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CTS 11.7 GHz Isolation Data
for the Calendar Year 1978

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1. INTRODUCTION

This report summarizes isolation measurements made on the CTS spacecraft 11.7 GHz circularly-polarized downlink during the 1978 calendar year. Attenuation statistics for the same time period were published in *Final Report for Third Year of Work on A Depolarization and Attenuation Experiment Using the Comstar and CTS Satellites* by C. W. Bostian *et al*, submitted for Contract NAS5-22577 and dated February 9, 1979. For information on the experimental hardware the reader should consult *Quarterly Technical Progress Report I* by C. W. Bostian *et al*, issued December 22, 1976, for the same contract. Details on the data reduction procedure used appear in *Final Report* (*Second Year of Work*) by C. W. Bostian, *et al*, issued February 9, 1978. Complete bibliographical information on these documents appears at the end of the report.

2. POLARIZATION ISOLATION

Isolation measured from a beacon signal is an indication of the crosstalk that precipitation scattering would introduce into a dual-polarized satellite communications system. With a single-polarized transmitter, isolation is the decibel ratio of the co-polarized component of the received signal to the cross-polarized component. CTS transmits a right-hand circularly polarized signal; when this encounters raindrops or ice crystals a small left-hand circularly polarized component is generated. The dual-polarized feed at the VPI&SU earth station antenna separates the right-hand and left-hand circular components and routes them to a dual-channel signal-processing receiver that measures the power level of each incoming signal. If the co- and cross-polarized signal power levels in watts are P_R and P_L, respectively, then the isolation I in dB is given by

$$I = 10 \log_{10} (P_R/P_L) \qquad (1)$$

If both the transmitting and receiving antennas were ideal, isolation I would be infinite in clear weather. In practice, both antennas possess some residual cross-polarization, and clear-weather values of I tend to be about 30 dB. When a small amount of precipitation is present, the cross-polarized signal that it generates may combine in-phase or out of phase with the residual cross-polarized signals from the antennas and cause the net I to increase or decrease from its clear-weather value. As the precipitation intensifies, path depolarization overrides antenna effects and I decreases. Generally rain effects begin to dominate at attenuation (A) values above 1 or 2 dB.

Because A and I are really two different measures of the same scattering phenomena, the two quantities should be related, at least for propagation through rain. (The attenuation caused by ice is negligible and ice depolarizes without introducing significant fades.) Several authors have postulated a relationship in the form

$$I = U - V \log (A) \qquad (2)$$

where U and V are constants. (The literature is inconsistent about the appropriate base for the logarithm; some authors use 10 and others use e.) Unanswered questions about these equations include:

1. Can universal U and V constants be found that describe the observed real-time behavior of I and A for a particular frequency and elevation angle?
2. Can isolation statistics be predicted from attenuation statistics using (2), thus avoiding the expense of separate isolation measurements?

This report addresses these two questions and provides monthly and annual percent-of-time data for I as measured at our earth station.

3. DATA REDUCTION PROCEDURE

The VPI&SU earth station receives CTS at a nominal elevation angle of 33 degrees. As described in earlier reports (See Section 1), our equipment monitors the incoming signals continuously and records a data point whenever a significant (approximately 1 dB) change occurs. These data are maintained on magnetic tape in a format that allows us to determine the value of any data variable at any time. The data reduction and display software samples the stored information and builds a file containing the values of measured quantities at thirty second intervals. These are used to study the instantaneous relationships between selected variables and to compute percent-of-time information. The processing is done with instantaneous signal values taken from detectors with 10-second time constants; no digital averaging is involved.

We normally process data for one calendar month at a time. Attentuation is calculated with respect to the monthly mean signal level and any negative values are set to zero. This reduces the uncertainty caused by spacecraft orbital motion. When the necessary signal levels are missing (because of receiver maintenance, equipment malfunction, spacecraft shutdown, a fade that exceeded the dynamic range of the receiver, etc.), attenuation values are filled in by scaling from one of the COMSTAR downlinks. Unfortunately there is no accepted way to scale isolation data, and the problem of how to handle missing isolation values had to be resolved before isolation statistics could be determined. In preparing this report, we followed several alternative approaches.

To determine the U and V coefficients that best relate simultaneous values of attenuation and isolation, we simply excluded any missing values. This means that our curve fits relating I to A on a real-time basis were derived from measured data alone; no scaled values were used.

For the percent-of-time data, we used two methods. In one, missing isolation values were ignored and the time base was corrected to include only those times when valid signals were present. In the second, missing values of isolation were arbitrarily set equal to 30 dB. The reason was that, with CTS (which never lost phaselock during any 1978 rain events) missing values should result only from receiver down-time for maintenance during clear weather. Hence it is reasonable to set the missing values equal to our nominal clear-weather level of 30 dB. For the isolation range of interest (I less than 30 dB), the two methods yielded essentially identical percent-of-time distributions.

4. DATA

Figures 1 through 13 display the percentages of time that the CTS 11.7 GHz isolation was less than the indicated values for each month of 1978 and for the year. These 'lessence' plots were made for exactly the same time periods as were the attenuation and rain rate distributions published in Reference 1.

Most of the figures contain three curves. As discussed in the previous section, these are

(1) measured isolation statistics with missing values set to 30 dB

(2) measured isolation statistics with missing values excluded from the data base

(3) isolation statistics PREDICTED from the attenuation statistics measured for the same time period.

For all except Figure 13, the predictions in (3) were based on a least-squares fit of equation (2) to simultaneous values of I and A for $5 < A < 30$ dB, when the data supported such a fit. The plotted points show the results that could be expected if isolation statistics were predicted from attenuation data, provided that the necessary coefficients U and V were known. For the yearly data (Figure 13), the prediction was based on equation 3 (p. 28), determined by statistical methods. For any one month, insufficient statistical data were available to provide meaningful values of U and V; hence we used the instantaneous fits.

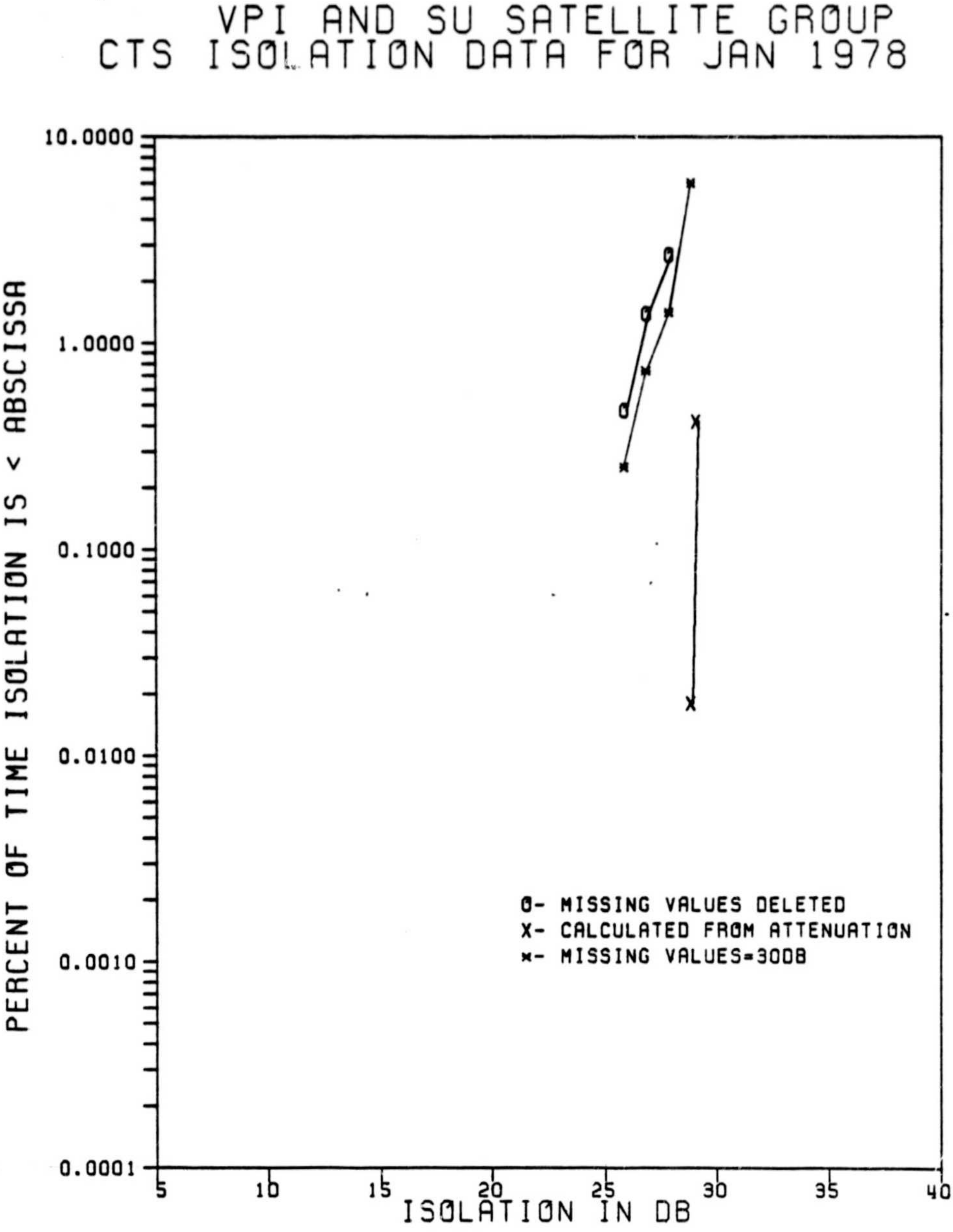

Figure 1. Isolation statistics for January, 1978.

