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PROGRESS REPORT ON OLYMPUS PROPAGATION EXPERIMENTS

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ABSTRACT

A summary of the activities of the OPEX (Olympus Propagation EXperimenters) group is given and some of the recent findings are presented.

1. BACKGROUND

OLYMPUS, a telecommunication satellite owned by the European Space Agency, was launched on 12 June 1989. After the in-orbit tests were completed (in September 1989) the first propagation experiments started. Throughout 1990 the spacecraft functioned very well and a large number of experimenters received the beacon signals. On 29 May 1991 the spacecraft became in-operational after a major technical problem. With a series of complicated procedures OLYMPUS was recovered on 15 August 1991 - the first time in history that a civilian telecommunications satellite was brought back to service after losing power and telemetry. The propagation experiments were back on the track. However, the recovery had used up so much fuel that the North-South station keeping had to be abandoned, which led to a natural increase of inclination at a rate of about 0.8° per year. On 10 October 1992 the second 30 GHz beacon tube failed, causing a loss of this beacon signal. The other two beacon frequencies continued to deliver a stable signal for more than two years. On 12 August 1993 the spacecraft experienced another problem with the attitude control, but this time there was not enough fuel left for a recovery maneuver and thus the mission had come to an end.

The table below gives a summary of the operational status of the OLYMPUS beacon payload:

	1989	1990	1991	1992	1993
Spacecraft bus	=====	==============	===== ====	============	========
B0 beacon (12.5 GHz)	===	==============	===== ====	============	========
B1 beacon (19.7 GHz)	===	==============	===== ====	============	========
B2 beacon (29.6 GHz)	===	==============	===== ====	==========	

Table 1: *Availability of beacon signals from OLYMPUS*

During the operational phase of the OLYMPUS satellite, the OPEX group met twice per year (OPEX 13 to OPEX 20) to discuss the measurements, the data processing and analysis procedures and to interpret the first results.

AFTER the early demise of OLYMPUS on 12 August 1993, the propagation experimenters concentrated on the analysis of the data collected.

2. DATA ANALYSIS AND COLLECTION OF STATISTICAL RESULTS

The data of most experiments were pre-processed using the DAPPER software [1] which was jointly defined by the members of the OPEX group. Also the analysis was done with DAPPER, although alternate approaches which followed the same philosophy were also used. In order to allow easy access to the statistical results of the different experiments and in particular to use the results for testing prediction methods, a database management system named DBOPEX has been set up which is completely compatible with the ITU-R SG5 electronic databank [2]. The experimenters convert their data to the DBOPEX flat file format and upload them to the ESTEC FTP server. There the data are imported into the existing database and stored in DBF (dBASE) format. The DBOPEX package itself is a self contained database management system written in CLIPPER (designed to run on MS-DOS compatible platforms). The user can:

- inspect the data (Browse-mode),
- set up the print format and print the data,
- make queries on the database to select data that meet certain conditions,
- extract the data to an ASCII file for further processing (e.g. for model tests),
- edit existing data and append new data,
- import data from a flat ASCII file which has the format of the "EXPORT"-file.

Compatibility with the ITU-R database facilitates the submission of the data to the ITU-R Study Group 3.

3. AVAILABLE ATTENUATION STATISTICS

The following table was prepared by the coordinator of the Attenuation Working Group [3].

Location and Country		Source	Analysed time period (MO/YR)
Darmstadt	DE	B1V, B2	01/90 - 12/90 & 10/91 - 09/92
Oberpfaffenhofen	DE	B1H	01/92 - 06/92
Eindhoven	NL	B0 B1V B1H B2 Radiometer (12/20/30)	09/90 - 08/93 12/90 - 08/93
Martlesham	GB	B0 B1V B2	11/89 - 05/91
Chilton	GB	B2	06/90 - 05/91
Albertslund	DK	B1V B2 Radiometer (20/30)	10/91 - 09/92 10/91 - 09/92
Spino d'Adda	IT	B0 B1V	08/92 - 08/93
Rome	IT	B0 B1H	01/92 - 12/93
Verona	IT	B1H	04/92 - 12/92
Naples	IT	B1H	03/92 - 12/92
Lessive	BE	B0 B1V B1H	01/90 - 12/90 & 01/92 - 12/92

Table 2: *Completed analysis of OPEX attenuation data (Status as of May 1994)*

4. RECENT FINDINGS

This section presents some results published since the OLYMPUS Utilization Conference in Seville [4], namely at OPEX 20 [5] and at OPEX 21 [6].

○ Attenuation and scintillation

A few experiments have so far provided cumulative statistics of attenuation [7]. Comparison with predictions (according to ITU-R Rec 618) generally shows reasonable agreement. In the low-margin region from 1 to 10 percent of the year however, the non-rain effects become dominant and here the current prediction methods which are based on Ku-band observations are not sufficient.

For fade durations several investigations were carried out [8],[9]. A modelling exercise [10] showed that the previously held assumption that the statistics of short fades can be described by a power-law function and that of long fades by a log-normal function ("COST 205 model" [11]) is still valid. However, the breakpoint between long and short fades is no longer 32 seconds but rather 1 minute.

Scintillations are particularly important for low margin systems. Spectral analysis of scintillation events at 20 and 30 GHz confirm the expected -8/3 slope of the power density with a corner frequency of between 0.1 and 0.5 Hz.

○ XPD

Depolarization can become a problem when frequency re-use is employed. For obtaining good depolarization data, complex procedures had to be established to remove all equipment effects [1],[3]. Comparison of experimental results with existing prediction models (ITU BR Rec 618) showed that ice induced XPD (which also occurs at clear sky conditions) is not properly accounted for in the prediction. This observation already lead to the development of "two population" hydrometeor models, where a clear distinction of the rain and ice induced depolarization mechanisms is made .

○ Impairment Restoration

Uplink power control was traditionally suffering from the need to scale the fade measured at the downlink frequency to the frequency used for transmitting. Instantaneous frequency scaling from 20 to 30 GHz has been studied by many experimenters and prediction errors of up to +/- 3 dB were found when applying a constant conversion factor. A small cell of intensive rain (large drops) can give the same path attenuation at 20 GHz as a long path through moderate rain (small drops) but at 30 GHz the two different events would have different attenuation values. Besides the drop size distribution, also the melting layer can influence the scale factor.

Site diversity may be the only viable means of meeting high availability requirements on Ka-band links. A first analysis of OPEX site diversity arrangements shows that the site diversity

gain predicted by the ITU BR Rec 618 is within acceptable bounds.
It has been shown however, that deriving site diversity gain from cumulative statistics (equiprobable approach) tends to underpredict. Analysing site diversity gain straight from the raw data gives more realistic results [12].

CONCLUSIONS

In spite of the shorter than expected lifetime of OLYMPUS the OPEX campaign brought the propagation research an important step forward. A major contributing factor to this success was the good collaboration between the different groups within OPEX. The exchange of data, ideas and expertise generated a most fruitful synergistic effect which is reflected in a number of jointly published papers. A joint presentation of the findings will be given at the OPEX Workshop from 8 to 10 November 1994 at ESTEC.

REFERENCES

1. Siemens Austria "DAPPER Software Users Manual, Preprocessing and Analysis Software", ESA Contract 7609

2. CCIR "Acquisition, Presentation and Analysis of Data in Studies of Tropospheric Propagation", ITU-R Recommendation 311-6, RPN Series, Geneva 1992

3. P.G. Davies, "Summary of Attenuation Statistics from OPEX Members", Proc. OPEX 21, Louvain, May 1994

4. OLYMPUS Utilization Conference, Seville, April 1993, ESA WPP-60

5. Proceedings of the 20th Meeting of OLYMPUS Propagation Experimenters, Darmstadt, November 1993

6. Proceedings of the 21st Meeting of the OLYMPUS Propagation Experimenters, Louvain-la-Neuve, May 1994

7. P G Davies, "Summary of Attenuation Statistics from OPEX Experiments", Proc OPEX 21, Louvain, May 1994

8. S. Upton, "Fade Durations and Intervals Measured in Denmark with Olympus", Proc. OPEX 21, Louvain, May 1994

9. A.P. Gallois, "Further Fade Duration Statistics", Proc OPEX 21, Louvain, May 1994

10. A. Paraboni, "A New Method for Fade Duration Statistics Prediction", Proc. OPEX 21, Louvain, May 1994

11. COST Project 205 "The Influence of the Atmosphere on Wave Propagation", European Community Commission Report 9923, Brussels 1985

12. P. Golé and J. Lavergnat, "Diversity Results at 20 and 30 GHz - Investigation of Instant Diversity Gain", Proc OPEX 21, Louvain, May 1994

SLANT PATH PROPAGATION MODELS RESULTING FROM OLYMPUS EXPERIMENTS IN THE U.S.

