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STATISTICAL RESULTS FROM THE VIRGINIA TECH PROPAGATION EXPERIMENT USING THE OLYMPUS 12, 20, AND 30 GHz SATELLITE BEACONS

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1. INTRODUCTION

Virginia Tech has performed a comprehensive propagation experiment using the Olympus satellite beacons at 12.5, 19.77, and 29.66 GHz (which we refer to as 12, 20, and 30 GHz). Four receive terminals were designed and constructed, one terminal at each frequency plus a portable one with 20 and 30 GHz receivers for microscale and scintillation studies. Total power radiometers were included in each terminal in order to set the clear air reference level for each beacon and also to predict path attenuation. More details on the equipment and the experiment design are found in [1].

Statistical results for one year of data collection have been analyzed. In addition, the following studies were performed: a microdiversity experiment in which two closely spaced 20 GHz receivers were used [2]; a comparison of total power and Dicke switched radiometer measurements, frequency scaling of scintillations [3], and adaptive power control algorithm development. In this paper we report on statistical results.

2. THE DATABASE

Data were collected from August 1990 through September 1992. The initial few months of operation were used for calibration and equipment adjustment. Beacon data for the period June through August, 1991, could not be used because the Olympus spacecraft was out of its assigned geostationary orbit. Since fall 1992 the inclination angle of the satellite has been high due to fuel conservation measures, no N-S stationkeeping is performed. This leads to severe diurnal fluctuations at our location, which renders the data of poor quality. The analysis year uses the following 12 months:

January - May, 1991; June - August, 1992; September - December, 1991

3. ATTENUATION STATISTICS

Perhaps the most important aspect of the Olympus propagation experiment is the attenuation statistics. These statistics include exceedance data for attenuation with respect to free-space (AFS), attenuation with respect to clear air (ACA), and radiometer derived attenuation (ARD). The most important data sets are those for which data exist simultaneously on all three frequencies. This permits direct comparison, frequency scaling, etc. Numerous graphs and tables on attenuation statistics have been generated.

Figure 1 shows exceedance plots of AFS and ARD for the analysis year for 12, 20, and 30 GHz. As is typical of radiometer data, ARD values are not accurate above about 10 dB. Comparison of AFS and ARD data leads to the following conclusions: (1) For fades of less than 3 dB, attenuation data derived from total power radiometer measurements can match beacon attenuation measurements to within 0.1 dB. (2) For fades up to 10 dB, attenuation data derived from total power radiometer measurements match beacon attenuation measurements to within 1 dB. These data are for a common time base; that is, data are used only when valid data exist on all three frequencies. Exceedance plots for individual frequencies and pairs of frequencies 12/20, 12/30 and 20/30 have also been generated.

Measured clear air attenuation (ACA), which is the loss of signal strength due to gases and water vapor present in the earth's atmosphere, is shown in Fig. 2 for the analysis year. Clear air attenuation predicted (from the CCIR model) and measured (50% occurrence level for the analysis year) values are: 0.3 and 0.68 dB for 12.5 GHz, 1.53 and 1.58 dB for 19.77 GHz, and 1.36 and 1.42 dB for 29.66 GHz.

Table 1 shows attenuation data at many occurrence levels for all frequencies.

4. ATTENUATION RATIOS

A unique aspect of the experiment is the controlled frequency dependence, i.e., all variables across the 12, 20, and 30 GHz receivers are identical. Therefore, any differences are due to frequency effects. Frequency dependence is presented in terms of attenuation ratio (RA). Attenuation with respect to clear air is used in RA calculations, because the clear air and rain frequency dependencies are much different and we wish to focus on the rain component. Plots of attenuation ratios for 30 to 20 GHz of a function of percent time of occurrence and as a function of the lower frequency attenuation level are shown in Fig. 3 for the analysis year. It is emphasized that RA is the instantaneous attenuation ratio and is obtained from the instantaneous data pairs at the two frequencies. This ratio relates directly to frequency scaling applications such as adaptive power control. It is noted that RA for 30/20 is very flat indicating potential application to adaptive control. Note from Fig. 3b that the median for the 30/20 ratio is about 2 at all levels with a spread from 1 to 99% between 1.4 and 2.6.

Statistical attenuation ratio (RAS), defined as the ratio of attenuation values obtained from cumulative attenuation statistics at the same level of occurrence, was also studied. The instantaneous nature of frequency scaling is not present in this parameter. Figure 4 compares the median values of RA to RAS for 30/20; similar results were obtained for 30/12 and 20/12. The excellent agreement between RA (50%) and RAS indicates that RAS, which is easily computed from separate exceedance statistics, is an accurate predictor of median instantaneous attenuation ratio.

5. SECONDARY STATISTICS

The secondary statistics include fade duration, interfade (non-fade) duration, fade slope, and ultimate fade depth. These statistics are valuable to system designers and also aid in the understanding of the nature of fading. Fade duration, FD, is defined as the length of time in seconds for which the attenuation with respect to clear air, ACA, exceeds a specified threshold level. Interfade duration is the complement of fade duration.

