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Radiometric observations of atmospheric attenuation at 20.6 and 31.65 GHz: The Wave Propagation Laboratory data base

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Abstract

The National Oceanic and Atmospheric Administration (NOAA) Wave Propagation Laboratory (WPL) presently operates five dual-channel microwave radiometers, one triple-channel microwave radiometer, and one six-channel microwave radiometer. The dual-channel radiometers operate at frequencies of 20.6 or 23.87 GHz and 31.4 or 31.65 GHz. The triple-channel radiometer operates at 20.6, 31.65, and 90.0 GHz. The six-channel radiometer operates at frequencies of 20.6, 31.65, 52.85, 53.85, 55.45 and 58.8 GHz. Recent brightness temperature measurements and attenuation values from some of the above radiometers are presented here. These radiometric measurements, taken in different locations throughout the world, have given WPL a diverse set of measurements under a variety of atmospheric conditions. We propose to do a more complete attenuation analysis on these measurements in the future. In addition, a new spinning reflector was installed recently for the dual-channel radiometer at the Platteville, Colorado site. This reflector will extend our measurement capabilities during precipating conditions. We also discuss locating the three-channel and portable dual-channel radiometers at or near Greeley, Colorado to support the Advanced Communications Technology Satellite (ACTS) program.

I. Introduction

Between 1985 and 1988, WPL operated a limited network of four dual-channel microwave radiometers in northeastern Colorado. These radiometers, operating at 20.6 and 31.65 GHz, were deployed for meteorological purposes to measure precipitable water vapor (PWV) and integrated cloud liquid water (CLW). Data from ground-based microwave radiometers are also commonly used to derive attenuation statistics (Ortgies et al. 1990; Vogel et al. 1991; Fionda et al. 1991) useful to communication engineers. Using the radiometric technique, these authors have shown that attenuation levels up to about 12 dB can be derived with good accuracy.

Data from two of the Colorado stations, Denver and Platteville, have previously been used to derive single-station and two-station attenuation statistics for two 3-month periods during 1988 (Fionda et al. 1991). Recently, Westwater et al. 1992, greatly extended that work by deriving attenuation and attenuation-diversity statistics for an entire year's data taken between 1 November 1987 and 31 October 1988 at each of the four stations of the Colorado network. We present the results of some new brightness temperature and attenuation measurements here.

A promising technique for measuring attenuation in precipating conditions is also discussed. This technique involves spinning the exposed reflector. This will help to minimize contaminated atmospheric data caused by the wet reflector (Jacobson et al. 1986) during precipating conditions.

Future attenuation studies that are related to the ACTS program are addressed.

Finally, WPL has also recently developed an airborne dual-channel radiometer which can view up and down (Fedor et al. 1988). The first experiment for this instrument will occur in September 1993, near San Clemente Island, California.

II. Description of Radiometers in WPL

A. *Radiometer characteristics*

WPL's radiometers were designed, constructed, and field-tested by WPL (excluding the portable radiometer which was designed and built by Radiometrics Corporation); a complete description of the systems is given by Hogg et al.(1983) and Westwater et al. (1987). A sketch of the triple-channel system is shown in Fig. 1. The WPL instruments were designed to operate continuously, unattended, in almost all weather conditions. The salient characteristics of the instruments are shown in Table 1. Note that the antenna beamwidths for the Denver radiometer, the three-channel radiometer, and one of the transportable radiometers differ from those of the other four stations. Field experiments (Snider et al. 1988), in which the three-channel radiometer with a beamwidth of 2.5 degrees was compared with the network radiometers with their beamwidths of 5 degrees, showed a correlation of 0.99 between the systems. The receivers of all seven radiometers are of the same construction. The radiometers are internally calibrated by switching between the antenna and two hot blackbody loads, and are externally calibrated approximately every two weeks using the "tipping curve" method (Hogg et al. 1983; Decker and Schroeder, 1991).

B. *Methodology to derive attenuation from emission*

The basic quantity measured by a radiometer is brightness temperature, T_b, which is closely related to input power present at the antenna (Ulaby et al. 1981). Although the probability distributions of T_b are of interest in themselves, the quantities needed by communication engineers are the distributions of attenuation. We derive the attenuation, τ(dB), from T_b by using the well-known formula (Westwater et al. 1990)

$$\tau(\mathrm{dB}) = 4.34 \ln\{(T_m - T_c)/(T_m - T_b)\} \quad , \qquad (1)$$

where

T_m = mean radiating temperature (K),

and

T_c = cosmic background temperature = 2.75 K.

In deriving τ, we used monthly mean values of T_m calculated from our radiative transfer and cloud models.

C. Single-station attenuation statistics

Data are taken by radiometers that operate unattended, although bimonthly, on-site calibrations are made. For the most part, the data are of high quality, although occasional outliers have to be removed. Such outliers can arise from liquid and ice buildup on the antennas, spurious signals of electromagnetic origin, calibration drifts in the receivers, and data transmission errors.

After the quality control methods discussed by Westwater et al. (1992) are applied to the data, cumulative distributions of brightness temperature and radiometrically derived attenuation are obtained for each station. An example of the four-station composite values of the Colorado Research Network are shown in Fig. 2. It is interesting to compare these radiometrically derived values of attenuation with forthcoming beacon measurements from ACTS (Chakraborty and Davarian, 1991).

III. Recent Radiometric Data

A. *Data from Norman, Oklahoma*

We operated a dual-channel radiometer at Norman, Oklahoma from February 1991 through February 1992 at frequencies of 20.6 and 31.65 GHz. Brightness temperature measurements for one month, October 1991, are shown in Fig. 3. Attenuation statistics for this period are currently being derived. An infrared radiometer, with a wavelength of operation around 10.6 micrometers, was also operated here. This instrument can sense clouds and is used to estimate cloud base temperature. Initial tests have shown agreement with radiosonde indications of cloud base temperature to within a degree Celsius (Shaw et al. 1993).

B. *Data from Coffeyville, Kansas*

We operated the three-channel radiometer near Coffeyville, Kansas from November through mid-December 1991 at frequencies of 20.6, 31.65, and 90.0 GHz. Attenuation measurements for three days are shown in Fig. 4. Notice the high attenuation measured by the 90.0 GHz channel relative to the attenuation at the two lower frequencies. This increased attenuation is due to the factor of five increase in cloud liquid attenuation coefficient (Westwater et al., 1990). An infrared radiometer, with a wavelength of operation around 10.6 micrometers, was also operated here. Furthermore, we operated our infrared spectrometer system (Shaw et al, 1991), known as FIRS (Fourier-transform InfraRed Sounder), at this location.

This instrument measures the atmospheric temperature and humidity profiles.