Warren Stutzman
Virginia Tech

NAPEX - June 1994

Vancouver, BC

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OVERVIEW

- Propagation Effects
- Data Presentation
- Modeling
    - Rain Rate
    - Attenuation
    - Attenuation Ratio
    - Fade Slope
    - Fade Duration

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PROPAGATION EFFECTS

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SUMMARY OF PROPAGATION EFFECTS

- EFFECTS

Effect	Responsible Mechanisms	Level	Time Scale
Attenuation (fading) (amplitude reduction)	Gases	A few dB	Slow
	Rain	Many dB	Fast (seconds to minutes)
	Clouds, fog, wet snow	A few dB	Fast
	Ice, dry snow	Small	------
Scintillations (Rapid fade/enhancement)	Gases	Several dB	Very fast (seconds)
Depolarization	Precipitation	Can reduce dual polarized channel isolation to unusable levels	Fast (seconds to minutes)
Dispersion			
Frequency variations over signal bandwidth	Gases	Not significant	------
	Hydrometeors	Not significant	

- SYSTEM IMPLICATIONS
  - Reduced quality of analog links
  - Increased error rate on digital links

● FREQUENCY DEPENDENCE OF EFFECTS

Mechanism	Frequency Dependence
Gaseous Attenuation	Increases with frequency Spectral line of water vapor at 22 GHz
Scintillations	RMS signal $\sim f^{7/12}$ [dB]
Rain Attenuation	$A \sim f^{2}$ [dB]
Rain Depolarization	$XPD_2 = XPD_1 - 21.5 \log \frac{f_2}{f_1}$ [dB]

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12/29/92

DATA PRESENTATION

- Quantities

  Rain rate R

  Attenuation AFS, ACA, ARD

  Other: Crosspolarization, Phase

- Types
  - Instantaneous (time histories)

    Quantities as a function of time

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- Statistics (average annual)
  - Primary
    - Rain rate
    - Attenuation
    - Attenuation ratio
  - Secondary
    - Fade rate
    - Fade duration
    - Interfade interval

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MODELING

Rain Rate

Attenuation

Attenuation Ratio

Fade Slope

Fade Duration

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CCIR Rain Regions

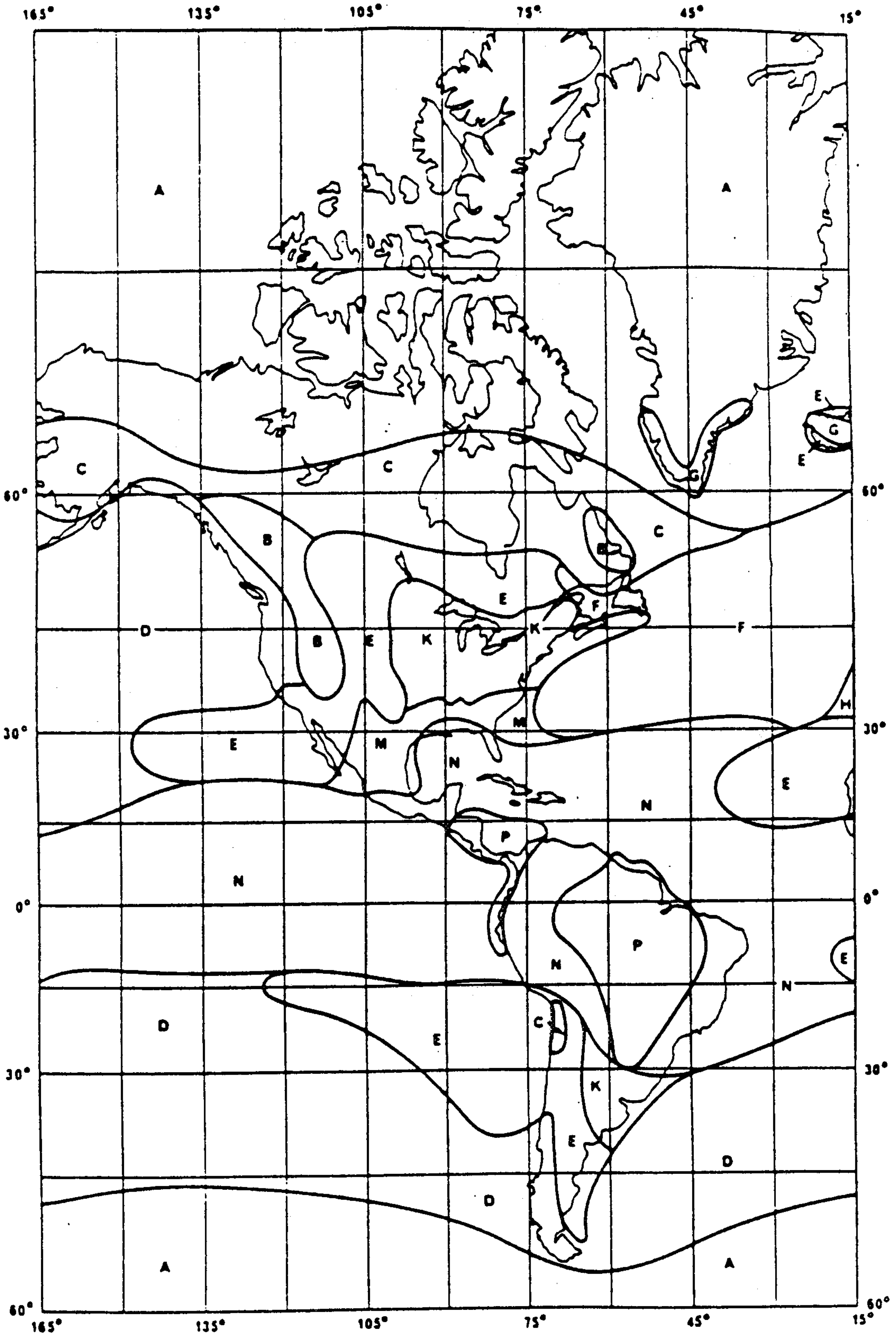
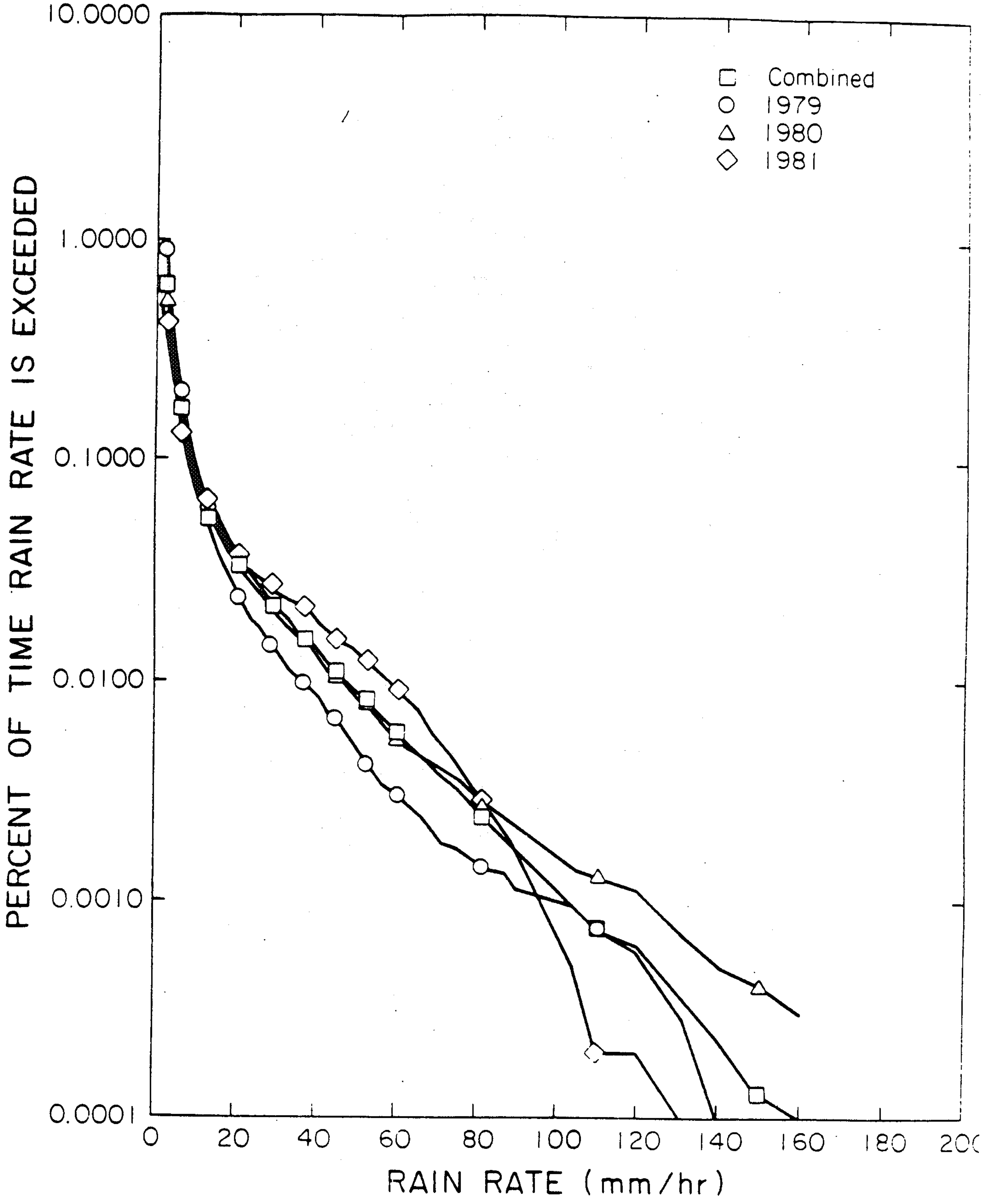