Fade and interfade durations statistics have been generated for threshold levels of -3, -1, 0, 1, 3, 5, 10, 15, 20, and 25 dB and durations exceeding 1, 6, 10, 20, 60, 600, and 3600 seconds. At each frequency, plots of the number of fade/non-fade events and the fade/interfade time as the percent time of the year for which data were collected versus fade/interfade duration are given for several threshold values. In order to eliminate the effect of scintillations on the number of fade/interfade events 10-second block averages of attenuation have been used. Fade duration statistics for the month of July 1992 are presented in Fig. 5 which illustrates the number of fades versus fade duration at 12, 20, and 30 GHz for several threshold levels. As an example, for a threshold level of 5 dB the number of fades with fade durations exceeding 10 seconds is 34 at 12 GHz, 87 at 20 GHz, and 164 at 30 GHz. It is observed that for the same fade duration exceeded the number of fade events generally decreases with the threshold level. A deviation from this trend occurs at 20 GHz for fade durations less than 60 seconds and threshold levels of 1 and 3 dB. In other words, the number of fade events with duration exceeding 1, 6, 10, and 20 seconds at 3 dB exceeds that at 1 dB by few hundreds for the 20 GHz beacon. Such behavior at low threshold levels and short fade durations should not be surprising. Comparison of Figs. 5 a, b, and c, also indicates that for the same threshold level (>3 dB) and the same fade duration exceeded, the number of fade events at 12 GHz is less than that at 20 GHz which in turn is less that at 30 GHz. For threshold levels of 1 and 3 dB no consistent behavior prevails.

Fade slope is the time rate of change of attenuation in units of dB/second. The ESA definition of fade slope at a given threshold level fade is the difference between attenuations (in dB) 5 seconds before the threshold is crossed and 5 seconds after the threshold is crossed divided by 10 (seconds). In order to alleviate sensitivity to small variations in the received signal, 10-second block averages of attenuation are used here in the calculation of fade slope. Attenuation block average is calculated from stored values of attenuation in dB in the i^{th} 0.1-s interval from the beginning of the day (00:00:00 UT), AFS_i. The block averaged attenuation values are found from

$$AFSB_m = \frac{1}{100} \sum_{i=m-49}^{m+50} AFS_i \qquad \text{[dB]}$$

Fade slope is calculated from block averages at the i^{th} sample point as

$$FSB_i\left(\overline{AFS_i}\right) = \frac{\left(AFSB_{i+50} - AFSB_{i-50}\right)}{10} \qquad \text{[dB/s]}$$

where $\overline{AFS_i}$ is the threshold attenuation with respect to freespace at the i^{th} time sample obtained by averaging over the central 10-s period:

$$\overline{AFS_i} = \frac{1}{100} \sum_{j=i-49}^{i+50} AFS_j \qquad \text{[dB]}$$

At each frequency we determine fade slope FSB for attenuation (AFS) thresholds ranging from -8 to 39 dB in 1 dB steps. Fade slopes are sorted into 0.05 dB/second bins. Plots of fade slope statistics for each channel and for several threshold levels have been generated for the analysis year and are displayed in Fig. 6.

Figure 7 plots the fade slope and attenuation at 20 GHz in real time of one rain event that occurred on May 14, 1991. The fade slope and attenuation for this plot were generated using a 3-minute moving block average which eliminated small variations in attenuation and made the first derivative relation between fade slope and attenuation evident. Data points were plotted every 30 seconds beginning at 17:50 GMT and ending at 18:32 GMT on May 14, 1991.

6. CONCLUSIONS

Results from a comprehensive propagation experiment involving beacon and radiometric measurements at 12, 20, and 30 GHz for one year of data were presented. Radiometer derived attenuations agree well with beacon measured attenuations for fade levels below 10 dB. Attenuation statistics, attenuation ratios, fade and interfade durations, and fade slope for all three frequencies have been examined.

REFERENCES

[1] W.L. Stutzman et al., "Initial results from the 12, 20, and 30 GHz OLYMPUS propagation experiment in Blacksburg, Virginia," IEEE AP-S Inter. Symp. Digest (Chicago), pp. 736-739, July 1992.

[2] J.C. Cardoso, A. Safaai-Jazi, and W.L. Stutzman, "Microdiversity in satellite communications," to appear in IEEE Trans. on Ant. and Prop..

[3] F. Haidara and C.W. Bostian, "Preliminary results on scintillation intensity frequency scaling from the Virginia Tech OLYMPUS experiment," IEEE AP-S Inter. Symp. Digest (Chicago), pp. 301-304, July 1992.

[4] W.L. Stutzman and K.M. Yon, "A simple rain attenuation model for earth-space radio links operating at 10 - 35 GHz," Radio Science, vol. 21, pp. 65-72, Jan/Feb 1986.