C. *Data from Porto Santo, Portugal*

This location provided attenuation measurements for the marine environment in the north Atlantic Ocean. We operated the three-channel radiometer on Porto Santo Island, Portugal, in June 1992. One of the transportable dual-channel radiometers made measurements aboard the NOAA ship Malcom Baldridge in June 1992. This ship cruised across the North Atlantic Ocean during this trip. The radiometer was then taken off the Malcom Baldridge ship and located on Porto Santo Island, Portugal in July 1992. It will be operating there until the end of June 1993, The dual-channel frequencies are 20.6 and 31.65 GHz. Two days of attenuation measurements from the three-channel system are shown in Fig. 5. As before, the 90.0 GHz attenuation measurements are much greater than the other two channels. Infrared radiometers, with a wavelengths of operation around 10.6 micrometers, were also operated in these locations.

D. *Data from Kavieng, Papua New Guinea*

This location provided an extremely high water vapor environment for the marine environment in the South Pacific Ocean. We operated one of the transportable dual-channel radiometers in Kavieng, Papua New Guinea during January and February 1993 at frequencies of 23.87 and 31.65 GHz. Two days of these attenuation measurements are shown in Fig. 6. In addition, we operated our FIRS instrument at this location.

IV. Spinning reflector

A dry reflector surface is required during precipating conditions to avoid contamination of the atmospheric data (Jacobson et al., 1986 and Stankov et al., 1992). Although a high velocity air stream has been used successfully to prevent rain from falling on small optical apertures of a few inches diameter, the technique is impractical for the large apertures used by WPL the microwave radiometers. An alternate solution is to spin the exposed reflector so that particles falling on the rapidly rotating disk will be thrown off, thereby reducing the liquid water layer buildup on the exposed flat. The Desert Research Institute (DRI), and the Commonwealth Scientific and Industrial Research Organization (CSIRO), which is located in Melbourne, Australia, both have implemented spinning disks on their radiometric systems. DRI has found that the spinning reflector has been effective in shedding liquid water and snow accumulations (Demoz et al. 1993).

We have recently designed and built a spinning flat reflector for the Platteville radiometer. The exposed circular flat is positioned at 45° with respect to the horizontal (see Fig. 7). The flat reflector is 3 feet in diameter and is currently rotating at 300 revolutions per minute (RPM), although the speed can be adjusted. A controlled experiment will be performed in the near future to determine how well the spinning flat sheds water.

V. Future Plans

We propose to analyze and publish attenuation statistics for the locations listed in Section III. In addition, we propose to locate the triple-channel radiometer near Greeley, Colorado, adjacent to the radar operated by the University of CHicago and the ILLinois State Water Survey (CHILL), beginning in the fall of 1993 for a period not to exceed 1 year. We plan to locate the portable dual-channel radiometer next to the ACTS receiver in Greeley, Colorado, also in the fall of 1993 for a maximum of one year. Measurements from this instrument would provide valuable information for the ACTS project.

VI. Acknowledgements

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Figure and Table Captions:

Fig. 1. Side view of the transportable triple-channel radiometer.

Fig. 2. Composite brightness temperature (A) and zenith attenuation (B) statistics for the four stations of the Colorado Research Network. These measurements were taken between November 1987 and October 1988 at frequencies of 20.6 and 31.65 GHz.

Fig. 3. Dual-channel radiometer observations at Norman, Oklahoma, taken for the month of October 1991 at frequencies of 20.6 and 31.65 GHz.

Fig. 4. Triple-channel radiometer observations near Coffeyville, Kansas. These measurements were taken during 1991, on (a) November 15, (b) November 19, and (c) November 21, at frequencies of 20.6, 31.65, and 90.0 GHz.

Fig. 5. Dual-channel radiometer observations from Porto Santo Island, Portugal. These measurements were taken on (a) 15 June 1992 and (b) 27 June 1992, at frequencies of 20.6 and 31.65 GHz.

Fig. 6. Dual-channel radiometer observations at Kavieng, Papua New Guinea. These measurements were taken on (a) 23 January 1993 and (b) 27 January 1993 at frequencies of 23.87 and 31.65 GHz.

Fig. 7. The spinning reflector structure, designed and built by WPL.

Table 1. Characteristics of the WPL radiometers.

WPL MICROWAVE RADIOMETER FACILITIES (January 3, 1993)

LOCATION	EQUIPMENT (ν in GHz)	VIEWING	STATUS
Stapleton International Airport Denver, CO	6-channel (20.6, 31.65 52.85, 53.85 55.45, 58.8)	Zenith, equal beamwidths at all channels (2.5°)	Operating (50 GHz channels to be replaced by MARK II)
Platteville, CO	2-channel (20.6, 31.65)	Zenith, equal beamwidths at both channels (5.0°)	Operating
Transportable: Porto Santo Island, Portugal	2-channel (20.6, 31.65)	Zenith, equal beamwidths at both channels (5.0°)	Operating
Transportable: Shipboard	2-channel 23.87, 31.4)	Zenith	Operating on RV Ala Moana
Airborne	2-channel (23.87, 31.65)	Zenith	Operating on NOAA P3 and NOAA King Air
Transportable	3-channel (20.6, 31.65, 90.0)	Steerable Full Sky Coverage, equal beam-widths (2.5°)	Operating in Erie, CO
Transportable	2-channel (23.87, 31.65)	Zenith equal beam-widths (2.5°)	Operating in Kavieng Papua NG

Table 1.

