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Abstract

In June 1996, Working Party 3M of the ITU-R presented research comparing the estimations of 10 rain attenuation models with the 186 station years of earth-space propagation data contained within the ITU-R database known as DBSG5. Now, twenty-one station years of new data taken exclusively in the Ka band (20.185 GHz and 27.505 GHz) across North America are measured against many of those same models. Results are presented both in terms of error statistics as well as in comparison to the ITU database results.

1.0 Introduction

In June 1996, Working Party 3M of the ITU-R presented research comparing the estimations of 10 rain attenuation models with the 186 station years of earth-space propagation data contained within the ITU-R database known as DBSG5. Twenty-two comparisons were performed by subdividing DBSG5 into groupings of different frequency ranges, latitude ranges, and elevation angle ranges. One of these tests compared 86 station years of propagation data taken between 15 and 35 GHz, see Table 8. Now, twenty-one additional station years of slant path propagation data have been taken at various locations around North America. The data is collected at 20.185 GHz and 27.505 GHz using the NASA Advanced Communication Technology Satellite (ACTS). The locations of the additional sites are displayed in Table 1. Each site has 3 years of data collected and processed.

Name	Lat (N)	Lon (W)	Alt (km)	Elev ( )	ITU Rgn
Fairbanks, AK	65	148	0.184	9	C
Vancouver, BC	49	123	1.000	30	D
Ft. Collins, CO	40	105	2.000	43	E
Tampa, FL	28	82	0.040	52	N
Clarksburg, MD	39	77	0.076	39	K
Las Cruces, NM	32	107	1.460	51	E
Norman, OK	35	97	0.420	49	M

Table 1: Locations of ACTS Propagation Data

The seven sites in Table 1 represent a wide variety of climatic conditions as shown by the difference in ITU rain regions. Fairbanks, Alaska is 1ocated south of the Arctic circle. Meanwhile, Tampa, Florida is a semi-tropical climate with much higher temperatures and humidity. Las Cruces, New Mexico is an arid climate near the U.S. border with Mexico. Vancouver, British Columbia is a damp, "drizzly" environment. Boulder, Colorado is a high altitude mid-latitude area. The remaining sites in Norman, Oklahoma and Clarksburg, Maryland are temperate, mid-latitude locations with differing extremes in the winter and summer.

2.0 Rain Attenuation Models

The propagation data used in the ITU-R study was compared against ten rain models. These models are shown in Table 2.

Model	Origin	Author(s)	Notes
ITU-R	Int'l	ITU	ITU-R Rec. P.618-4, 1991
CCIR	Int'l	CCIR (Now ITU)	CCIR Report 564-3, 1986
Brazil	Brazil	M. Pontes	ITU-R model enhanced for tropical locations
Japan	Japan	Yoshio Karasawa	ITU-R model enhanced for lower availabilities

DAH	USA	Dissanayake, Allnut, Haidara	A comprehensive update to the ITU-R model.
Two Component	USA	R.K. Crane	Mathematically intensive. Consider cell & debris.
Leitão-Watson	U.K.	M.J. Leitão & P.A. Watson	A nonempirically derived model based on radar.
Misme-Waldteufel	France	P. Misme & P. Waldteufel	An extension of their 1975 terrestrial model
ExCell	Italy	Capsoni, Fedi, & Paraboni	Estimates rain attenuation on a cell-by-cell basis
Spain	Spain	J.A. Garcia-Lopez	A simple method optimized for intense rain.

Table 2: Rain attenuation models used in the ITU-R study

Each of the above models is derived with a specific intent. The CCIR[1] and ITU-R[2] models have the objective of being globally applicable across a wide range of frequencies, elevation angles, and rain climates. The DAH[3] model seeks to improve upon the overall ITU-R model performance by modifying path profiles as well as adjusting the calculations across a wider range of availabilities. Both the Japan[4] model and Brazil[5] model are developed as refinements to the ITU-R model which focus on improving prediction accuracy at lower system availability levels. The Brazil model adds the additional refinement of increasing accuracy for systems operating in tropical and/or equatorial regions.