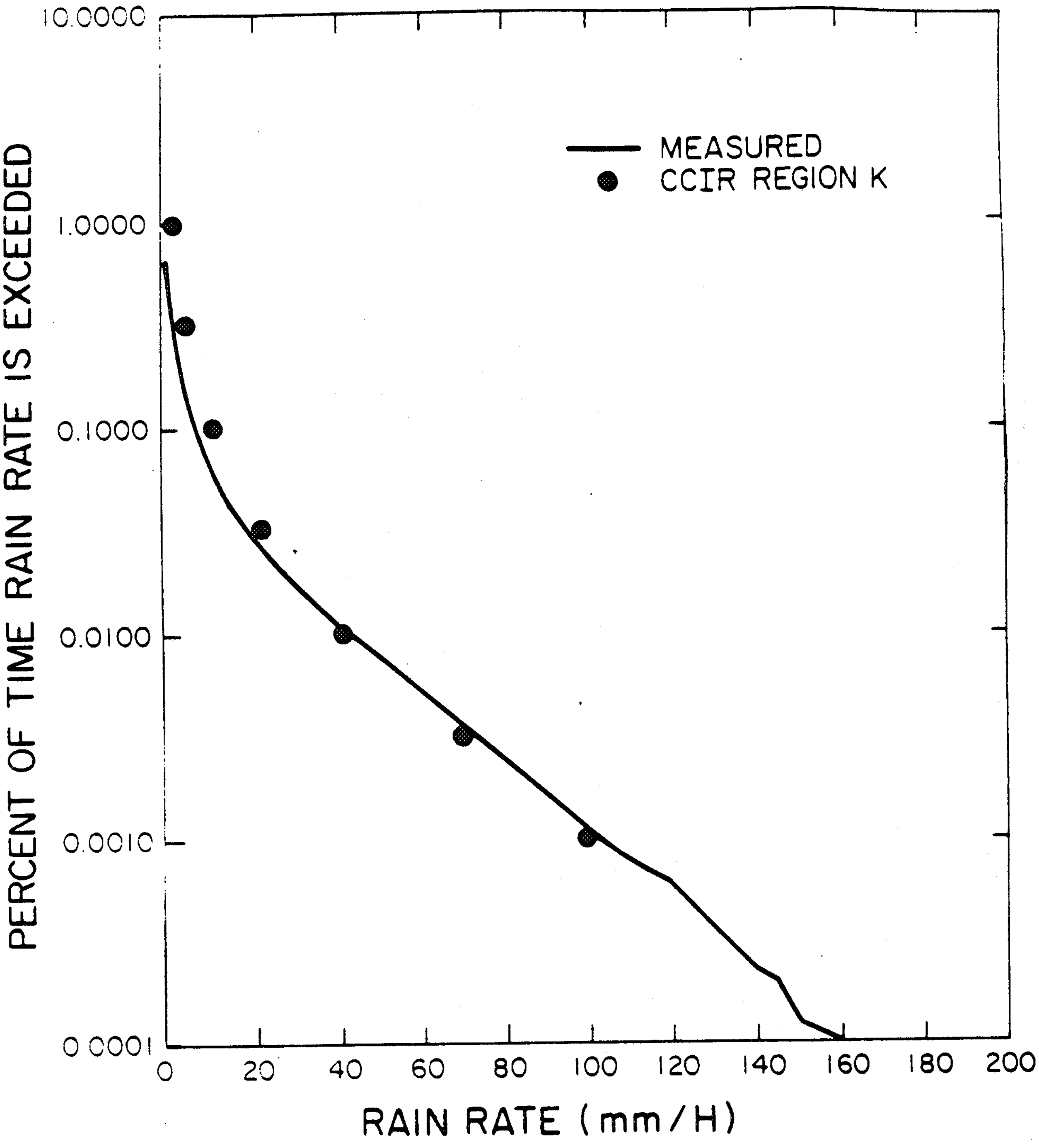
FIGURE 15
(see Table 1)

[CCIR, Rept. 563-4, 1990]

RAIN RATE

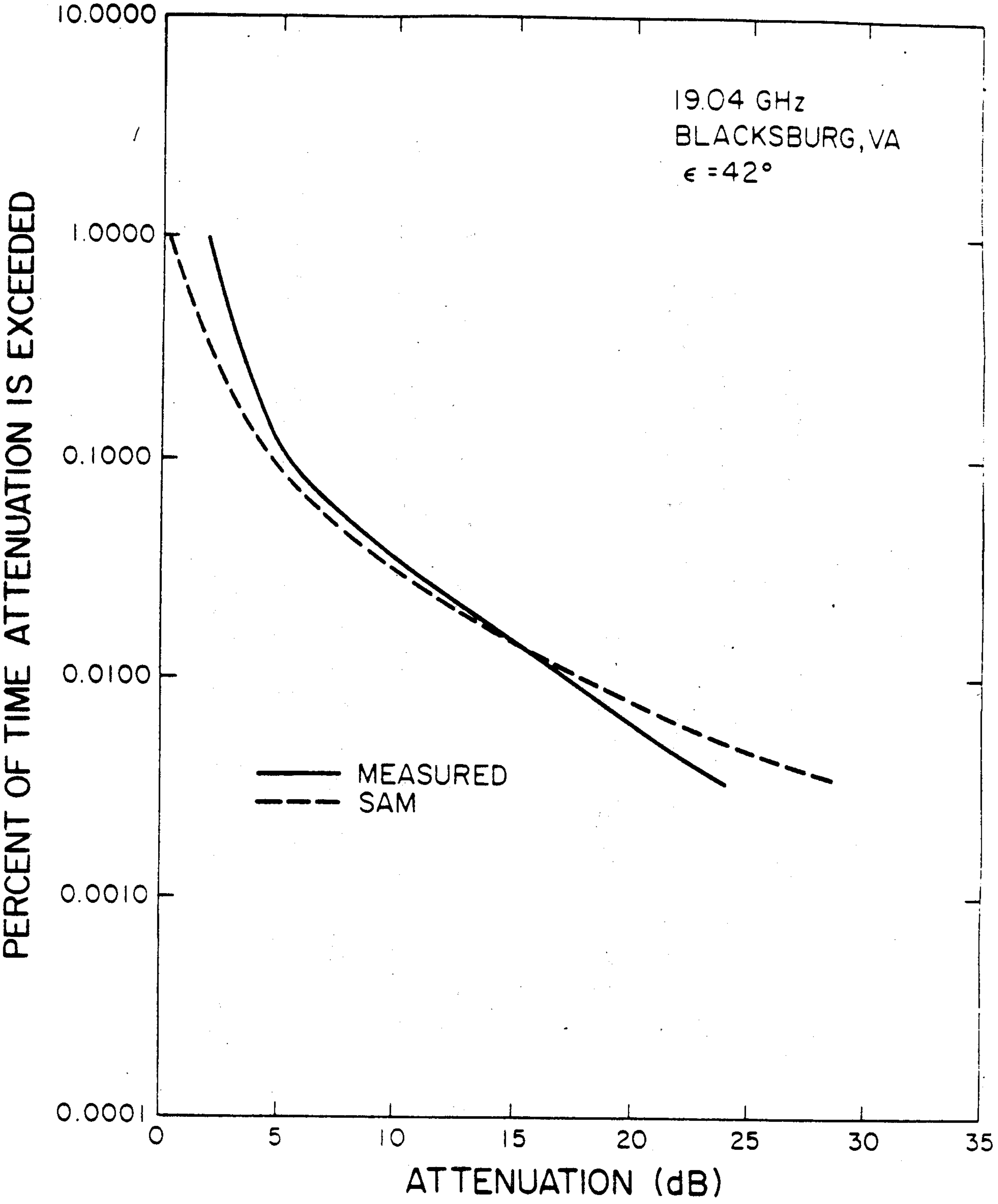
- Example of Multiple Years of Measured Data




10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
PERCENT OF TIME RAIN RATE IS EXCEEDED
MEASURED
● CCIR REGION K
0
20
40
60
80
100
120
140
160
180
200
RAIN RATE (mm/H)

1979-81

EXAMPLE OF MODEL PREDICTIONS COMPARED TO MEASUREMENTS



32 months of data from the COMSTAR satellite (solid curve)

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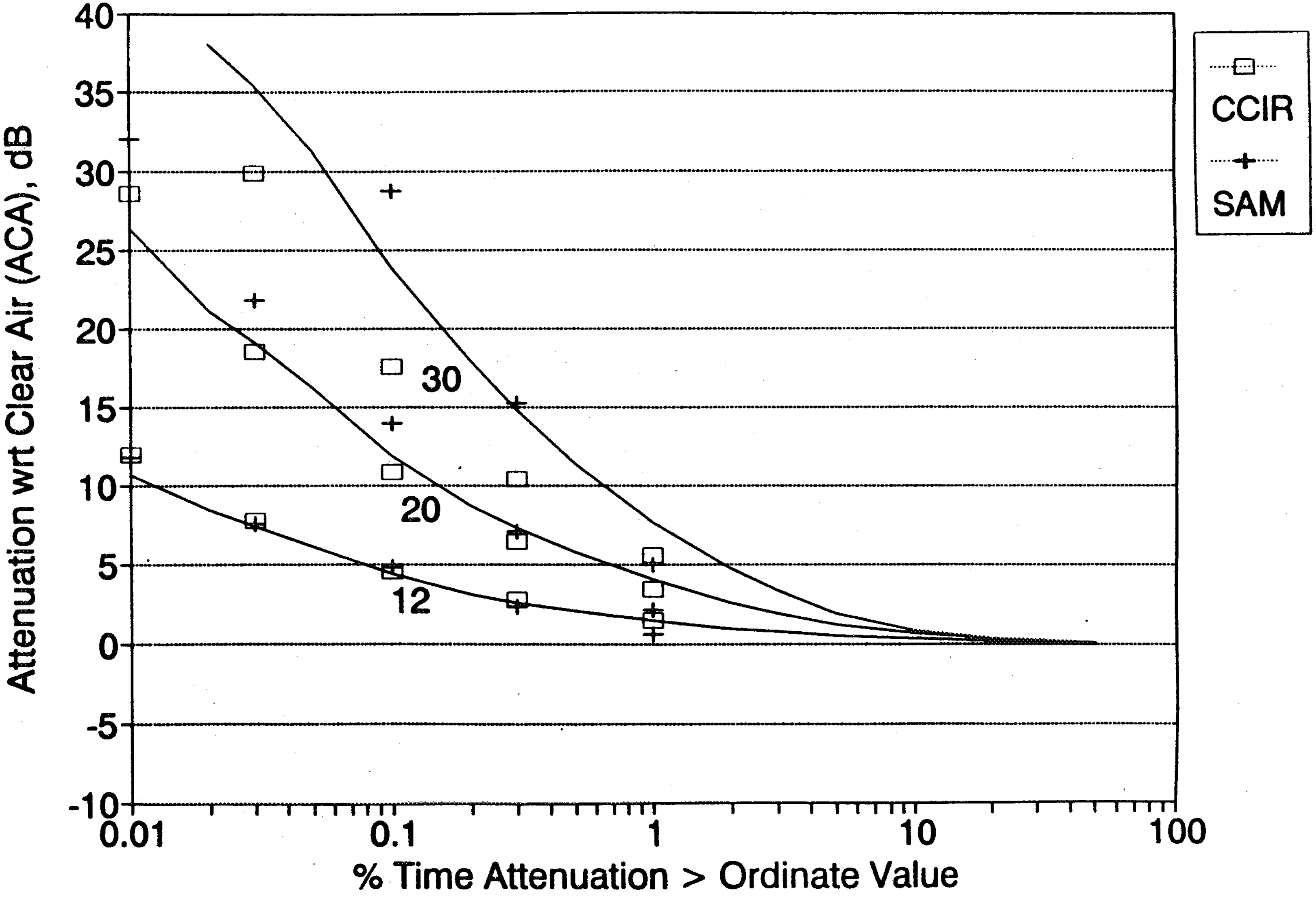
ATTENUATION WITH RESPECT TO CLEAR AIR
12, 20, & 30 GHz - One Year (91/92)