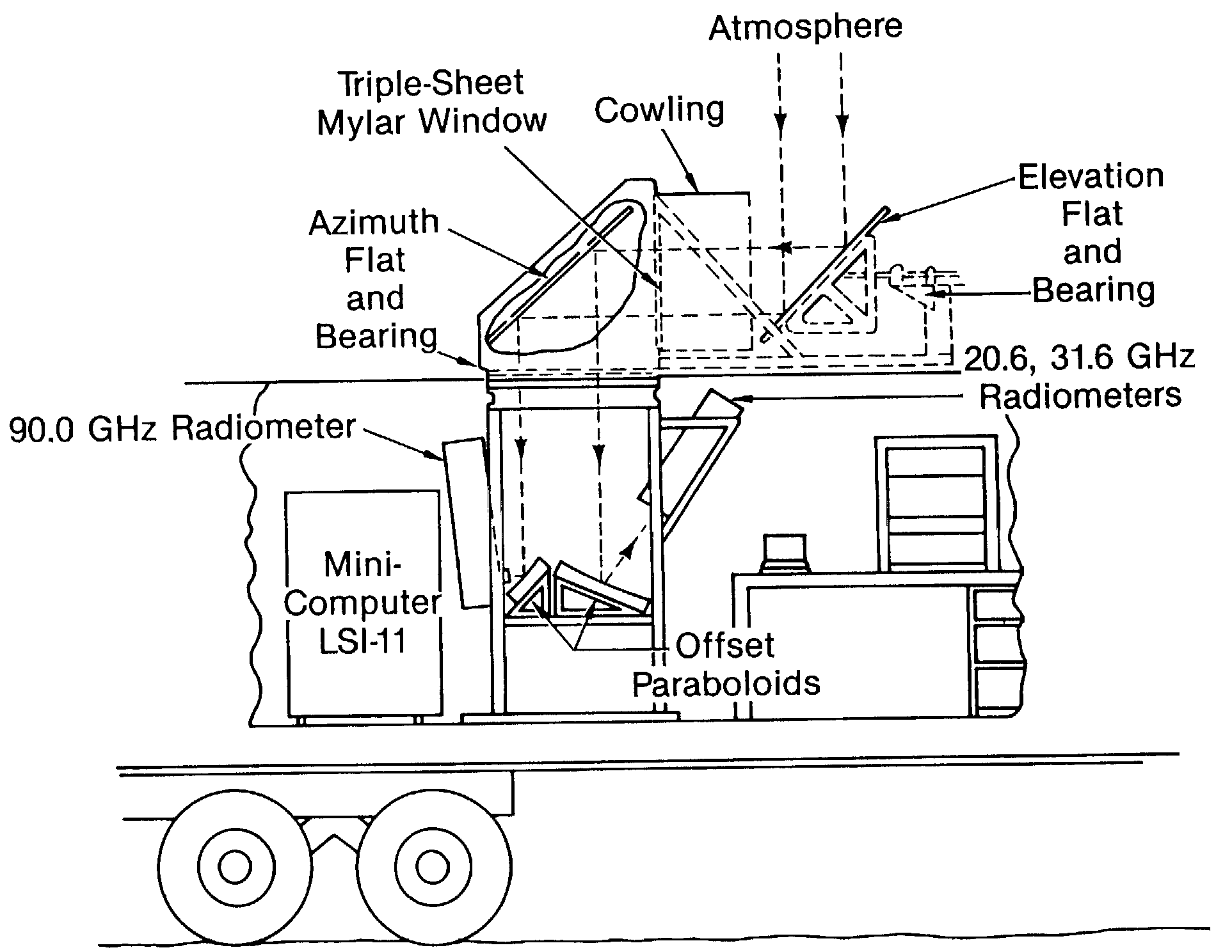
Atmosphere
Triple-Sheet
Mylar Window
Cowling
Elevation
Flat
and
Bearing
Azimuth
Flat
and
Bearing
20.6, 31.6 GHz
Radiometers
90.0 GHz Radiometer
Mini-
Computer
LSI-11
Offset
Paraboloids

Figure 1.

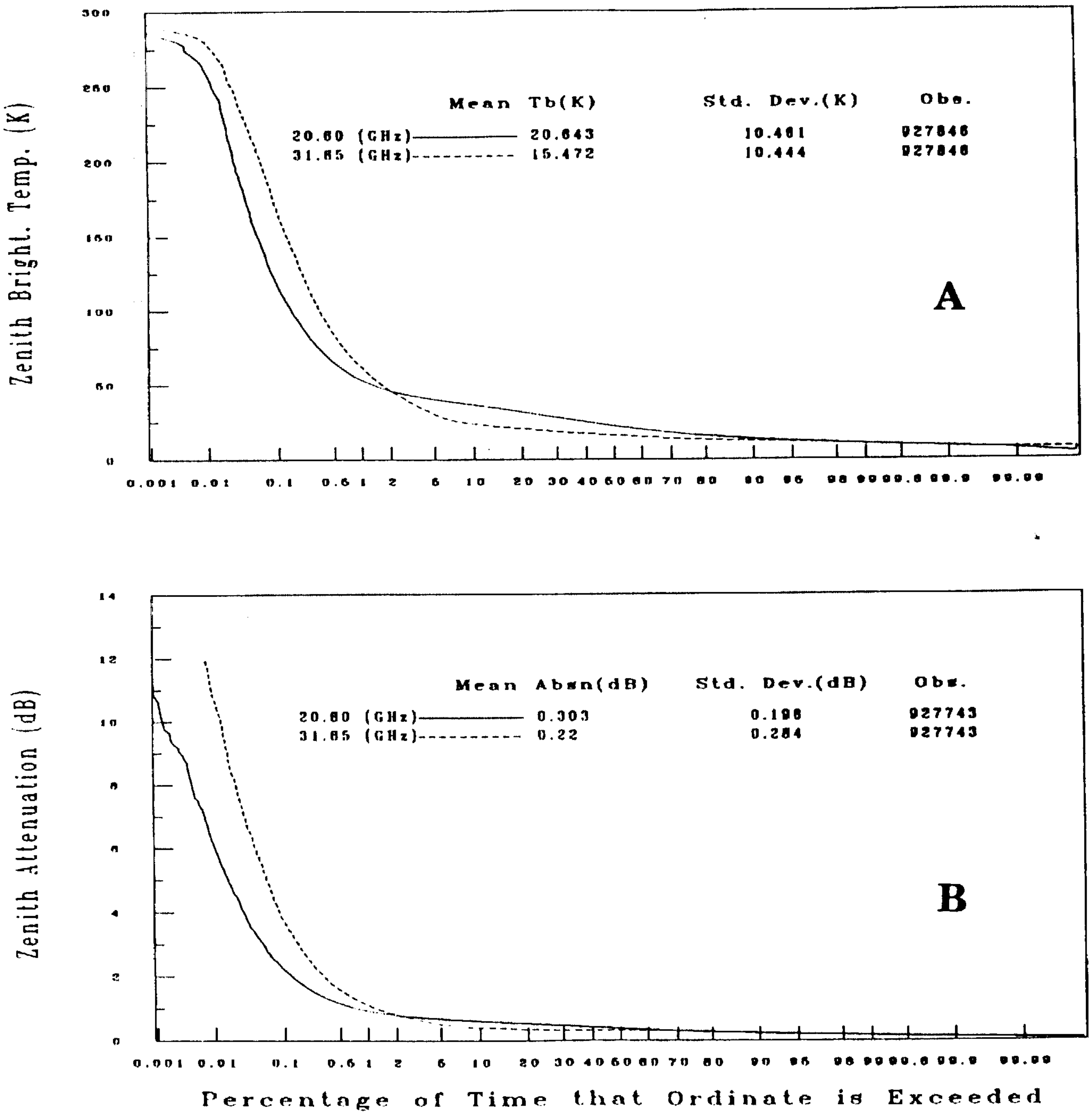
Zenith Bright. Temp. (K)
300
250
200
150
100
50
0
Mean Tb(K)
Std. Dev.(K)
Obs.
20.60 (GHz) 20.643 10.461 927846
31.65 (GHz) 15.472 10.444 927846
A
0.001 0.01 0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.9 99.99
Zenith Attenuation (dB)
14
12
10
8
6
4
2
0
Mean Absn(dB)
Std. Dev.(dB)
Obs.
20.60 (GHz) 0.303 0.198 927743
31.65 (GHz) 0.22 0.284 927743
B
0.001 0.01 0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.9 99.99
Percentage of Time that Ordinate is Exceeded

Figure 2.