The remaining five models are independently derived and are primarily based on radar data. Misme and Waldteufel's[6] model is an extension of their terrestrial rain attenuation model which considers rain to consist of a circular cell with uniform rain rate and "a weakly rainy area" surrounding the cells. The Two Component model[7] also proposes a technique for individually calculating the effects of isolated cells and the surrounding "debris." The two sources of rain attenuation are derived independently and then summed. The Leitão-Watson[8] model attempts a "first principals" approach which extrapolates point to path characteristics from dual polarization radar cross section data and applies that data to scattering theory. The extension to Earth-space paths is essentially a geometric exercise. ExCell[9] is an abbreviation for EXponential CELL model. This model, which is also derived from radar measurements, takes an empirical approach to modeling a typical cell structure. Multiple cells are then used to recreate the total distribution of rain rates occurring across a path. Garcia-Lopez[10] provides a technique which is optimized for simplicity of calculations and maximum accuracy at the highest attenuation values.

In comparing the ACTS propagation data with the above propagation models the following assumptions were made.

1) Any assumptions made to the models in the ITU-R study were also made in the ACTS study. These assumptions are outlined in ITU-R 3M4B Document 1.

2) Rain attenuation statistics are created by measuring a total attenuation and subtracting the gaseous absorption. Data included in DBSG5 is typically processed by subtracting a mean gas constant over a period of a month to a year from the rain attenuation. For this reason, the ACTS data was processed by subtracting an annual mean absorption from each site from the total attenuation.

3) Two additional models not included in the original ITU-R study were included in the analysis of ACTS data. These models are the Global Rain Attenuation Model[11] developed by Robert Crane and the Simple Attenuation Model[12] (SAM) developed by Warren Stutzman. These models are displayed in Table 3.

Model	Origin	Author(s)	Notes
Global	USA	R.K. Crane	Widely used for system planning
SAM	USA	W. Stutzman	Optimized for simplicity

Table 3: Additional rain models used to compare the ACTS data

4) One model included in the original ITU-R study was not included in the analysis of ACTS data. This model is the Misme-Waldteufel model.

3.0 Calculations

The error of a prediction at a particular probability level is determined by the formula

$$=(A_{PRED}-A_{MEAS})/A_{MEAS}*100\%.$$

where A_{MEAS} is the attenuation value based on the ACTS propagation measurements, and A_{PRED} is the rain attenuation model prediction. Values of are collected for the probability levels 1, 2, 3, and 5 x 10^{-n}% between 0.1% and 0.001% for all measured attenuations < 20 dB. The 20 dB value was chosen as a maximum value because it represents the dynamic range of the ACTS propagation terminal receivers. For this reason, results will be biased toward probabilities > .1%. This is considered acceptable for the analysis because Ka band system planners are most interested in availabilities in the 99% to 99.9% range. For each probability level with a measured attenuation below 20 dB, an was produced. The values of were collectively measured across the distribution to create a mean and RMS error.

Note, the ITU database comparison was performed in two ways which lead to significant differences in the magnitude of the numerical values of the results. First, error statistics in the ITU comparison were generated using ITU-R Recommendation P.311. This recommendation provides a method for comparing the accuracy of models through an "emphasis factor" which normalizes all attenuations to 10 dB. Second, the ITU-R comparison did not consider any attenuation occurring above the 0.1% probability level (i.e. availability was assumed to be *at least* 99.9%).

It should be remembered that at probabilities above 0.1% (availabilities < 99.9%), attenuation values will have smaller absolute values than at probabilities above 0.1%. Therefore, a larger relative error is does not necessarily correspond to a larger absolute dB error. Though the technique identified in Rec. P.311 was not used to generate the error statistics shown here for the ACTS data, it should be mentioned that the technique was used in a separate assessment of the data and did not change the overall ranking of the models.

