Online Journal of Space Communication

Volume 1
Issue 2 *NASA's Advanced Communications Technology Satellite [ACTS] (Fall 2002)*

Article 11

September 2002

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Charles E. Mayer

Bradley E. Jaeger

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Charles E. Mayer
University of Alaska Fairbanks
Electrical Engineering Department
P.O. Box 755915
Fairbanks, AK 99775-5915
Phone: 907-474-6091
Fax: 907-474-5135
E-mail: ffcem@uaf.edu

Bradley E. Jaeger
University of Alaska Fairbanks
Electrical Engineering Department
P.O. Box 755915
Fairbanks, AK 99775-5915
Phone: 907-474-7815
Fax: 907-474-5135
E-mail: fsbej1@uaf.edu

I. INTRODUCTION

The Advanced Communications Technology Satellite (ACTS) propagation experiment has yielded five years measurements of rain rates and attenuation at 20.185 GHz and 27.505 GHz in seven diverse climate regions throughout North America. Figure 1 shows the former locations of ACTS propagation terminals. In the pursuit of rain attenuation models, rain has generally been classified as stratiform, convective, or cyclonic. Location has everything to do with how much of each of these types of rain a communications link will experience. In addition, changes in drop size distribution, drop shape, and canting angle are to be expected. Perturbations in average rain characteristics are common with El Nino. This paper discusses the ACTS propagation measurements in contrast to the Revised Two Component model and the DAH model.