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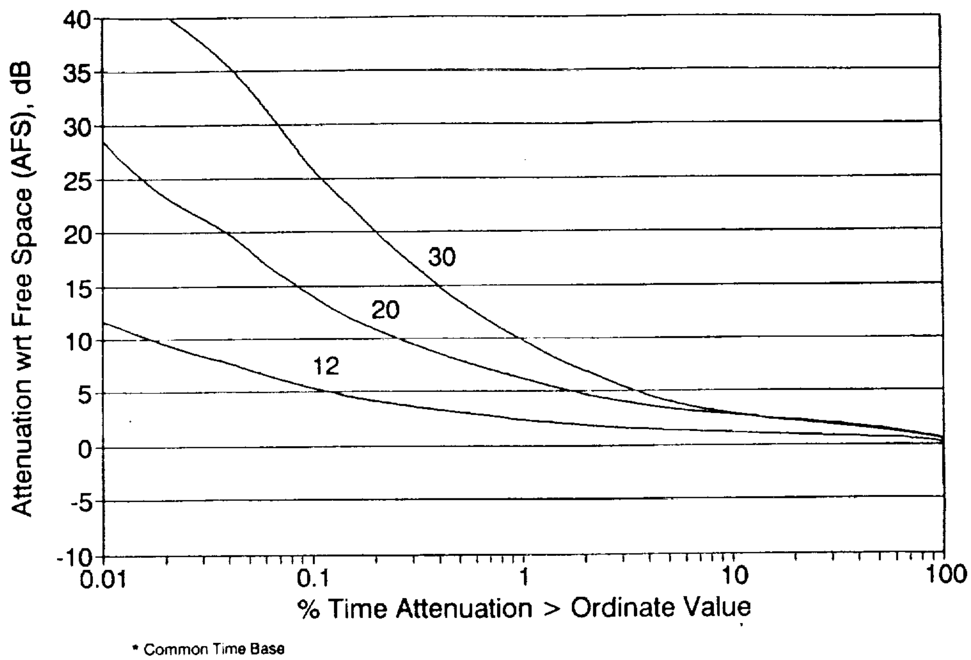
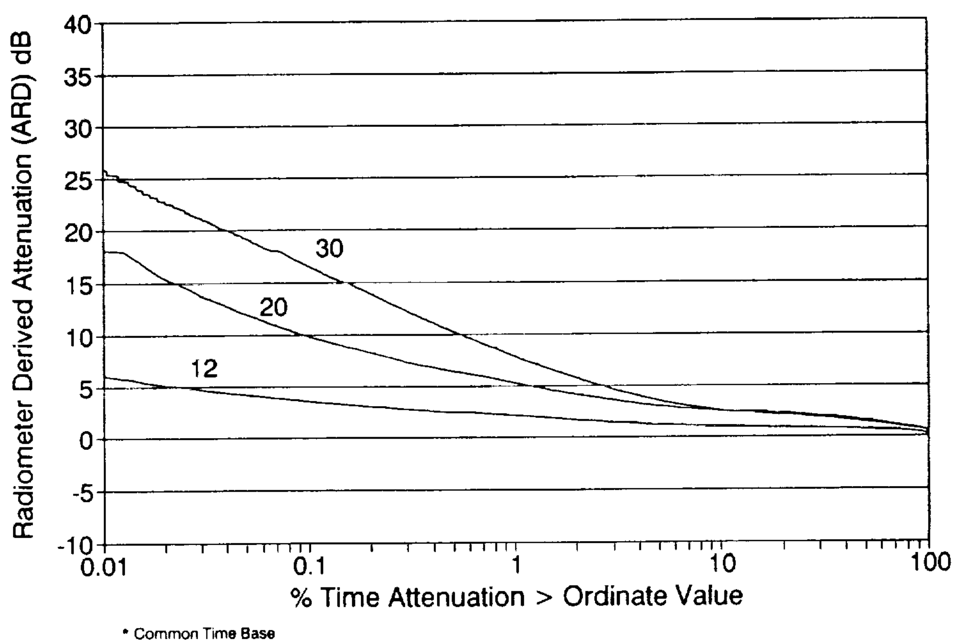
Table 1

Measured Attenuation Statistics for One Year of Data

Percent Time Exceeded	AFS			ARD			ACA		
	12	20	30	12	20	30	12	20	30
50.000	0.68	1.58	1.42	0.70	1.55	1.41	0.01	0.04	0.04
30.000	0.85	2.03	1.89	0.81	1.97	1.82	0.10	0.17	0.20
20.000	0.96	2.31	2.23	0.86	2.23	2.08	0.17	0.31	0.36
10.000	1.17	2.77	2.89	0.98	2.59	2.62	0.31	0.65	0.82
5.000	1.42	3.37	4.04	1.19	3.08	3.61	0.51	1.22	1.88
3.000	1.67	4.05	5.50	1.41	3.68	4.69	0.71	1.88	3.33
2.000	1.91	4.70	6.93	1.65	4.22	5.78	0.94	2.54	4.76
1.000	2.42	6.21	9.87	2.08	5.33	7.83	1.41	4.04	7.69
0.500	3.04	7.93	13.55	2.50	6.46	10.29	2.03	5.76	11.38
0.300	3.61	9.47	16.99	2.79	7.32	12.16	2.59	7.31	14.82
0.200	4.12	10.90	20.08	3.08	8.21	13.85	3.11	8.73	17.90
0.100	5.39	14.11	26.05	3.63	9.86	16.57	4.37	11.93	23.87
0.050	7.10	18.37	33.47	4.26	11.92	19.13	6.08	16.21	31.29
0.030	8.38	21.28	37.66	4.75	13.66	21.13	7.37	19.12	35.50
0.020	9.50	23.31		5.12	15.39	22.60	8.48	21.15	38.06
0.010	11.74	28.60		6.09	18.08	25.83	10.72	26.43	
0.005	13.92	33.55		7.47	20.72	28.39	12.90	31.37	
0.003	14.96	36.44		10.18	22.84	31.32	13.94	34.27	
0.002	15.67	38.56		18.05	24.39	31.39	14.65	36.39	
0.001	17.16				27.33		16.14		