ATTENUATION RATIO

Instantaneous Attenuation Ratio

$$RA(f_L, f_U, t) = \frac{ACA(f_U, t)}{ACA(f_L, t)}$$

(smoothed using a 30-s moving average to remove scintillations)

RA_{med} = 50% value of $RA(t)$ over year

RA_{med_i} = median for ith 1-dB bin on the base frequency attenuation

RA_{ave} = average of RA_{med_i} over all valid bins

Statistical Attenuation Ratio

$$RAS(f_L, f_U, P) = \frac{ACAS(f_U, P)}{ACAS(f_L, P)}$$

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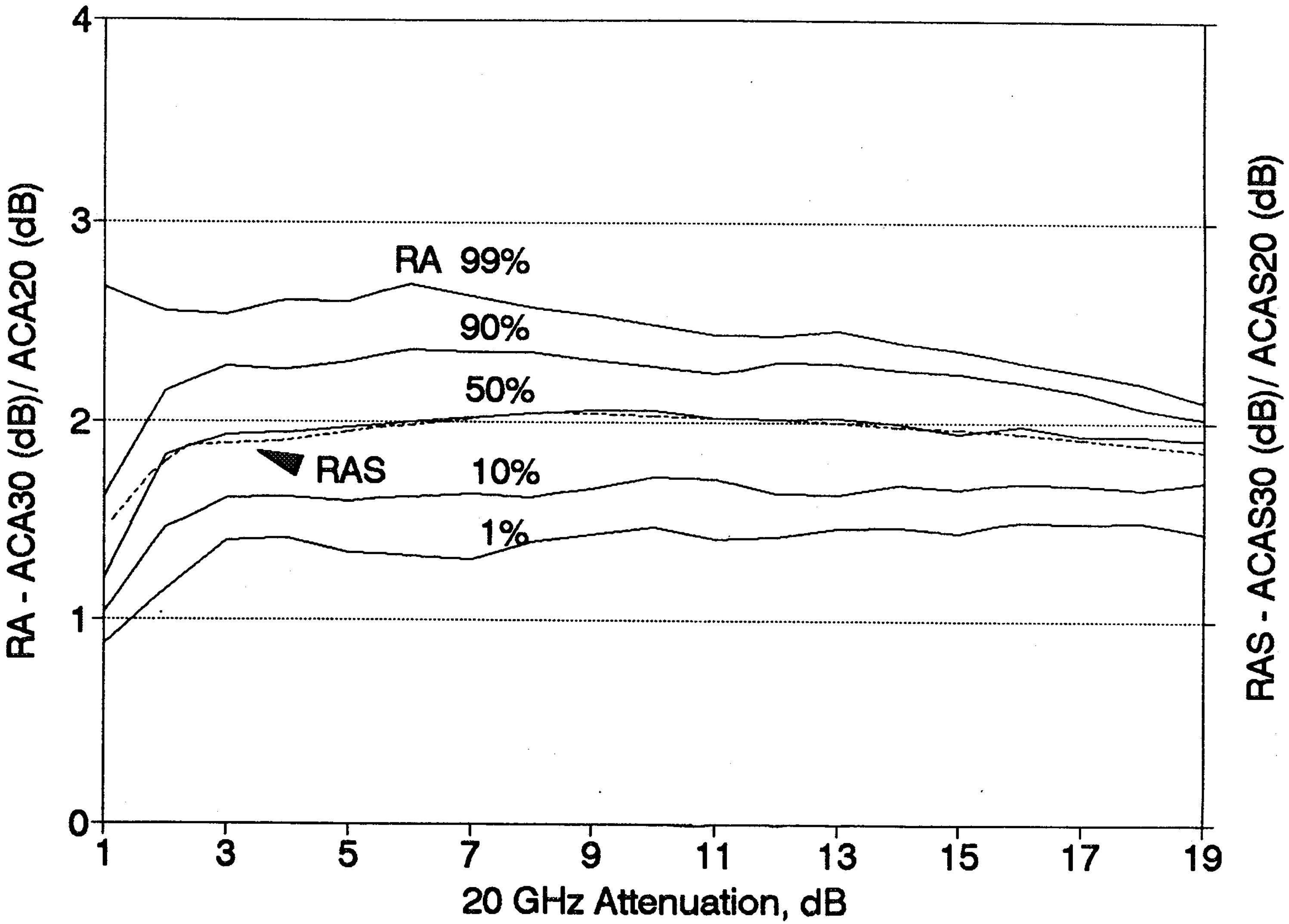
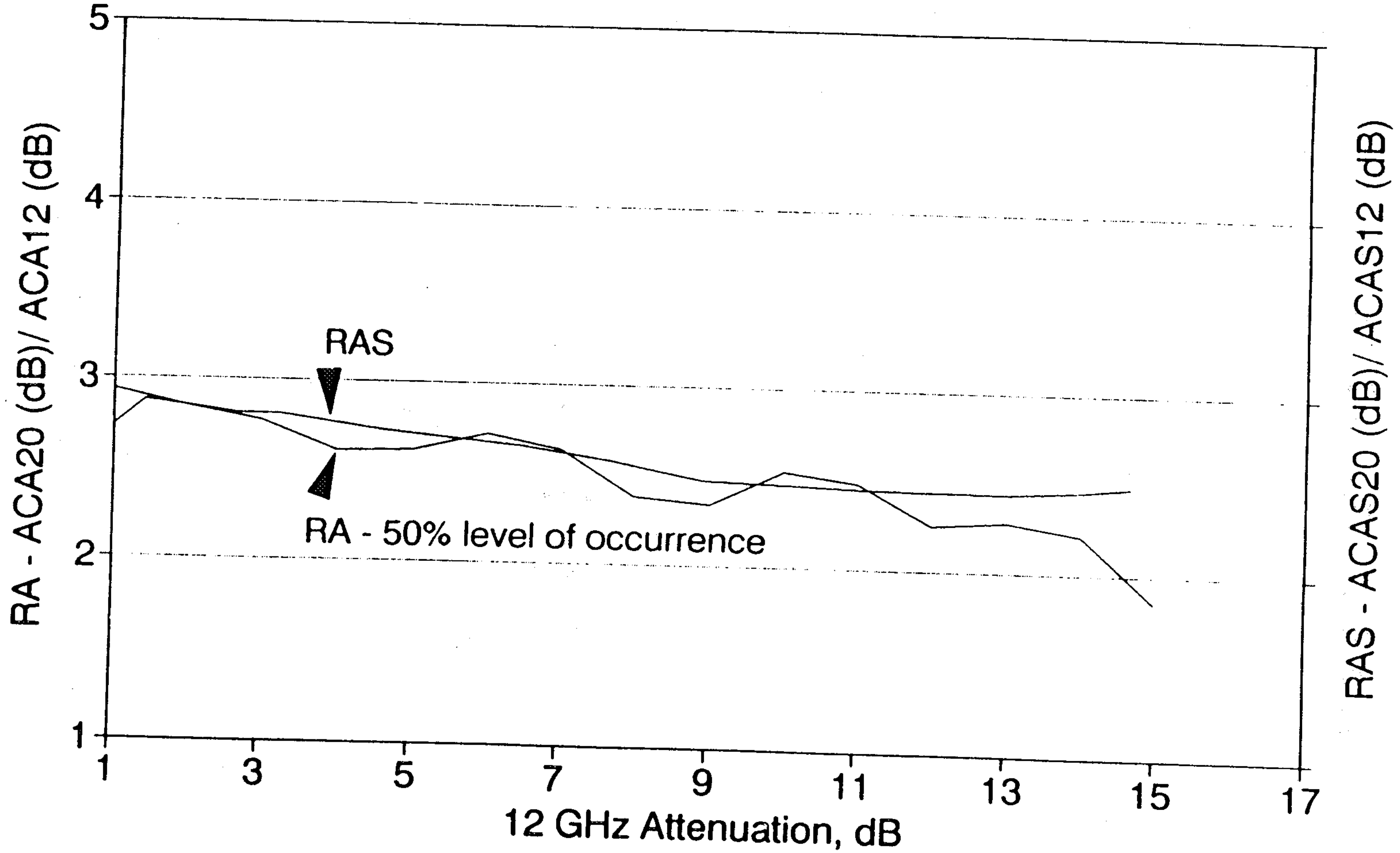
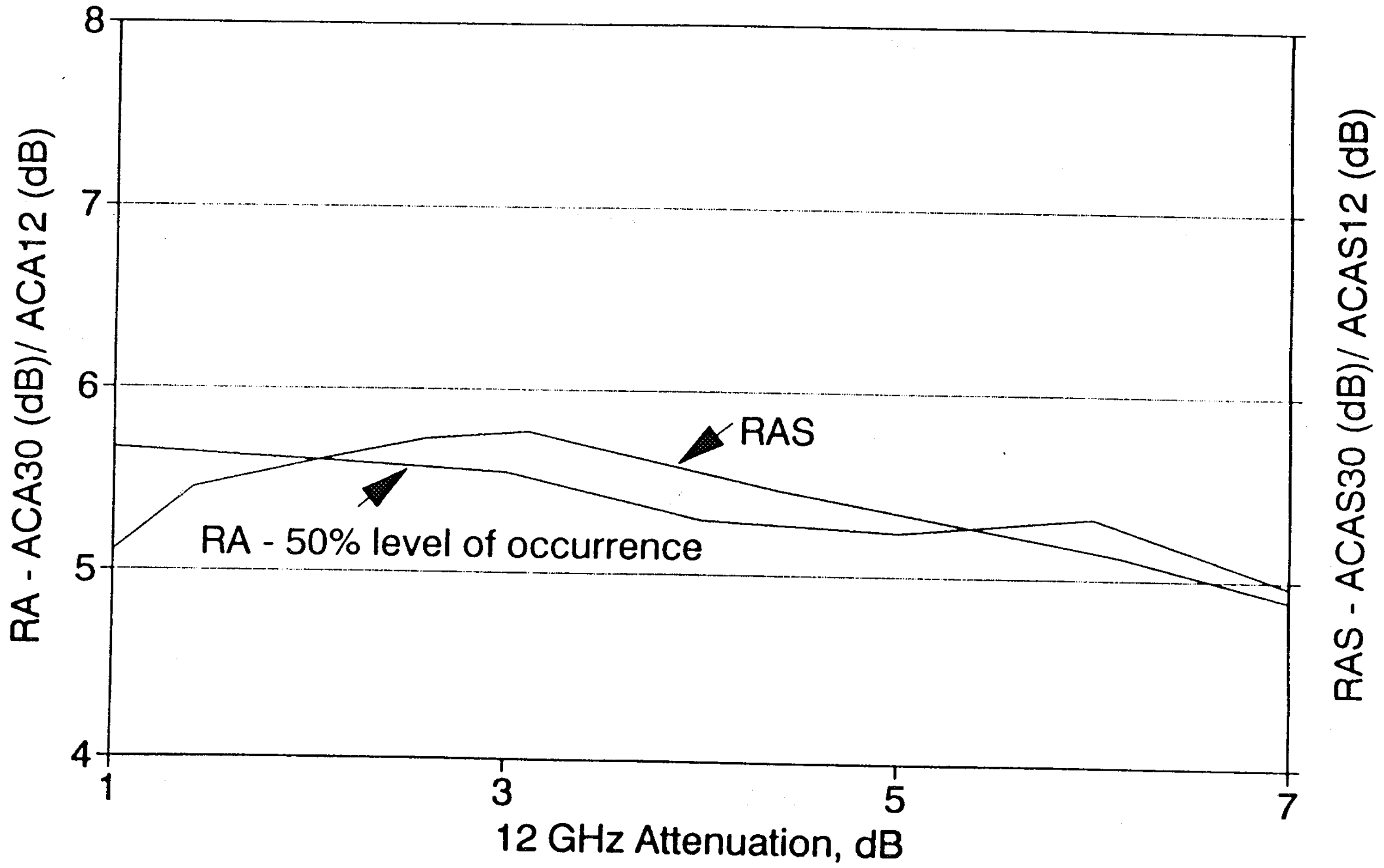
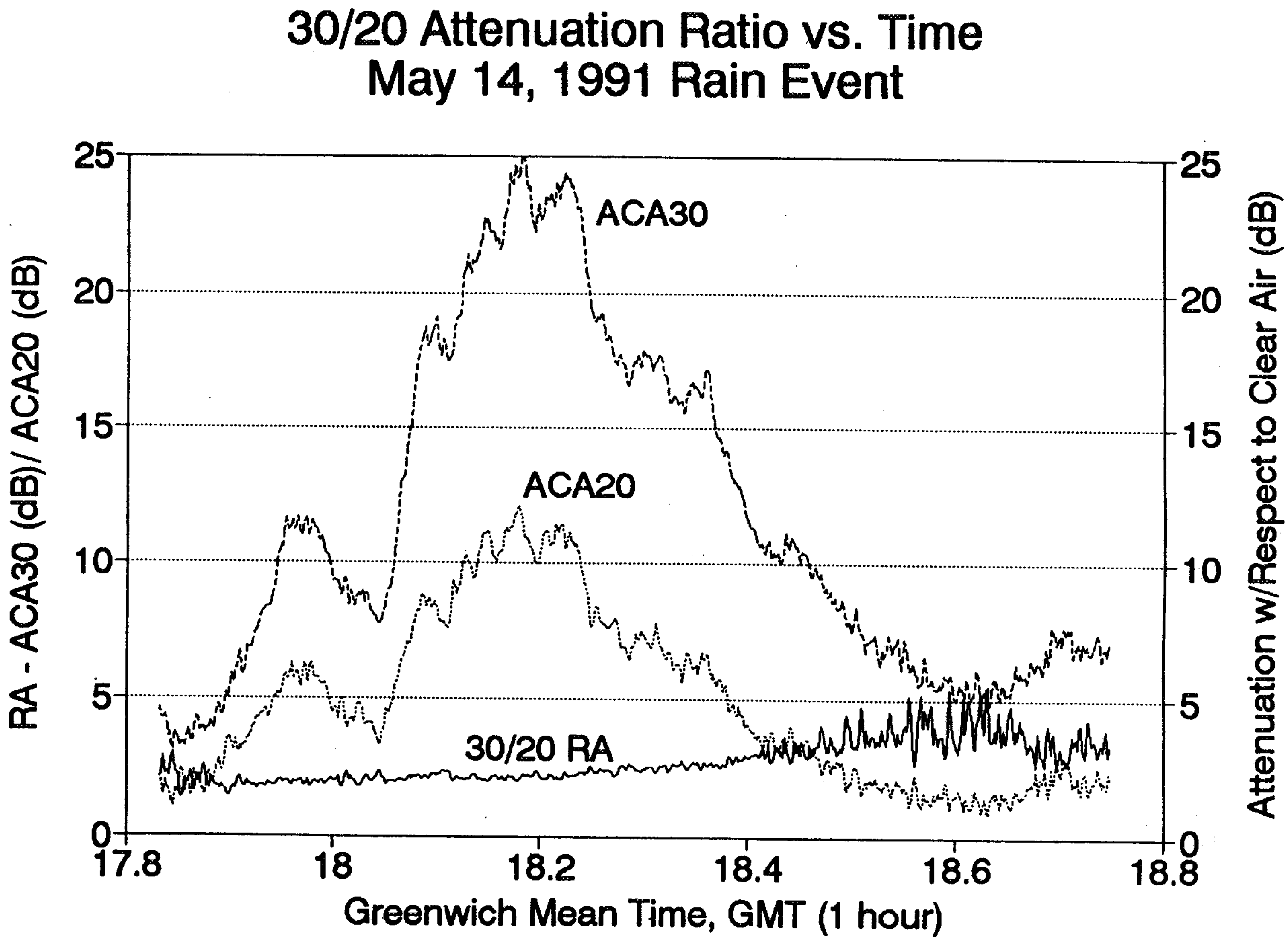

