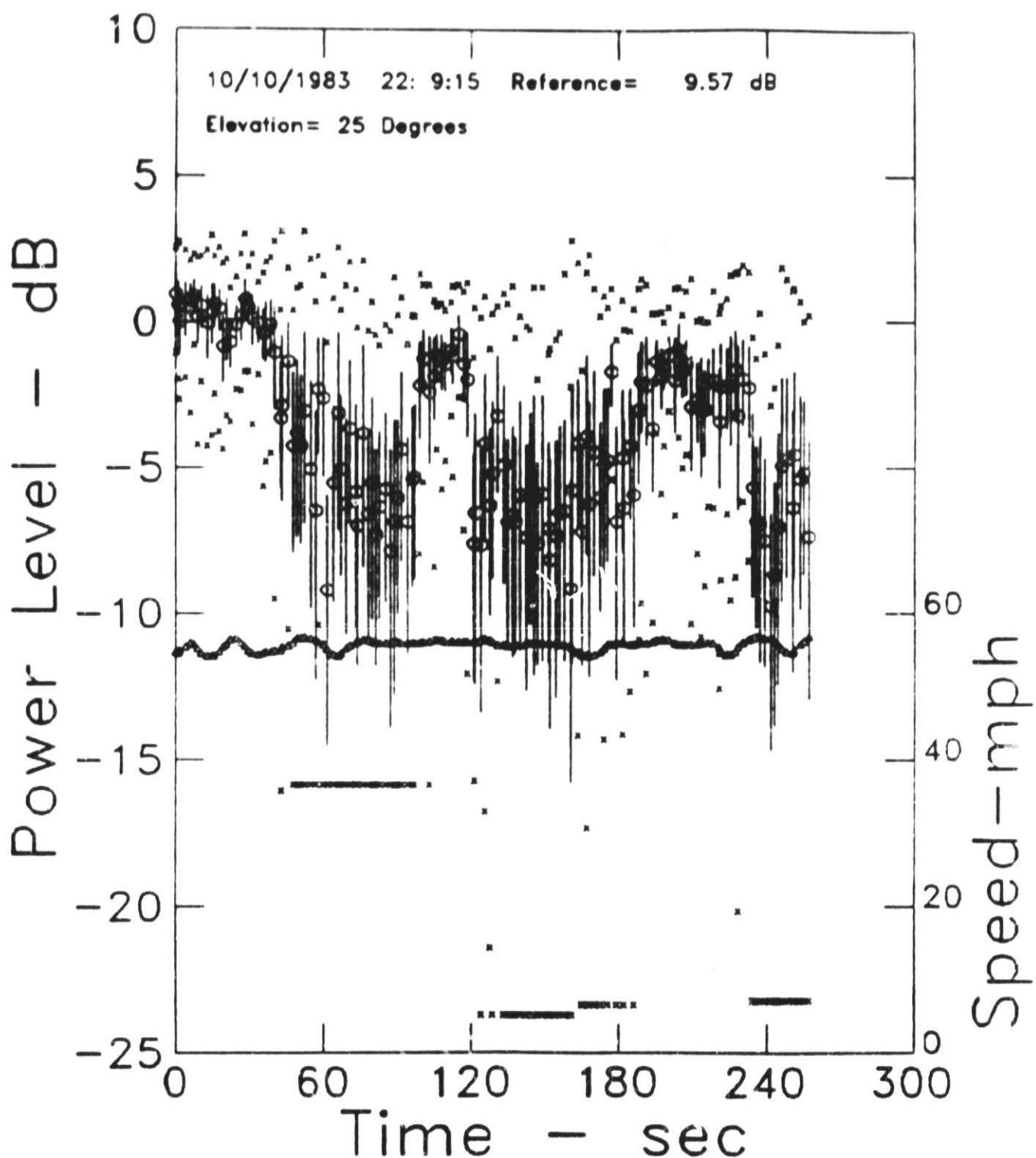
Fig.13   The speed of the van (triangles), the mean signal level
         (circles), the +/- 1 standard deviation limits (vertical
         line), and the extreme values (x) for each one second
         record of the five minute file starting at 22:09:15 CST.
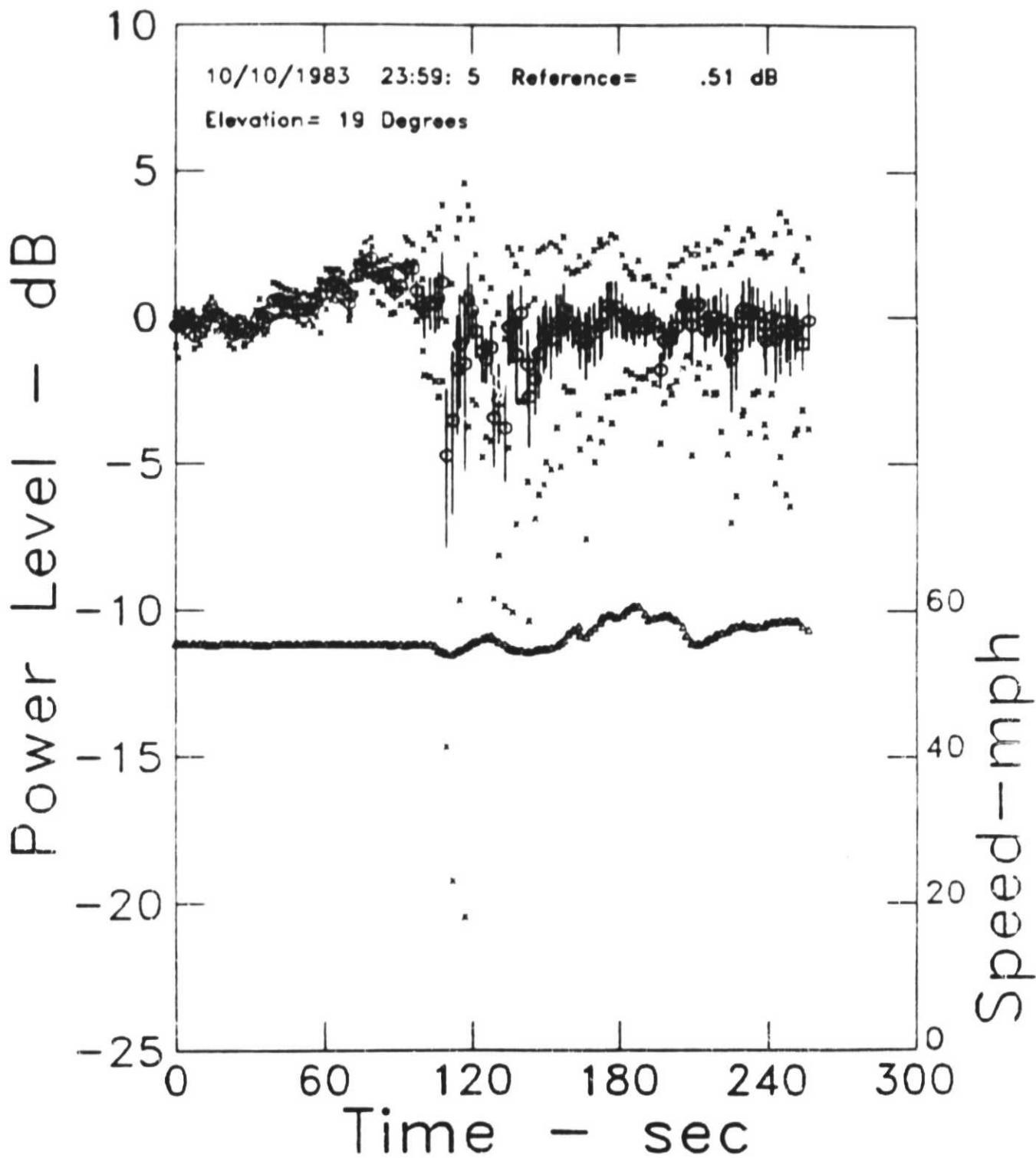
Fig.14   The speed of the van (triangles), the mean signal level
(circles), the +/- 1 standard deviation limits (vertical
line), and the extreme values (x) for each one second
record of the five minute file starting at 23:59:05 CST.
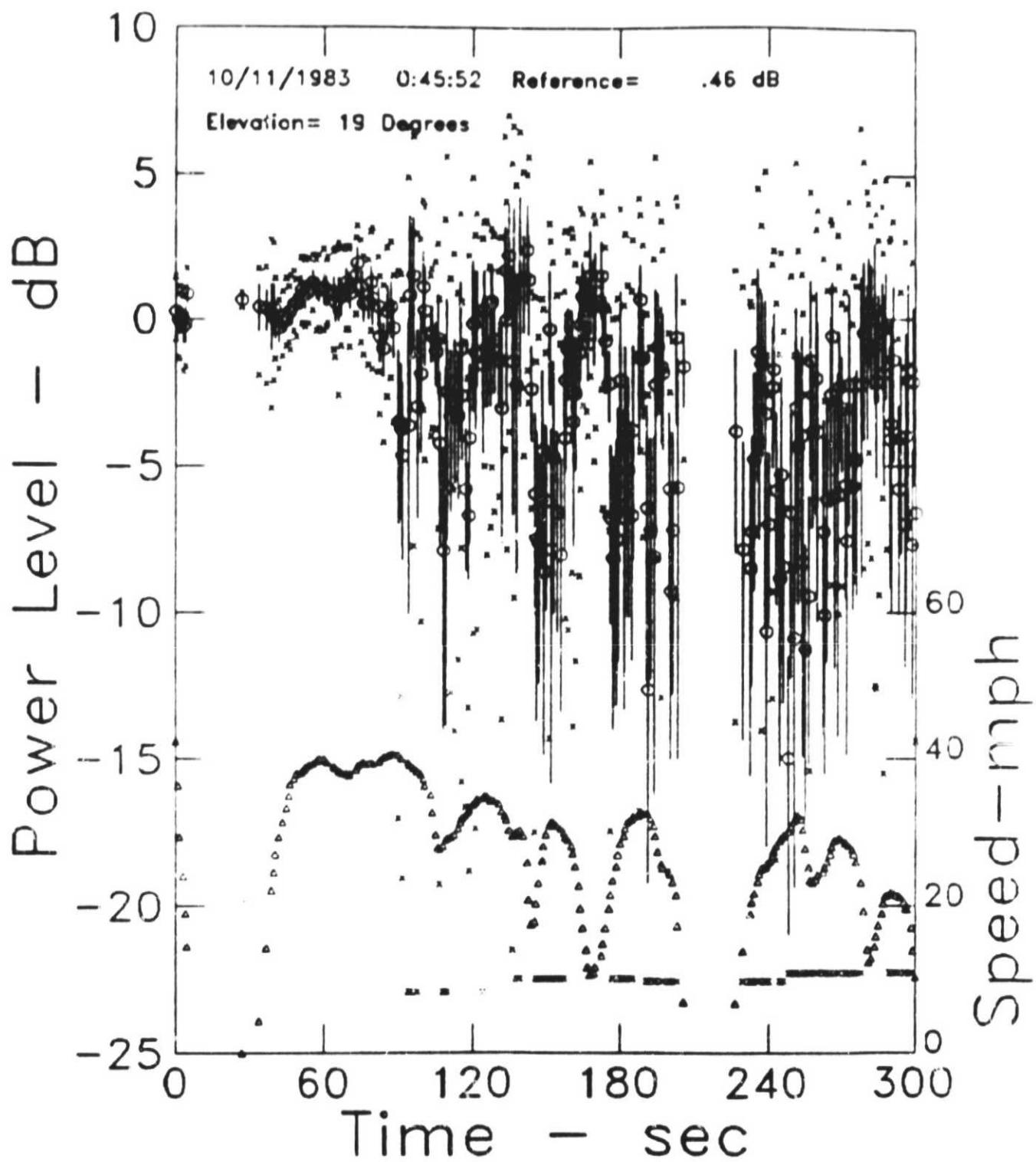
Fig. 15   The speed of the van (triangles), the mean signal level
           (circles), the +/- 1 standard deviation limits (vertical
           line), and the extreme values (x) for each one second
           record of the five minute file starting at 00:45:52 CST.