(a)



(b)

Figure 1. Measured results at 12, 20, and 30 GHz for the analysis year of Jan-May and Sep-Dec, 1991 and Jun-Aug, 1992: (a) Attenuation with respect to free space (AFS), (b) Attenuation derived from radiometer data (ARD). A common time base is used for all three frequencies.

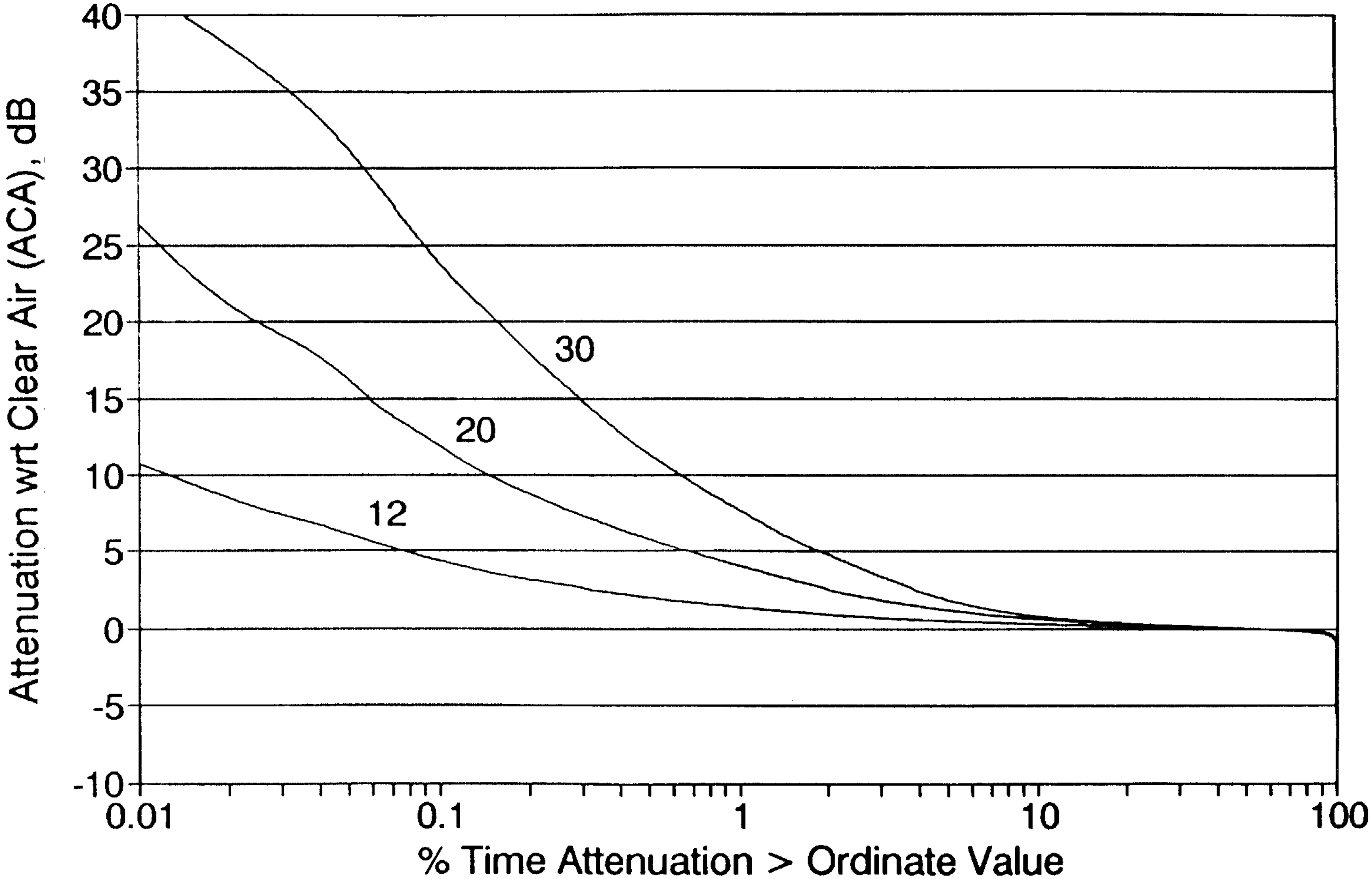
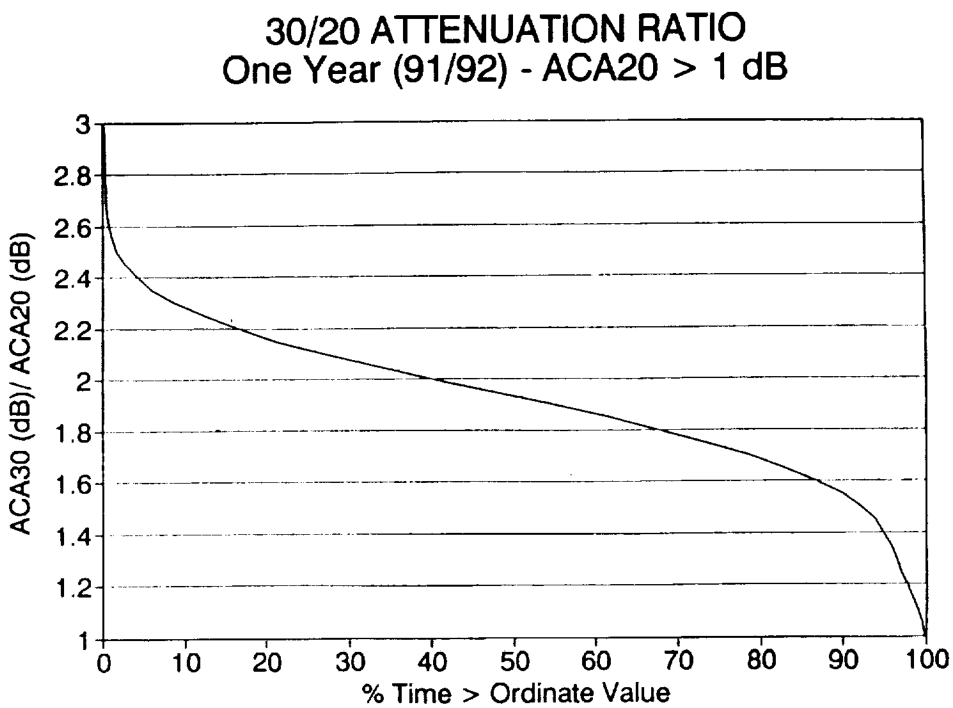
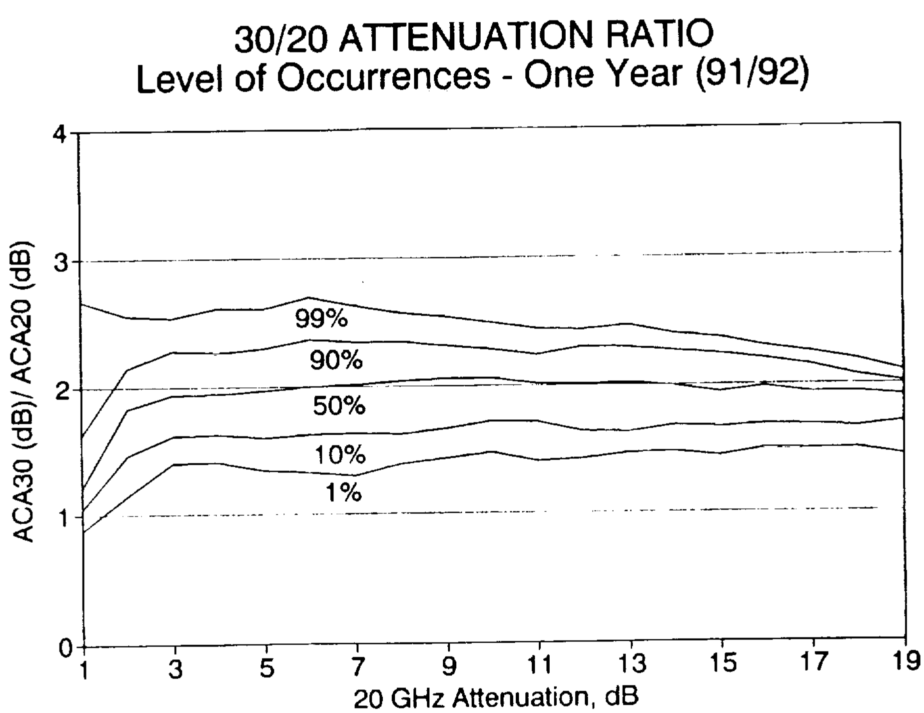


