C-8-1 A DEMONSTRATION OF METHODS FOR PREDICTING ATTENUATION DUE TO RAIN USING THE 28 GHz COMSTAR BEACON SIGNAL WITH RADAR, DISDROMETER, AND RAINGAGE DATA

Julius Goldhirsh
Applied Physics Laboratory
The Johns Hopkins University
Laurel, Maryland 20810

Abstract

As extensions of previous efforts [1,2], a program to measure the rain attenuation of the COMSTAR beacon signal at 28.56 GHz was implemented in March of 1977 at Wallops Island, Virginia. During the summer of 1977, simultaneous radar and disdrometer measurements were also made and used for predicting path attenuation. The best fit values of a and b of the relation $k = a\,Z^b$ were deduced for each rain period from the raindrop size measurements; where k is the attenuation coefficient [dB/km] and Z is the reflectivity factor [mm^6/m^3]. The measured k-Z relations and the simultaneous radar reflectivity measurements along the beacon path were injected into a computer program for estimating the path attenuation. Predicted attenuations, when compared with the directly measured ones, showed generally good correlation on a case by case basis and very good agreement statistically.

A predictive method is also demonstrated enabling the extrapolation of fade statistics (at 28 GHz) to another frequency (f = 19 GHz) using simultaneous raingage data and overall best fit disdrometer data.

The results demonstrate the utility of using radar in conjunction with disdrometer and raingage measurements for predicting fade events and long term fade distributions associated with earth-satellite telecommunications.

SUMMARY

The experimental configuration consists of a phase locked loop receiving system operating at 28.56 GHz, an S-band radar (f = 2.84 GHz) located 30 m away, and a system of three raingages and two disdrometers (for measuring raindrop size distributions) located in the immediate vicinity of the receiving antenna. The receiving system has a maximum dynamic range of 33 dB below the free space CW power received which is -106 dBm. Both the receiving and radar antennas have beamwidths of 0.4° and look in the direction of the COMSTAR satellite (elevation = 41.6°, azimuth = 210°). During periods of rain the radar measures the backscatter of rain along the path with a range resolution of 150 m. The reflectivity factor, Z, is measured with the radar at each of the range bins.

The disdrometer used is an electromechanical sensor whose output is an impulse voltage whenever a drop impacts on a 50 cm^2 cross section area of a plexiglass sensor [3]. For drops falling at terminal velocities, the voltage outputs are proportional to the drop momentums. Through calibration, the drop diameters are related to the voltage outputs and the ground drop size distributions are determined. By using a given integration time interval (e.g., 30 seconds), the reflectivity factor, Z, is calculated on the ground. An additional parameter calculated using the measured drop size distribution is the attenuation coefficient, k, at 28.56 GHz. The radar power recorded in each of the adjacent range bins is converted into reflectivity factor levels, Z, and these are injected in the formulation for path attenuation given by,

$$A_R(t) = \sum_{i=1}^{N} k_i \, \Delta r \qquad [\text{dB}] \tag{1}$$

where

$$k_i = a \, Z_i^{\,b} \qquad [\text{dB/km}] \tag{2}$$

and where $A_R(t)$ is the radar predicted attenuation at time, t, k_i is the attenuation coefficient pertaining to i^{th} range bin, Z_i is the reflectivity factor at i^{th} range bin, Δr is the range resolution interval (150 m), and N is the number of range bins used in the summation. The values of a and b were arrived at by sampling continuous 30 second drop size distributions (hereafter referred to as DSD) with the APL disdrometer during each rain period and calculating k and Z.

In Fig. 1 is depicted an example of an attenuation event within the same interval of time as the disdrometer sampling (20 hrs, 3 min to 20 hrs, 31 min GMT). The vertical scale represents the path attenuation due to rain and horizontal scale the time in GMT. The solid curve represents measured attenuation at the satellite receiver (sampled every 3 seconds). The dashed curve represents the predicted attenuation using the radar reflectivities and the determined values of a and b obtained via the disdrometer measurements for that rain period ($a = 3.47 \times 10^{-3}$, $b = 0.733$). Also plotted (dot-dash curve) is the predicted attenuation using the radar reflectivities and the values of a and b derived from well known Marshall-Palmer (hereafter referred to as M-P) distribution; namely $a = 2.01 \times 10^{-3}$, $b = 0.773$. The radar predicted levels were sampled every 10 seconds. We note the receiver results appear to reach saturation at 29 dB. This represents a loss of lock condition where the overall receiver dynamic range of 33 dB is exceeded; the additional 4 dB being due to the diurnal variation of the satellite as well as water on the antenna feed horn. We note for the case shown that the disdrometer derived and the M-P results are similar and agree generally with the fades below 29 dB attenuation. Above this level no one to one correlation is possible. It is interesting to note that other days exist showing good agreement with the DSD-radar predicted case but poor correlation with the M-P-radar case.

The resulting fade distributions covering the approximate five rain days of sampling (corresponding to 13 attenuation events and five hours of simultaneous radar data) are shown in Fig. 2. The vertical scale represents the probability the attenuation exceeds the abscissa; the abscissa corresponding to various attenuation levels. The solid points, circles, and square points represent, respectively, the directly measured, the DSD-radar predicted, and the M-P radar predicted distributions. On an absolute basis the DSD predicted curve is in good agreement with the directly measured one whereas the M-P shows significantly poorer agreement. A numerical comparison is given in the indicated table. We note an rms dB deviation between the two curves of 1.2 and an average probability ratio $(P_1/P_2)_{avg}$ of 1.09 (larger to smaller probabilities).

