Characteristics of Rain Fading on Ka-Band Satellite–Earth Links in a Pacific Maritime Climate

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***Abstract*—Characteristics of rain-induced attenuation at Ka-band measured over a four-year period (1994–1997) with the advanced communications technology satellite (ACTS), Vancouver, BC, Canada, are reported. Event-based analyses of fading are performed and examples of the instantaneous 30/20-GHz frequency-scaling ratio are presented. Long-term cumulative statistics of rain rate as derived from rain-gauge measurements, along with annual attenuation statistics at 20 and 30 GHz, are provided. Finally, attenuation statistics are compared with the ITU-R model and aspects related to local climatic characteristics are considered, aiming to improve the predictions of attenuation due to rain.**

***Index Terms*—Ka-band propagation, maritime climate, rain attenuation, satellite communications.**

I. INTRODUCTION

A PROPAGATION campaign was conducted in Vancouver, BC, Canada, from December 1993 to March 1999 with the advanced communications technology satellite (ACTS) to provide attenuation measurements at Ka-band for a Pacific maritime climate. Maritime climates are characterized mainly by widespread rain events, inducing low attenuation levels of long duration. This information is relevant for low-availability systems, in particular, for very small aperture terminal (VSAT) applications in which the fade margin is typically small. The ACTS satellite transmits beacon signals at 20.2 and 27.5 GHz (referred to for simplicity as 20 and 30 GHz in this paper). The Communications Research Centre Canada (CRC) operates a second ACTS receive facility in Ottawa, ON, Canada [1].

The receive station in Vancouver was one of seven ACTS propagation terminals (APTs) provided by the National Aeronautics and Space Administration (NASA) for the Ka-band propagation campaign, the other six being installed at sites representing different geographical and climatic regions in continental North America. The APTs utilize a common antenna to receive the signals from the satellite beacons, and to perform radiometric measurements at the same frequencies. *In situ* measurements of rain-rate, temperature, atmospheric pressure, and relative humidity are also recorded and stored.

Five years of data (1994–1998) were collected and preprocessed at the site located on the campus of the University of British Columbia (UBC), Vancouver, BC, Canada. This paper presents results of rain fading derived by the CRC from beacon measurements covering the period from 1994 to 1997.

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TABLE I
CHARACTERISTICS OF THE ACTS SATELLITE LINK FROM VANCOUVER

Site coordinates	49.25° N latitude 123.25° W longitude
Elevation angle	29.3°
Azimuth	150.4° CWN (clock-wise from north)
Polarization tilt angle	18.9° from vertical
Receiver frequencies	20.185 and 27.505 GHz
Data acquisition rate	1 Hz
Radiometer frequencies	Same as beacons
Antenna diameter	1.2 m, offset fed (Common antenna for beacon and radiometers)

A summary of the characteristics of the satellite link is shown in Table I.

Vancouver experiences a Pacific maritime climate with strong orographic influences. It receives little heavy rain, but a great deal of widespread drizzle and low-rate rainfall. The annual rainfall is considerable, but the number of days with thunderstorms averages only seven per year. The summer months (June–August) are dry, with only about 10% of the annual total precipitation falling during this season. October-April is the rainy season. Pacific air streams ensure mild winters, mild but not hot summers, and relatively small seasonal temperature differences. The presence of the western mountains aligned parallel to the coast and the prevailing westerly airflow flowing off the Pacific generates a distinct orographic rain pattern in Vancouver. Important differences in average annual precipitation can be observed between areas located just several kilometers apart. Thus, over a distance of 50 km in the south–north direction, the annual rainfall accumulation can vary from 1000 to 3500 mm [2]. The long-term annual average rainfall at the Vancouver International Airport, some 8 km south of the UBC site, is approximately 1020 mm; the average snowfall is 60 cm. The average daily temperature ranges from 0 °C to 24 °C over the year.