◎ ACTS Propagation Terminal (APT) Site

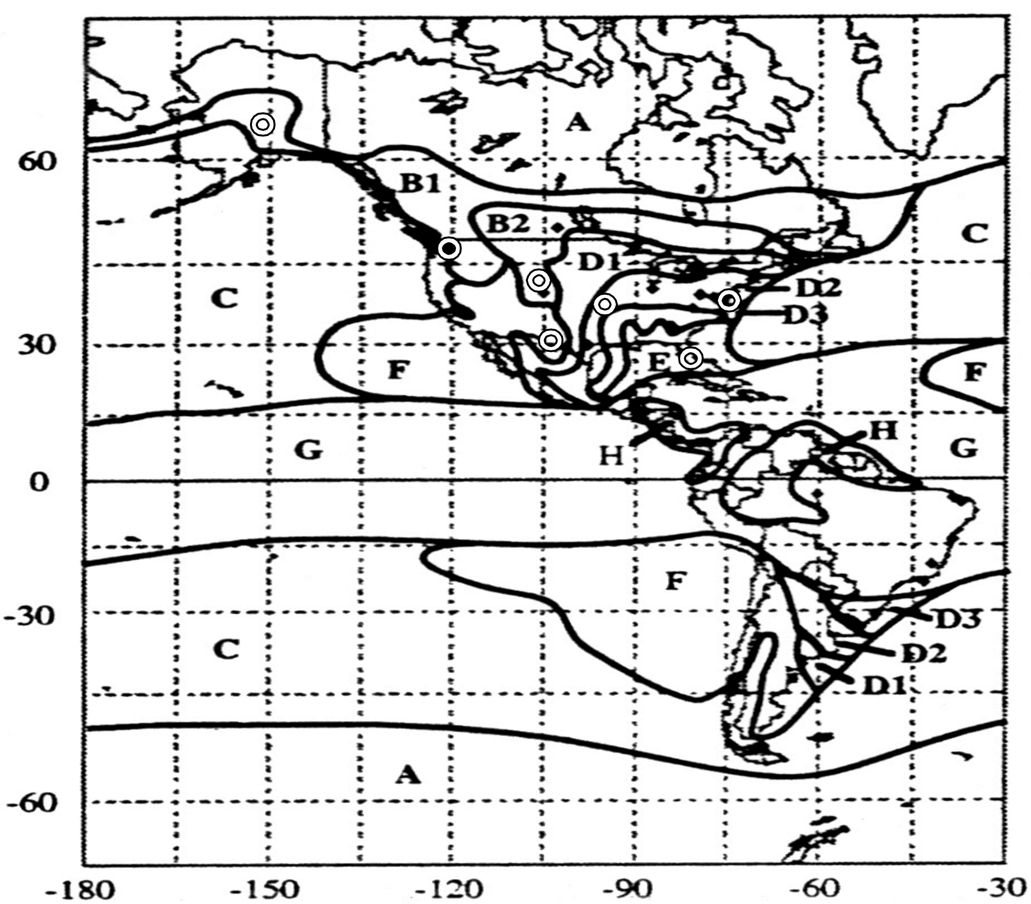

FIGURE 1 PLACEMENT OF ACTS PROPAGATION EXPERIMENT SITES IN CRANE GLOBAL RAIN ZONES

II. PROCEDURE

Depending on location, rain rate measurements were obtained from one or both of two types of rain gauges. Rain rates from a capacitive gauge were calculated using a simple linear regression for the slope of rain accumulation over one minute. This method, developed by Stephen Horan, helped to reduce the unwanted electronic noise in the rain rate measurement. Rain rates from tipping bucket gauges were calculated using the equation, rate=3600.0·0.254/(tip_time-last_tip_time) [mm/hr].

The reference level for beacon attenuation measurements was set using a calibration program, written by Robert Crane, which matched theoretical estimates of sky temperature, in clear conditions, to sky temperatures obtained from APT radiometer measurements [1]. Quality control was handled in the calibration program by way of a text file experimenters could edit to specify removal of sun or moon intrusions, equipment adjustments, etc. The differing propagation effects which beacon and radiometer measurements represent dictated that beacon attenuation empirical distributions and radiometer attenuation empirical distributions should match between 2 dB and 6 dB. The beacon attenuation, or attenuation with respect to free space (AFS), can be thought of as composed of gaseous attenuation (AGA), clear air attenuation (ACA), and antenna wetting factor (AWF) so AFS=AGA+ACA+AWF. Uncorrected clear air attenuation is ACA+AWF. Since antenna wetting factor is highly dependent upon antenna design, rain attenuation models do not predict it. In order to isolate attenuations representative of rain, gaseous attenuation was subtracted from the time series of total beacon attenuation and antenna wetting factor was subtracted from the empirical distributions of uncorrected clear air attenuation. Regressions by Robert Crane allowed hourly surface measurements of temperature, pressure, and water vapor density to be used to predict sky temperature, medium temperature, and hence gaseous attenuation. Antenna wetting factors were calculated using Matlab code written by Atle Borsholm [2]. The cumulative distributions for antenna wetting factor rain rates were obtained from Crane's summary files on the 5-year propagation data compact disks. The expected value of the difference of the annual uncorrected ACA empirical distribution (which is random) minus the true cumulative distribution for antenna wetting factor (which is constant) is the difference of the true cumulative distribution of uncorrected ACA minus the true cumulative distribution of antenna wetting factor. This is the true cumulative distribution of clear air attenuation. Table 1 shows parameters, for each of the ACTS propagation terminals, relevant to rain attenuation prediction models. In the discussion of the Revised Two Component and DAH models to follow, the Crane Global model rain zones will be used [3].

TABLE 1 SITE PARAMETERS FOR ACTS PROPAGATION TERMINALS

Location	Organization	N. Lat. (°)	W. Long. (°)	Height (km)	Crane Global Rain Zone	Elev. (°)	Az. (°)	Tilt Angle from Horiz. (°)	20.185 GHz EIRP (dBW)	27.505 GHz EIRP (dBW)
Fairbanks, AK	U. of AK	64.85	147.82	0.18	B1	8.1	129.3	70.6	9.5	10
Vancouver, BC	U. of BC	49.25	123.22	0.01	C	29.3	150.5	71.1	14	14
Greely, CO	CO State U.	40.33	104.61	1.9	B2	43.1	172.8	84.6	19	17
Tampa, FL	U. of South FL	28.06	82.42	0.05	E	52	214	60.4	16	15
Reston, VA	COMSAT	38.95	77.33	0.08	D2	39.2	213.3	64.4	17	16
White Sands, NM	NM State U.	32.54	106.61	1.46	F	51.5	167.8	79.7	18	17
Norman, OK	U. of OK	35.21	97.44	0.42	D2	49.1	184.4	86.4	19	17