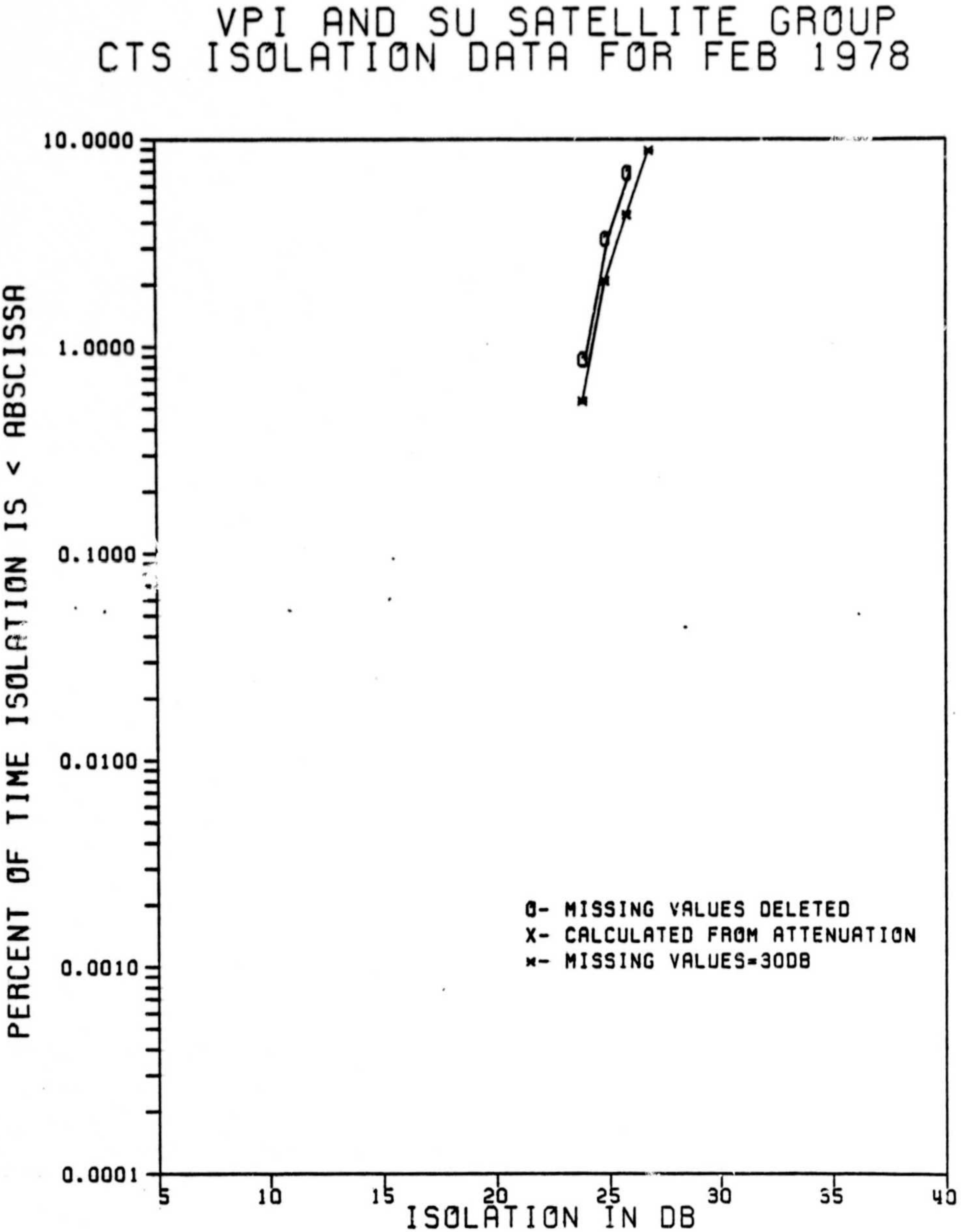

Figure 2. Isolation statistics for February, 1978.

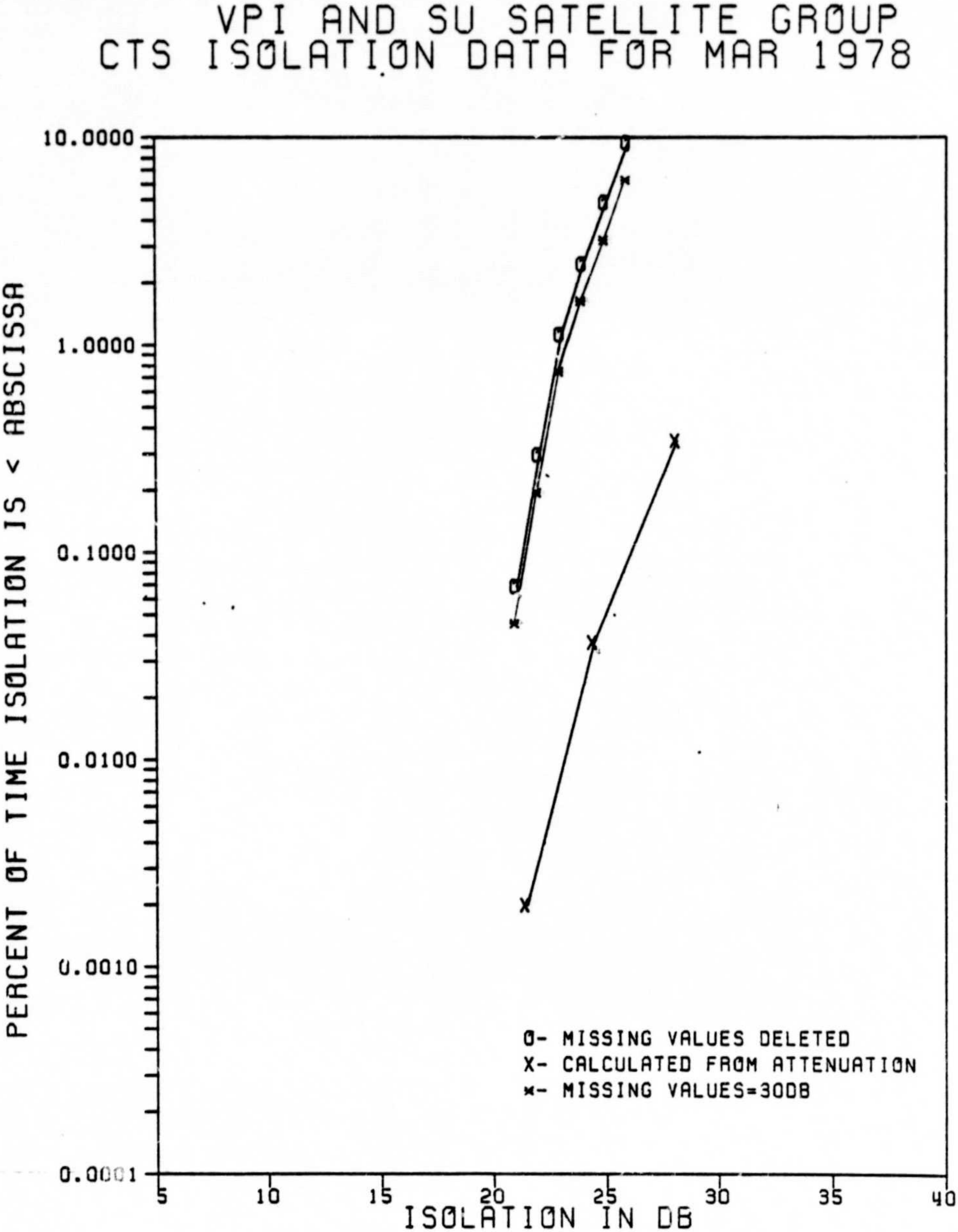

Figure 3. Isolation statistics for March, 1978.