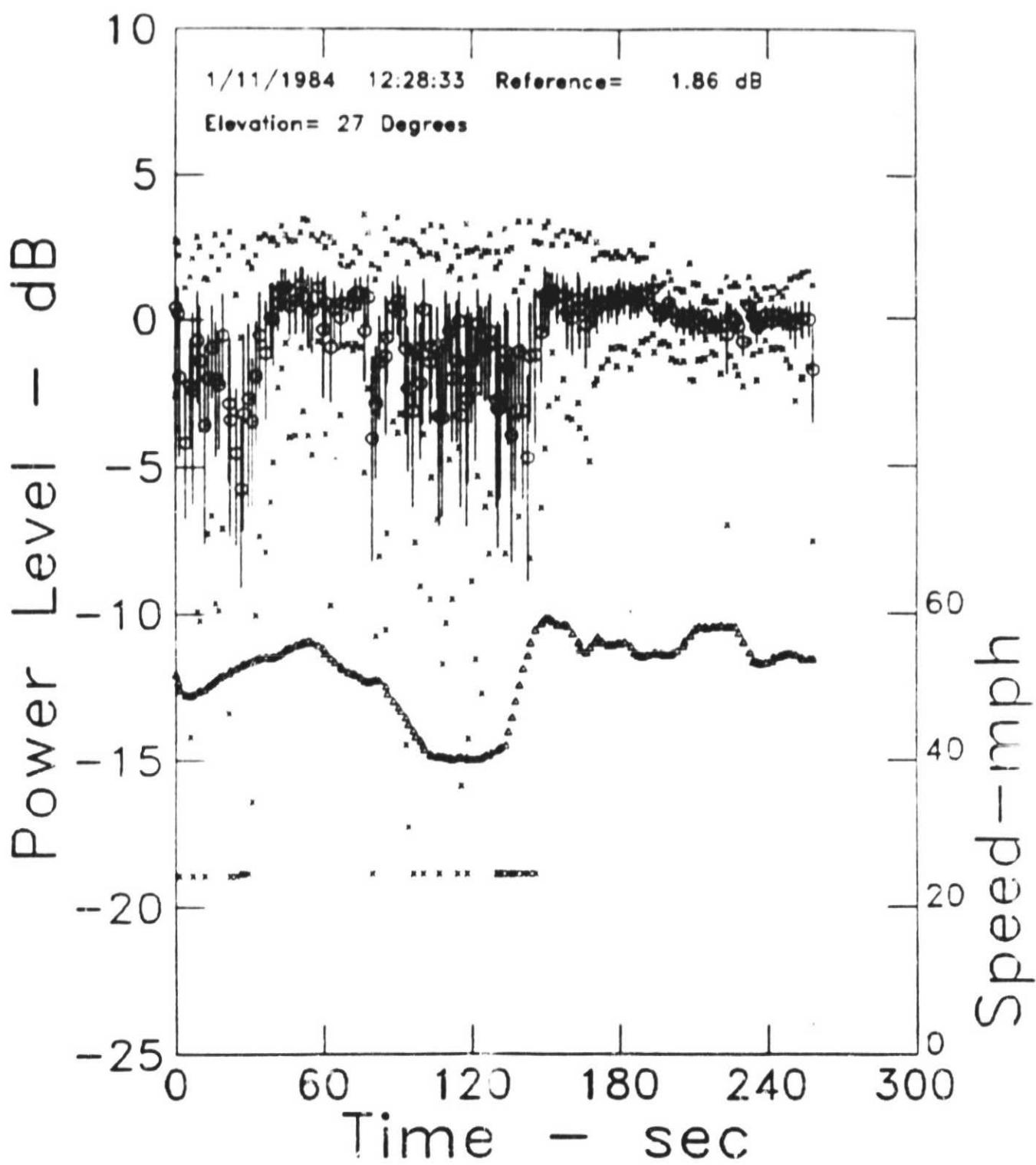
Fig.16 The speed of the van (triangles), the mean signal level (circles), the +/- 1 standard deviation limits (vertical line), and the extreme values (x) for each one second record of the five minute file starting at 12:28:33 CST.
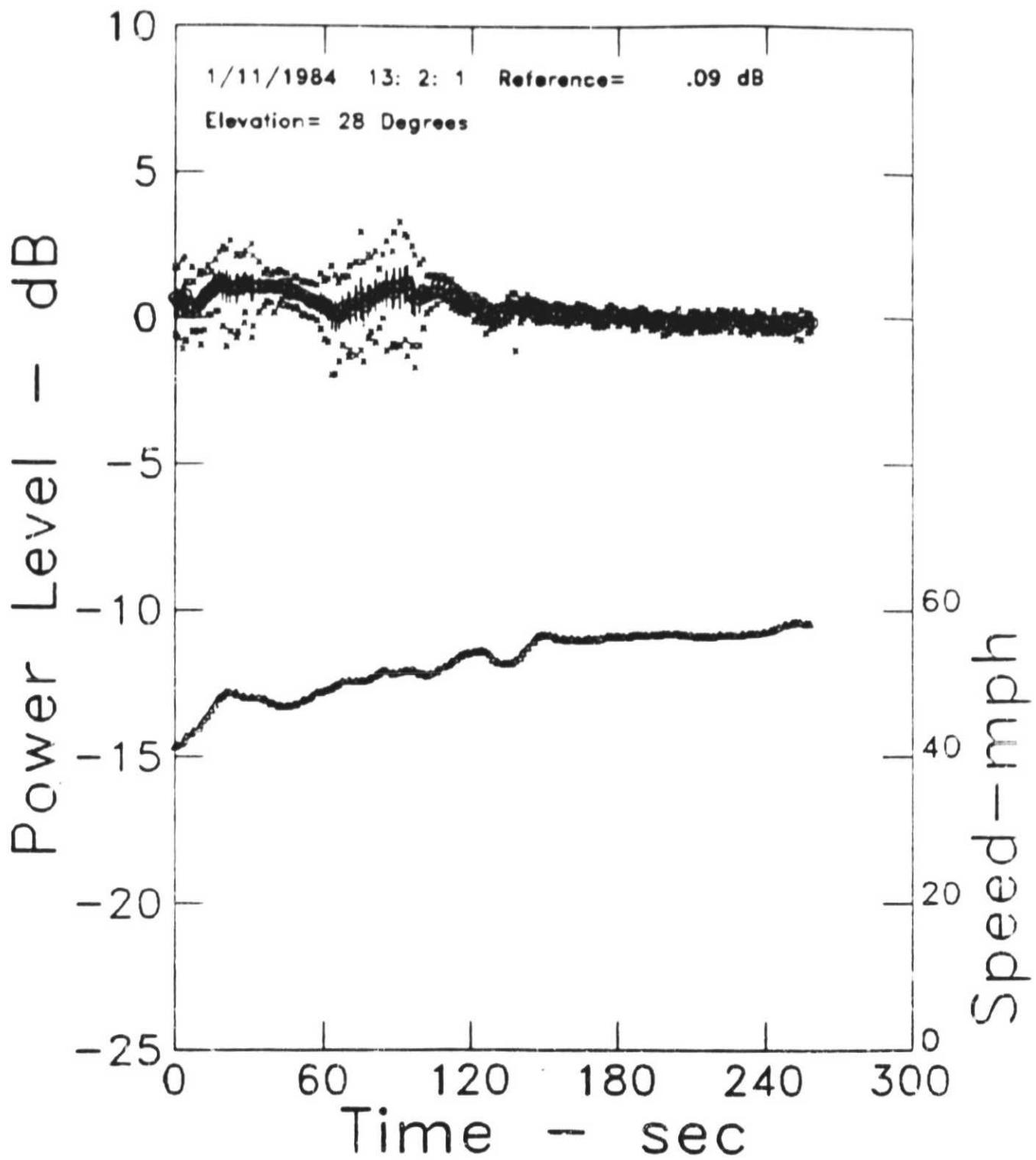
Fig. 17 The speed of the van (triangles), the mean signal level
(circles), the +/- 1 standard deviation limits (vertical
line), and the extreme values (x) for each one second
record of the five minute file starting at 13:02:01 CST.
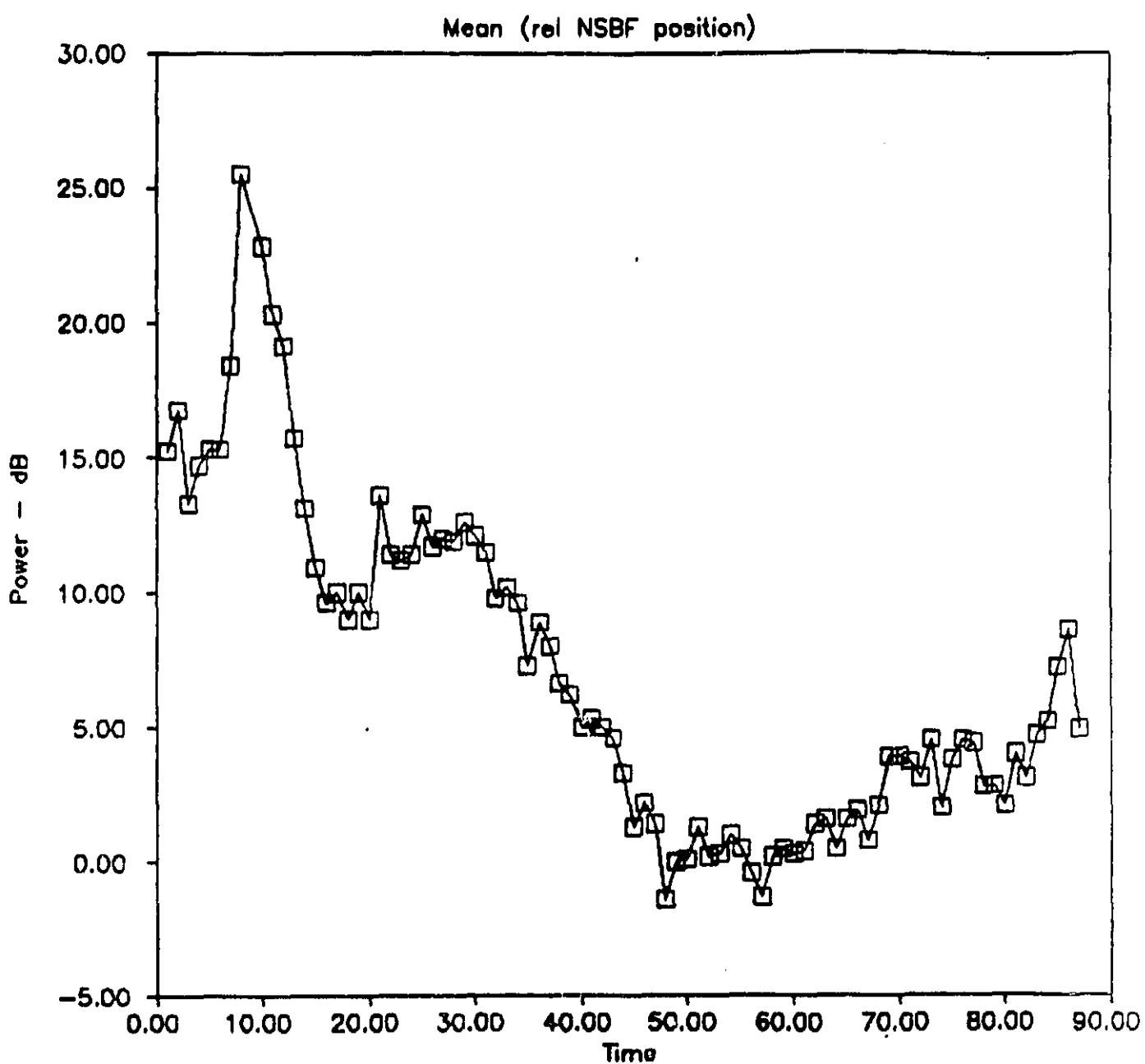
Fig.18   The file referenc means of the October 1983 balloon
         flight deviate from the free space calculation by up to
         25 dB because of the uncertainty of the balloon
         position, the antenna pattern, and the variation in
         transmitted power with temperature.
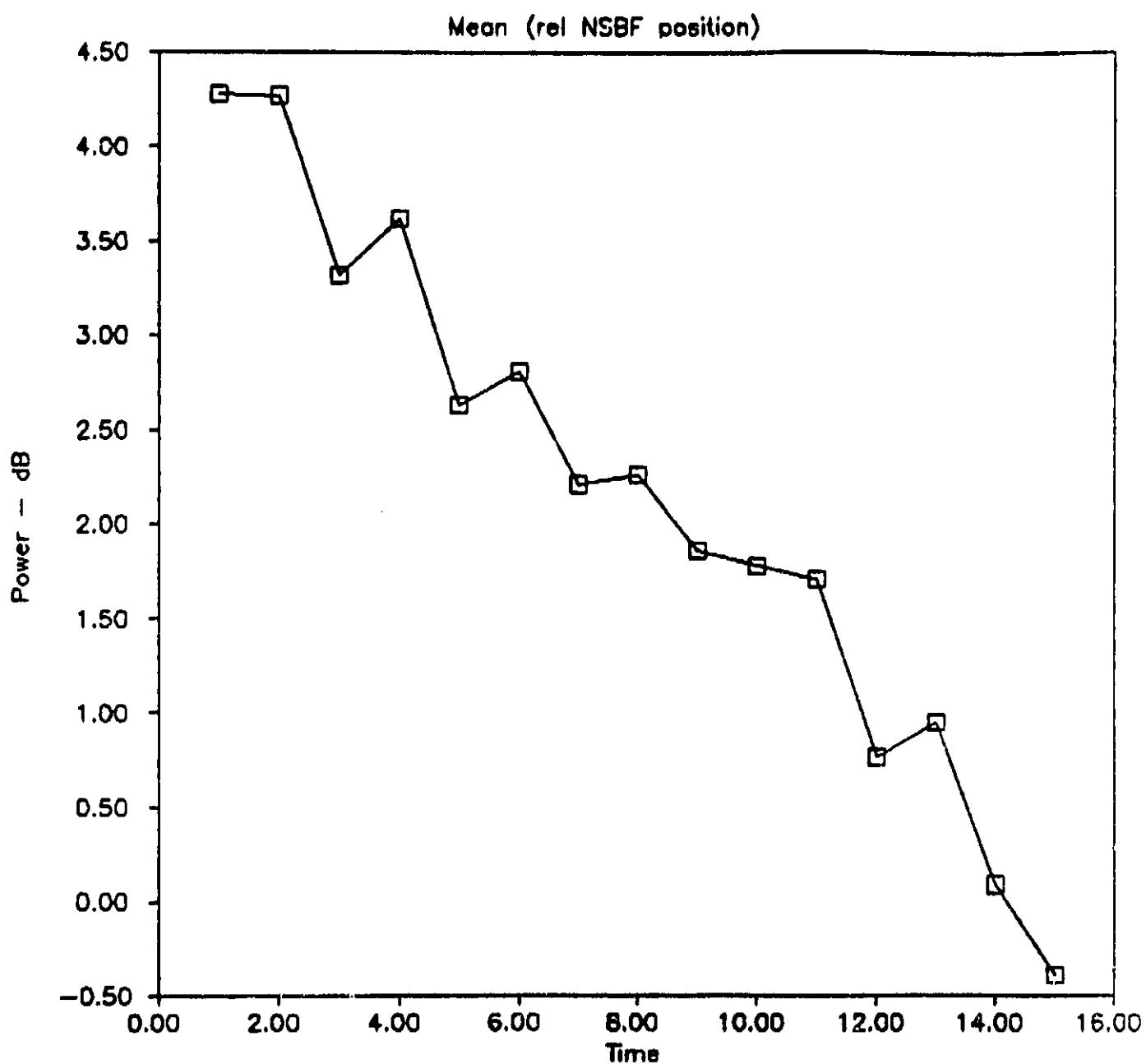
Fig.19   The file reference means of the January 1984 flight vary
         by 4 dB, probably because of temperature variations.