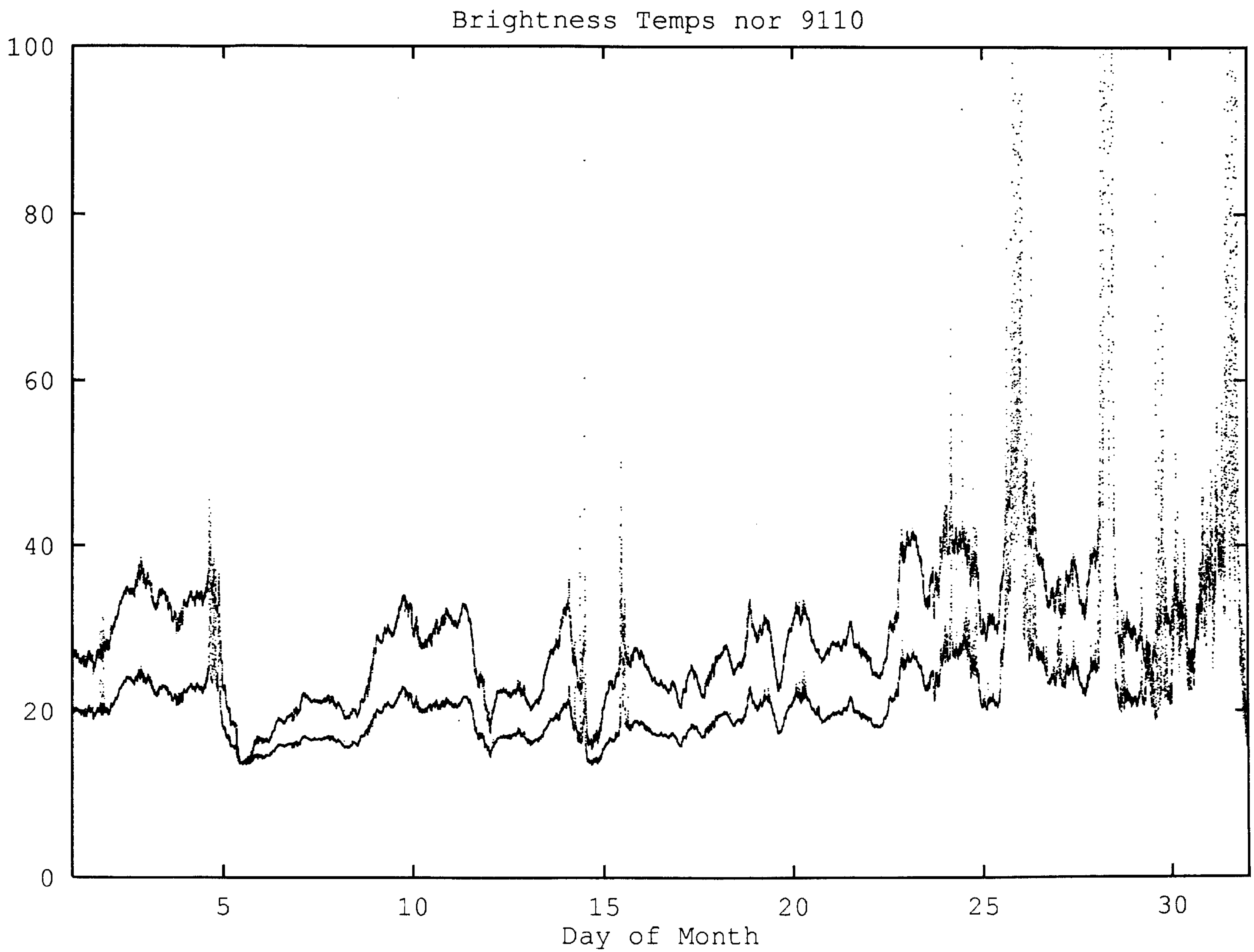
Brightness Temps nor 9110
100
80
60
40
20
0
5
10
15
20
25
30
Day of Month

Figure 3.

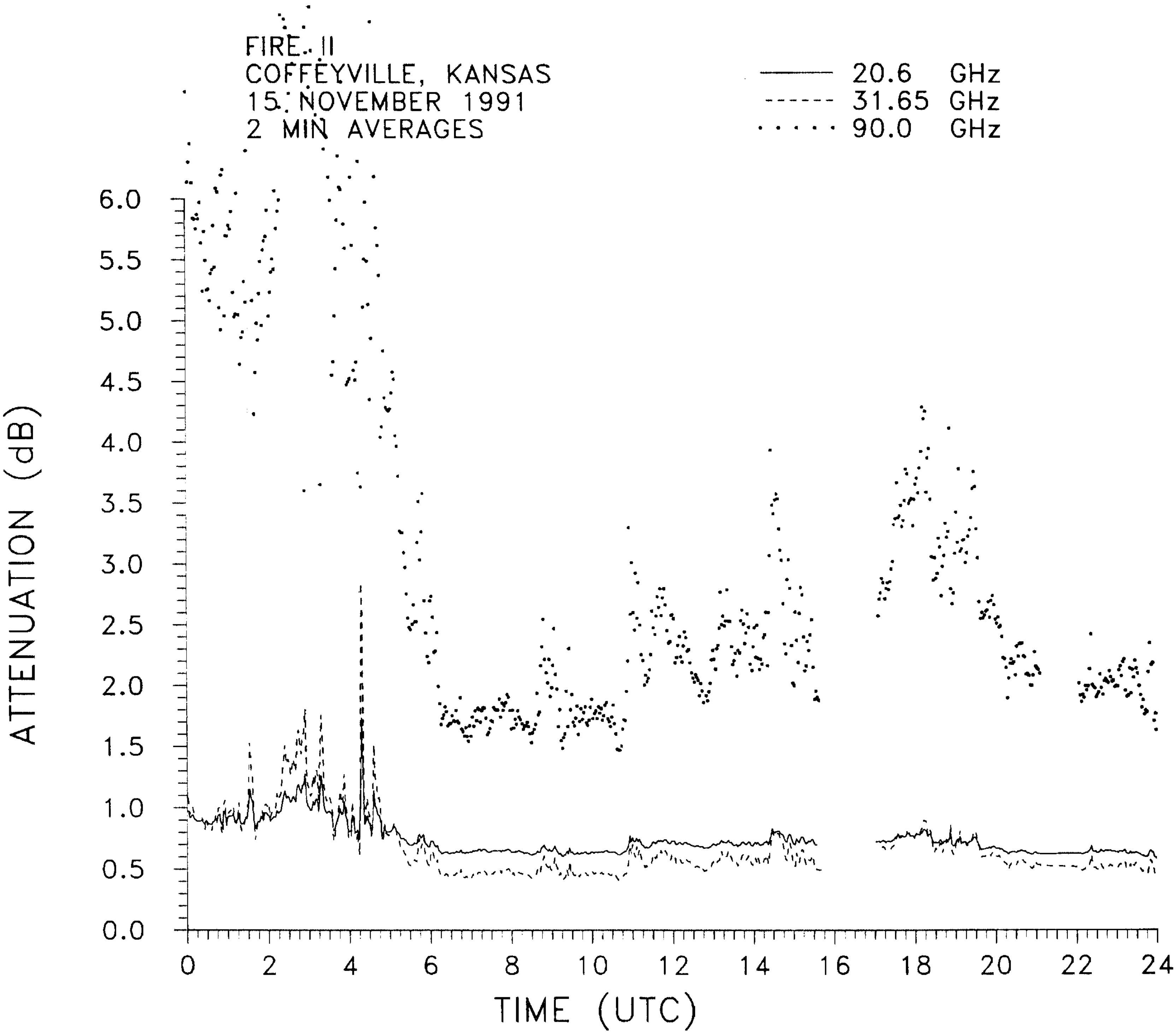
FIRE II
COFFEYVILLE, KANSAS
15 NOVEMBER 1991
2 MIN AVERAGES
20.6 GHz
31.65 GHz
90.0 GHz
ATTENUATION (dB)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (UTC)

Figure 4a.