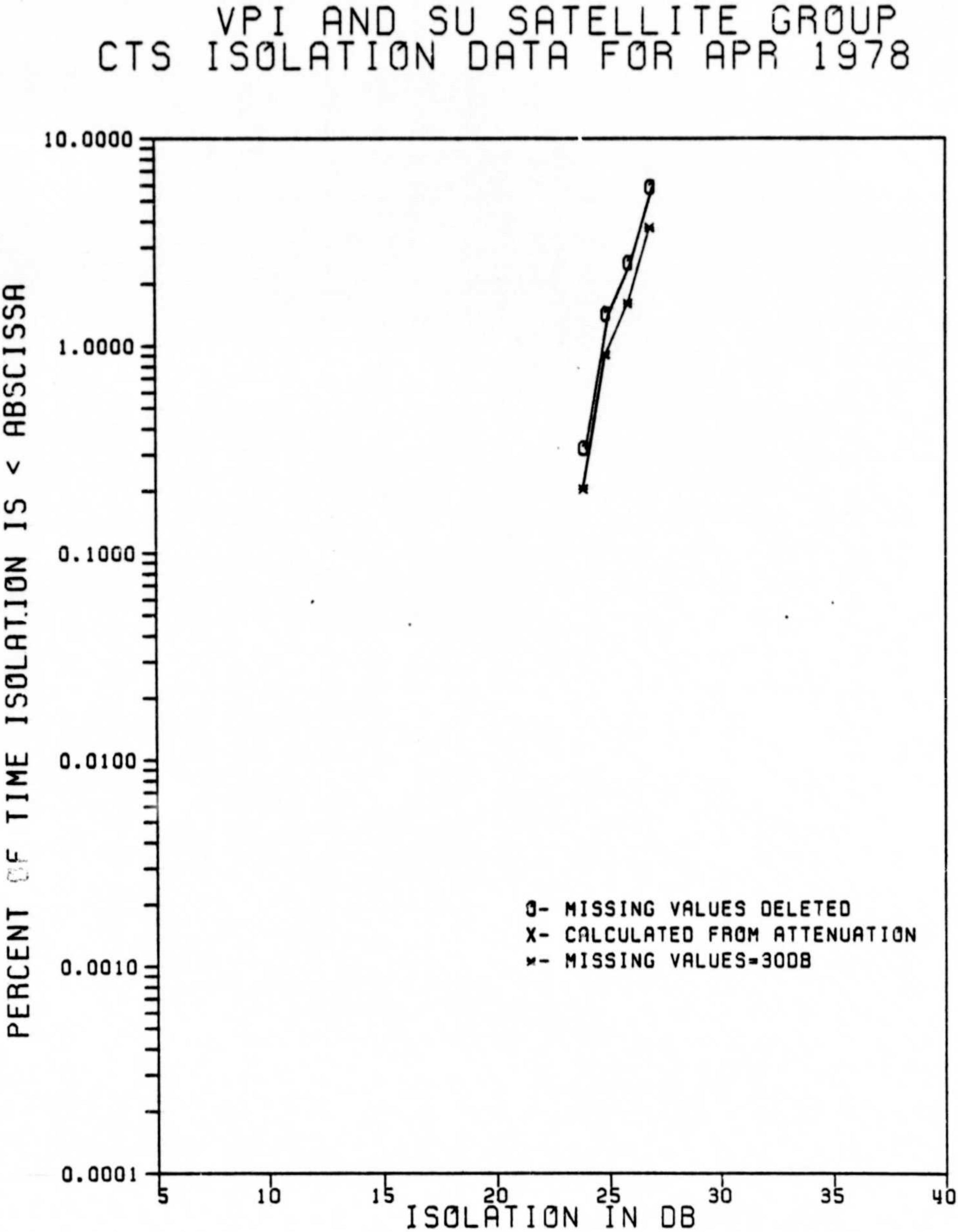

Figure 4. Isolation statistics for April, 1978.

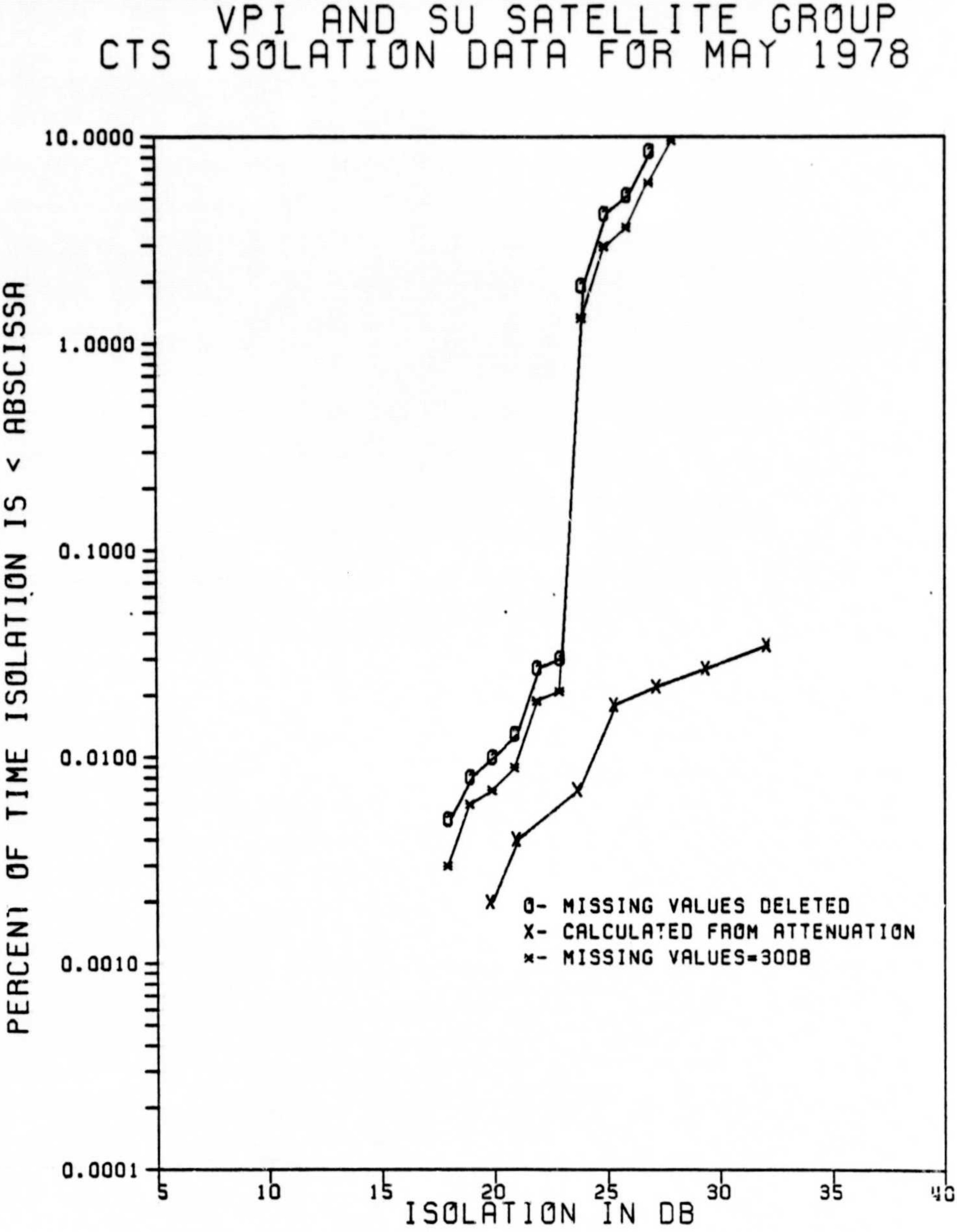

Figure 5. Isolation statistics for May, 1978.