Regarding the level of precipitation during the measurement period, 1997 was an exceptional year averaging about 20% wetter than normal along the southern Pacific Coast of Canada. The rain accumulation for almost every month in 1997 was above normal, especially during the rainy season [3], [4]. This effect has been related to the influence of the El Niño event that had an important presence in 1997 and part of 1998.

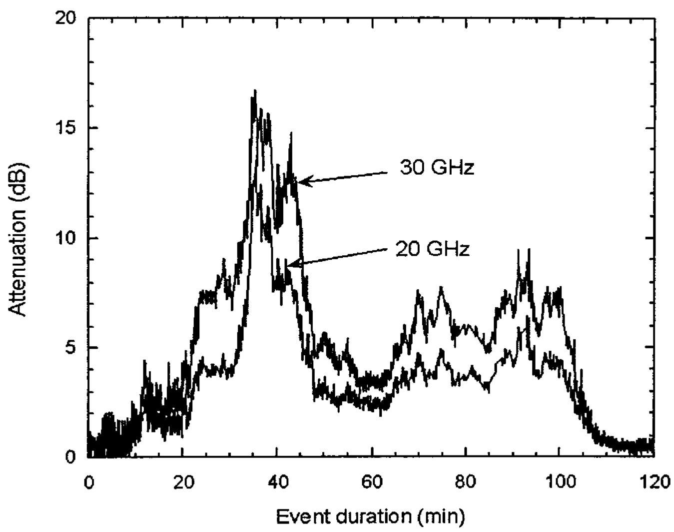

Fig. 1. Rain attenuation event measured at the Vancouver site on 5 July 1997, 15:16 UTC.

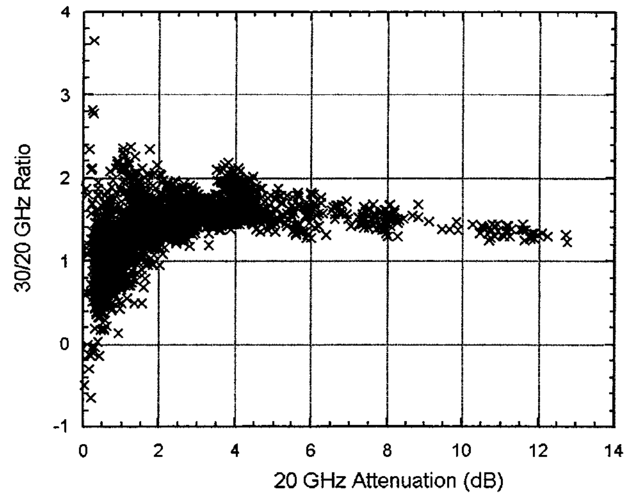

Fig. 2. Instantaneous 30/20-GHz frequency scaling factor for the event shown in Fig. 1.

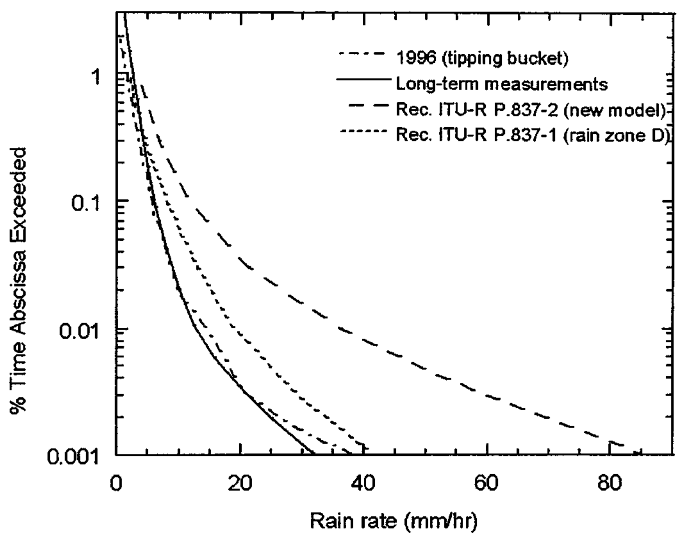

Fig. 3. Point rainfall rate cumulative distributions from measurements at Vancouver and ITU-R rain-rate models.