4.0 Results

Table 4 displays the percent RMS and mean errors for the three years of ACTS propagation data. As a comparison Table 5 presents the results for only the first two years of data. For the first two years of data, all models performed within typically expected error ranges with RMS error values of ±30 to 60%. For all sites except Vancouver, B.C., the third year of data provided the greatest RMS error. For all sites except, Vancouver, B.C. and Fairbanks, AK, the third year also provided the largest mean error which appeared as large under predictions of attenuation by the models. It is yet to be determined if the large differences in model performance due to the third year of data are the result of an uncharacteristically dry year leading to improper removal of water vapor and oxygen from the total attenuation, changes in data processing techniques, or aging propagation measurement hardware. However, it should be noted that these results correspond well with the findings in the ITU-R study that a large part of the error in the models is due to year-to-year variability rather than just error in the models estimation capabilities.

An increase in RMS error with the third year of data is apparent when comparing the three-year statistics in Table 4 to statistics of just the first two years shown in Table 5. It is also interesting to notice that across all models the prediction at 27 GHz experienced less error than at 20 GHz in terms of both RMS and mean error. The difference in mean error for each model between 20 and 27 GHz has little correlation with the difference in RMS error (r=-0.39). A possible reason for the apparent increased accuracy at 27 GHz is the fact that most models are optimized for higher values of attenuation and, for a given rain rate, the 27 GHz signal will be attenuated more.

Error statistics for the models may, at first glance, appear large. However, it should be reiterated that the dynamic range of the propagation terminals is only 20 dB. This means that a 1 dB error in a prediction is *at least* 5% error. Therefore, it is not unexpected that absolute values of error are slightly greater than the typical ±30 to 40%. In addition, most models were derived for optimal performance at availabilities above 99.9%. This level of performance is not of interest to many Ka band system planners. A Ka band system in a temperate climate can easily achieve attenuations in excess of 10 dB at 99.9%.

Model	RMS20	Model	RMS27	Model	Mean20	Model	Mean27
DAH	45.97	**DAH**	39.20	**DAH**	-35.43	**DAH**	-21.10
ExCell	48.31	**ExCell**	40.64	**ExCell**	-38.12	**ExCell**	-27.40
ITU	53.28	**TC**	44.38	**Global**	-42.04	**TC**	-35.99
TC	53.78	**ITU**	46.35	**TC**	-45.46	**Brazil**	-39.02
CCIR	55.34	**CCIR**	48.60	**ITU**	-47.50	**Global**	-40.04
Brazil	55.35	**Brazil**	50.89	**CCIR**	-47.59	**ITU**	-42.72
Global	56.38	**Global**	51.36	**Brazil**	-50.35	**CCIR**	-43.47
Japan	58.54	**Japan**	54.87	**Japan**	-57.18	**Japan**	-54.16
Spain	63.82	**Spain**	58.57	**Spain**	-62.92	**Spain**	-57.61
SAM	65.95	**SAM**	59.95	**SAM**	-64.90	**SAM**	-58.93
Leitão	70.48	**Leitão**	63.83	**Leitão**	-69.95	**Leitão**	-63.22

Table 4: Three Year RMS and Mean Error Statistics at 20.185 and 27.505 GHz

Model	20 GHz	Model	27 GHZ
DAH	39.16	**DAH**	32.18
ExCell	43.11	**ExCell**	35.12
ITU	48.10	**TC**	39.03
TC	48.61	**ITU**	41.37
Global	49.09	**CCIR**	43.89
CCIR	50.56	**Global**	45.88
Brazil	50.96	**Brazil**	46.47
Japan	53.93	**Japan**	50.58
Spain	59.84	**Spain**	55.10
SAM	62.17	**SAM**	56.63
Leitão	66.91	**Leitão**	60.20

Table 5: % RMS Errors for Two Year Statistics[13]