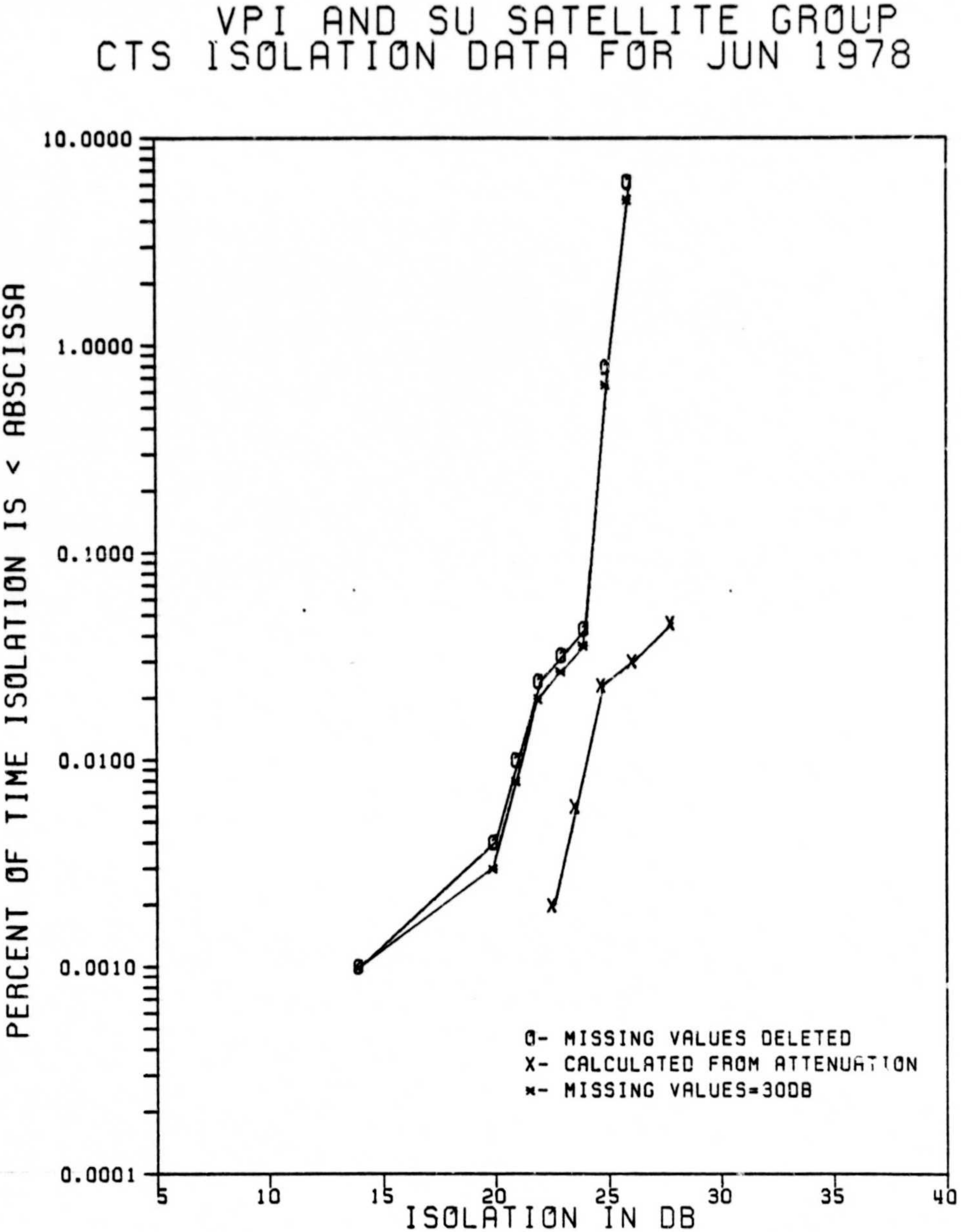

Figure 6. Isolation statistics for June, 1978

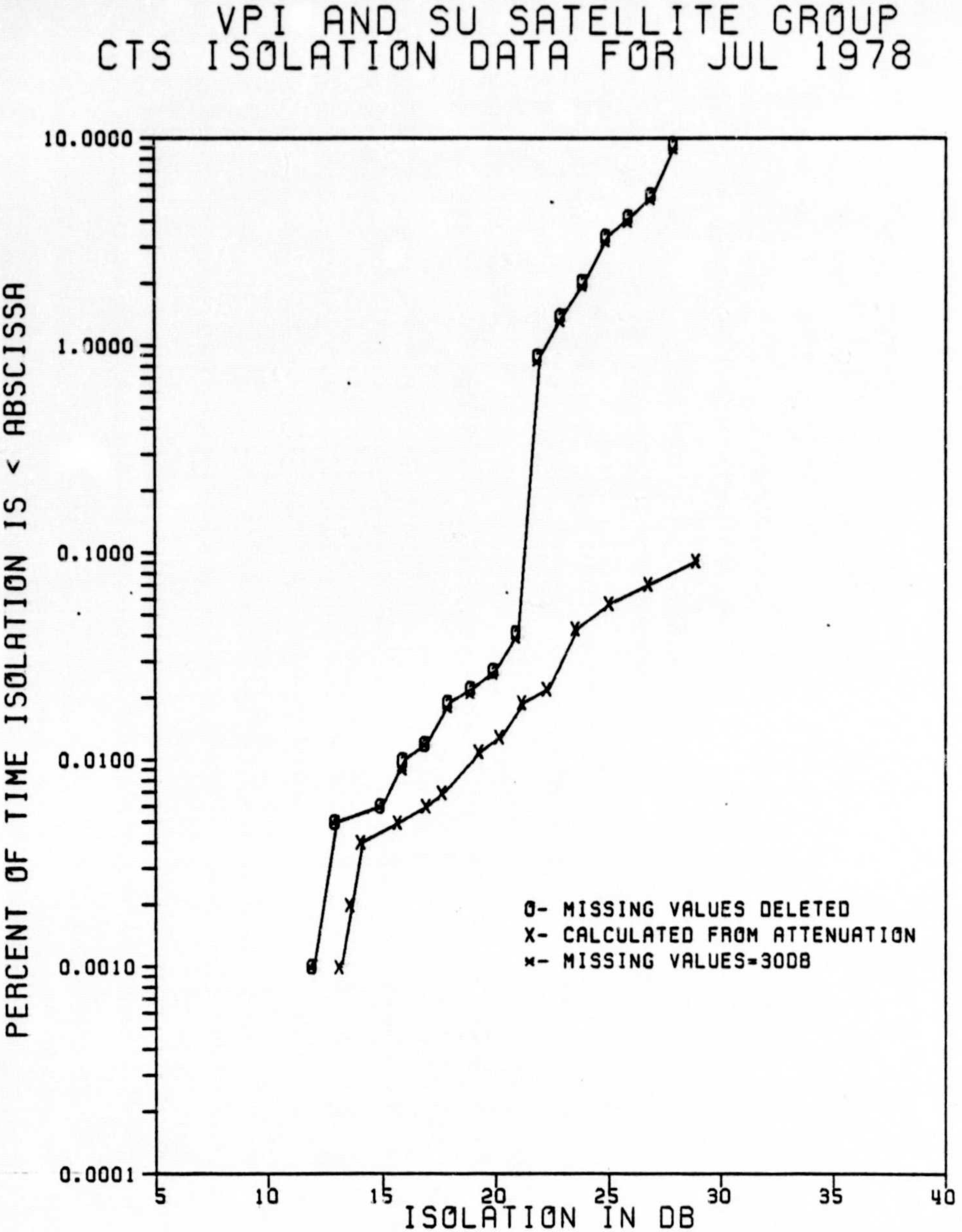

Figure 7. Isolation statistics for July, 1978.

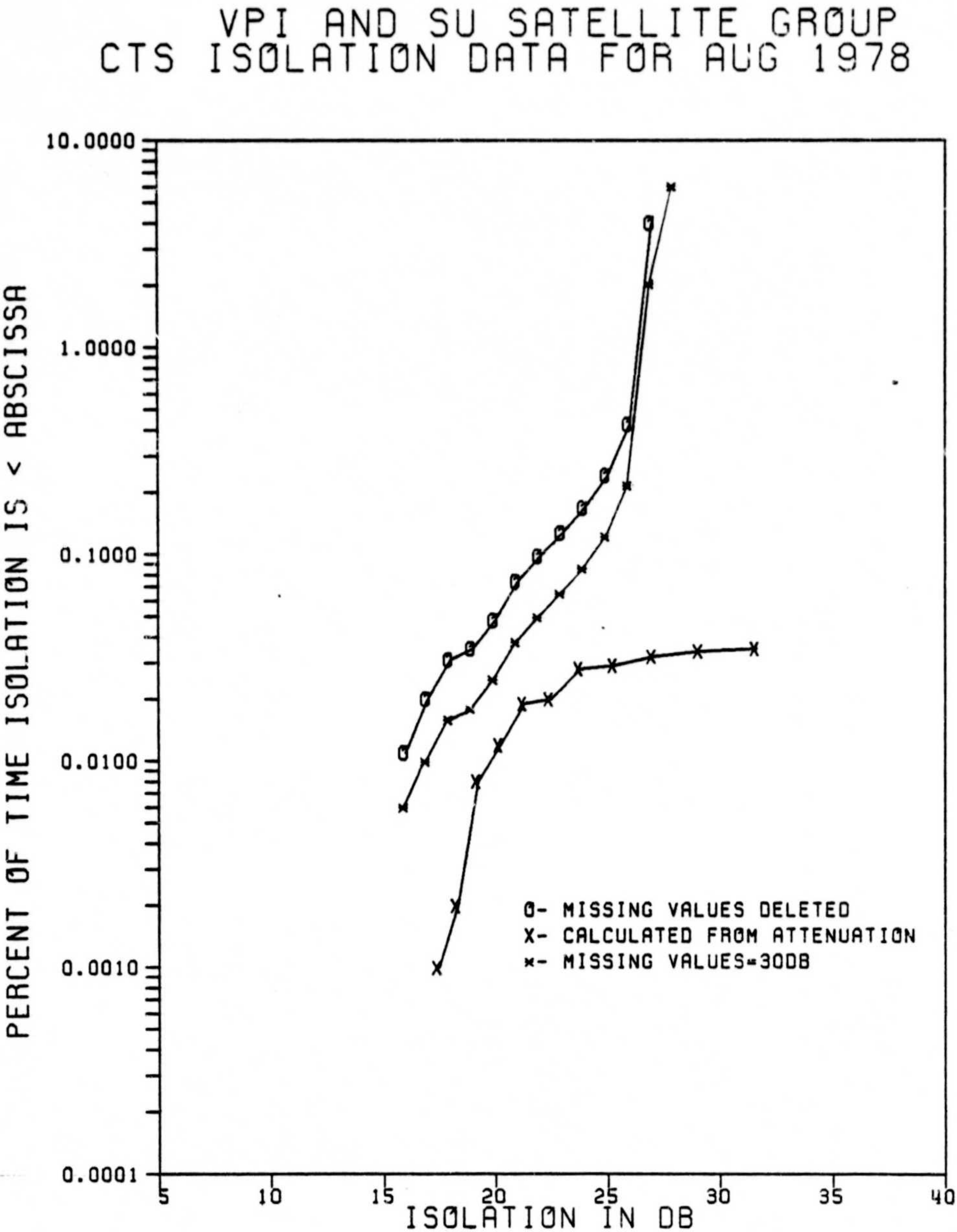

Figure 8. Isolation statistics for August, 1978.