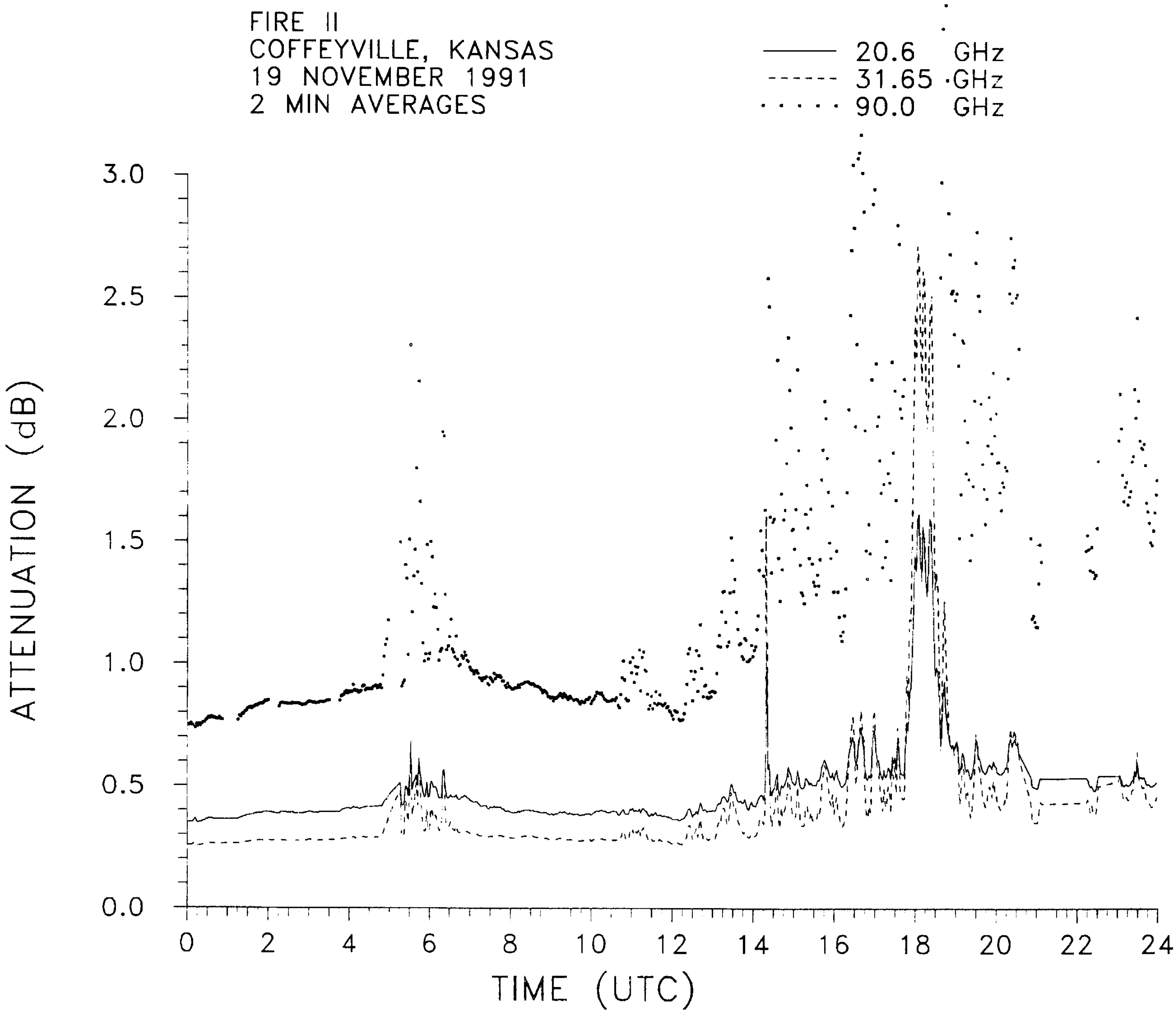
FIRE II
COFFEYVILLE, KANSAS
19 NOVEMBER 1991
2 MIN AVERAGES
20.6 GHz
31.65 GHz
90.0 GHz
ATTENUATION (dB)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (UTC)

Figure 4b.

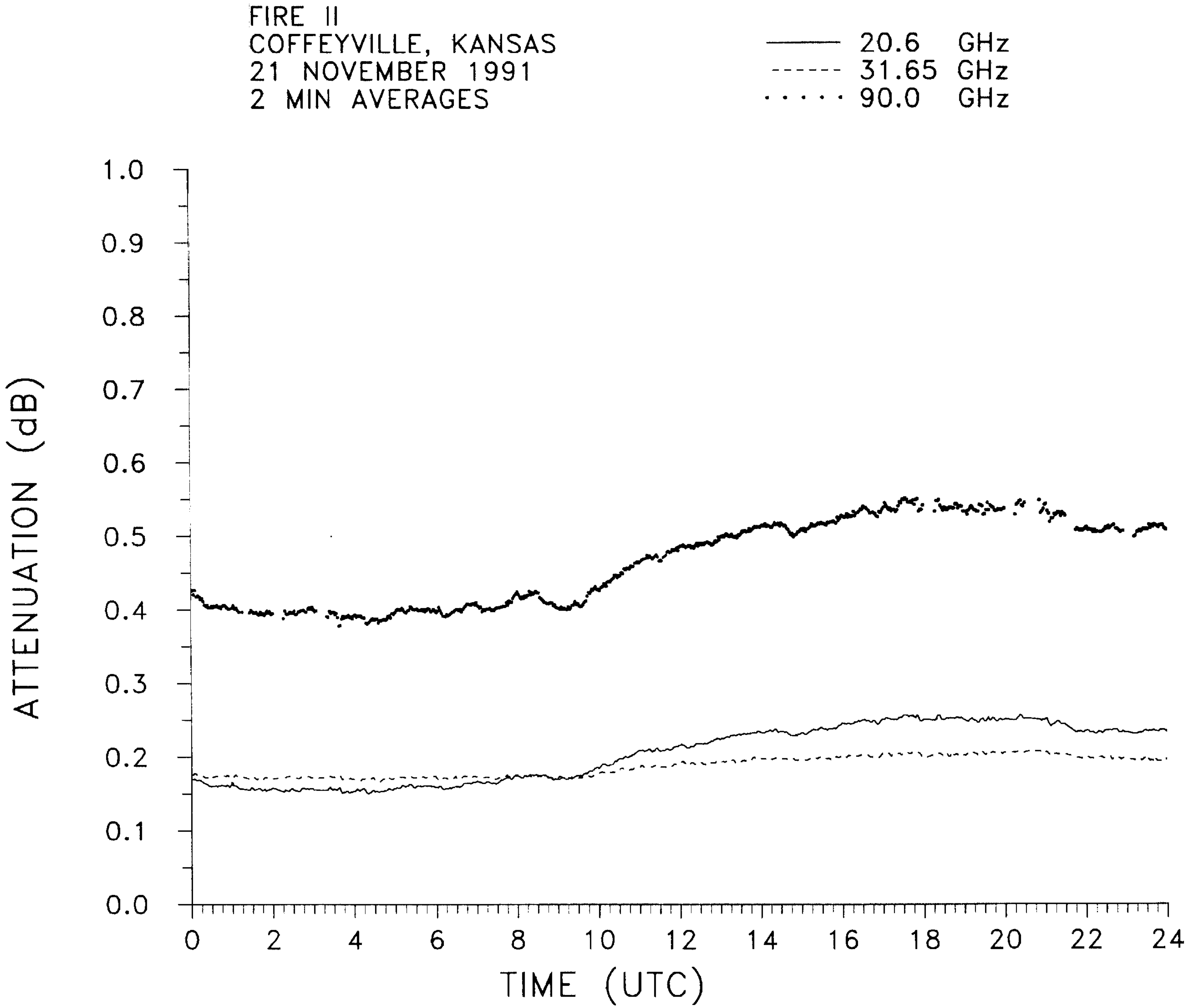
FIRE II
COFFEYVILLE, KANSAS
21 NOVEMBER 1991
2 MIN AVERAGES
20.6 GHz
31.65 GHz
90.0 GHz
ATTENUATION (dB)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (UTC)

