Rain Attenuation Statistics and Yearly Variability of Ka and Ku Band Satellite Signals obtained for Twenty Years in Japan

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1. Introduction

It is well known that rain attenuation effects are significant in satellite communications and broadcast using frequency of higher than 10 GHz [1], [2]. Rain attenuation statistics are usually predicted by rainfall rate statistics observed on the ground for a long period. Typical statistical values such as rainfall rate with a yearly time percentage of 0.01% and average 0℃ height are used in the prediction methods recommended by ITU-R [3]. These statistical values of 0.01% for rainfall rate and rain attenuation, however, indicate a considerable yearly variation with the standard deviation of about 20% around the mean values [4]. Also, rain height and equivalent path length expected from the 0℃ isotherm height seem to have a similar yearly variation according to the change of average ground temperature and rainfall types.

In this study, long-term rain attenuation statistics and variability are discussed using Ka and Ku band satellite signal observations conducted at Osaka Electro-Communication University in Neyagawa, Japan, from 1986 to 2006. The mean values and standard deviations of 0.01% values of rainfall rate and rain attenuation are presented for the entire observational period, and their distributions are described in terms of normal distributions. The worst month statistics are then examined for the cumulative time percentages in each year, and their variability is also discussed in relation to rainfall statistics. Finally, a yearly variation of equi-probability values between rainfall rate and rain attenuation and its relationship with equivalent path length are investigated.

2. Yearly Variation of Rain Attenuation Statistics

First, yearly statistics of rainfall rate and rain attenuation are presented for the whole observational period of more than twenty years from 1986 to 2006. Figure 1 shows cumulative time percentages of rainfall rate obtained for each year from 1986 to 2006. These cumulative distributions are based on 1-min rainfall rate with resolution of 0.1 mm, so the data points are plotted at 6 mm/h intervals. These yearly distributions are divided into four panels with five or six plots in each panel. Similarly, Fig.2 shows yearly cumulative time percentages of rain attenuation of Ka-band satellite signal at 1 dB interval for the twenty one years. In these periods, the Ka-band satellite signal attenuation has been observed using the beacon signal of Japan's domestic communications satellites: CS-2 during Jun.1986-Mar.1988, CS-3 during Apr.1988-Mar.1996, and N-Star during Apr.1996-Dec.2006, respectively. The frequency is 19.45 GHz, the elevation angle is 49.5°, and the polarization is right-hand circular. The dynamic range of the beacon receiver is more than 30 dB, using LNA (Low Noise Amplifier) in the antenna front end.

It is found in Figs.1 and 2 that both rainfall rate and rain attenuation statistics have fairly large yearly variations. For example, the mean value of rainfall rate with the time percentage of 0.01% ($R_{0.01}$), which is important in the ITU-R prediction methods [3], is 62 mm/h during the whole observational period, while the standard deviation of yearly variation around this mean value amounts to 14 mm/h, yielding about 20% fluctuation of yearly rainfall rate statistics. Similarly, the mean value and standard deviation of yearly statistics of the Ka-band rain attenuation are 26.3 dB and 5.5 dB, respectively, giving rise to about 20% yearly fluctuation.

Next, Fig.3 depicts equi-probability values of (a) rainfall rate, (b) Ka-band rain attenuation, and (c) Ku-band rain attenuation for three cumulative time percentages of 0.01% (cross), 0.03% (triangle), and 0.1% (circle), respectively, obtained in each year from 1986 to 2006. The Ku-band attenuation shown in Fig.3(c) has been observed using the signal of Japan's Broadcasting Satellite (BS) since May 1988. The frequency is 11.84 GHz, the elevation angle is 41.4° , and the polarization is right-hand circular. Thus, Fig.3 clearly shows the fairly large variations of rainfall rate and attenuation in both frequency bands, reaching 20% of the mean values as was indicated in Figs.1-2. These yearly fluctuations basically depend on the amount of rainfall in each year [5].