II. Rain Attenuation Events

Widespread rain typical of maritime climates induces long-duration low-level fading at Ka-band. The time series of a rather strong rain-induced attenuation event recorded simultaneously at 20 and 30 GHz at the Vancouver site is shown in Fig. 1. The event, which occurred on 5 July 1997, began at 15:16 UTC and lasted about two hours. At the peak of the attenuation event, the 30-GHz receiver lost track of the signal during several seconds due to the deep fading. The nominal signal levels received at the Vancouver site (and at the NASA site in Alaska) are lower than those received at the other ACTS sites within the continental U.S. due to the location of the station relative to the boresight of the ACTS beacon antennas. This factor reduces the maximum values of attenuation that can be measured by the receivers.

The instantaneous frequency-scaling factor between attenuation (in decibels) at 20 and 30 GHz for this event is displayed in Fig. 2. The 30/20-GHz attenuation ratio is given as a function of attenuation at 20 GHz. The scatter in the data is due to natural variation in the drop-size distribution as the event progresses and to a component due to measurement error particularly evident for small values of 20-GHz attenuation. The varying drop-size distribution as attenuation increases could explain the decrease in the scaling factor that assumes average values from 1.8 to 1.2.

The latter ratio is significantly lower than the ratio of about 1.8 expected for average rain. The impact of antenna wetting effects has to be considered in these results. Experiments and simulations carried out during the ACTS propagation campaign have shown that water on the antenna reflector surface and feed window can induce significant values of undesirable attenuation [5]. The effect is strongly related to rain rate. The ratio between fading at 20 and 30 GHz due to this effect is not the same as the ratio due to rain along the propagation path, as can be deduced from [5, Figs. 1 and 2].

III. Long-Term Statistics of Rain Rate and Rain Attenuation

Tipping-bucket and capacitor rain gauges were used at the Vancouver site to provide rain-rate measurements. In addition, long-term statistics of rain rate from measurements conducted over a ten-year period at the Vancouver International Airport were available from a previous study [6]. According to the former ITU-R rain zone classification [7], Vancouver falls in zone D (close to the border with zone B). A new model for the calculation of the rain rate has been recently adopted by the ITU-R [8]. One of the drawbacks of the rain zone model is that the maps have discontinuities at the borders of the climate regions adding uncertainty to the predictions. The new ITU-R model uses precipitation parameters specified worldwide and derives from these data the cumulative distribution of precipitation for short integration times. A comprehensive description of the new model can be found in [9].

Cumulative distributions of rain rate, as obtained from measurements with the tipping bucket rain gauge in 1996 and from the long-term measurements at the Vancouver airport, are displayed in Fig. 3, along with the ITU-R model curves. Measurements and the ITU-R rain zone model show good agreement, but the new ITU-R model clearly overestimates the rain rate. Spot

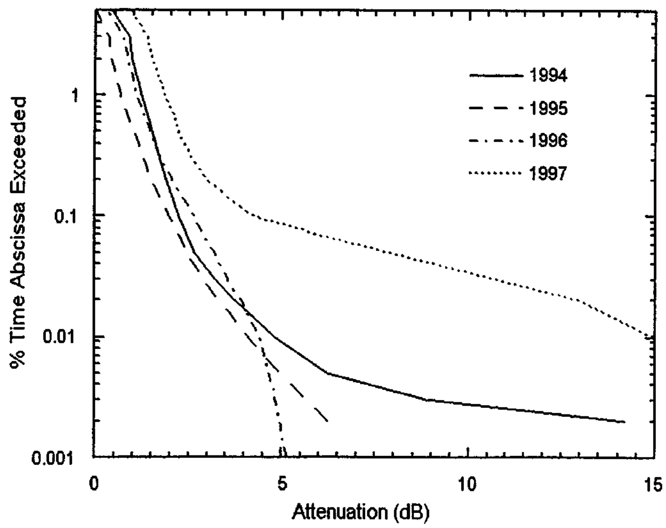

Fig. 4. Annual cumulative distributions of rain attenuation at Vancouver derived from beacon measurements at 20 GHz.