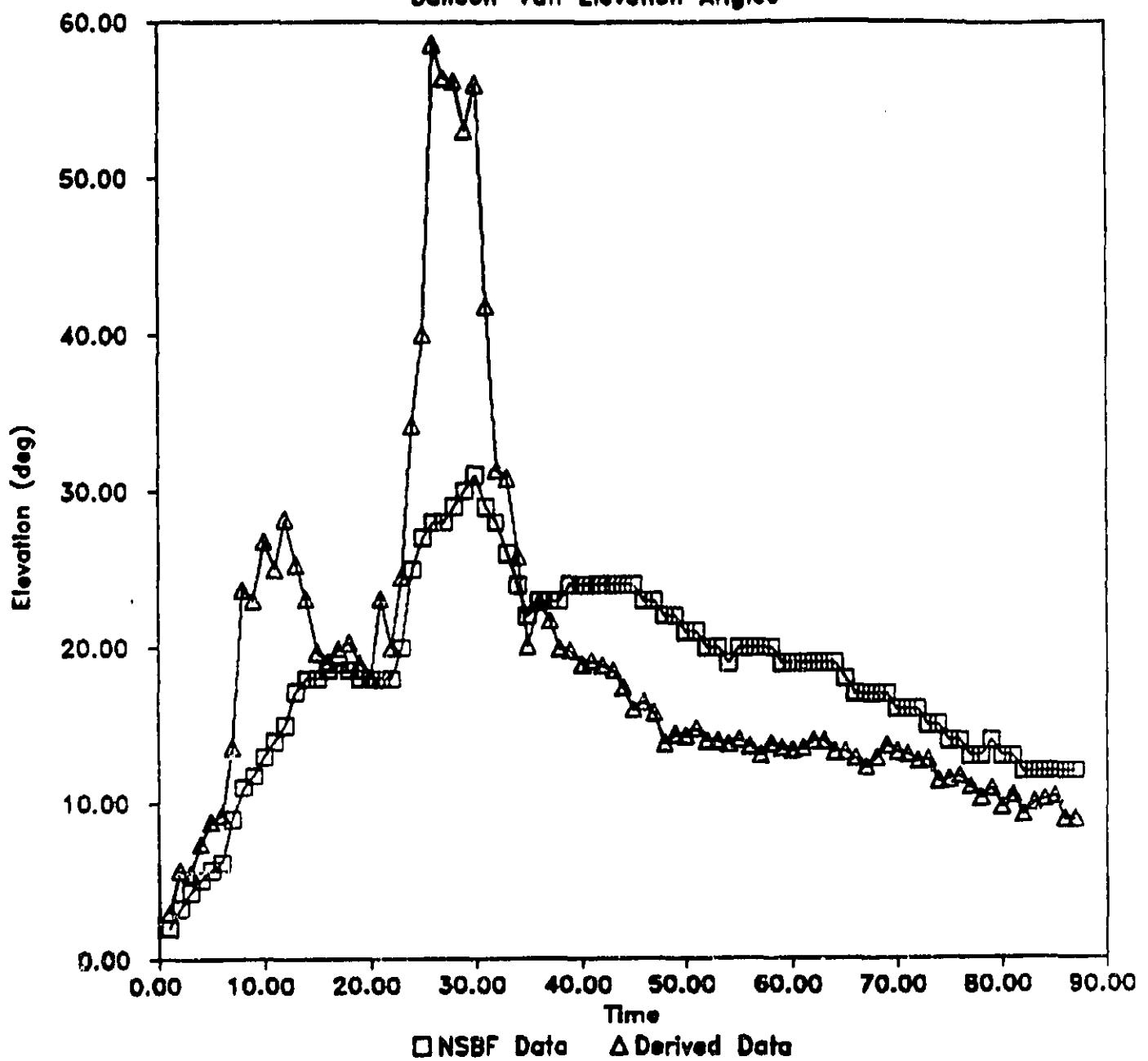
Fig.20   Results of an iterative solution to find true elevation
         angles based on the measured power levels.
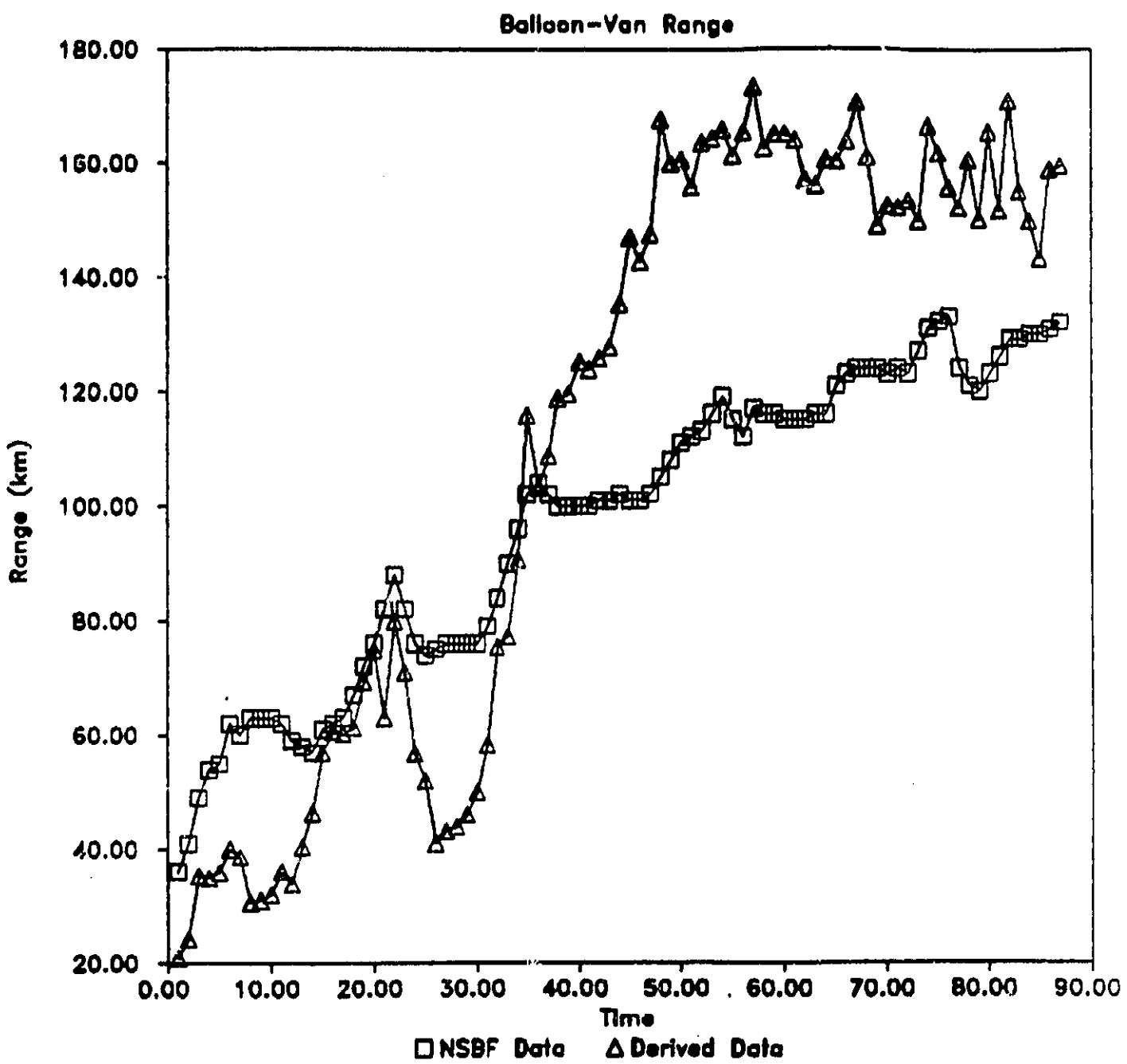
Fig.21   Results of an iterative solution to find true range
          based on the measured power levels.
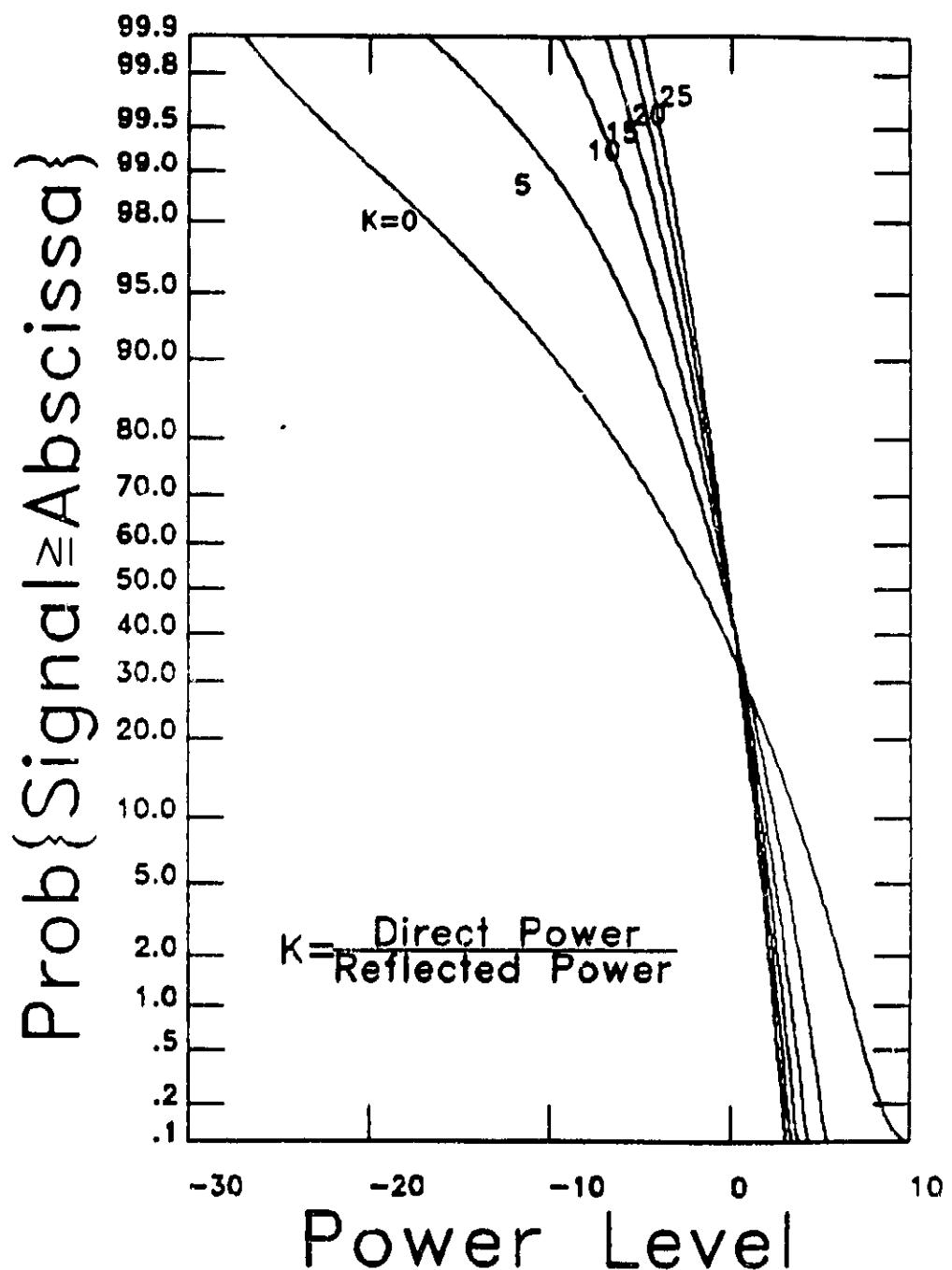
Fig.22   The Rician power density distribution functions for
         direct to reflected power ratios from 0 to 25.