RA - ACA30 (dB)/ ACA20 (dB)
RAS - ACAS30 (dB)/ ACAS20 (dB)
20 GHz Attenuation, dB
0
1
2
3
4
1
3
5
7
9
11
13
15
17
19
RA 99%
90%
50%
RAS
10%
1%



Comparison of statistical attenuation ratio (RAS) to median instantaneous attenuation ratio ($RAmed_i$) for 20/12 GHz.



Comparison of statistical attenuation ratio (RAS) to median instantaneous attenuation ratio ($RAmed_i$) for 30/12 GHz .



30/20 Attenuation Ratio vs. Time (with ACA30 & ACA20), May 14, 1991

Statistics of Attenuation Ratio for One Year of Olympus Data

$(ACA(f_L) > 1\ \text{dB})$

Frequency Pair, f_U/f_L	30/20	20/12	30/12
VA Tech RA_{med}	1.93	2.86	5.56
VA Tech RA_{ave}	2.01	2.52	5.43
Std. Dev. of Error of RA_{ave}	0.34	0.90	0.44

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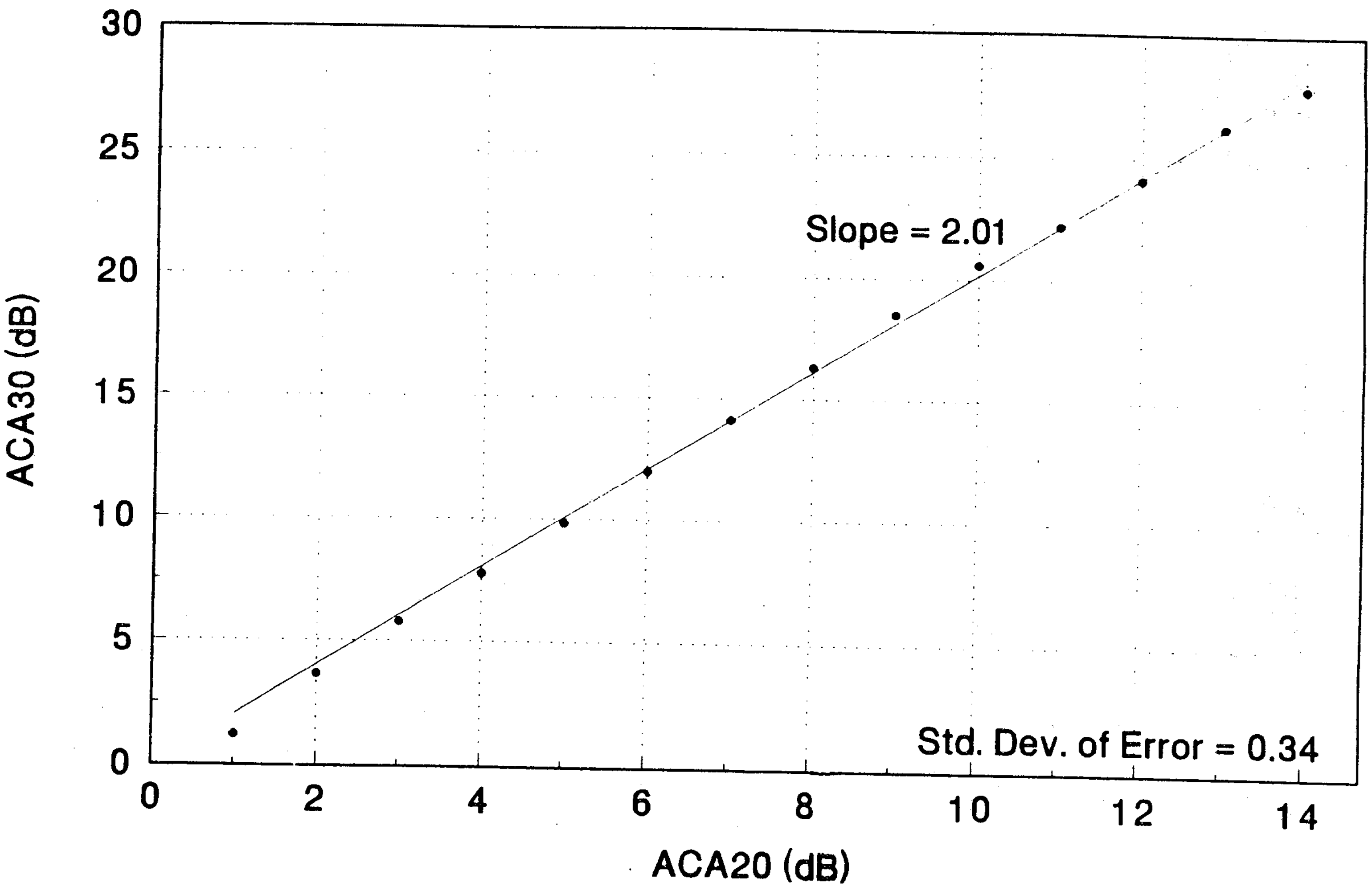
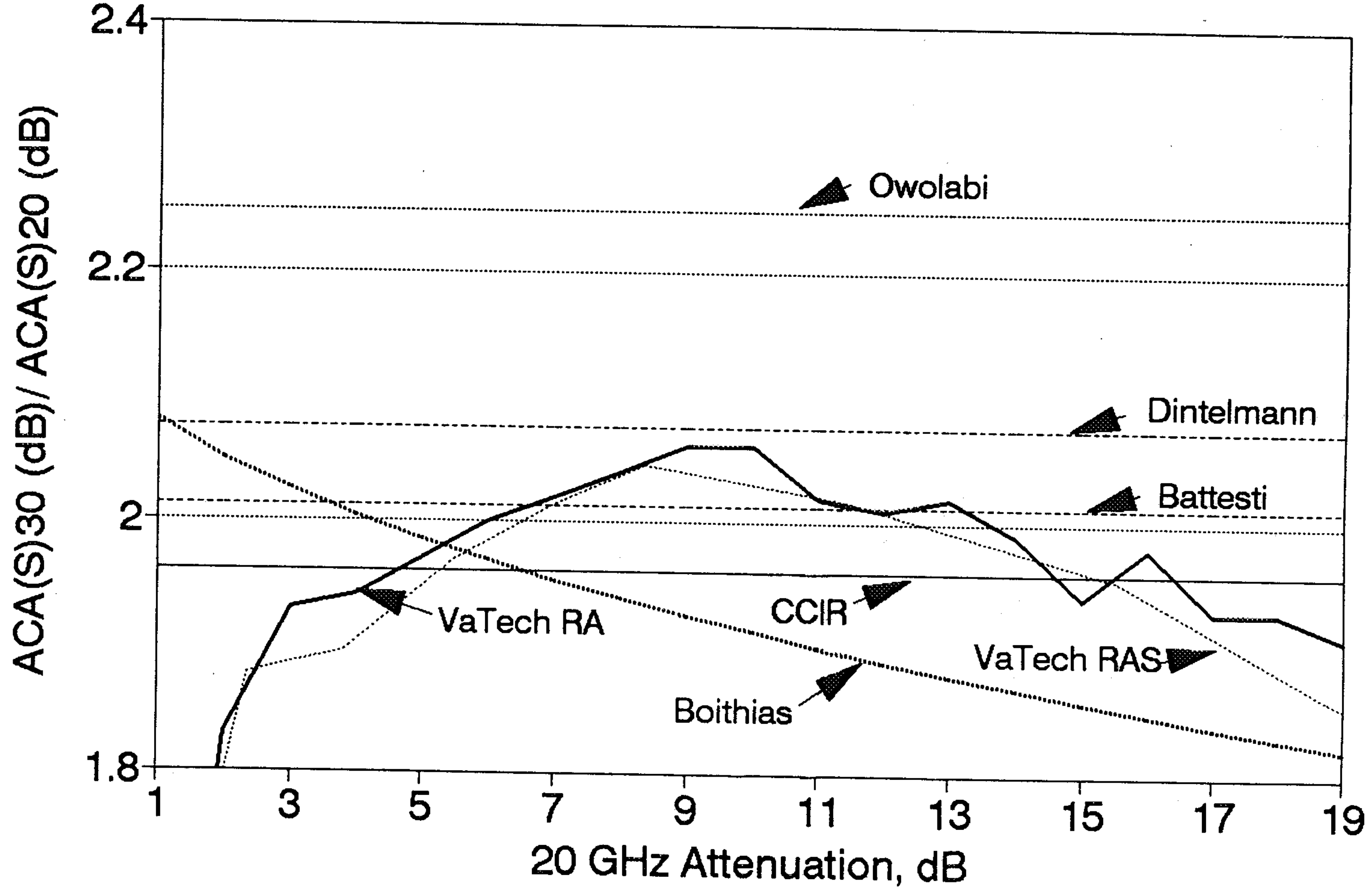


Median 30-GHz attenuation for each 1-dB interval of 20-GHz attenuation using all data from the analysis year. The least mean squared derivation straight line fit is also shown.

Statistics of Attenuation Ratio Compared to Model Predictions for OLYMPUS Frequencies

	Frequency pair, f_U/f_L		
Model or Data	30/20	20/12	30/12
VA Tech RA_{med} data	1.93	2.86	5.56
VA Tech RA_{ave} data	2.01	2.52	5.43
Battesti model	2.01	2.12	4.23
CCIR model	1.96	2.18	4.28
Dintelmann model	2.07	2.28	4.74
Drufuca model	----	2.20	----
Owolabi/Ajayi model	2.25	2.50	5.63