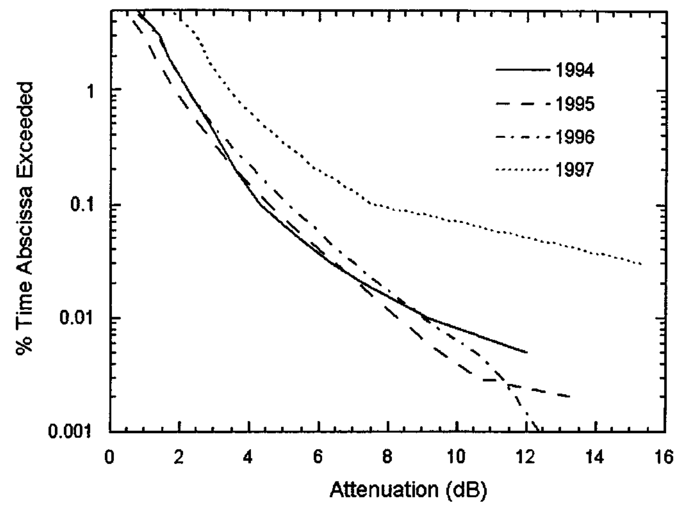

Fig. 5. Annual cumulative distributions of rain attenuation at Vancouver derived from beacon measurements at 30 GHz.

checks of the new model against long-term rain-rate data for other Canadian locations [6] indicate good agreement for sites in eastern Canada, but poorer agreement in western Canada. The cause for this behavior has not yet been determined.

Statistics of attenuation at 20 and 30 GHz obtained from measurements of the ACTS satellite beacons are affected by additional losses caused by antenna wetting. A physical model developed to estimate the additional signal loss produced by the wet antenna reflector surface and feed window [5] can predict the attenuation caused by the antenna wetting as a function of the rain rate, considering the elevation angle and the polarization orientation of the antenna. An additional problem affects the 30-GHz recorded data. As there is no isolator in this channel, water on the feed window produces a mismatch between the antenna and receiver low-noise amplifier (LNA), inducing additional loss.

Figs. 4 and 5, respectively, show the annual cumulative distributions of attenuation due to rain derived from beacon measurements at 20 and 30 GHz, with compensation for the estimated antenna wetting effect.

The attenuation statistics are clearly dominated by 1997 at both frequencies, reflecting the unusually high amount of rainfall in that year. The distributions for 1994–1996 show little inter-annual variability for annual time percentages above 0.01%.

IV. Modeling Considerations

In this section, the long-term attenuation statistics presented in Section III are compared with the ITU-R prediction model considering local characteristics of point rainfall rate and rain height.

The method recommended by the ITU-R to predict long-term rain attenuation on slant paths [10], based on the Dissanayake *et al.* model [11], calculates the cumulative distributions of fading from the local point rainfall rate for 0.01% of an average year. In the ITU-R rain zone classification, the rain rate for 0.01% of an average year in Vancouver (zone D) is 19 mm/h [7]; the new ITU-R model for rain rate [8] gives a value of 36 mm/h. Local long-term measurements at Vancouver indicate a rain rate of 13 mm/h for the same time percentage [6].