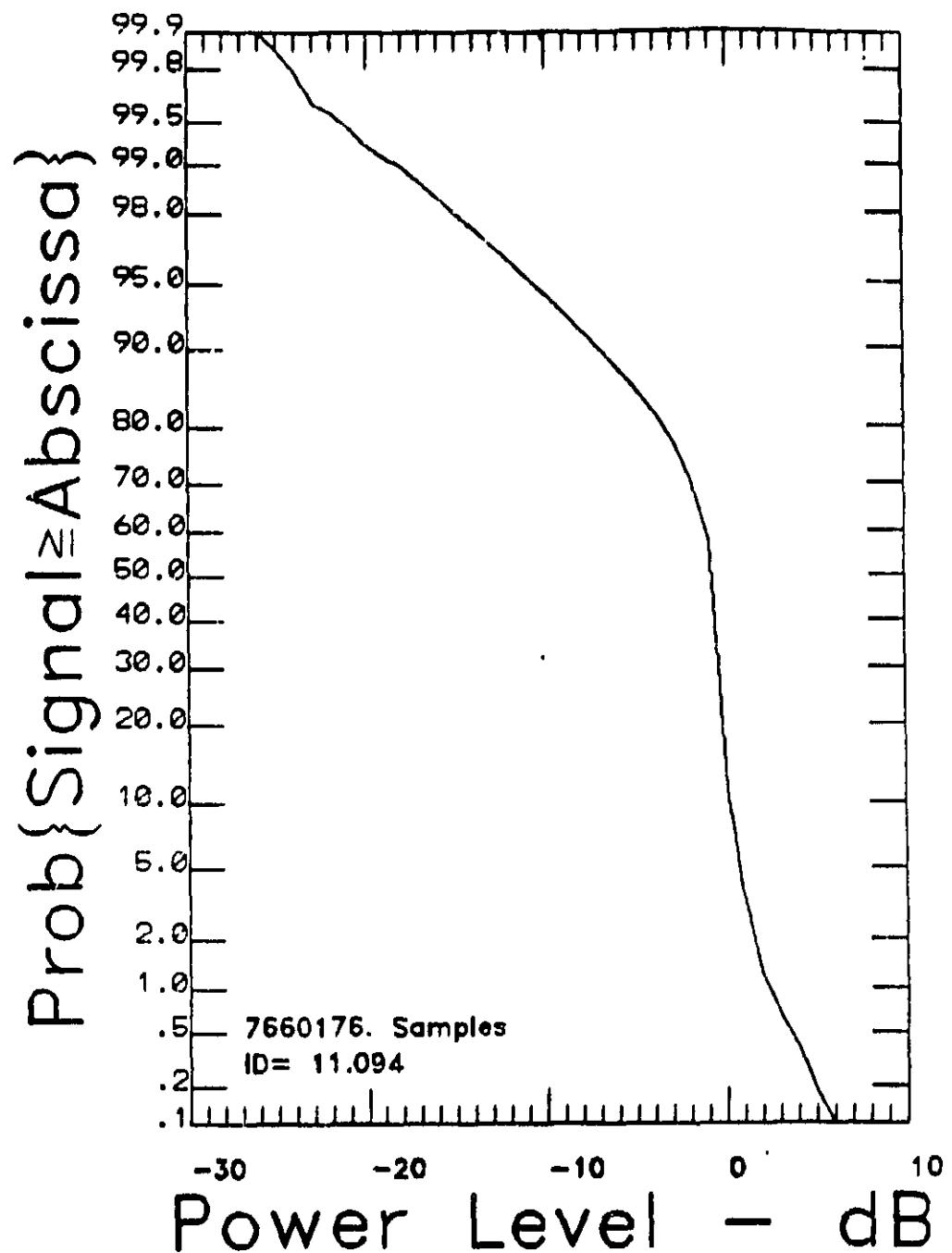
Fig.23 The overall power distribution function for elevation
angles from 10 degrees to the maximum measured at below
35 degrees.
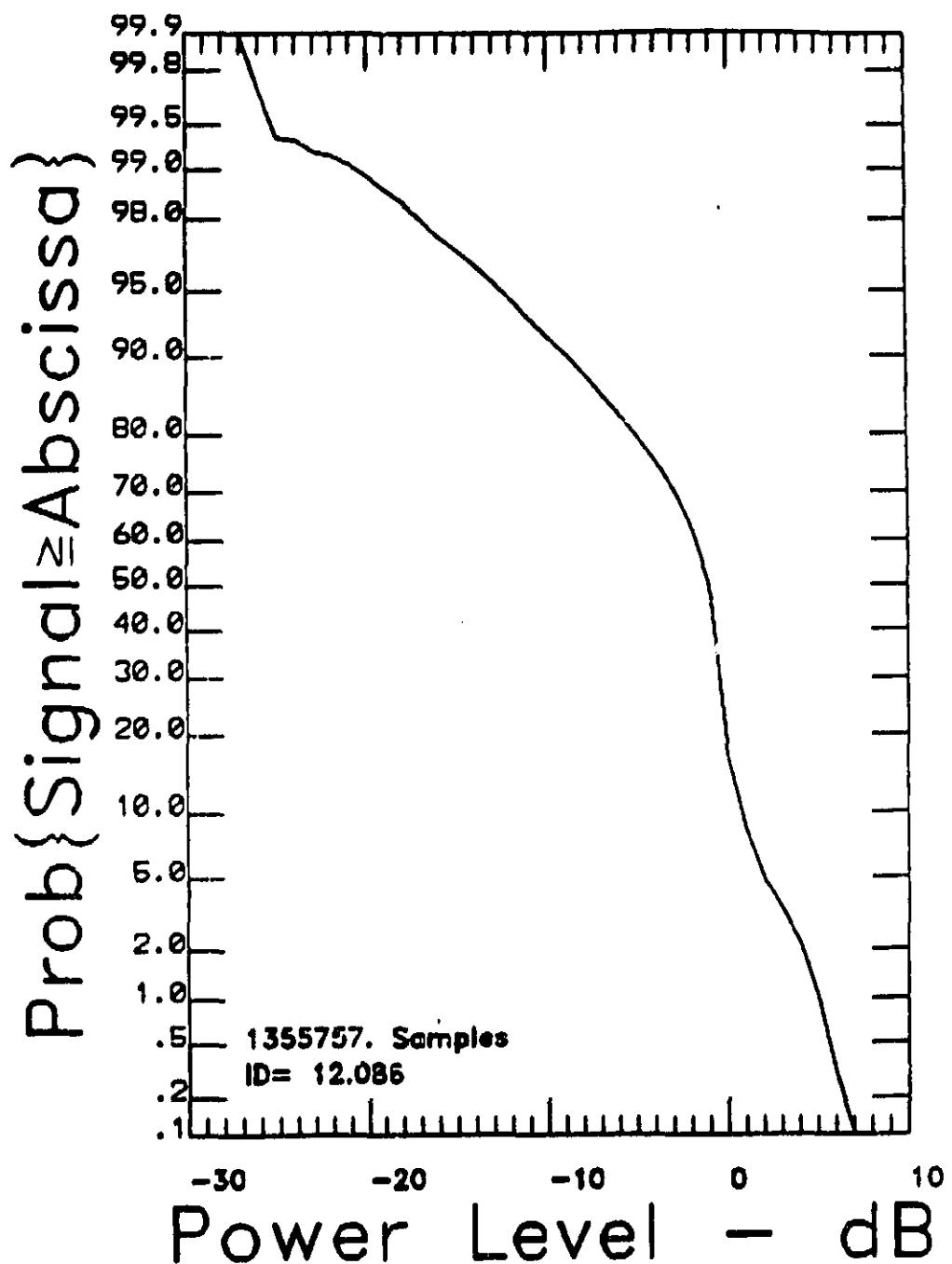
Fig.24   The power distribution function for elevation angles of
         10 to 15 degrees.
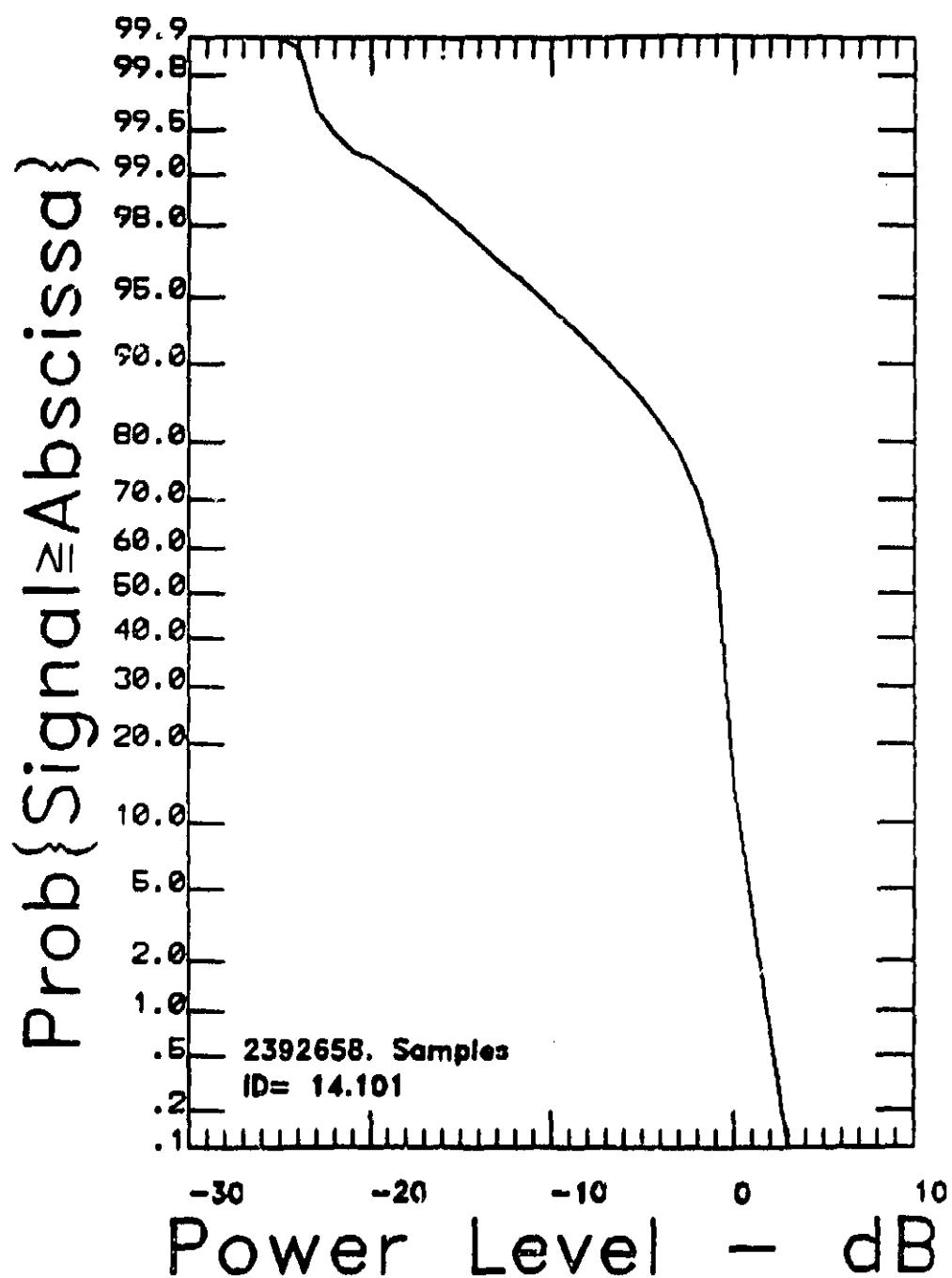
Fig.25   The power distribution function for elevation angles of
          15 to 20 degrees.
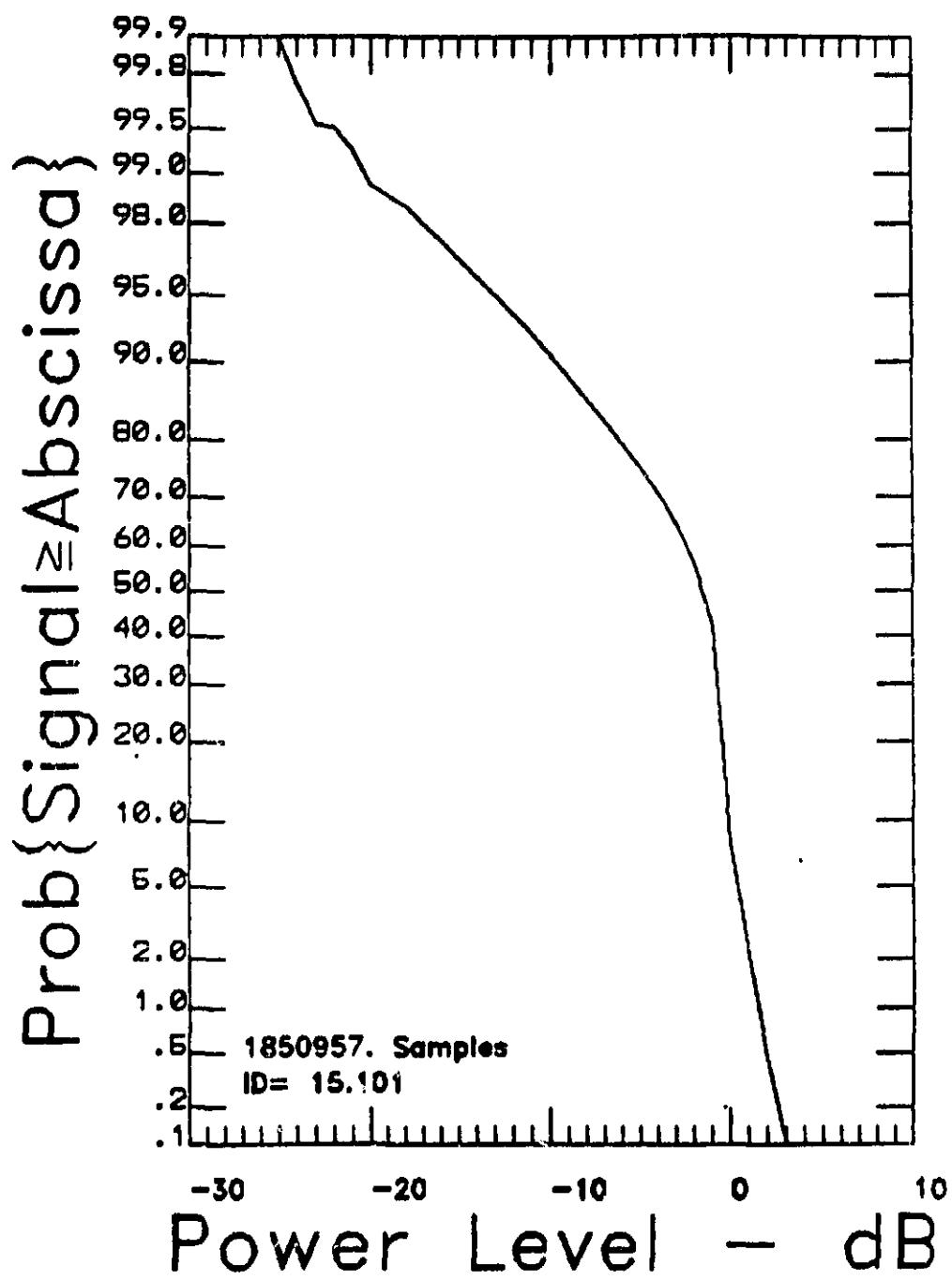
Fig.26   The power distribution function for elevation angles of
20 to 25 degrees.