Figure 2. Measured results for ACA at 12, 20, and 30 GHz for the analysis year of Jan-May and Sep-Dec, 1991, and Jun-Aug, 1992. A common time base is used for all three frequencies.



(a)



(b)

Figure 3. Attenuation ratio (RA) for frequency pairs 30/20 for the analysis year: (a) As a function of percent time, (b) As a function of 20 GHz attenuation.

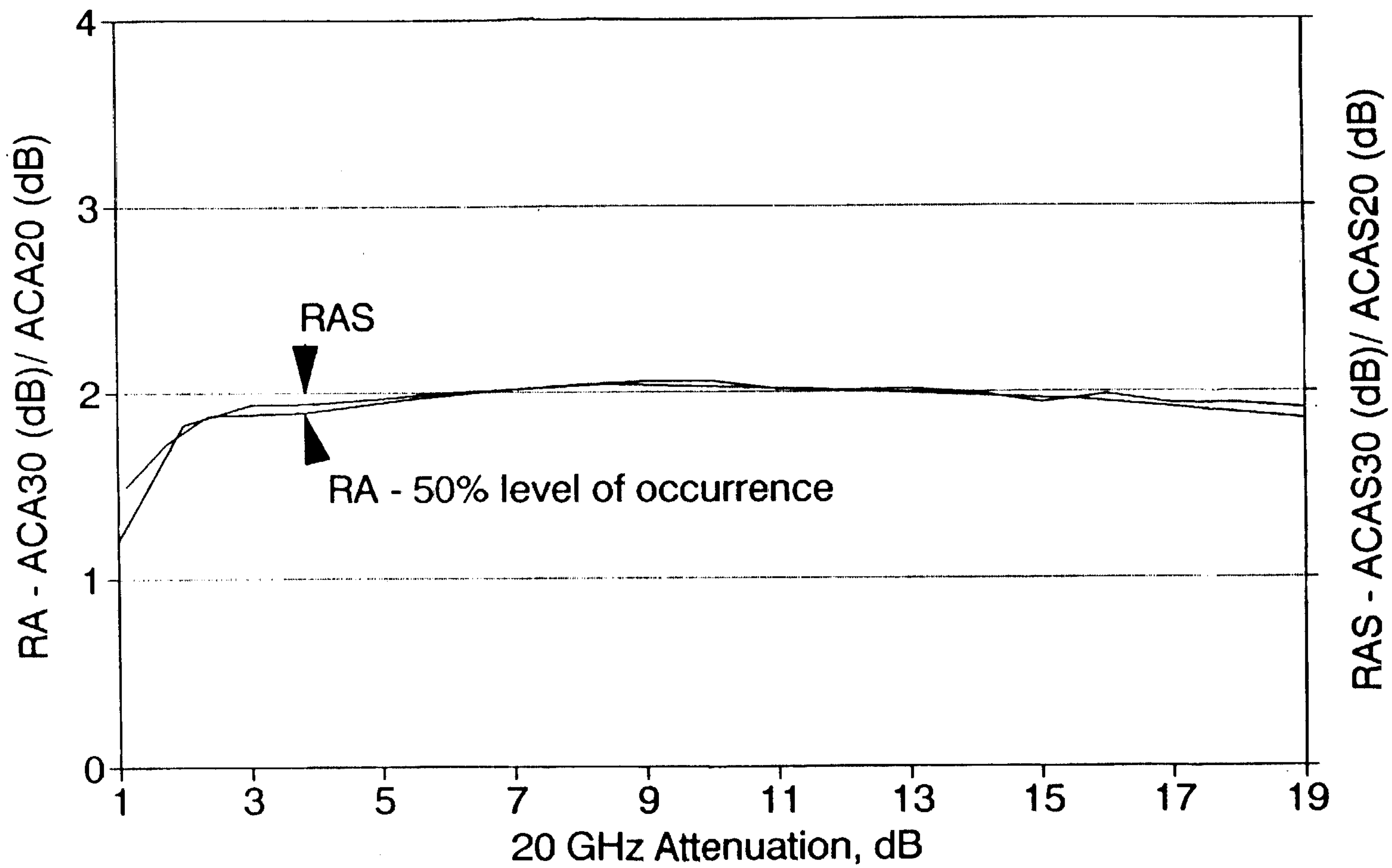


Figure 4. Comparison of statistical attenuation ratio (RAS) to median instantaneous ratio (RA) for 30/20.