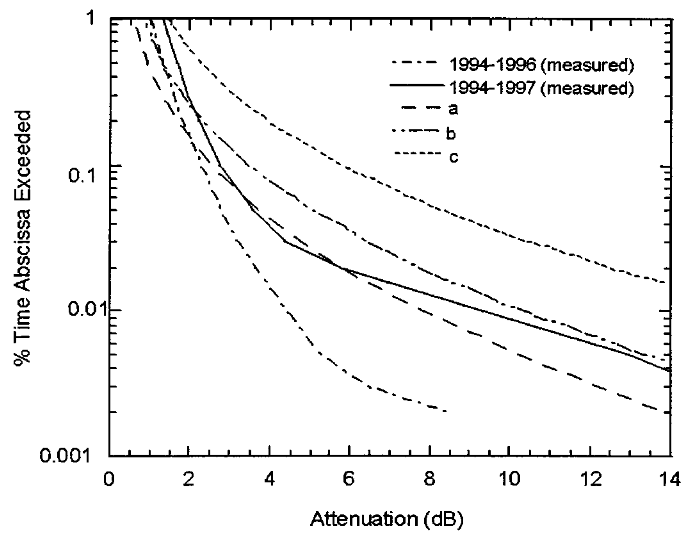

Fig. 6. Annual cumulative distributions of rain fading measured at 20 GHz and predicted by the ITU-R attenuation model using: (a) locally measured rainfall rate, (b) rain rate for ITU-R rain zone D, and (c) rain rate calculated using the new ITU-R model.

Fig. 6 shows the comparison of annual average cumulative distributions of rain attenuation for the periods 1994–1996 and 1994–1997, derived from measurements at 20 GHz, with the ITU-R attenuation prediction model, calculated using the following values for rain rate for 0.01% of the time: 13, 19, and 36 mm/h. It is noted that the use of local rainfall data results in a better agreement between predicted and measured statistics when the four years of data (1994–1997) are considered. This indicates that the rain-rate values derived from the ten-year local measurements represent well the average conditions for this climate.

A second important parameter intervening in the prediction of rain-induced attenuation is the rain height. In the ITU-R model for rain attenuation [10], the effective rain height is

TABLE II
SEASONAL AND ANNUAL AVERAGE FREEZING LEVEL HEIGHTS (KILOMETERS ABOVE GROUND LEVEL)

Station	Winter D-J-F	Spring M-A-M	Summer J-J-A	Fall S-O-N	Annual average	ITU-R
Vernon	0.89	1.42	2.71	1.78	1.70	2.96
Port Hardy	1.25	1.43	2.83	2.18	1.92	2.92

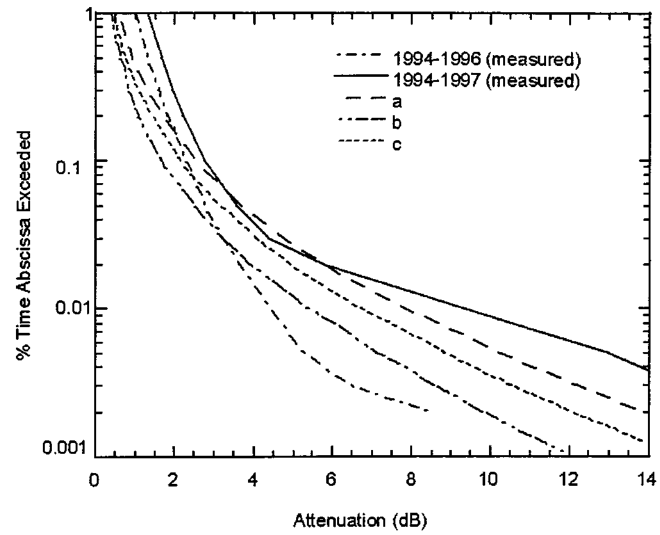

Fig. 7. Comparison of cumulative distributions of attenuation measured at 20 GHz and predicted by ITU-R using: (a) locally measured rainfall rate, (b) local rain rate and rain height = 2 km, and (c) rain height = 2.5 km.

taken as the height of the 0 °C isotherm or the freezing level height during rainy conditions, calculated as a function of the location latitude. The freezing level heights at selected stations representing different climate regions across Canada were obtained from radiosonde data for the period 1979–1990 [12]. Two of the stations considered in the study are located in southern British Columbia and can provide a good indication of the freezing level height during rainy conditions at Vancouver. The stations are Vernon (50.14°N, 199.17°W) and Port Hardy (50.41°N, 127.22°W). Port Hardy is located on Vancouver Island and experiences a maritime climate.