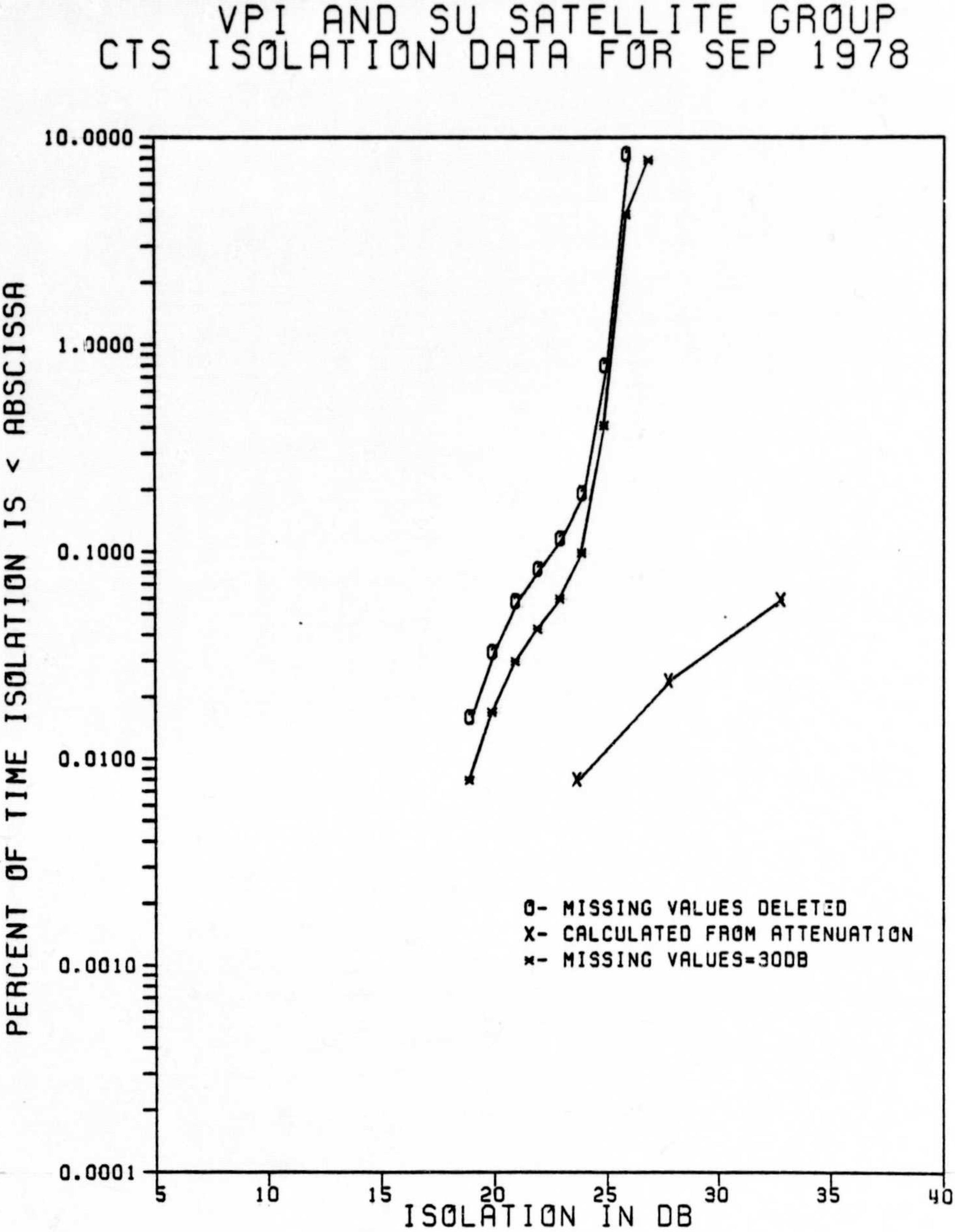

Figure 9. Isolation statistics for September, 1978.

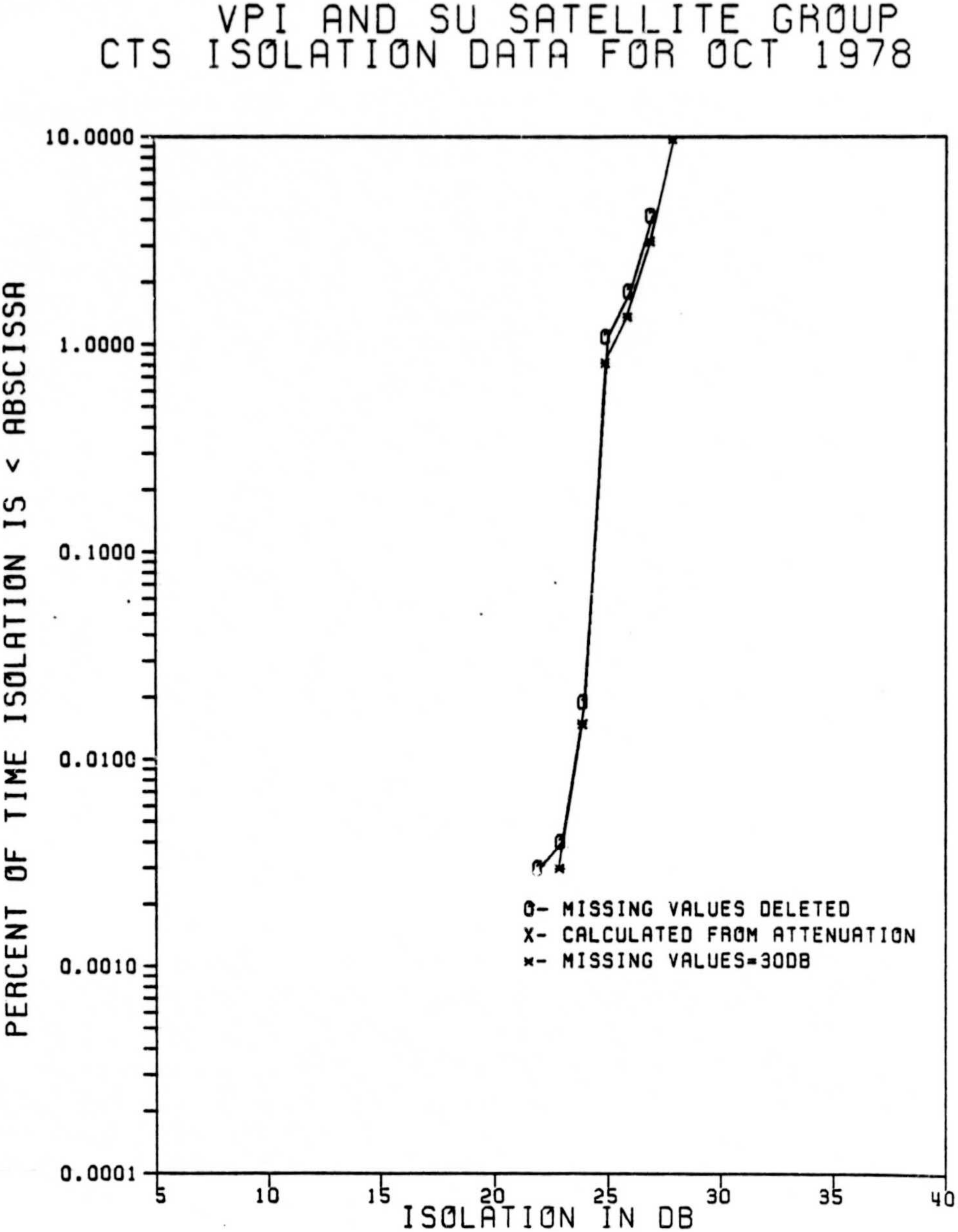

Figure 10. Isolation statistics for October, 1978.

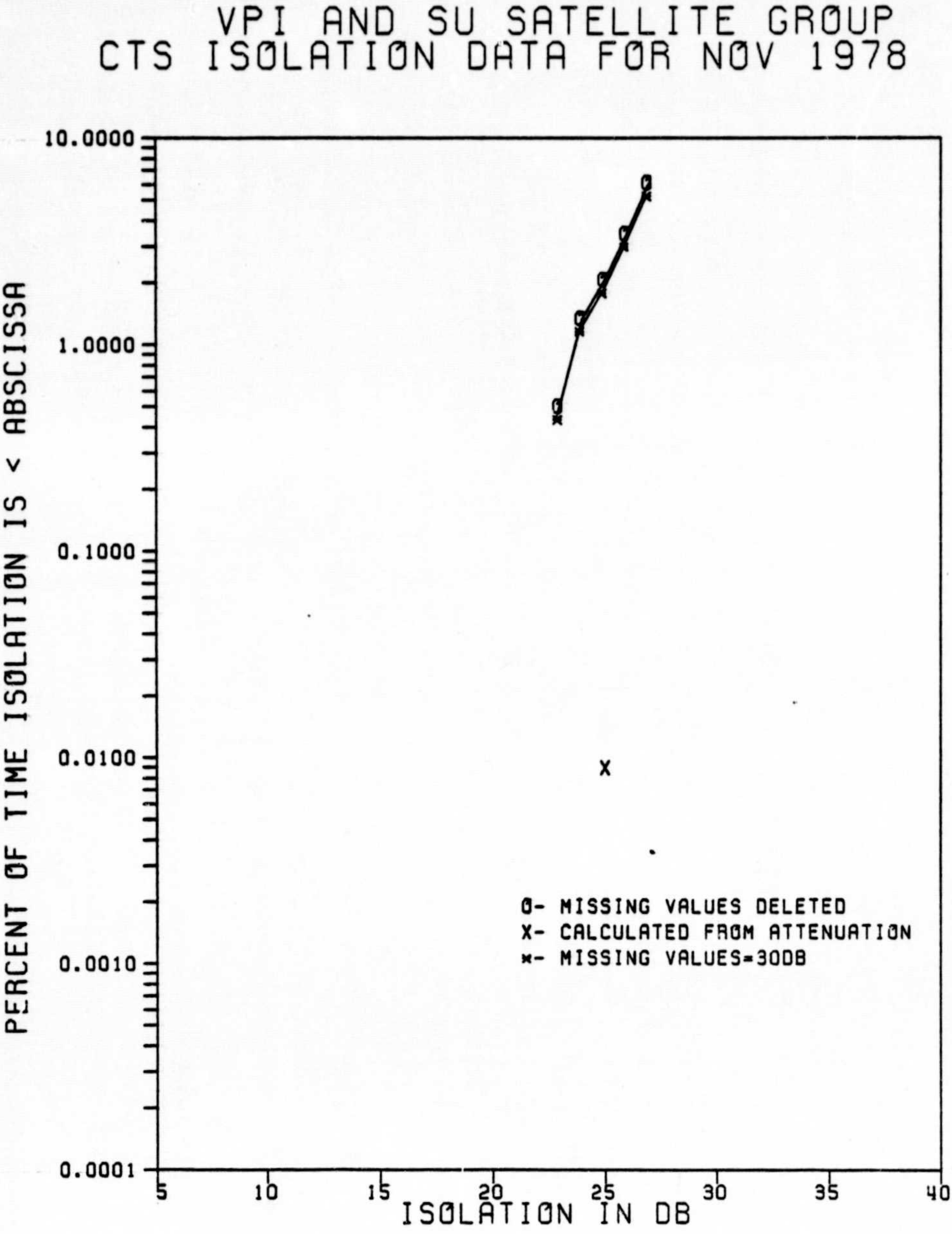

Figure 11. Isolation statistics for November, 1978.