30/20 RA, RAS, and MODELS
One Year (91/92) -vs. 20GHz Attenuation



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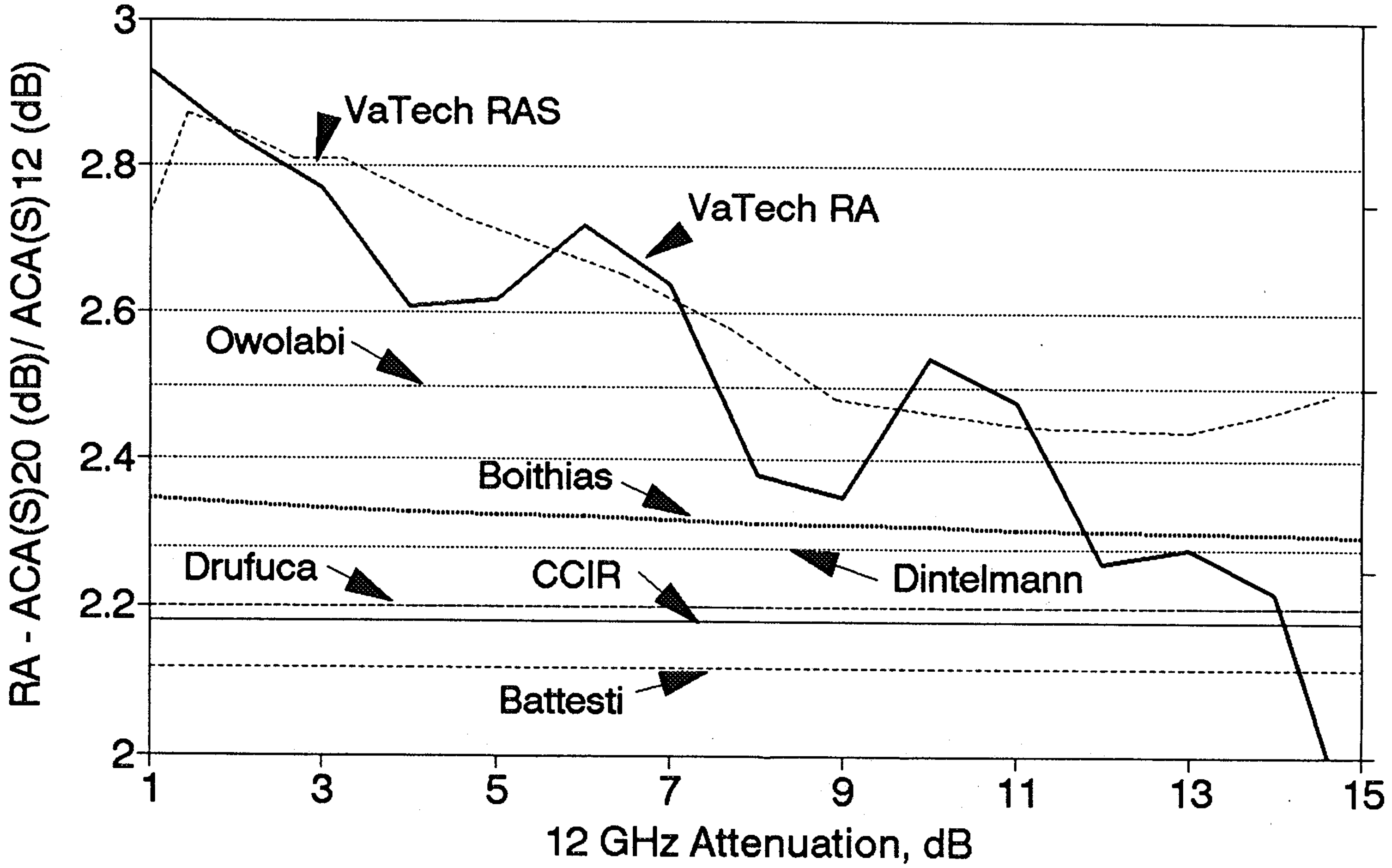
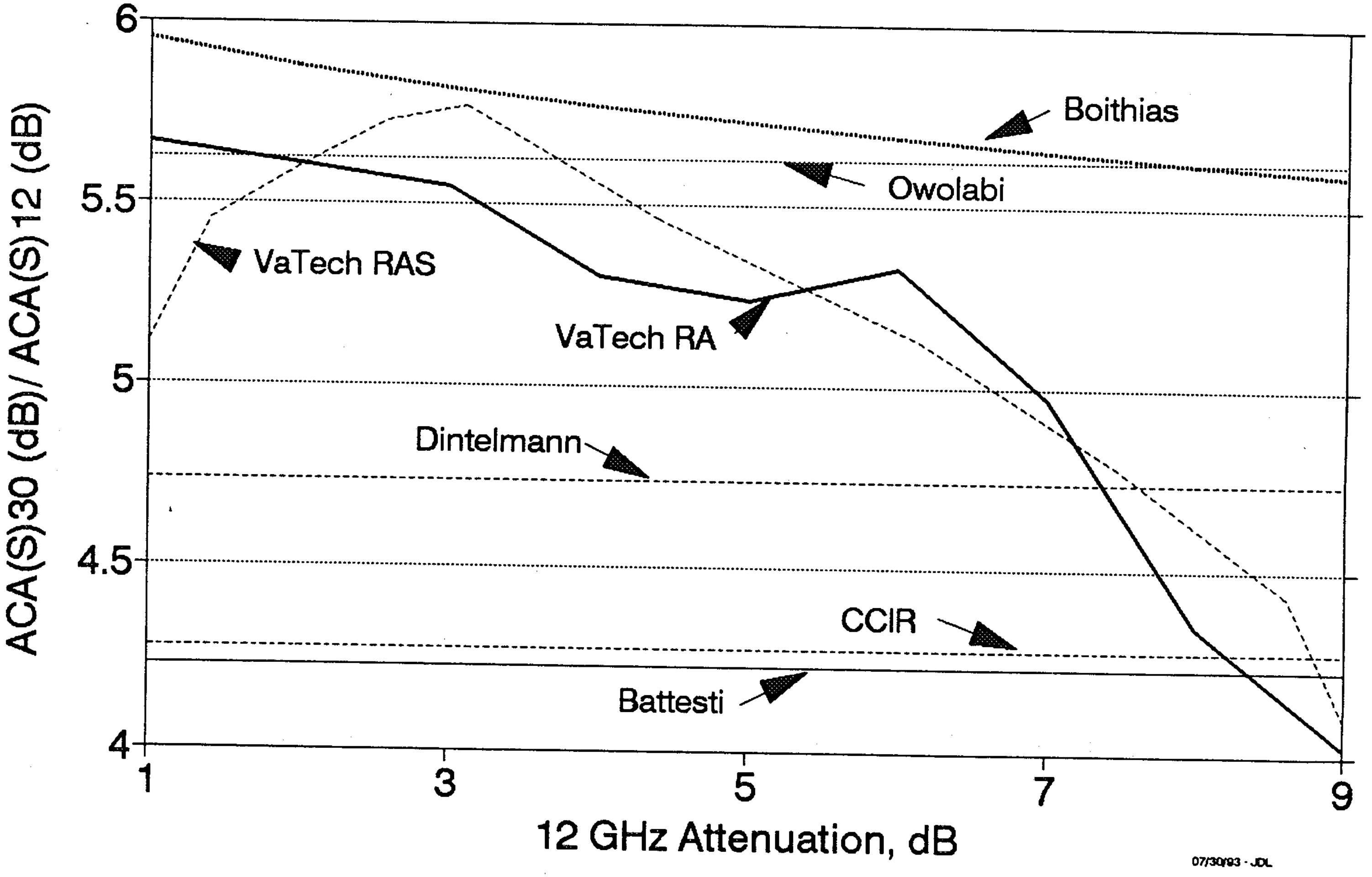
20/12 RA, RAS, and MODELS
One Year (91/92) -vs. 12GHz Attenuation



07/30/93 · JDL

30/12 RA, RAS, and MODELS
One Year (91/92) -vs. 12GHz Attenuation



Simple Power Law Model $RA = \left(f_U / f_L\right)^n$

	Frequencies f_U / f_L			Average n
	30/20	20/12	30/12	
Power n for RA_{med}	1.62	2.29	1.99	1.97
Power n for RA_{ave}	1.72	2.02	1.96	1.90

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Comparison of Attenuation Ratio Values for Three Long Term Experiments Using OLYMPUS

	Frequencies f_U / f_L		
	30/20	20/12	30/12
BT Labs (best fit slope of $A(f_U)$ vs. $A(f_L)$)	1.8	2.5	4.3
Dintelmann (*RA* computed with $n = 1.8$)	2.07	2.28	4.28
Virginia Tech Measured RA_{ave}	2.01	2.52	5.43

FADE SLOPE

Block average of attenuation

$$\overline{AFS_i} = \left(\frac{1}{100}\right)\left(\sum_{j=i-49}^{i+50} AFS_j\right) \qquad [\mathrm{dB}]$$

where AFS_j is the instantaneous value of attenuation at each 0.1-s interval.

Fade slope is defined as the 10-s block average of attenuation centered at 5 s before a threshold subtracted from a 10-s block average of attenuation centered at 5 s after the threshold, divided by 10 s:

$$FSB_i\left(\overline{AFS_i}\right) = \left(\frac{1}{10}\right)\left(\overline{AFS_{i+50}} - \overline{AFS_{i-50}}\right) \qquad [\mathrm{dB/s}]$$

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Empirical model of percent time P the fade slope for 12 to 30 GHz is in the bin centered on FSB:

$$P(FSB)=a\cdot e^{b\cdot|FSB|}$$

where

$$a(A_T,f)=\frac{a(A_T,20)-a(A_T,12)}{20-12}\cdot(f-12)+a(A_T,12)\ \ for\ A_T>3,\ 12\le f\le 20$$

$$a(A_T,f)=\frac{a(A_T,30)-a(A_T,20)}{30-20}\cdot(f-20)+a(A_T,20)\ \ for\ A_T>3,\ 20\le f\le 30$$

$$b(A_T,f)=\frac{b(A_T,20)-b(A_T,12)}{20-12}\cdot(f-12)+b(A_T,12)\ \ for\ A_T>3,\ 12\le f\le 20$$

$$b(A_T,f)=\frac{b(A_T,30)-b(A_T,20)}{30-20}\cdot(f-20)+b(A_T,20)\ \ for\ A_T>3,\ 20\le f\le 30$$

where A_T is the threshold attenuation (*AFS*) level in dB and f is the frequency in GHz.

$$a\left(A_T,12\right)=52.93\,e^{\left(0.07\,A_T-1.45\,A_T^2-0.0013\,A_T^3\right)}$$

$$a\left(A_T,20\right)=717.71\,e^{\left(-1.07\,A_T+0.038\,A_T^2-0.00056\,A_T^3\right)}$$

$$a\left(A_T,30\right)=404.22\,e^{\left(-1.05\,A_T+0.063\,A_T^2-0.0018\,A_T^3\right)}$$

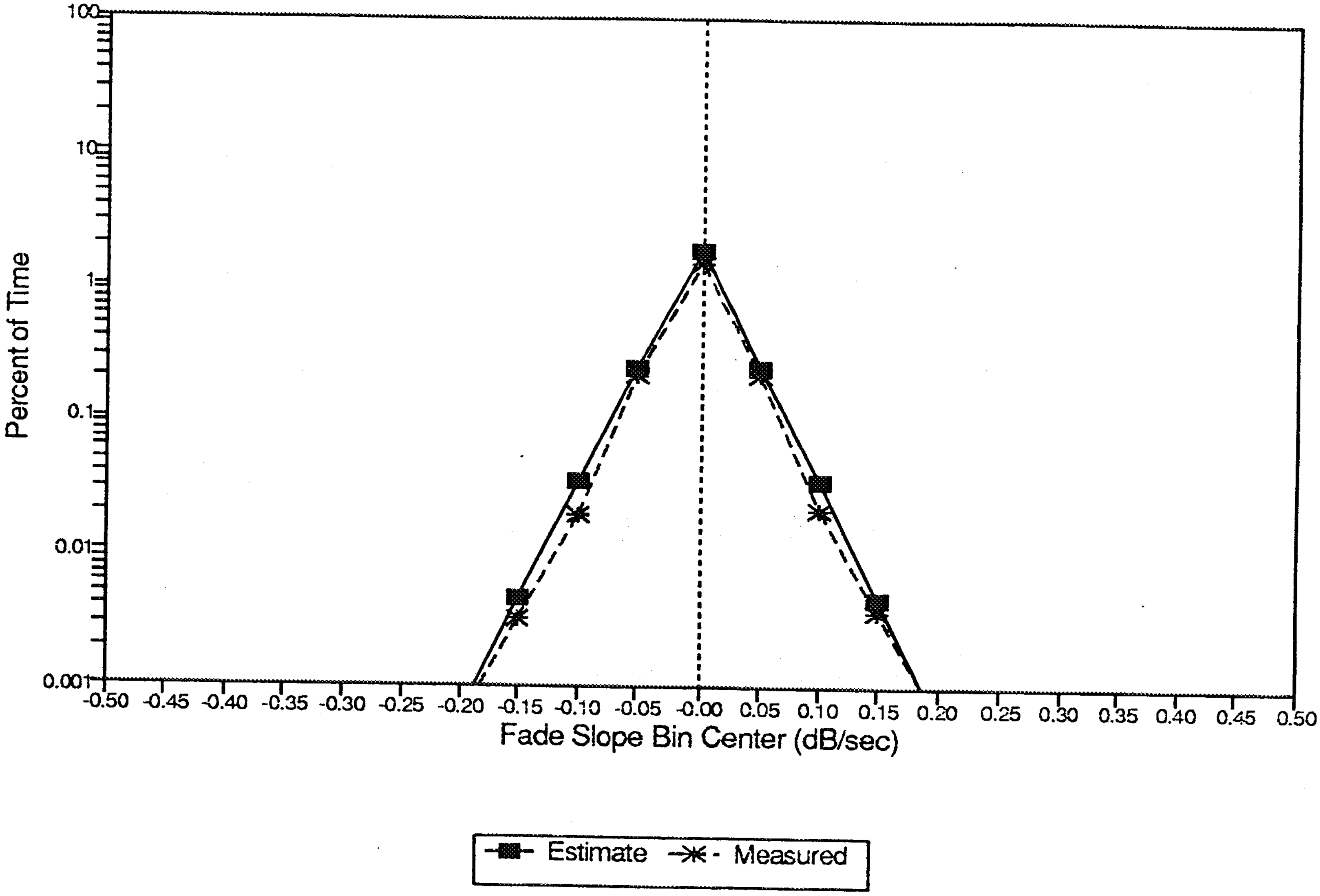
$$b\left(A_T,12\right)=-0.0315\,A_T^3+1.168\,A_T^2-14.94\,A_T+72.72$$