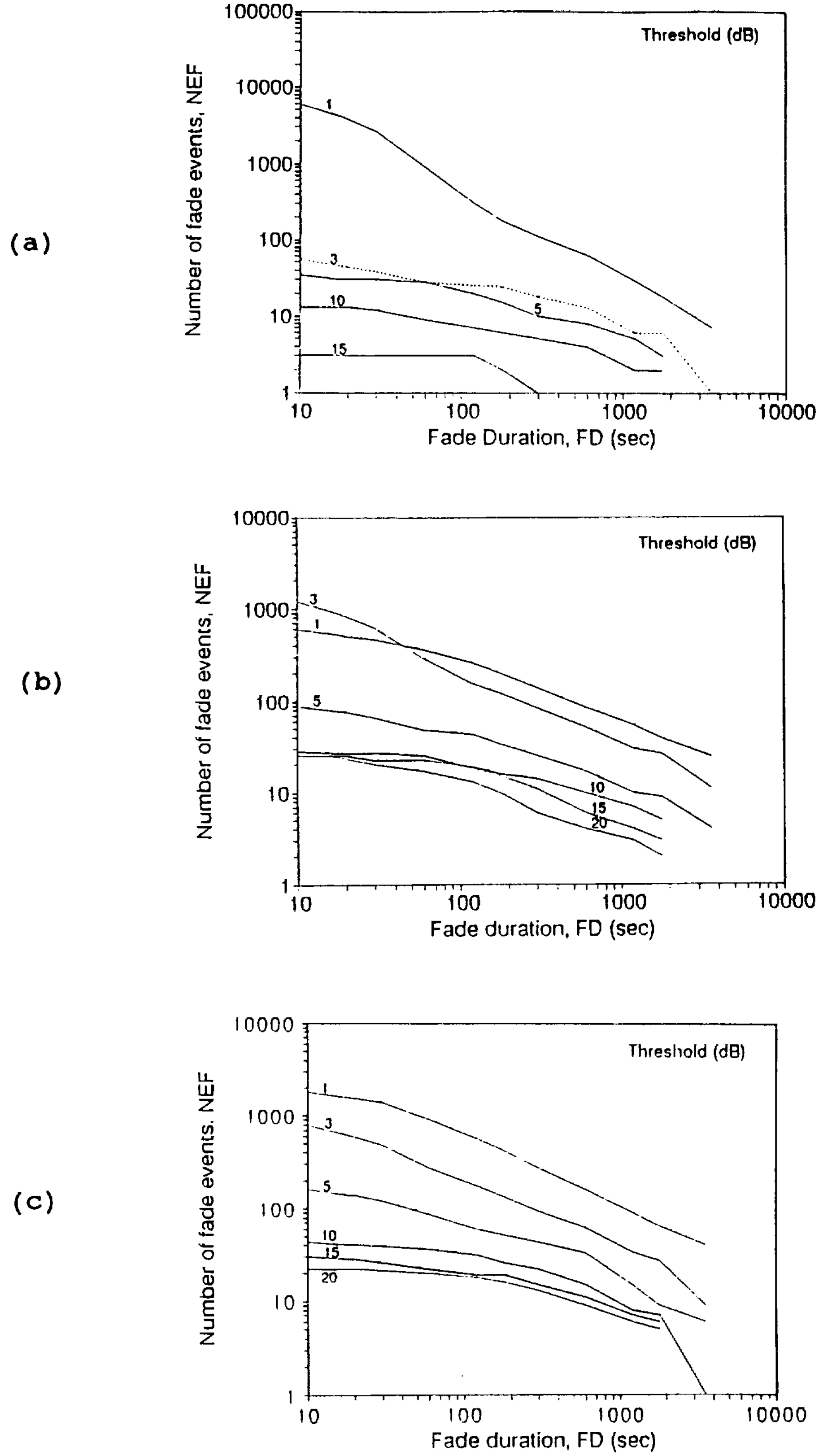


Figure 5. Number of fade events versus fade duration for the month of July 1992 at (a) 12 GHz, (b) 20 GHz, and (c) 30 GHz.