III. RESULTS

A. Rain Rate

The continuous sampling of rain rates, at a given location, over yearly intervals is used to estimate the mean empirical distribution of rain rates, the annual cumulative distribution. Since the ACTS propagation experiment spanned multiple years, the empirical distributions for rain rate collected can also be used to estimate the year to year variability in empirical distributions. Figure 2 shows average 1-minute least squares capacitive rain rate empirical distributions in dashed lines. The solid lines indicate the Revised Two

Component model. Markers for data are the same as for the model for each site. Figure 3 displays tipping bucket rain rate empirical distributions.

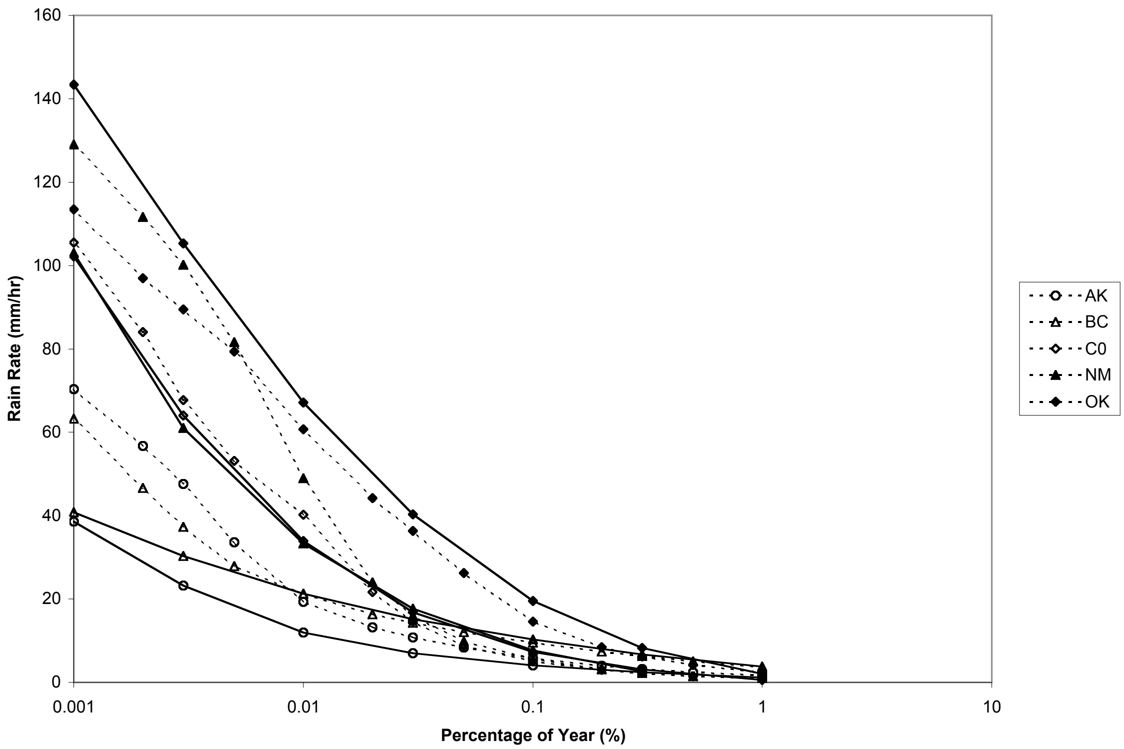

FIGURE 2 1-MINUTE LEAST SQUARES CAPACITVE RAIN RATE AVERAGE ANNUAL EMPIRICAL DISTRIBUTION

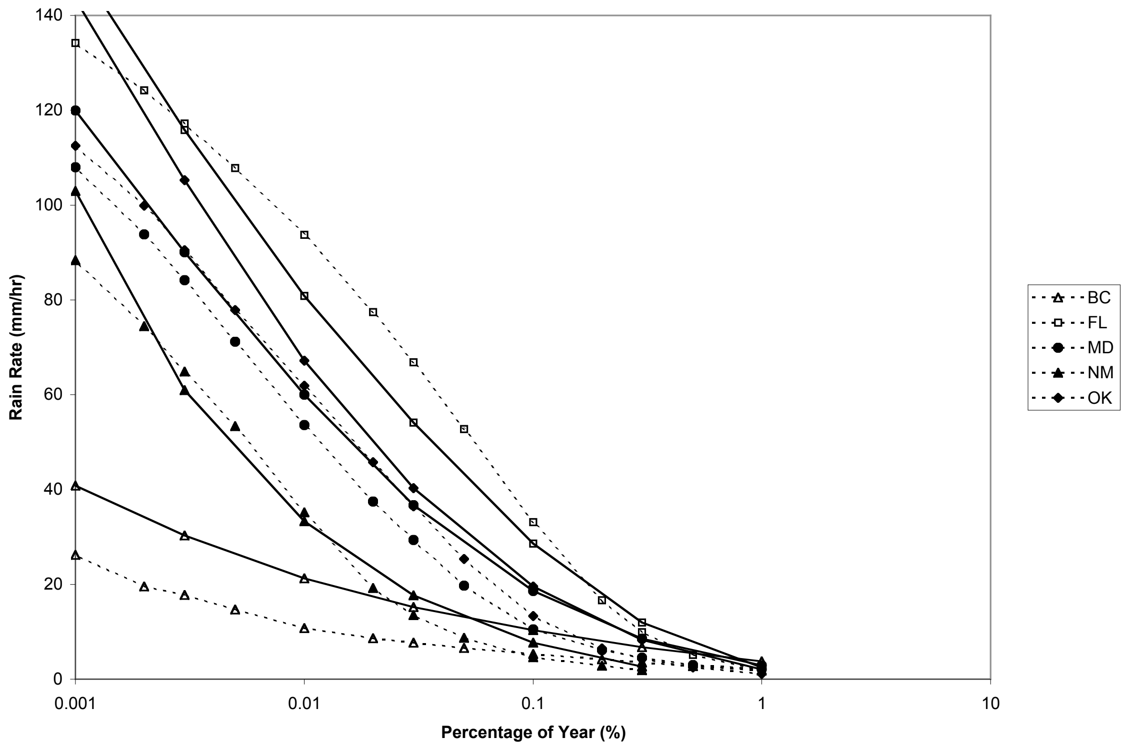

FIGURE 3 TIPPING BUCKET RAIN RATE AVERAGE ANNUAL EMPIRICAL DISTRIBUTION

The Revised Two Component model estimates rain rates using the four climate dependent parameters probability of a cell, average cell rain rate, probability of debris, and average debris rain rate. Bias error in each year was calculated using the convention bias=ln(R_{meas}/R_{model}). Table 2 shows bias errors by site for all capacitive gauge and tipping gauge rain rate empirical distributions.

TABLE 2 REVISED TWO COMPONENT MODEL ANNUAL RAIN RATE BIAS ERRORS

	Avg	stdev	rms	#points
AK	0.37	0.41	0.55	28
BC	-0.16	0.41	0.44	42
CO	0.06	0.32	0.33	30
FL	0.03	0.19	0.19	24
MD	-0.31	0.35	0.47	24
NM	-0.06	0.41	0.41	52
OK	-0.27	0.24	0.37	33

Model validation requires that a collection of yearly empirical distributions not excessively breach model bounds at a specified level of risk. As part of constructing model bounds, the Revised Two Component model specifies that the standard deviation of ln(R_{meas}/R_{model}) is constant, Da=0.21, across percentages of time between 1 and 0.001 [4]. Qualitatively, there is no real pattern of bias or low variability in the standard deviations plotted in figure 4.