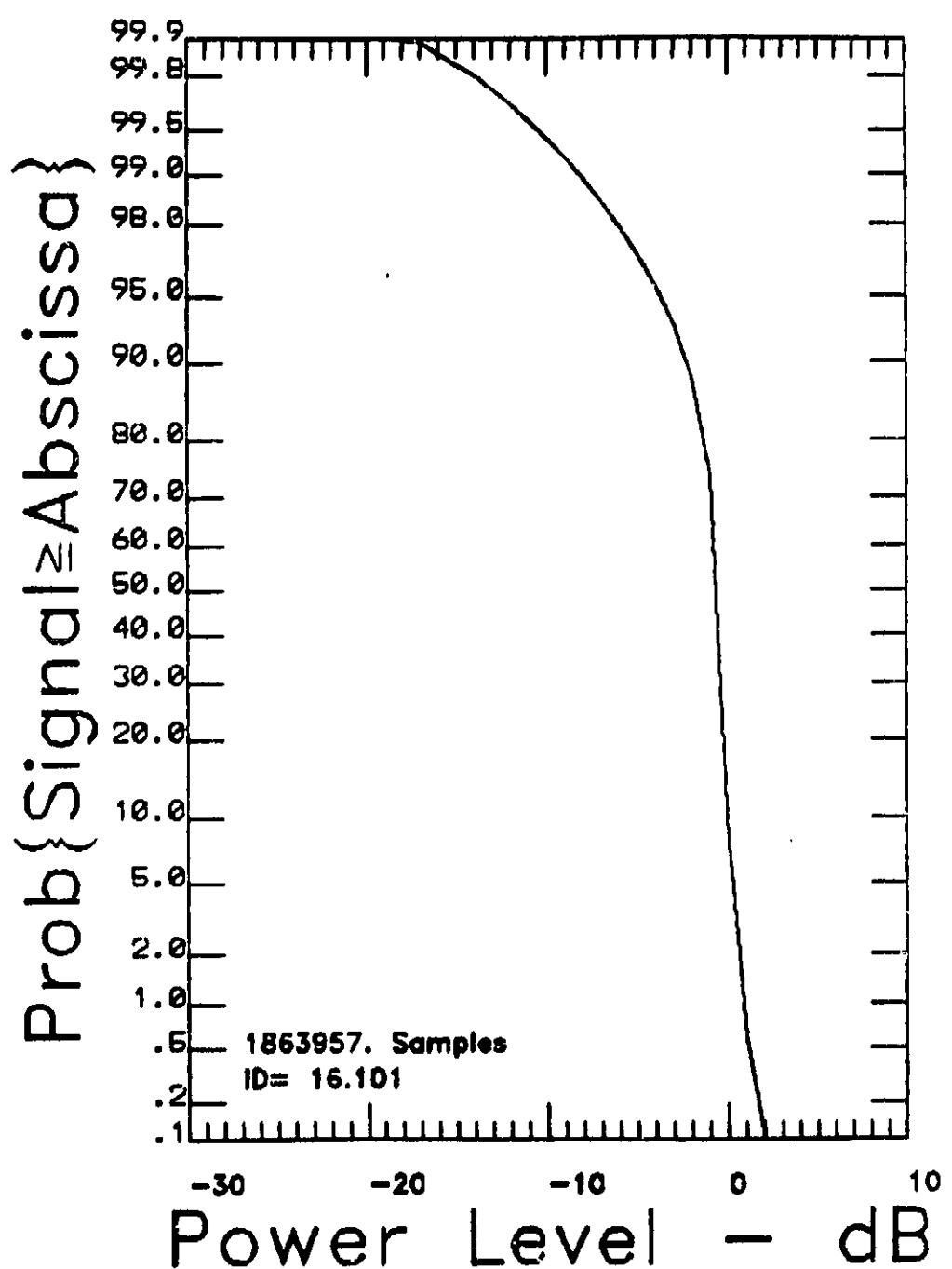
Fig.27   The power distribution function for elevation angles of
25 to 30 degrees.
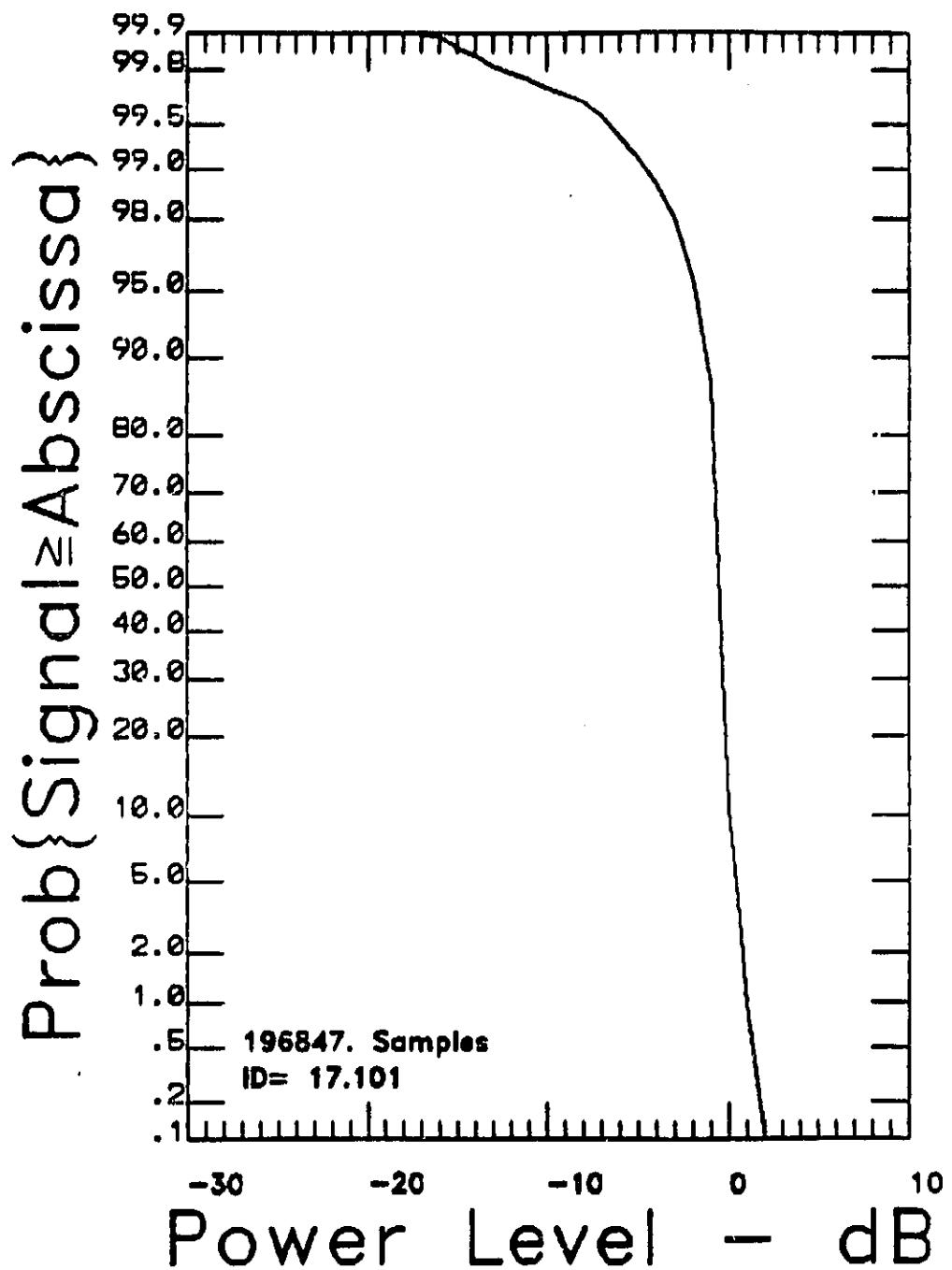
Fig.28   The power distribution function for elevation angles of
30 to 35 degrees.
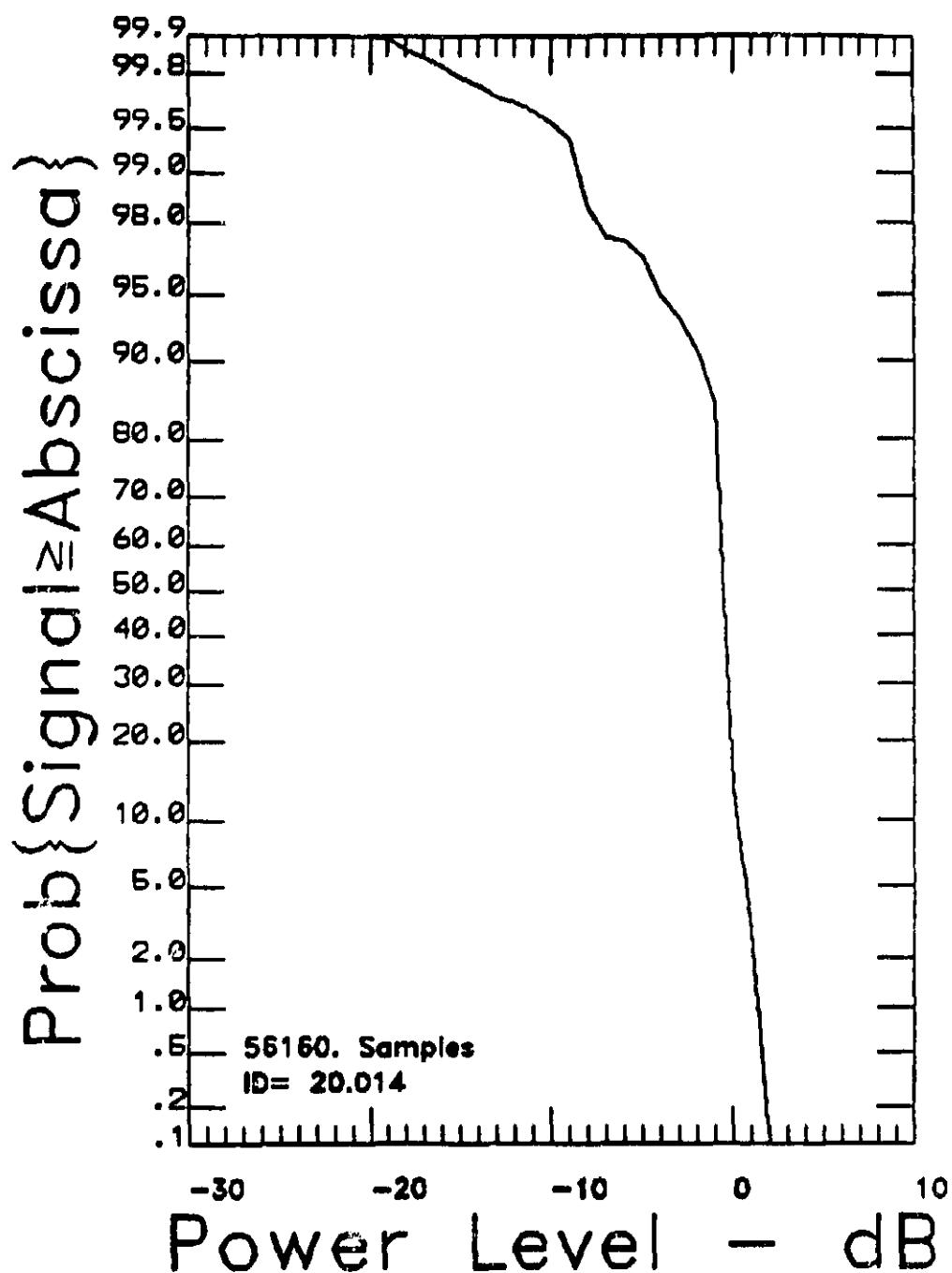
Fig.29   The power distribution function for elevation angles of
10 to 35 degrees, collected while the van speed was
below 1 mph.