Tables 6 and 7 provide the ranking of the models based on RMS error by ground site location at 20 and 27 GHz respectively. Overall, the DAH model provided the best performance of the eleven models in terms of both RMS and mean error when compared with the three year cumulative statistics. In only one case (Alaska at 27 GHz) did the DAH model fall lower than fourth when compared with the other models. The ExCell model performed well except for they more humid locations, in Maryland and Florida. The TC and Global models performed inconsistently performing very well in Oklahoma and Maryland and poorly in the other locations. The Brazil model, which was enhanced for tropical regions performed well in the rainy Vancouver environment. The remaining models, the SAM and Leitão models, performed at the bottom of the ranking. Perhaps the most significant result is that there appears to be no "one best model" for use in the Ka band. When comparing the seven different sites at 20 GHz, there are six different models which perform with the lowest RMS error. At 27 GHz the best model is any one of five different models depending on the site location.

OVERALL	AK	BC	CO	FL	MD	NM	OK
DAH	4	3	1	2	4	1	3
ExCell	1	2	2	10	6	2	5
ITU	5	6	***3***	5	3	3	4
TC	***3***	11	11	6	2	11	***1***
CCIR	6	8	4	9	1	4	6
Brazil	***2***	***1***	6	7	8	6	8
Global	11	10	8	1	5	7	***2***
Japan	8	7	7	3	7	5	7
Spain	7	4	9	8	9	8	9
SAM	9	5	10	4	10	10	10
Leitão	10	9	5	11	11	9	11

Table 6: Ranking of Models by Site at 20 GHz

OVERALL	AK	BC	CO	FL	MD	NM	OK
DAH	10	3	1	***2***	***1***	1	3
ExCell	1	2	2	10	6	2	4
TC	2	10	8	7	2	7	***1***
ITU	3	6	3	***3***	4	***3***	5
CCIR	5	8	5	5	3	4	6
Brazil	6	***1***	6	8	8	6	8
Global	11	11	10	***1***	5	9	2
Japan	7	7	7	6	7	5	7
Spain	4	4	9	9	9	11	9
SAM	8	5	11	4	10	10	10
Leitão	9	9	4	11	11	8	11

Table 7: Ranking of Models by Site at 27 GHz

Table 8 provides a side by side comparison of the ranking of models in four comparisons. When a correlation coefficient is derived to compare model rankings between the overall ITU-R and the ITU-R 15 to 35 GHz test cases, a very low correlation value of r=0.248 is the result. This indicates that models with general applicability are not necessarily optimal for Ka band systems. Though the ranking of the models between the two ACTS frequencies is highly correlated (r=0.991), the ranking of the models using the ACTS data has little correlation with either of the ITU-R test cases.

Model	*ITU Overall*	*ITU 15-35 GHz*	*ACTS 20 GHz*	*ACTS 27 GHz*
DAH	*1*	*2*	*1*	*1*
ITU	*2*	*3*	*3*	*4*
ExCell	*3*	*8*	*2*	*2*
Japan	*4*	*5*	*8*	*8*
Brazil	*5*	*6*	*6*	*6*
CCIR	*6*	*7*	*5*	*5*
Leitão	*7*	*4*	*11*	*11*
Misme	*8*	*10*	*N/A*	*N/A*
TC	*9*	*9*	*4*	*3*
Spain	*10*	*1*	*9*	*9*
Global	*N/A*	*N/A*	*7*	*7*
SAM	*N/A*	*N/A*	*10*	*10*

Table 8: Comparison of Rankings Between the Various Tests

5.0 Conclusions

This paper presented a comparison between 11 rain attenuation prediction models and 21 station years of Earth-space propagation data from the NASA ACTS experiment. In general, the model errors were slightly greater than typical 30% to 40%. For North America, the overall best performing models were the DAH, based on the ITU model, and the ExCell model, empirically based on radar measurements. The ranking differs from the ITU database comparison. For model selection, system designers should consider the model that has the least error for the system ground site location, climate, elevation angle, frequency and availability.

6.0 References:

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