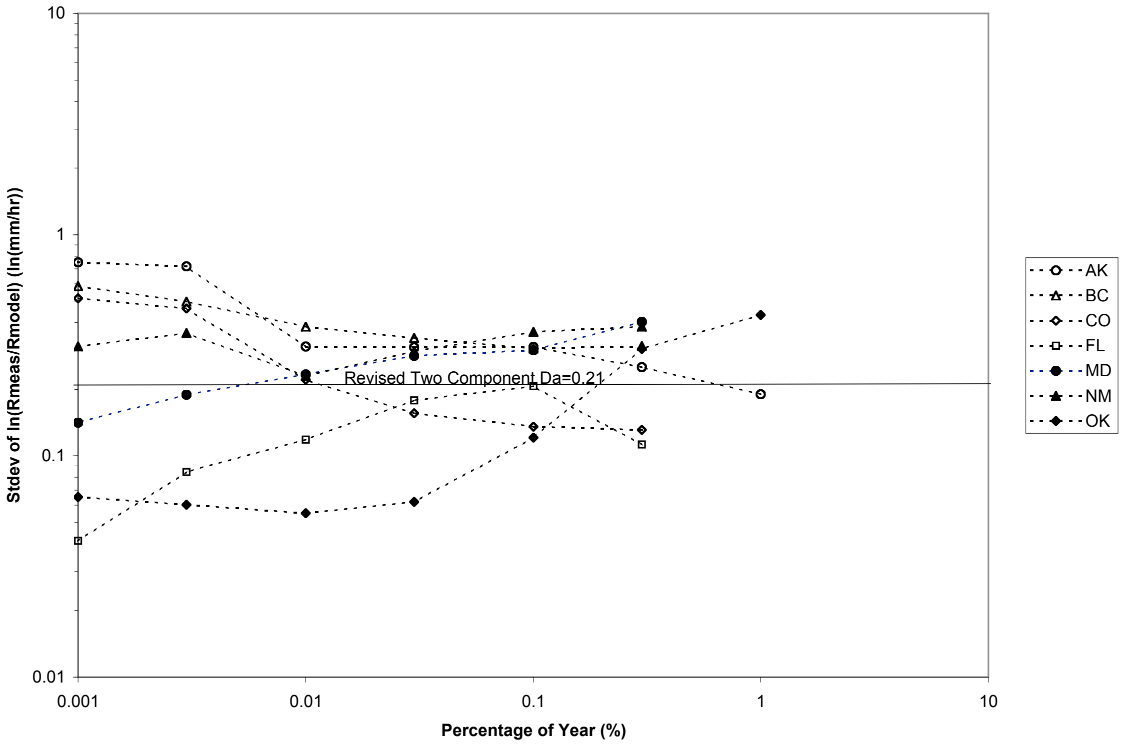

FIGURE 4 YEAR TO YEAR VARIABILITY IN RAIN RATE EMPIRICAL DISTRIBUTIONS

B. Rain Attenuation

The multiple years over which beacon attenuation measurements were taken were intended to narrow an uncertainty in attenuation at any percentage of time to 11% [1]. Figure 5 shows 20.185 GHz clear air empirical distributions by site, indicated by dashed lines. Solid lines indicate the Revised Two Component model.