Table II shows the seasonal and annual average freezing level heights (in kilometers above ground level) during rainy conditions for both stations, as determined from radiosonde measurements [12], as well as the result obtained using the ITU-R empirical relationship for the mean freezing level height [10].

The values obtained utilizing the ITU-R formula agree fairly well with the observed summer heights, otherwise the heights are overestimated. Similar results can be expected for Vancouver, for which a rain height of 3 km is calculated. As noted before, the amount of precipitation during the summer season in Vancouver accounts for only about 10% of the average annual total precipitation. It seems then necessary to use a lower value of rain height when computing attenuation statistics for Vancouver with the ITU-R prediction model.

Fig. 7 shows comparisons of the measured annual statistics of attenuation at 20 GHz with the ITU-R model. Three different curves are obtained with the model: the first one uses the rain height calculated with the ITU-R formula and local rain-rate data; the other two curves also use local rain-rate data, but assume effective rain heights of 2 and 2.5 km, respectively. It is seen that the use of a rain height of 2 km gives some improvement to the prediction when the period of measurements 1994–1996 is considered, especially around 0.01% of the time.

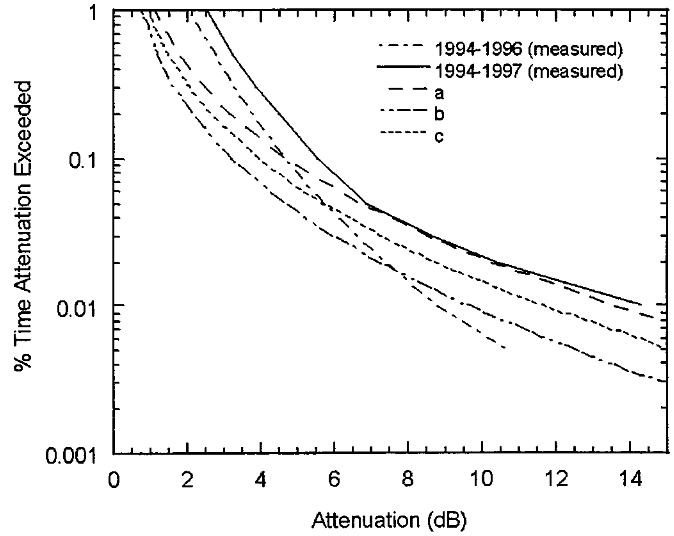

Fig. 8. Comparison of cumulative distributions of attenuation measured at 30 GHz and predicted by ITU-R using: (a) locally measured rainfall rate, (b) local rain rate and rain height = 2 km, and (c) rain height = 2.5 km.

Comparisons of the ITU-R model with the cumulative distributions at 30 GHz (Fig. 8) show results somewhat similar to those obtained at 20 GHz. The model curve calculated using a rain height of 2 km acceptably predicts measured attenuation for the period 1994–1996 at 0.01% of the time, but clearly underpredicts at higher time percentages. This might be explained by the additional loss induced by the mismatch between the antenna and LNA due to antenna wetting.

V. CONCLUSIONS

Rain attenuation statistics extracted from 20- and 30-GHz ACTS satellite beacon measurements at Vancouver during the period 1994–1997 have been presented in this paper. The results have illustrated particular features of a maritime climate, though with important orographic influences, as well as the strong influence of the 1997 El Niño phenomenon, on the path attenuation statistics. Improved performance of the ITU-R prediction method for rain attenuation have been obtained by incorporating site-specific rain-rate information, but little improvement was observed by reducing the freezing level heights. Additional analyses of these data are in progress.

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