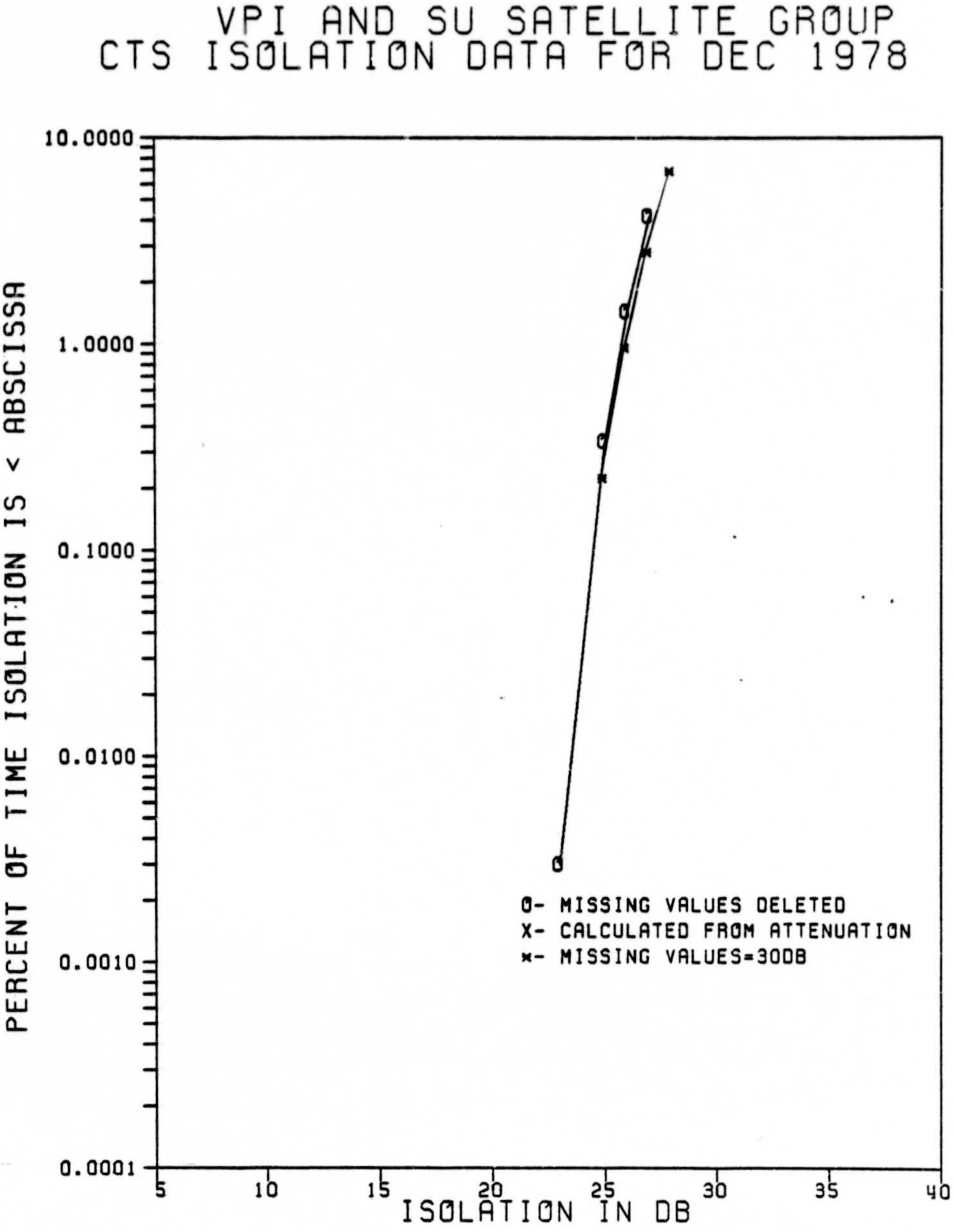

Figure 12. Isolation statistics for December, 1978

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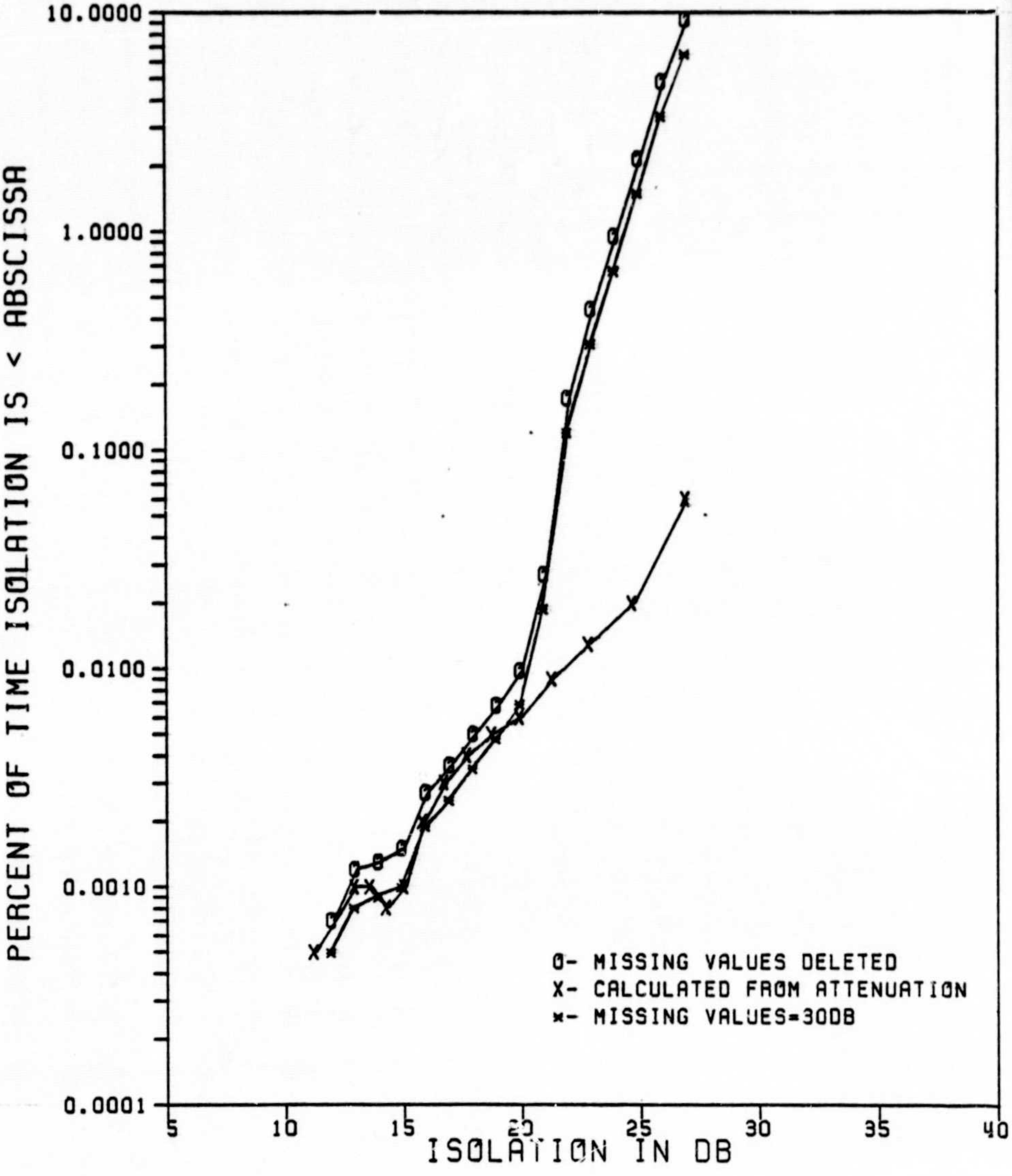

Figure 14 is a theoretical plot of yearly isolation statistics calculated from our measured rain rate data under the assumption of ideal antennas at both ends of the path. The theoretical calculation also ignores the effects of ice. At 11.7 GHz our theoretical model tends to underestimate attenuation and overestimate isolation; hence the theoretical curve shows better isolation for a given percent of time than was measured. Antenna effects and possible ice depolarization also cause the measured isolation to be poorer than the theoretical value. Of course what happens with ideal antennas is somewhat academic; practical communications systems use real antennas and imperfect pointing techniques and they will experience isolation that is poorer than that predicted theoretically for ideal conditions.