Figure 4c.

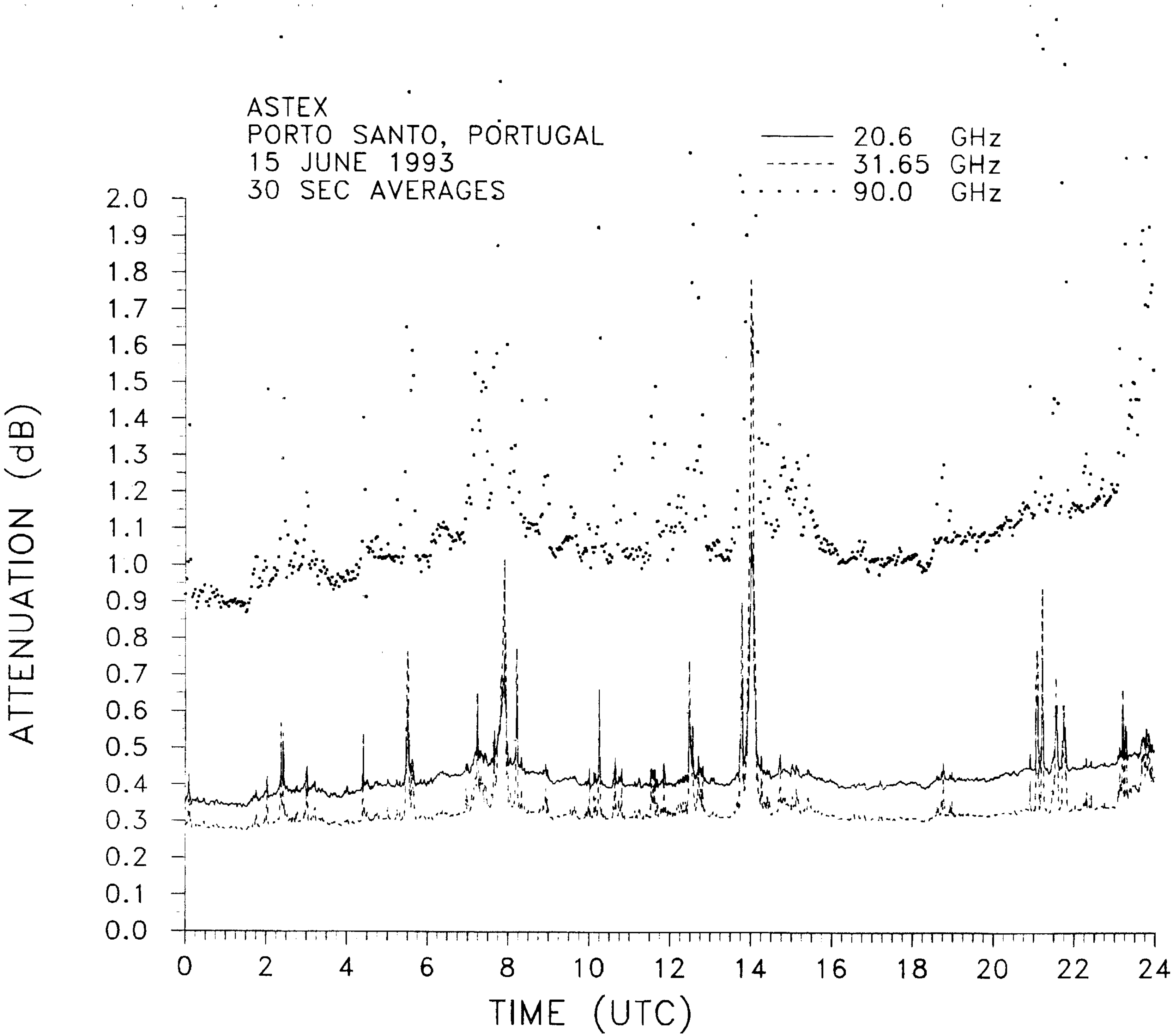
ASTEX
PORTO SANTO, PORTUGAL
15 JUNE 1993
30 SEC AVERAGES
20.6 GHz
31.65 GHz
90.0 GHz
ATTENUATION (dB)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (UTC)

Figure 5a.