$$b\left(A_T,20\right)=0.0202\,A_T^3-0.3149\,A_T^2-3.105\,A_T+61.62$$

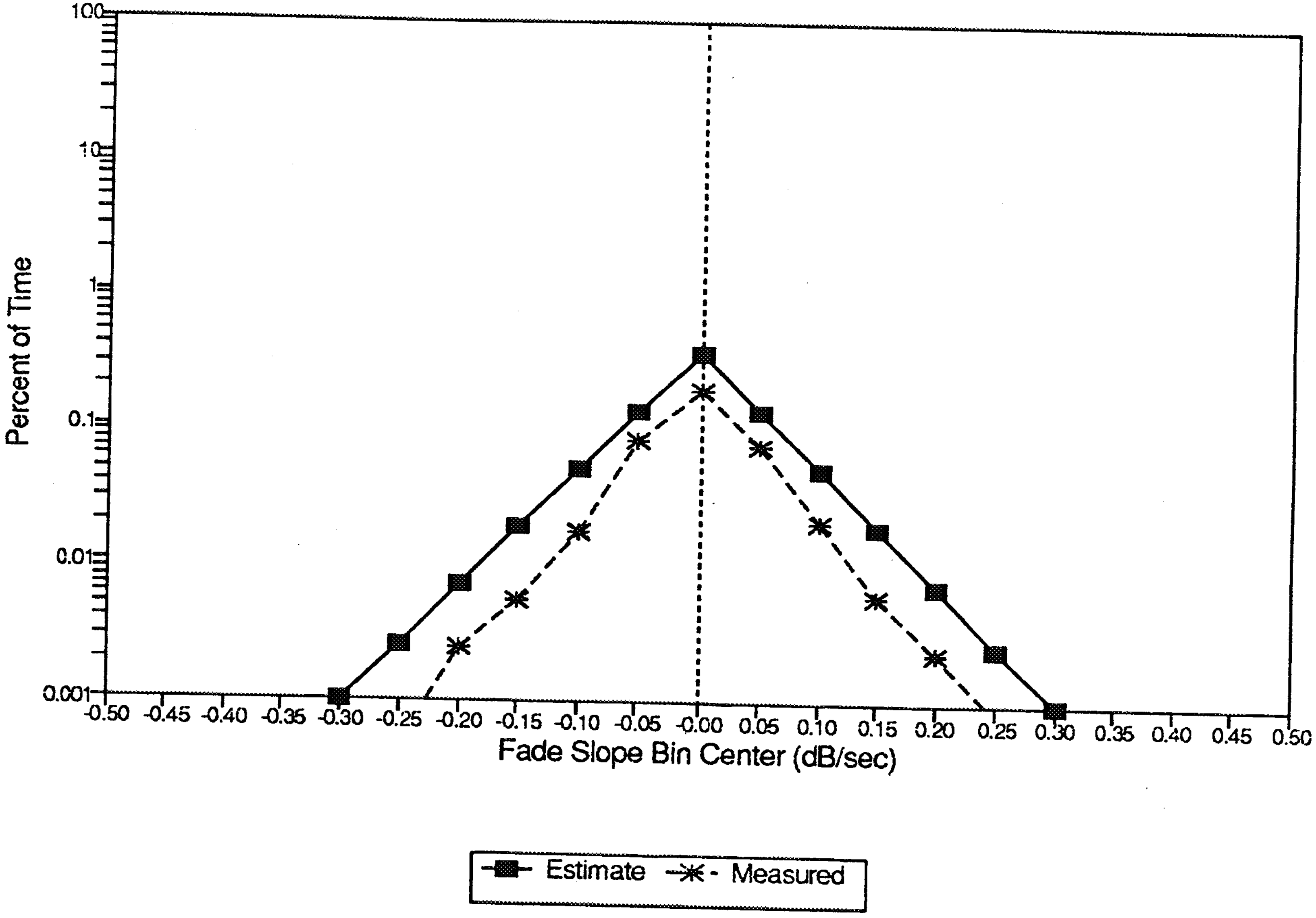
$$b\left(A_T,30\right)=0.0134\,A_T^3-0.2647\,A_T^2-1.178\,A_T+47.82$$

This third order model agrees to Olympus measured data within 5%.
A seventh order model fits to within 1%.

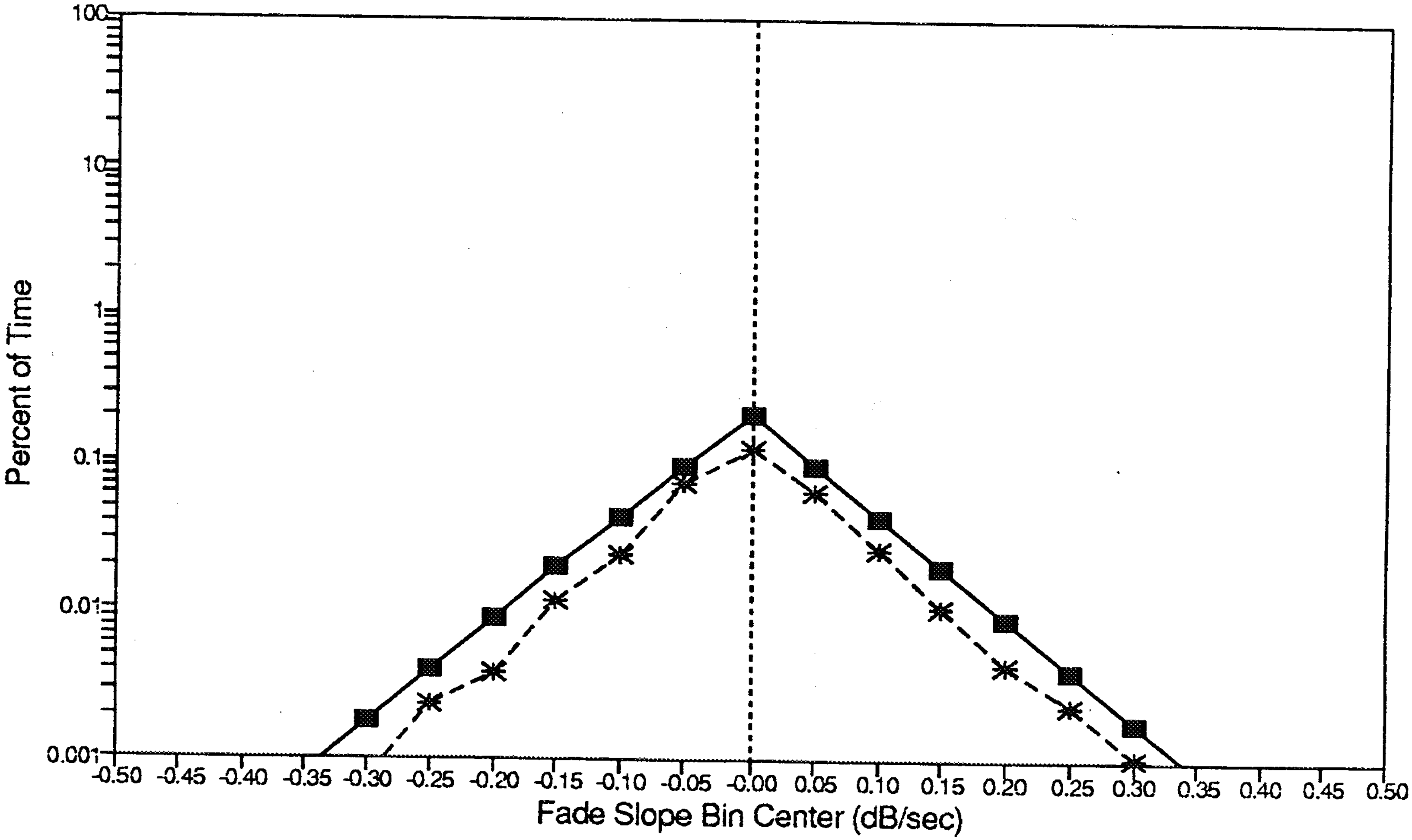
MEASURED VS MODELED FADE SLOPE
One Year In Rain -- 12 GHz at 3 dB



MEASURED VS MODELED FADE SLOPE
One Year In Rain -- 20 GHz at 10 dB



MEASURED VS MODELED FADE SLOPE
One Year In Rain -- 30 GHz at 15 dB



SUMMARY

Models that agreed well with Olympus data:

Rain Rate	CCIR
Attenuation	CCIR, SAM
Attenuation Ratio	CCIR, n = 1.90

Models developed during Olympus investigation:

- Attenuation Ratio
  - RA ≈ RAS
  - Power law (n = 1.90)
  - Empirical model for A (P = 99%)
- Empirical model for fade slope statistics for any frequency in 12 to 30 GHz range and any attenuation threshold
- Empirical model for fade duration

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