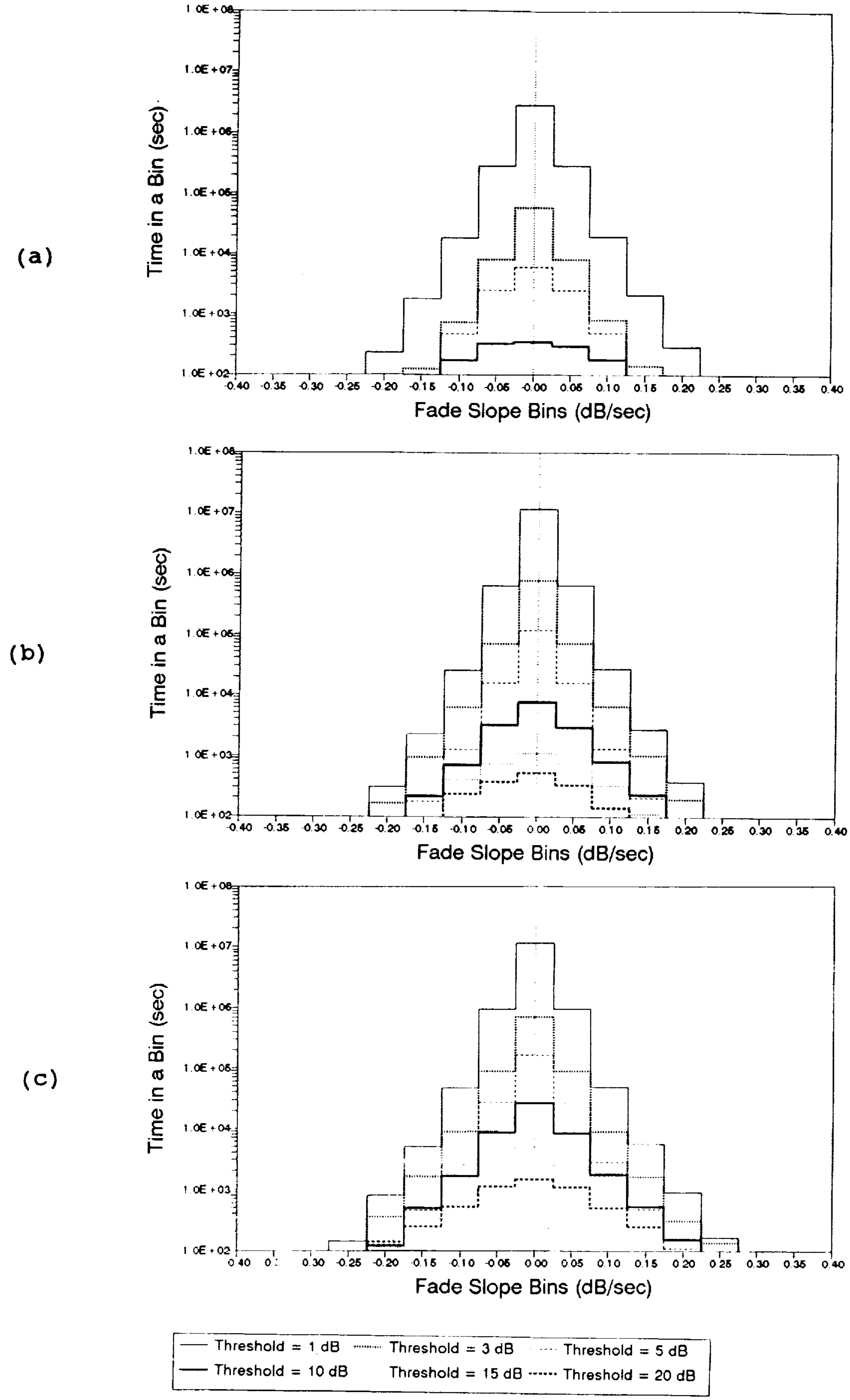


Figure 6. Fade slope ($\overline{FSB}$) for the analysis year for (a) 12 GHz, (b) 20 GHz, and (c) 30 GHz.

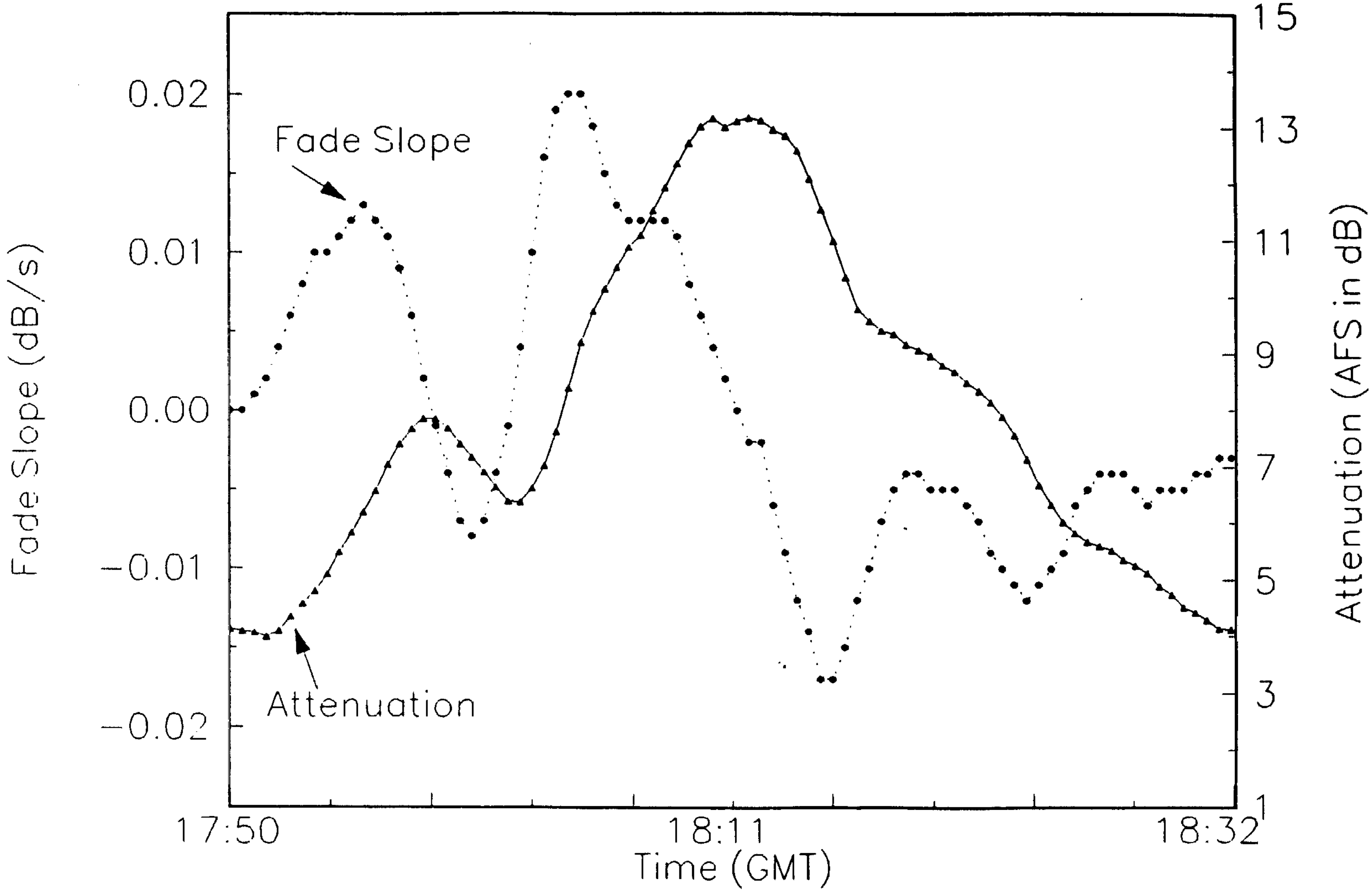


Figure 7. A typical rain event (May 14, 1991) showing fade and fade slope (3-minute block averaged).