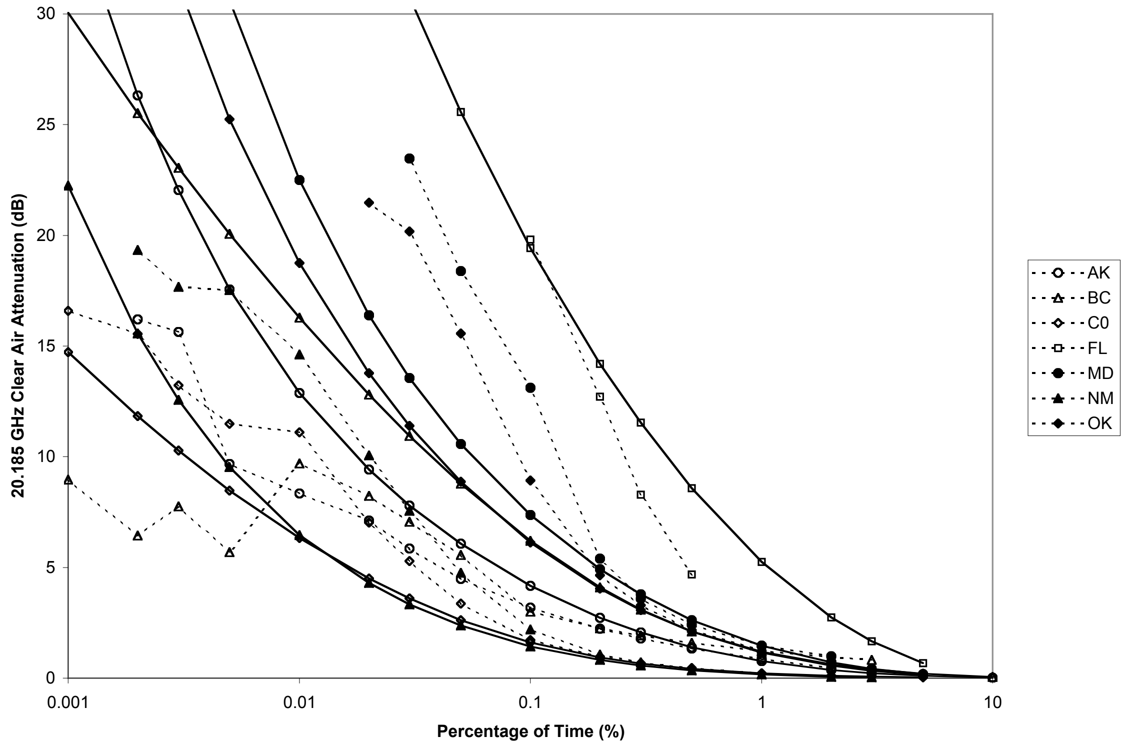

FIGURE 5 AVERAGE ANNUAL 20.185 CLEAR AIR ATTENUATION EMPIRICAL DISTRIBUTIONS

The Revised Two Component model and the DAH model take two different approaches to rain attenuation modeling. The Two Component model is based on climate dependent probability distributions for rain in a cell and rain in debris. Its climate dependent parameters were discussed previously. The DAH model takes the approach of assuming the best fit to all available attenuation data. Its climate dependent input parameter is the rain rate at 0.01% of the time. Table 3 shows computed bias errors for the Revised Two Component model and the DAH model at 20.185 GHz.

TABLE 3 20.185 GHZ CLEAR AIR ATTENUATION ANNUAL BIAS ERRORS

	Revised Two Component				DAH			
	avg	stdev	rms	#points	avg	stdev	rms	#points
AK	-0.32	0.42	0.53	26	-0.41	0.39	0.56	26
BC	-0.64	0.58	0.87	30	-0.62	0.56	0.83	30
CO	0.25	0.62	0.67	26	-0.11	0.64	0.65	26
FL	-0.24	0.23	0.34	7	0.18	0.21	0.28	7
MD	0.18	0.44	0.47	14	0.11	0.50	0.52	14
NM	0.44	0.66	0.79	20	-0.14	0.84	0.85	20
OK	0.23	0.33	0.40	19	0.05	0.42	0.42	19

27.505 GHz average annual empirical distributions are shown in figure 6. Empirical distributions are truncated to account for limited dynamic range. Anything below –5 dBW EIRP in table 1 was considered below the dynamic range of the APT receiver.