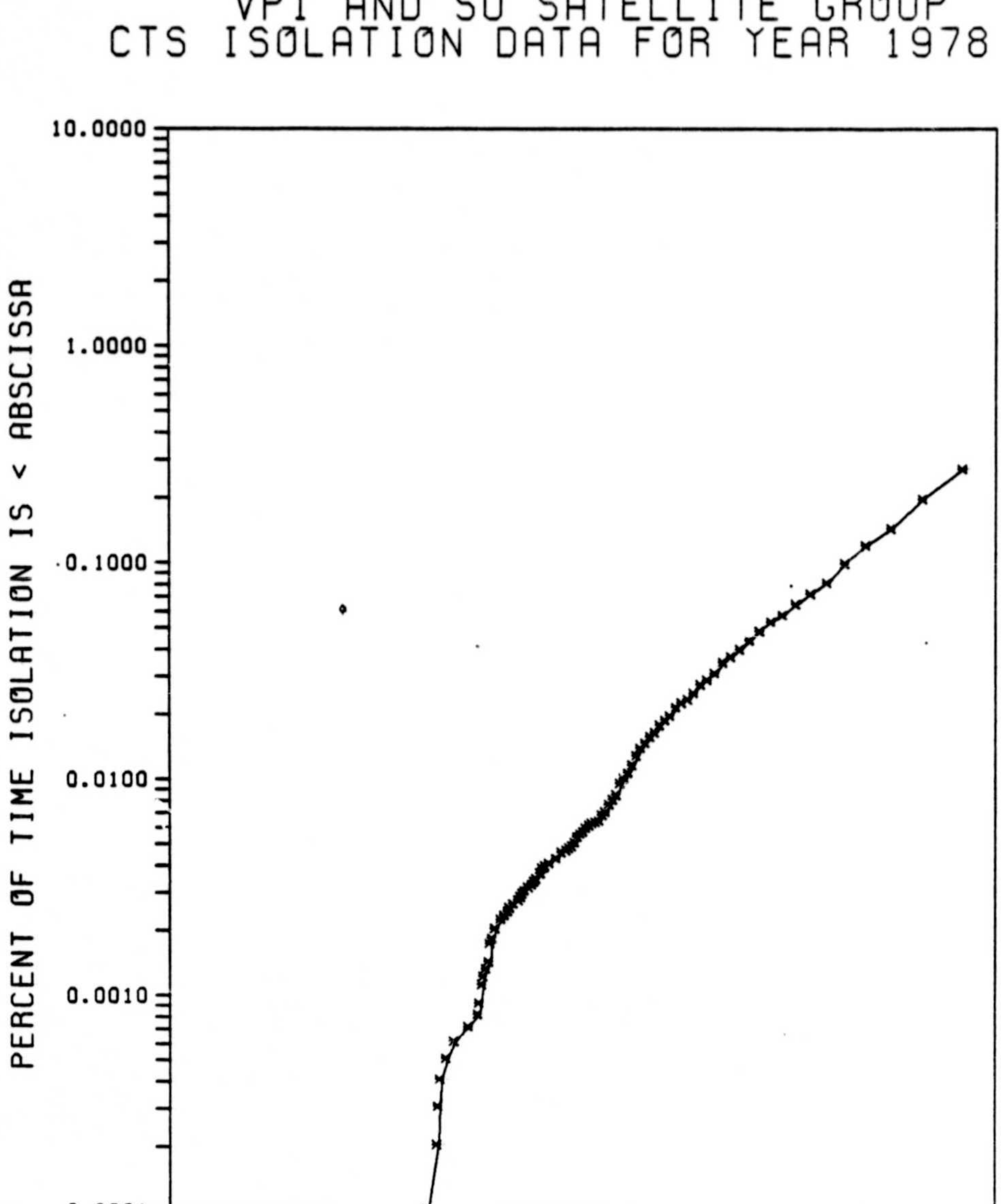

Figure 14. Theoretical isolation statistics for ideal antennas based on measured rain data

5. RELATING ISOLATION TO ATTENUATION

Parts a and b of Table 1 summarize the results of fitting equation (2) to simultaneous I and A values for $3 < A < 30$ dB and $5 < A < 30$ dB, respectively. Better fits are obtained in the second case because it eliminates the wide isolation scatter generally observed at attenuations in the 3 to 5 dB range. The coefficients in part b of Table 1 correspond to those published by W. J. Vogel of the University of Texas on page 10 of Reference 4.

Figure 15 is a scatter plot of isolation versus attenuation for all the $A > 3$ dB data taken during 1978. Superimposed on it are plots from the $A > 3$ dB and $A > 5$ dB curve fits. Figure 16 plots the mean value of I observed in 1978 for all attenuations greater that 3 dB; the error bars extend plus and minus one standard deviation from the mean. Figure 17 presents the same information after the isolations for each integer value of attenuation have been combined.

Another approach to relating I and A is to determine U and V values statistically. To do this we find the values A(P) that the attenuation was greater than and I(P) that the isolation was less than for P percent of the time. A curve fit in the form of equation (2) can then be developed if the data set contains sufficiently many P values for which we have both A(P) and I(P)

To illustrate the month-to-month variation in corresponding I-A values, Table 2 lists the integer values of I that correspond to each integer value of A during each month of the year and for the year as a whole. Since it is rare to find a percentage P for which <u>both</u> the attenuation exceeded for P percent of time <u>and</u> the

Table 1. Results of least-square fitting $I = U - V*\log_{10}(A)$ to 1978 isolation and attenuation data. Except where noted, values are for $3 < A < 30$ dB. The quantity R indicates goodness of fit (1.0 indicates a perfect fit) and P is the number of data points used in the analysis.

	a. Instantaneous. 3 < A < 30				b. Instantaneous. 5 < A < 30				c. Statistical. Values taken from Table 2.		
Month	U	V	R²	P	U	V	R²	P	U	V	R²
J	30.57	1.71	.00	99	30.79	2.62	.00	22	29.00	4.97	1.00
F*	33.55	-11.63	.00	2471	**				**		
M	35.74	18.13	.47	3667	51.18	38.18	.63	309	26.00	4.19	1.00
A	25.33	- .17	.00	87	**				**		
M	28.14	5.69	.03	1420	49.01	27.93	.90	30	27.66	7.99	.88
J	36.70	15.51	.61	61	38.42	17.53	.56	38	41.68	24.15	.98
J	28.22	8.04	.11	1255	42.23	21.94	.80	74	29.22	14.55	.57
A	39.73	18.79	.70	38	47.31	25.99	.47	28	25.00	1.80	1.00
S	62.05	50.54	.62	146	64.20	51.93	.32	50	25.36	6.47	.79
O	35.87	17.64	.21	292	**				27.02	6.54	1.00
N	4.92	-35.32	.16	1115	27.59	4.11	.04	7	**		
D	42.13	24.91	.37	8	**				27.00	6.65	1.00
Year	32.50	12.17	.15	10670	36.29	16.22	.36	574	29.43	12.00	.86
								***	40.99	23.23	.95

* No rain fell this month.

** Insufficient data to support a curve fit.

*** Fit for A > 5.

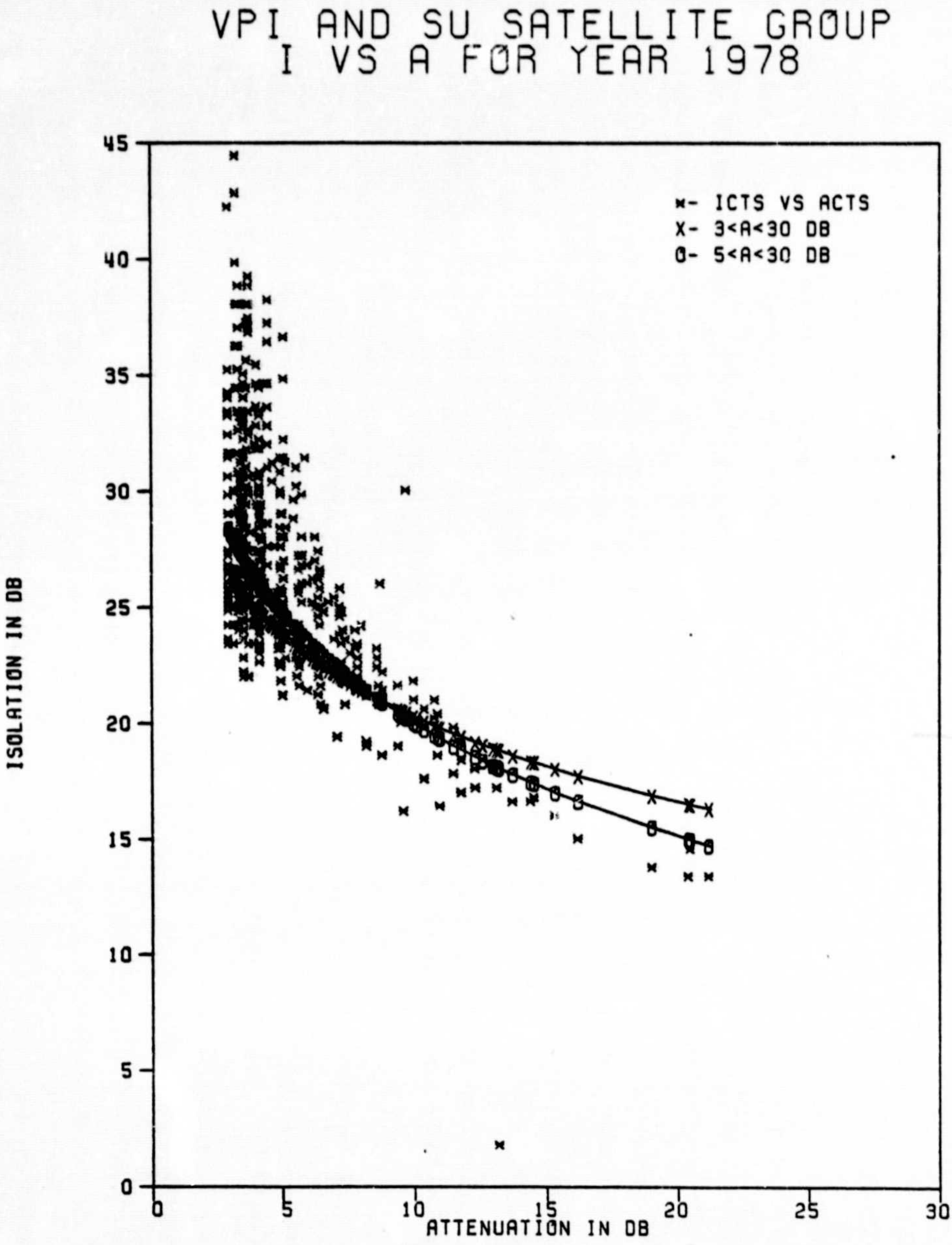

Figure 15. 1978 yearly scatter plot of isolation versus attenuation for A > 3 dB. Also shown are curve fits for 3 < A < 30 and 5 < A < 30 dB.