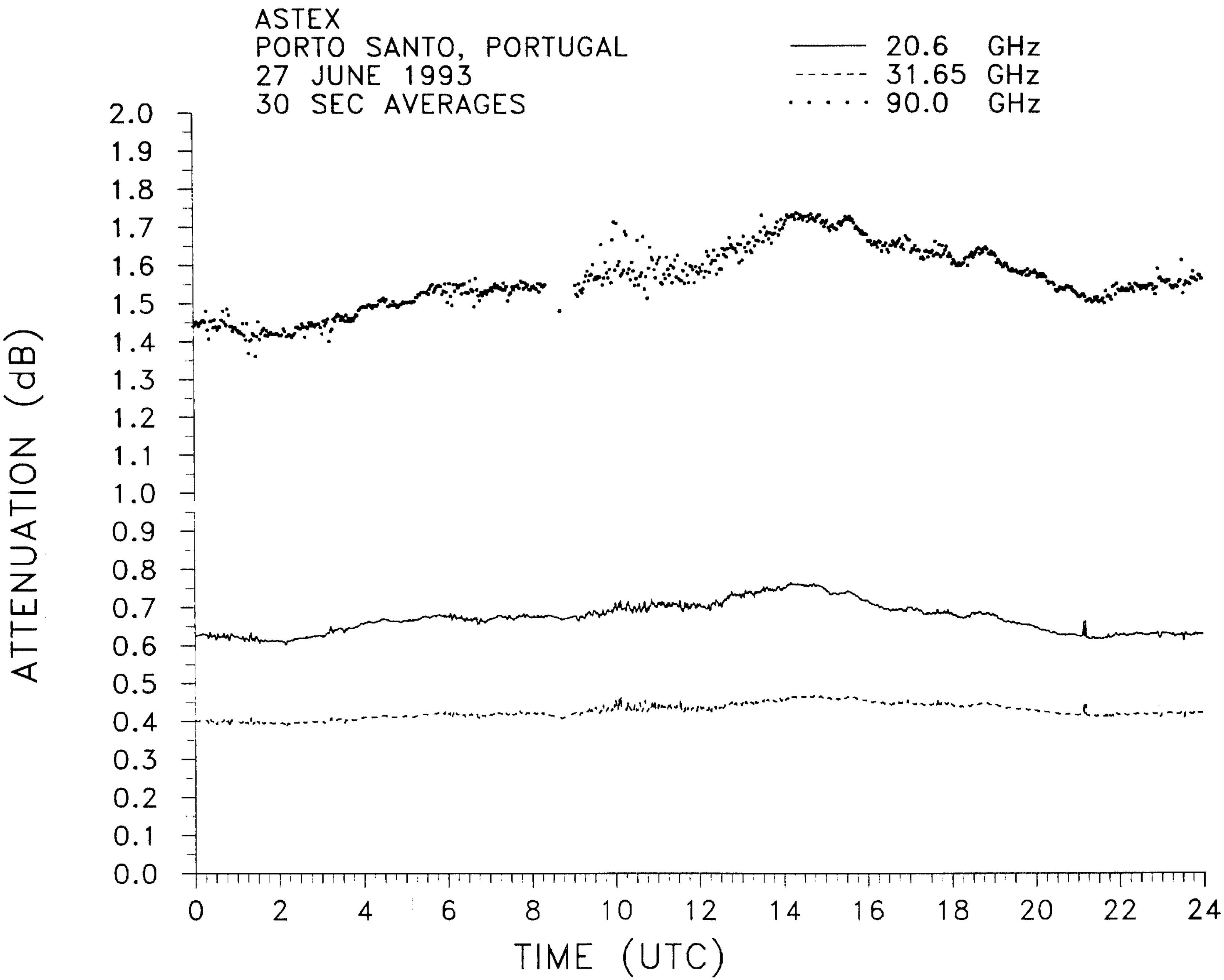
ASTEX
PORTO SANTO, PORTUGAL
27 JUNE 1993
30 SEC AVERAGES
20.6 GHz
31.65 GHz
90.0 GHz
ATTENUATION (dB)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (UTC)

Figure 5b.

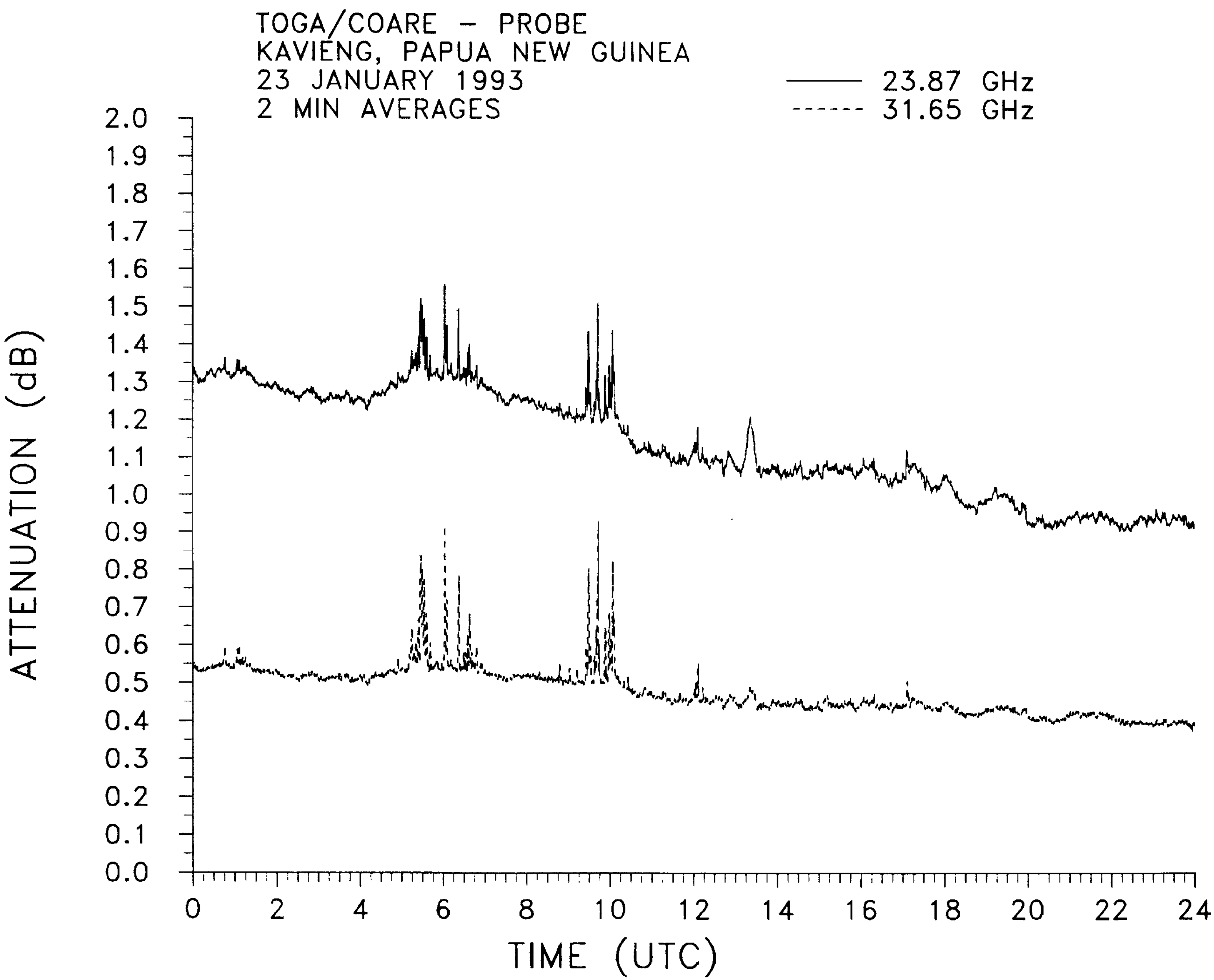
TOGA/COARE - PROBE
KAVIENG, PAPUA NEW GUINEA
23 JANUARY 1993
2 MIN AVERAGES
23.87 GHz
31.65 GHz
ATTENUATION (dB)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (UTC)

Figure 6a.