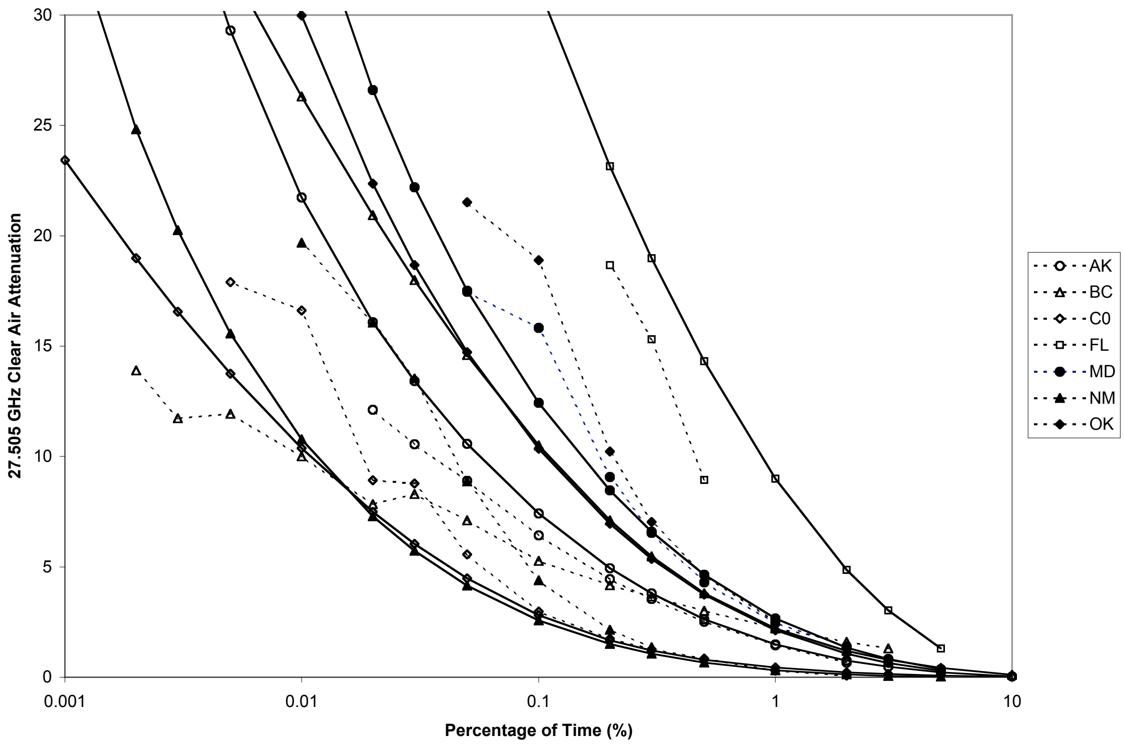

FIGURE 6 AVERAGE ANNUAL 27.505 GHZ CLEAR AIR EMPIRICAL DISTRIBUTIONS

Table 4 shows bias errors by location for 27.505 GHz rain attenuation.

TABLE 4 27.505 GHZ CLEAR AIR ATTENUATION ANNUAL BIAS ERRORS

	Revised Two Component				DAH			
	avg	stdev	rms	#points	avg	stdev	rms	#points
AK	-0.14	0.28	0.31	18	-0.24	0.29	0.38	18
BC	-0.62	0.42	0.75	26	-0.61	0.38	0.72	26
CO	0.15	0.81	0.83	21	-0.31	0.86	0.91	21
FL	-0.23	0.22	0.32	5	0.08	0.22	0.24	5
MD	0.03	0.25	0.25	12	-0.10	0.31	0.32	12
NM	0.47	0.53	0.71	17	-0.20	0.68	0.71	17
OK	0.33	0.30	0.44	15	0.06	0.37	0.37	15

Figure 7 shows that the mean standard deviation D_A=0.23 is used by the Revised Two Component model to establish bounds on attenuation. The year to year variability in attenuation empirical distributions is plotted by percentage of time. Both 20.185 and 27.505 GHz data are plotted. Qualitatively, there is no apparent pattern, considering both frequencies.