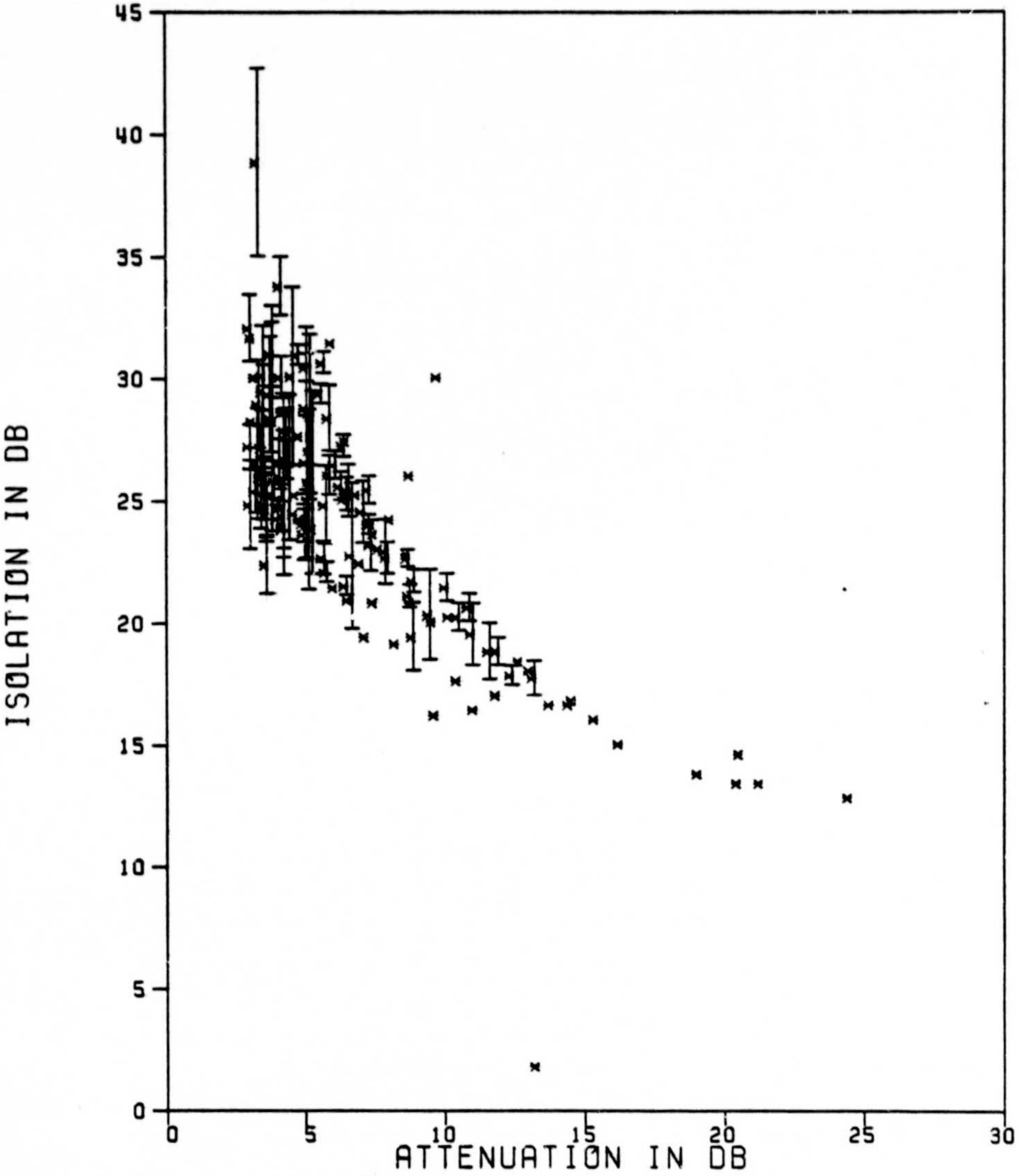

Figure 16. For each 1978 observed value of attenuation greater than 3 dB, this plot shows the mean value of isolation. The error bars extend ± one standard deviation from the mean.

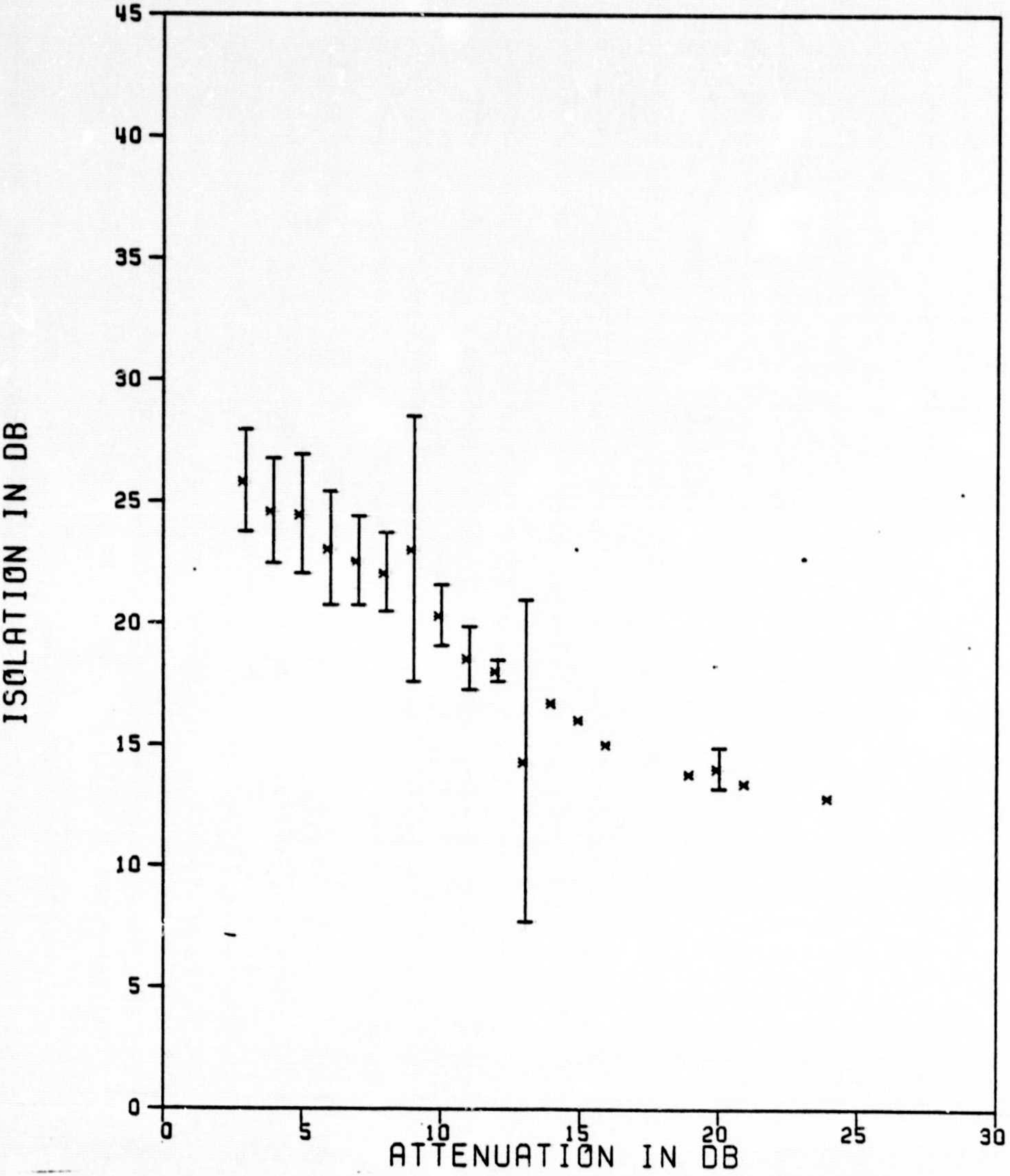

Figure 17. For each 1978 integer value of attenuation greater than 3 dB, this plot shows the mean value of isolation. The error bars extend ± one standard deviation from the mean.

Table 2. Integer values of isolation that approximately correspond to integer values of attenuation for each month in 1978 and for the year. See text for explanation.

A	J	F	M	A	M	J	J	A	S	O	N	D	Y
1	29	27	26	26	28			25	25	27		27	26
2					24		23				24		
3			24							24			
4	26								23	23		23	
5									21				21
6					23	23			19				
7					22	21							
8					20	20	20						20
9							18						19
10													18
11					18								17
12													
13								23					15
14													13
15							14						
16							13						
17													
18													
19													12
20													
21							12						

value that the measured isolation was less than for P percent of time are available, some of the entries in Table 2 are approximate and should be interpreted as being correct to within about 1 dB.

Values of U and V based on Table 2 appear in part c of Table 1. The yearly fit for $A > 5$ dB,

$$I = 40.99 - 23.23*\log_{10}(A) \tag{3}$$

is quite similar to the result

$$I = 41 - 20.6*\log_{10}(A) \tag{4}$$

published in Reference 4. For ideal antennas, our theoretical model predicts

$$I = 36.05 - 18.35*\log_{10}(A) \tag{5}$$

Over the range $5 \leq A \leq 20$, the I values predicted by (3) and (5) differ by less than 1.5 dB.

6. CONCLUSIONS

Like other investigators, we find considerable scatter in the values of isolation observed at a given attenuation (5) and in the U, V coefficients for different time periods (4). Presumably this occurs because isolation is much more sensitive to the fine details of drop shape and orientation than attenuation. Another potential factor is scattering by ice crystals, which depolarize but do not attenuate (6). These effects make the prediction of monthly isolation statistics from monthly attenuation statistics difficult, as Figures 1-12 illustrate.

7. REFERENCES

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