A method was also employed using a measured 28 GHz fade distribution with simultaneous rain rate distribution and disdrometer data to predict fade statistics at 19 GHz. This method employs the concept of effective rain rate and reflectivity over an effective path length which establish the measured 28 GHz attenuations at given probability levels. Once the effective values are calculated, they may be used at the same probability levels to predict the 19 GHz fades. The predicted fade statistics at 19 GHz were checked against the independently arrived at statistics obtained using radar. The resulting comparisons are shown in Fig. 3. The indicated table shows an rms dB deviation between the two curves of less than 1.0 and an average probability ratio, $(P_1/P_2)_{avg}$ of 1.14. Even significantly closer agreement was achieved when radar predicted attenuation statistics at 28 GHz were used (0.4 dB rms deviation and $(P_1/P_2)_{avg} = 1.04$).

The above results demonstrate the utility of using radar in conjunction with disdrometer and raingage measurements for predicting fade events as well as long term fade distributions associated with satellite communications through rain.

ACKNOWLEDGEMENTS

The author is grateful to John R. Rowland for the development of data processing instrumentation including the disdrometer system. The useful comments and suggestions of Isadore Katz are very much appreciated. This work was supported by NASA/Goddard Space Flight Center, NASA NDPR S50748A; Radar Prediction of Rain Attenuation for Earth-Satellite Paths.

REFERENCES

1. Goldhirsh, J., "Attenuation of Propagation Through Rain for an Earth-Satellite Path Correlated with Predicted Values Using Radar", IEEE Trans. on Antennas and Propagation, Vol. AP-23, No. 6, pp 786-791, Nov 1975.

2. Goldhirsh J., "Prediction Methods for Rain Attenuation Statistics at Variable Path Angles and Carrier Frequencies Between 13 and 100 GHz", IEEE Trans. on Antennas and Propagation, Vol. AP-23, No. 6, Nov 1975.

3. Rowland, J. R., "Comparisons of Two Different Raindrop Disdrometers", Proc. 17th Conf. on Radar Meteor., Seattle, Wash., pp 398-405, Oct. 26-29, 1976, (Americal Meteorological Society, 45 Beacon St., Boston, Mass. 02108).

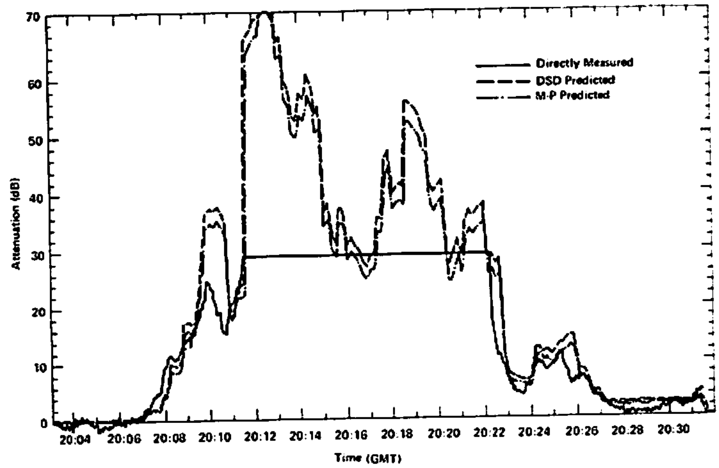
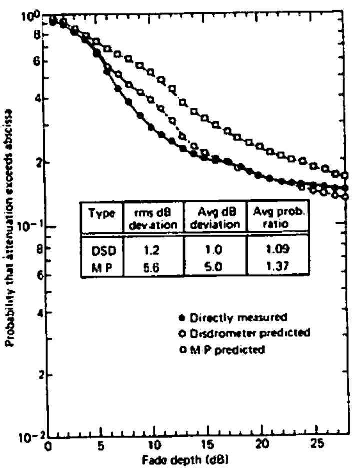
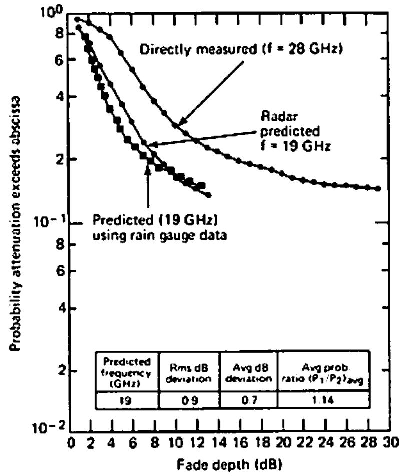


Fig. 1. Comparison of Directly Measured Fade Event with DSD-Radar Predicted and M-P-Radar Predicted for September 14, 1977 (day 257) from 20 hr, 03 min to 20 hr, 32 min GMT.



Type	rms dB deviation	Avg dB deviation	Avg prob. ratio
DSD	1.2	1.0	1.09
M P	5.6	5.0	1.37

Fig. 2. Comparison of Cumulative Distributions for Directly Measured, DSD-Radar Predicted and M-P-Radar Predicted Cases.



Predicted frequency (GHz)	Rms dB deviation	Avg dB deviation	Avg prob. ratio $(P_1/P_2)_{avg}$
19	0.9	0.7	1.14

Fig. 3. Comparison of Predicted and Radar Derived Fade Distributions at 19 GHz.