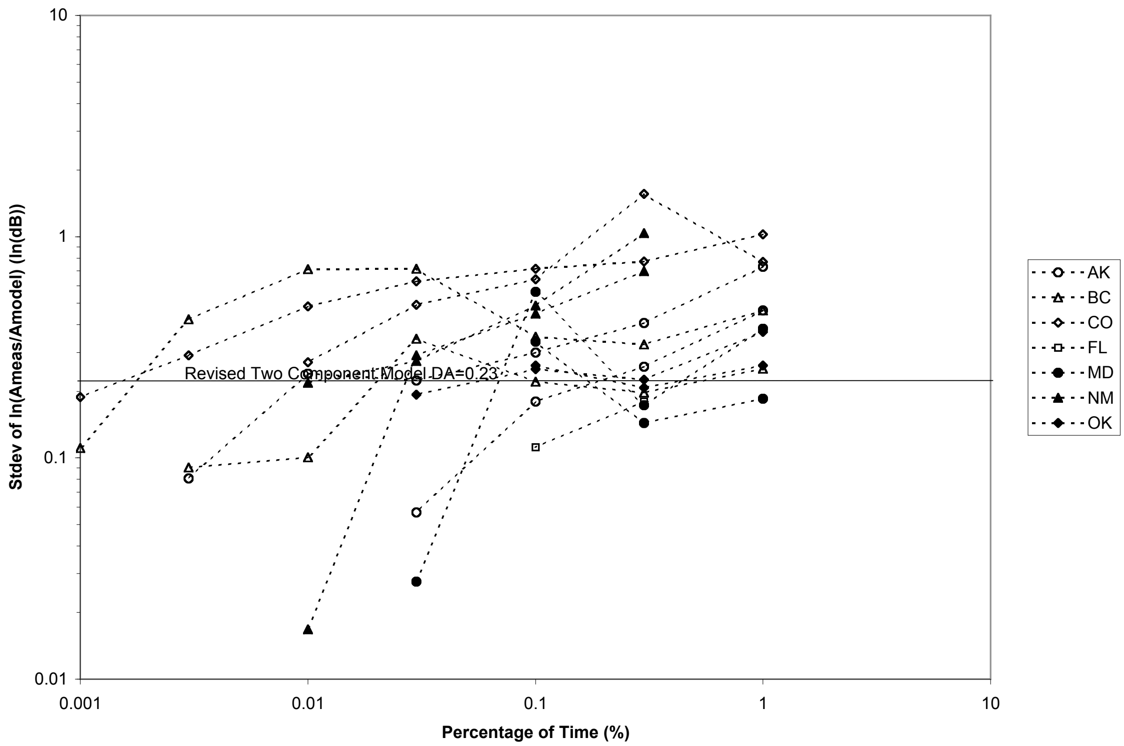

FIGURE 7 YEAR TO YEAR VARIABILITY IN CLEAR AIR ATTENUATION, BOTH FREQUENCIES

IV. CONCLUSIONS

Since Crane has established that bias, as defined above, follows a normal distribution, it is possible to test the hypothesis that the Revised Two Component and DAH models predict rain attenuation equally well [4]. An F-test for unequal variance of average bias values (both frequencies) is not significant, p-value=0.106. A t-test for unequal mean average bias is also not significant, p-value=0.208. In summary, in the context of the ACTS propagation data, the Revised Two Component and DAH models do not provide statistically different predictions when used with the Crane Global climate zones.

V. REFERENCES

[1] R.K. Crane, "ACTS Propagation Experiment: Experiment Design, Calibration, and Data Preparation and Archival," *Proceedings of the IEEE*, pp. 863-878, June 1997.
[2] http://telsat.nmsu.edu/~shoran/apt/thesis.PDF.
[3] http://rossby.metr.ou.edu/~actsrain/
[4] R.K. Crane, *Electromagnetic Wave Propagation Through Rain*, New York: Wiley-Interscience, 1996, pp 245-259.