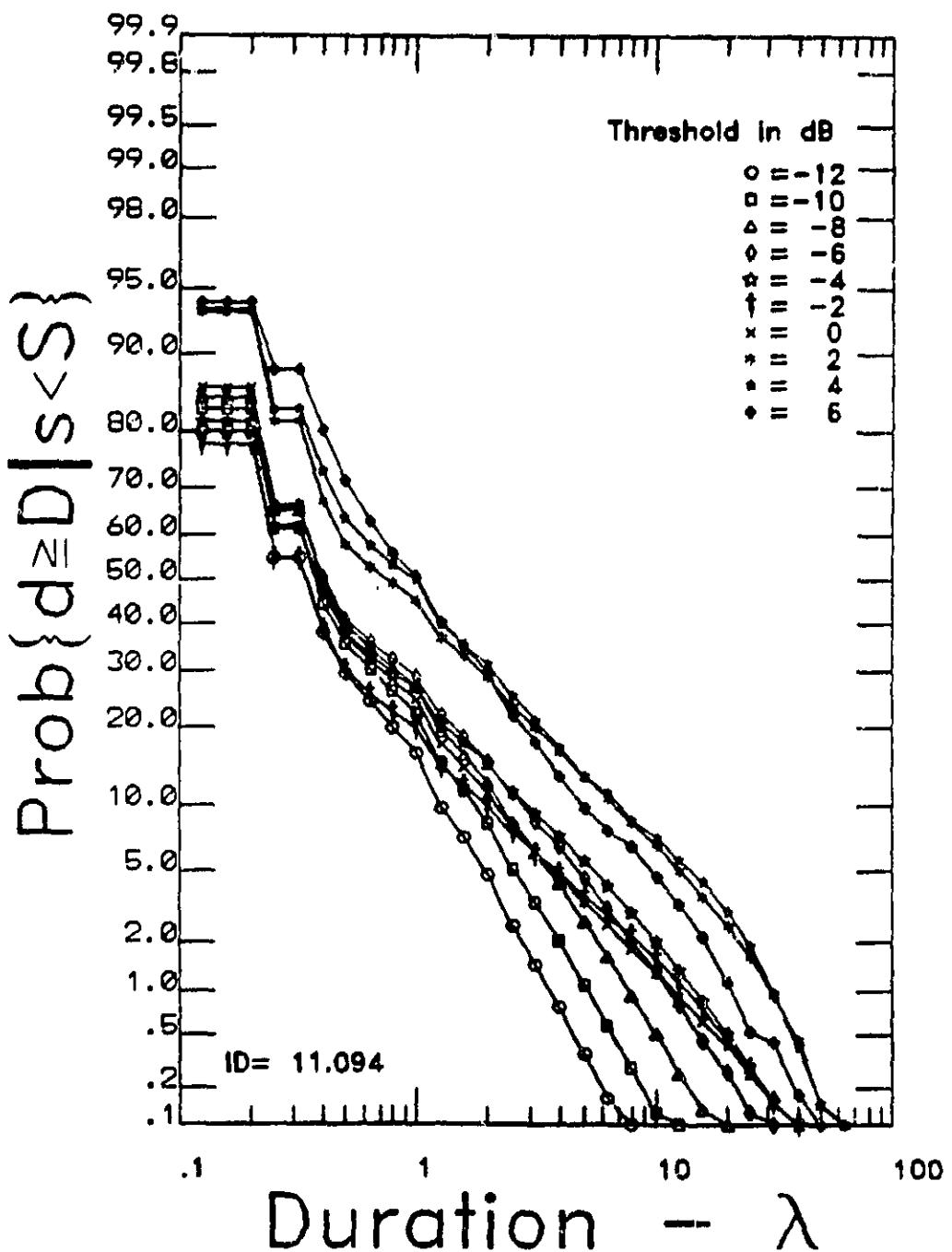
Fig.30   The conditional duration probability distribution
         function for all the data from 10 to 35 degrees
   elevation.
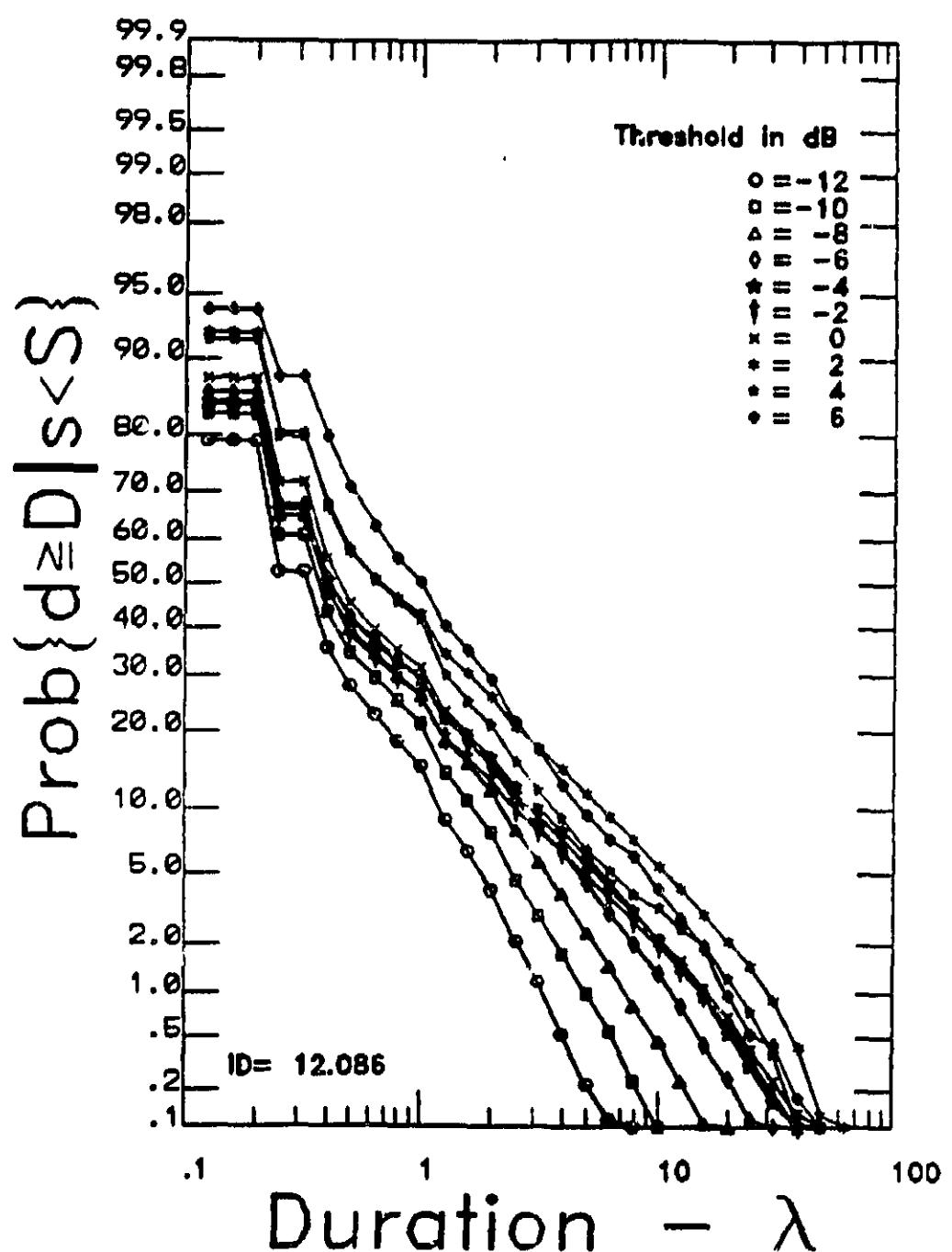
Fig.31   The conditional duration probability distribution
          function for elevation angles from 10 to 15 degrees.
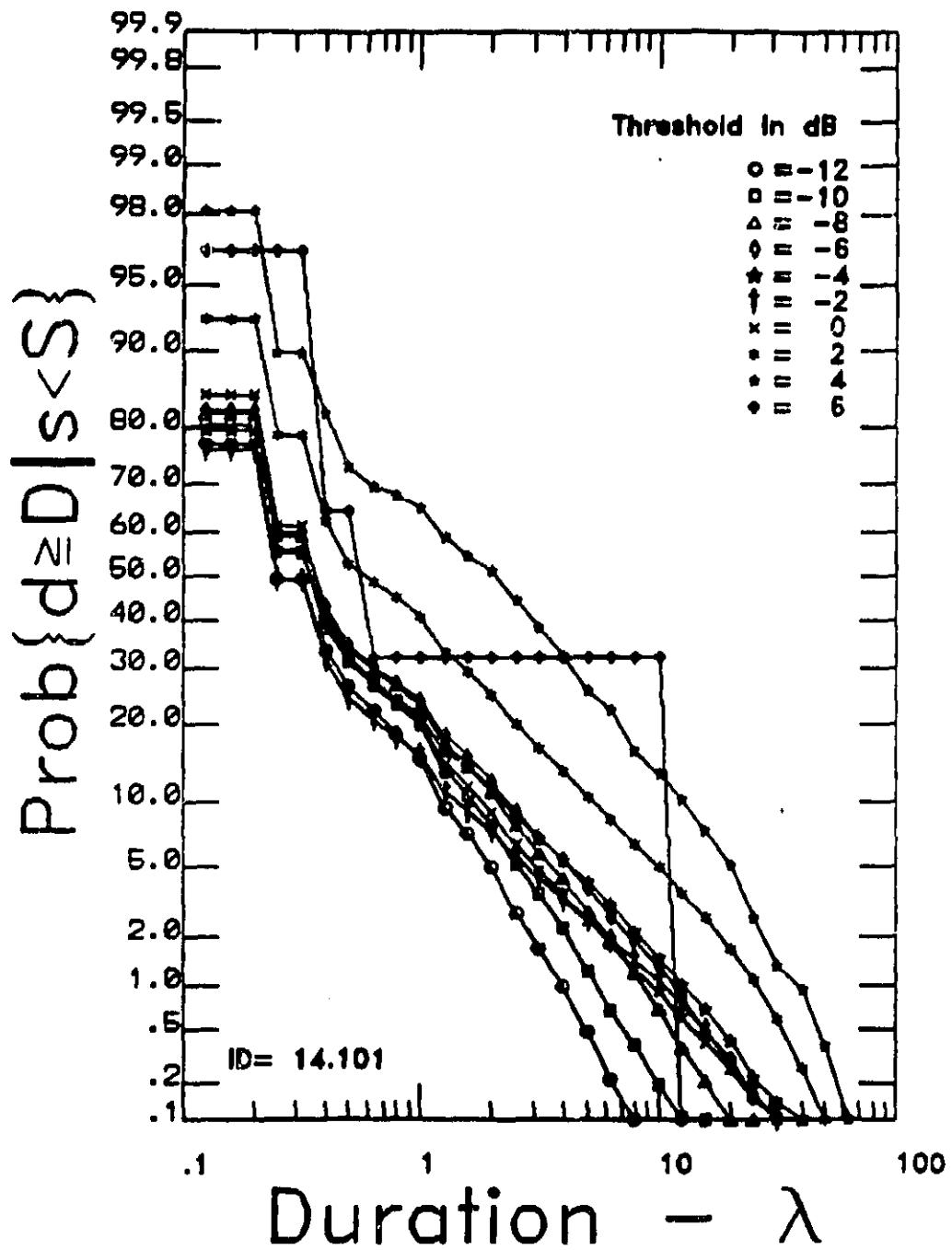
Fig.32   The conditional duration probability distribution
   function for elevation angles from 15 to 20 degrees.
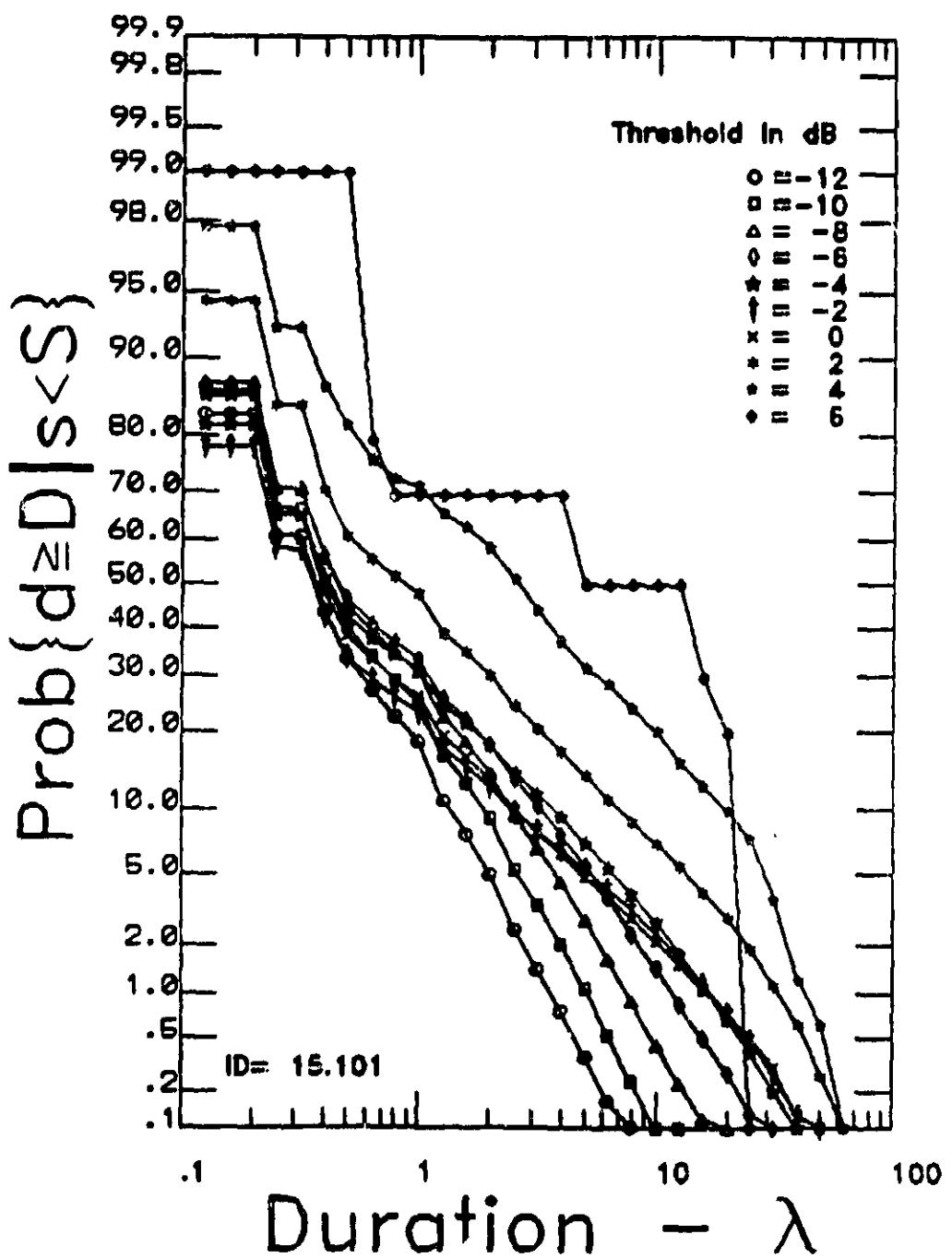
Fig.33   The conditional duration probability distribution
   function for elevation angles from 20 to 25 degrees.