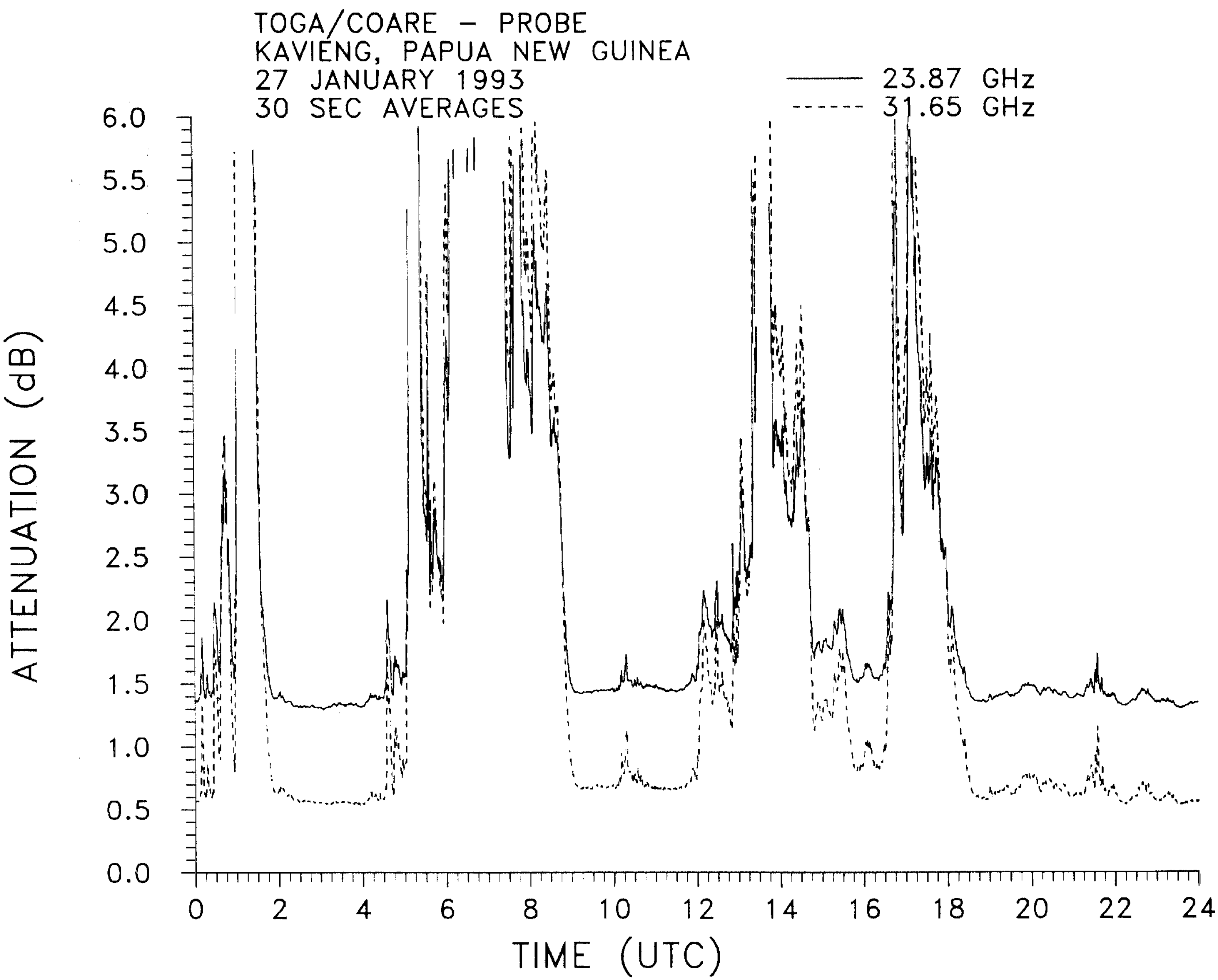
TOGA/COARE - PROBE
KAVIENG, PAPUA NEW GUINEA
27 JANUARY 1993
30 SEC AVERAGES
23.87 GHz
31.65 GHz
ATTENUATION (dB)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (UTC)

Figure 6b.

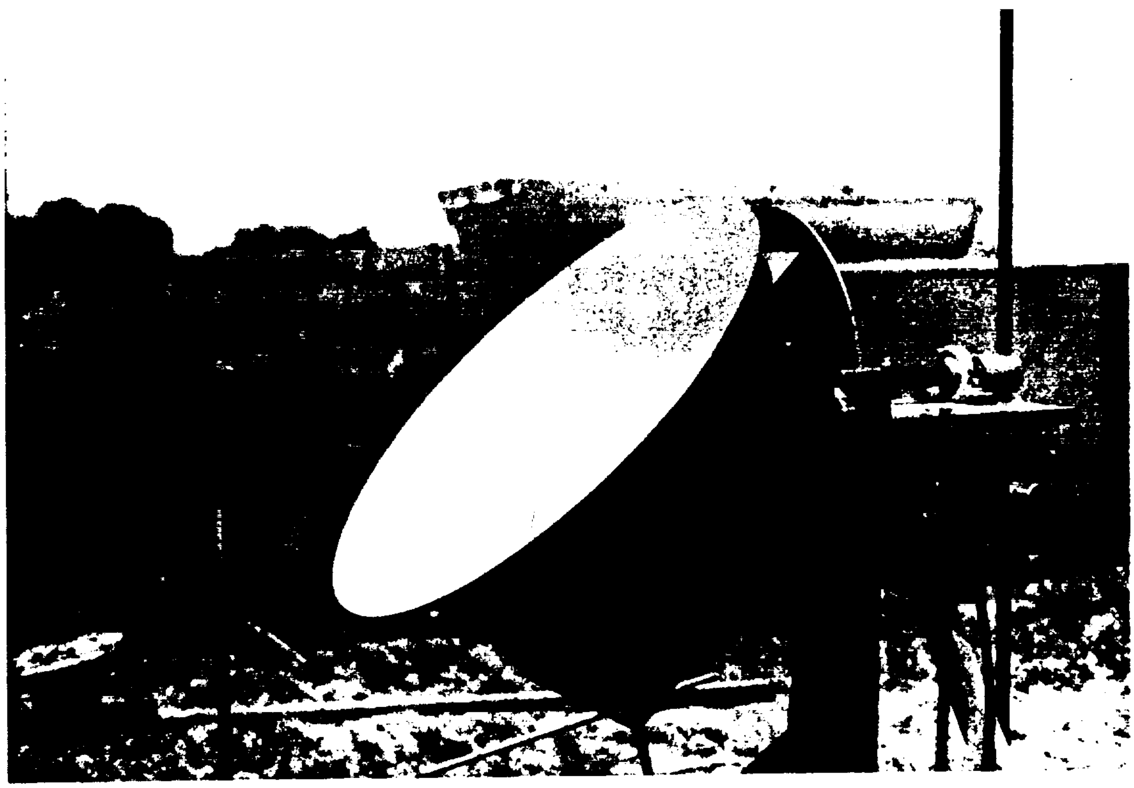

Figure 7.