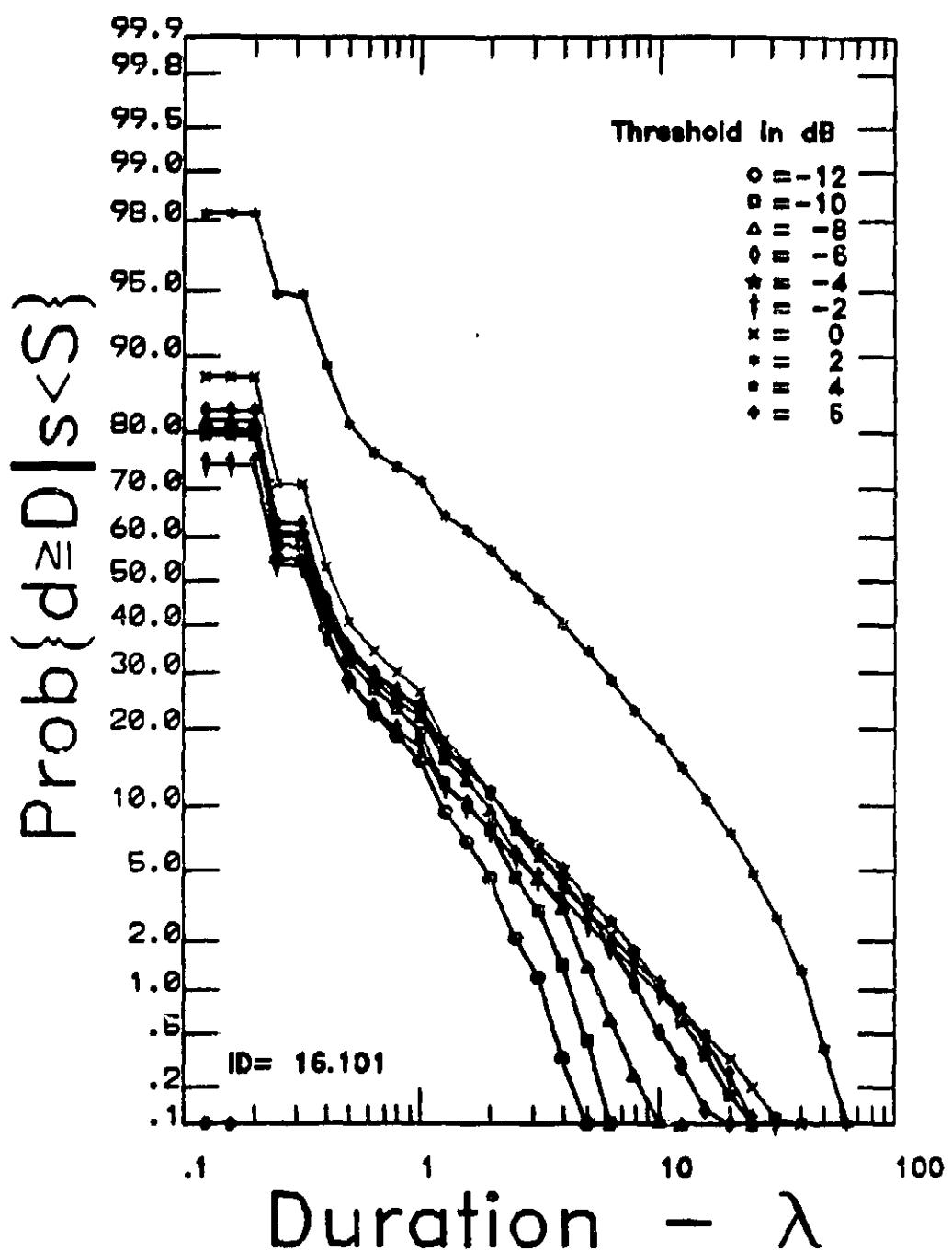
Fig.34 The conditional duration probability distribution
function for elevation angles from 25 to 30 degrees.

Fig.35   The conditional duration probability distribution
          function for elevation angles from 30 to 35 degrees.

Threshold in dB

o	=	-12
□	=	-10
△	=	-8
◇	=	-6
☆	=	-4
↑	=	-2
×	=	0
*	=	2
*	=	4
♦	=	6

ID= 11.094

$Prob\{r \geq R \mid s < S\}$
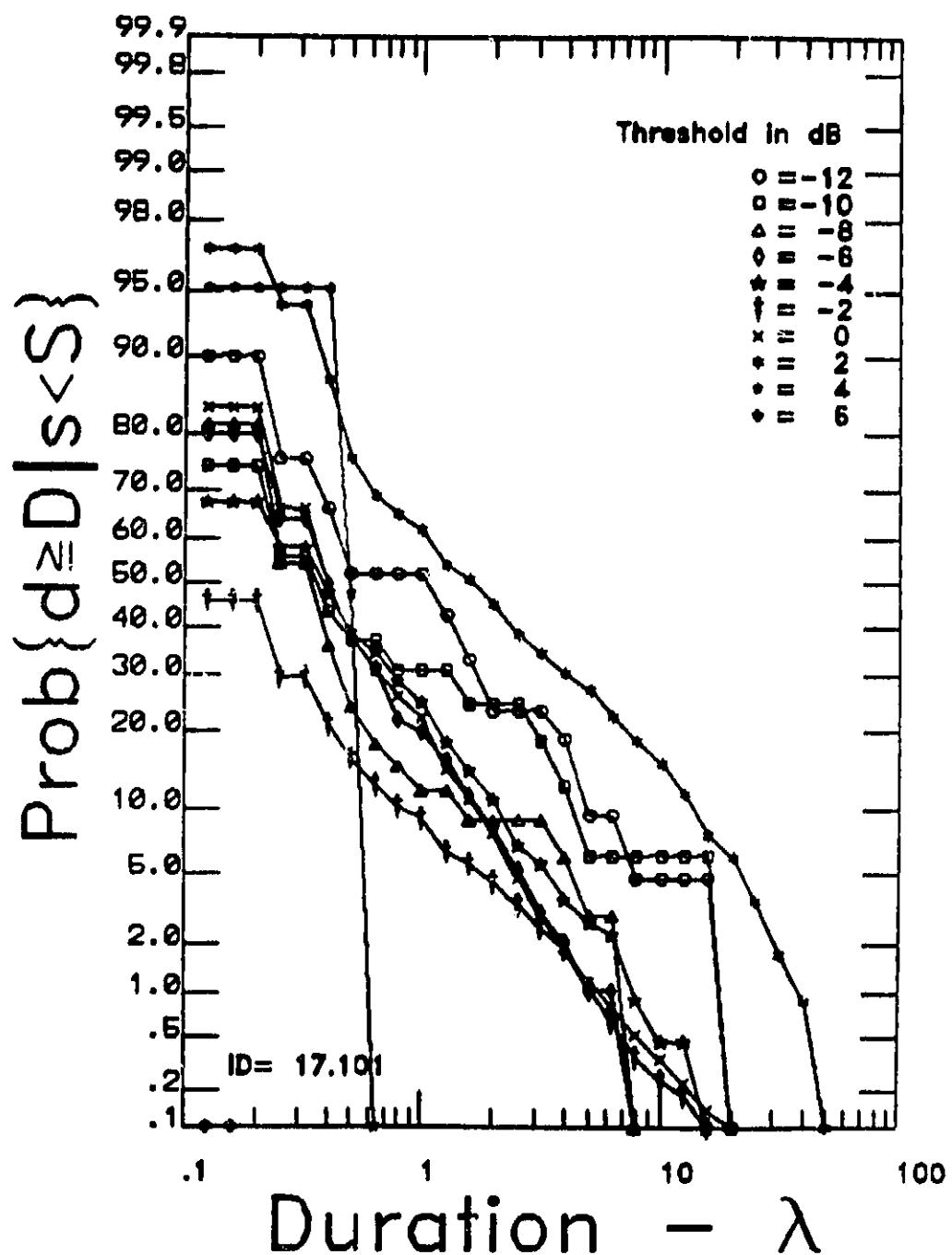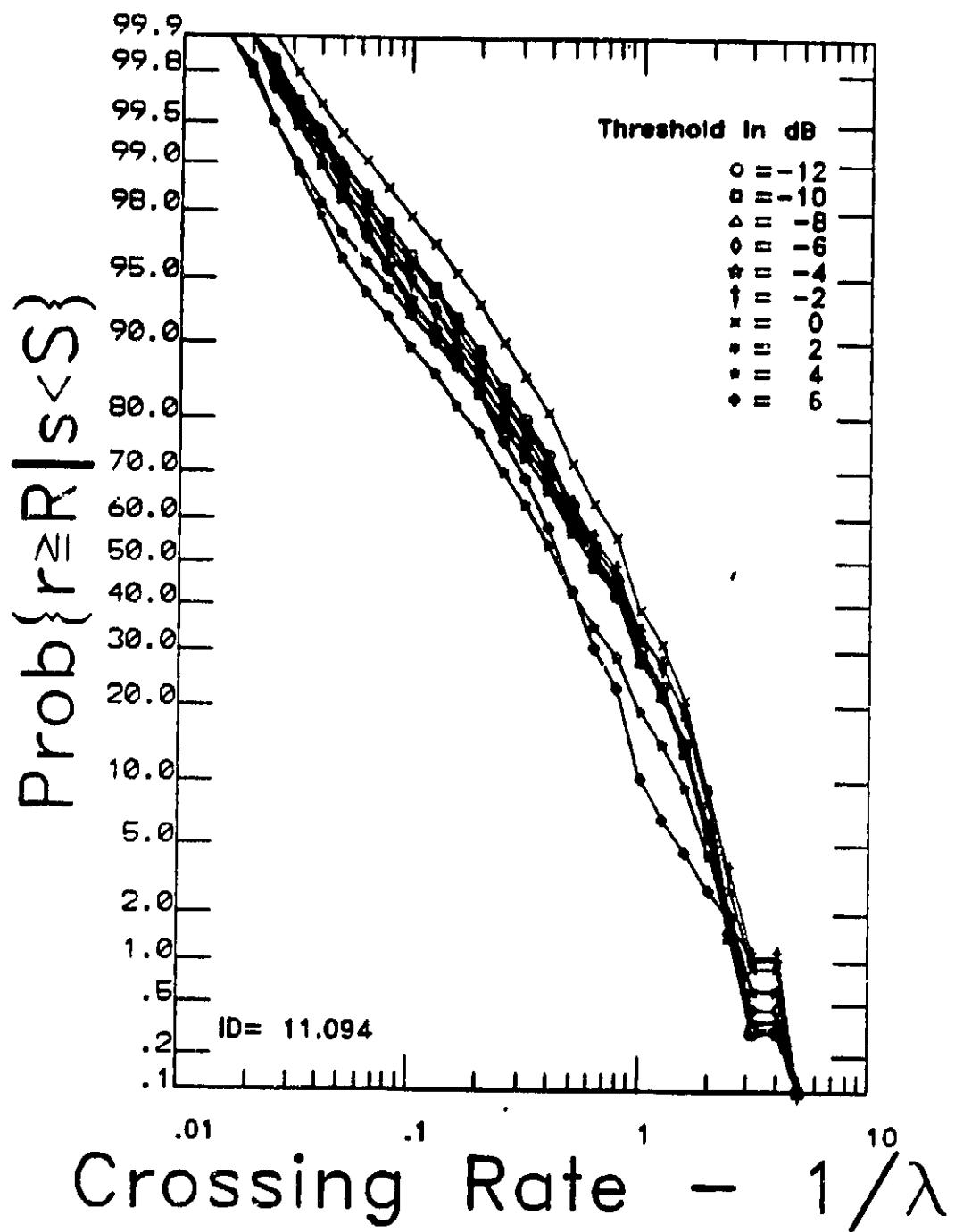
Crossing Rate — $1/\lambda$

Fig.36   The conditional level crossing rate distribution
function for all the data between 10 and 35 degrees.
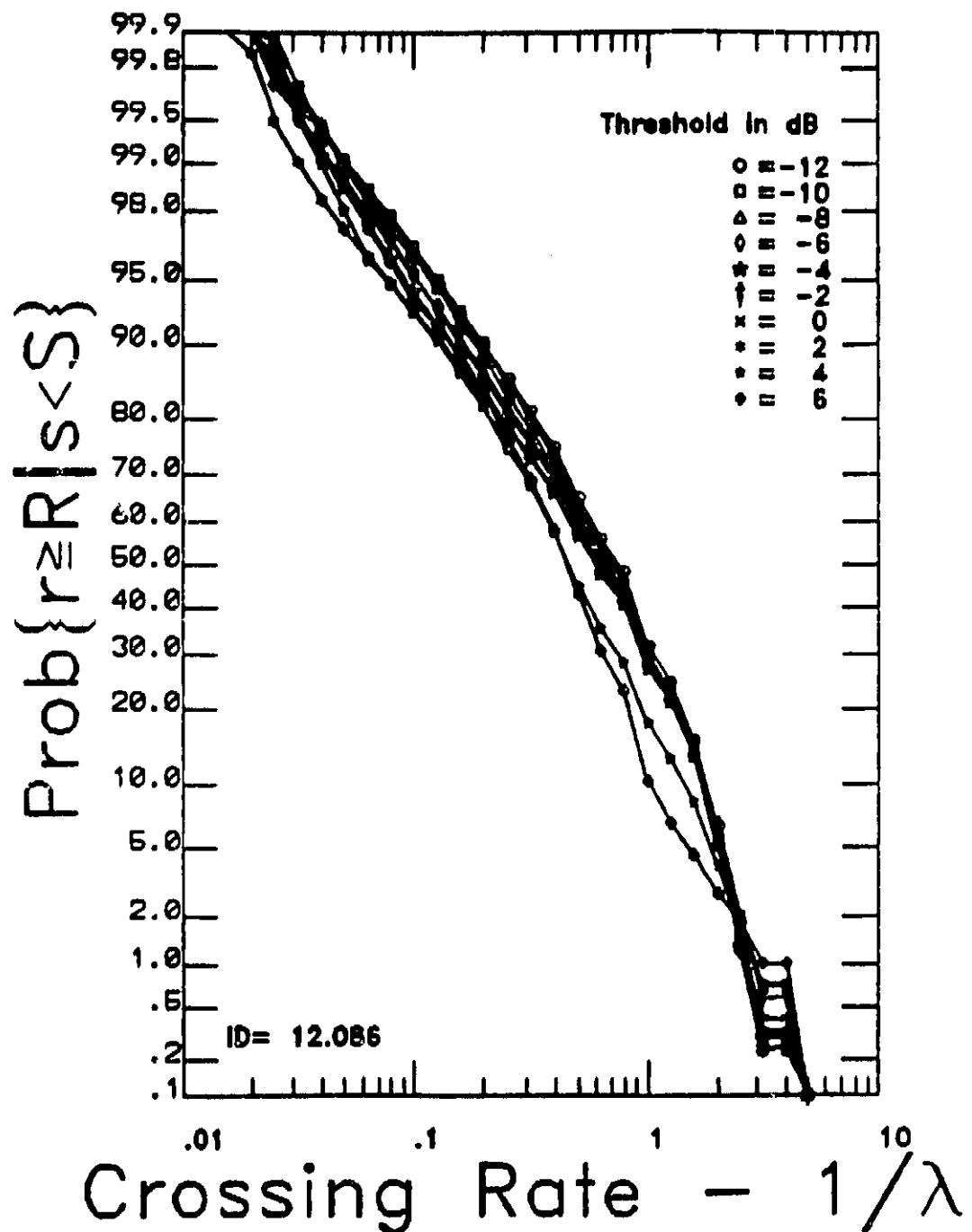
Fig.37 The conditional level crossing rate distribution
function for elevation angles from 10 to 15 degrees.
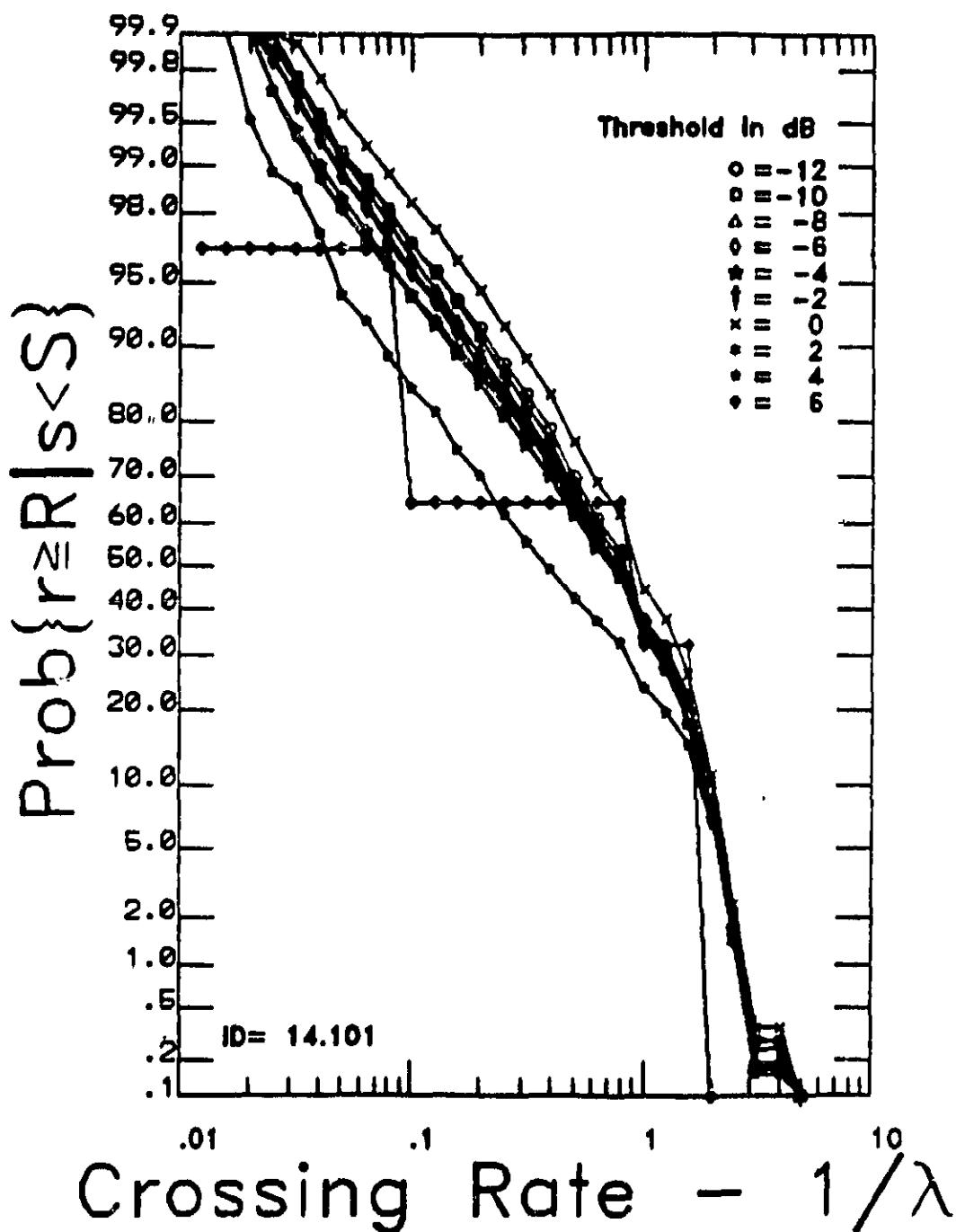
Fig.38   The conditional level crossing rate distribution
   function for elevation angles from 15 to 20 degrees.
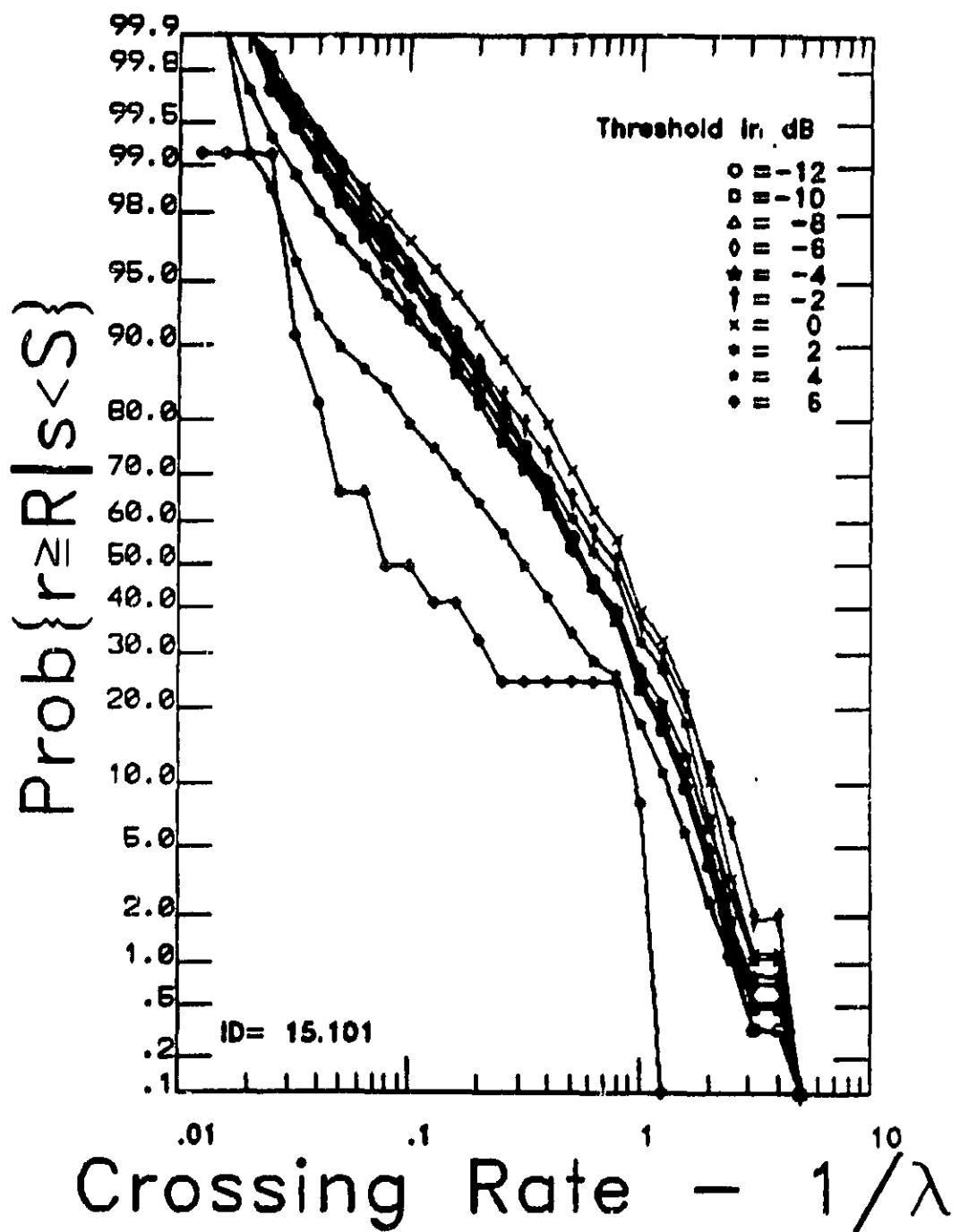
Fig.39   The conditional level crossing rate distribution
   function for elevation angles from 20 to 25 degrees.
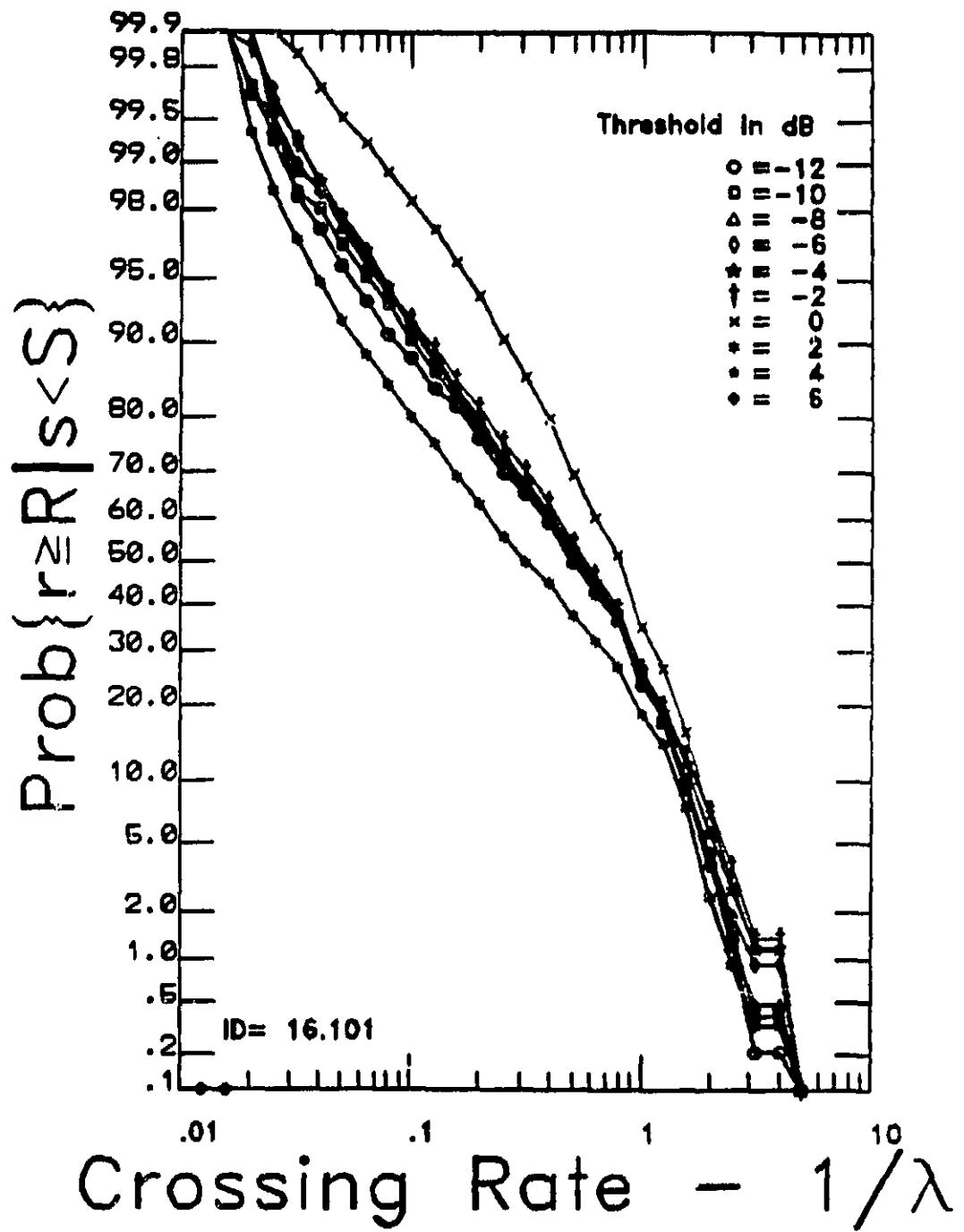
Fig.40   The conditional level crossing rate distribution
   function for elevation angles from 25 to 30 degrees.

Fig.41   The conditional level crossing rate distribution
         function for elevation angles from 30 to 35 degrees.