The yearly fluctuations for 0.01% values of the observed rainfall rate and attenuation are further investigated in a form of normal or Gaussian distribution. Figure 4 indicates the distribution of 0.01% values of (a) rainfall rate, (b) Ka-band, and (c) Ku-band attenuation, respectively, and those fitted by Gaussian functions (thin lines) with the same mean (μ) and standard deviation (σ) as was mentioned before in Fig.2. Thus, these yearly fluctuations are fairly well approximated by Gaussian distribution with the same statistics parameters. Next in Fig.5, the yearly fluctuations of these 0.01% values are converted to cumulative distribution, and each distribution is plotted against the normal axis for (a) rainfall rate, (b) Ka-band, and (c) Ku-band attenuation, respectively. Dashed lines similarly indicate the approximation of Gaussian distribution for each yearly fluctuation. It is found in Fig.5 that the yearly fluctuations of these 0.01% values for rainfall rate and attenuation are almost linearly aligned in the normal axis and well fitted by the Gaussian distribution. It is also noted that the right-down end (1%) of each fitted approximation line may estimate a 0.01% value occurring "once in a hundred years".

3. Yearly Variation of the Worst Month Statistics

In the actual operations of communications or broadcasting satellites, monthly unavailable time percentages are often more important than long-term yearly time percentages at any level of rainfall rate or rain attenuation. Figure 6 shows cumulative time distribution of the worth month statistics of the Ka-band rain attenuation obtained for each year from 1986 to 2006. Note that the time percentages of the worst month statistics are, as a whole, increased nearly by one order in the attenuation range of higher than 20 dB, compared to the yearly statistics in Fig.2. Figure 7 depicts the cumulative distribution of 0.05% values for the worst month statistics of (a) rainfall rate, (b) Ka-band, and (c) Ku-band attenuation, respectively, and those fitted by Gaussian functions (dashed lines) against the normal axis. The fluctuations around the mean values of these worst month statistics are about 20% similar to the yearly fluctuations. Also, Fig.8 indicates the cumulative distribution of 0.01% values for those worst month statistics. It should be here noted that the 0.01% values of Ka-band rain attenuation are, however, inferred from those of Ku-band attenuation using frequency scaling method [3], since the these 0.01% values of the Ka band exceed the dynamic range of the attenuation measurements. Thus, the yearly fluctuations of the worst month statistics are also found to be well approximate by the normal distribution, and the right-down end (1%) may similarly estimate their 0.05% or 0.01% values occurring "once in a hundred years".

4. Yearly Variation of Equivalent Path Length

Finally, the equi-probability values of rainfall rate and rain attenuation shown in Fig.2 are compared, and yearly average equivalent path lengths of Ka and Ku band satellite signals are estimated using the specific attenuation (α [dB/km]) [3] for rainfall rate of greater than 20 mm/h. Figure 9 shows the results for (a) Ka and (b) Ku band satellite signal attenuation, respectively. In addition, Fig.10 depicts scatter plots of the yearly equivalent path lengths of (a) Ka and (b) Ku band rain attenuation against the ground temperature averaged during the rain time from May to October in each year. It is found from Figs.9-10 that the yearly equivalent path lengths show a fairly large variation from 4 to 5 km with a time scale of about 3-6 years, and that the yearly variation is well correlated with the yearly average ground temperature during the rain time from May to October where the rainfall is primarily observed. It is well known by a number of radar observations that the rain height approximately given by 0℃ isotherm height or bright band is nearly proportional to the ground temperature in the temperate zone. This may suggest that the propagation path length of the satellite signals against the rain region should be also proportional to the ground temperature. If it is the case, the equivalent path lengths should be increased by 25% as the ground temperature is increased from 20 to 25℃ in Fig.10. The fitted lines in Fig.10, however, indicate that the equivalent path length may be further increased by about 50% in this temperature range from 20 to 25℃. This additional increase of the path length is probably due to the rain types peculiar to summer time such as typhoon and thunderstorm which have wider and higher distribution of clouds.

5. Conclusions

The long-term rain attenuation characteristics are obtained from Ka and Ku band satellite signal observations conducted in Neyagawa, Osaka, from 1986 to 2006. The 0.01% values of Ka and Ku band attenuation indicate fairly large yearly variations which amount to about 20% around the mean values. Besides the yearly rainfall rate statistics, these variations seem to be caused by difference in the equivalent path length in each year, which becomes longer as the average ground temperature at the rain time from May to October becomes higher. However, the increase of the equivalent path length is not fully explained by that of rain height, but rather related to the rain types which frequently appear in summer time with much larger cloud sizes.

References

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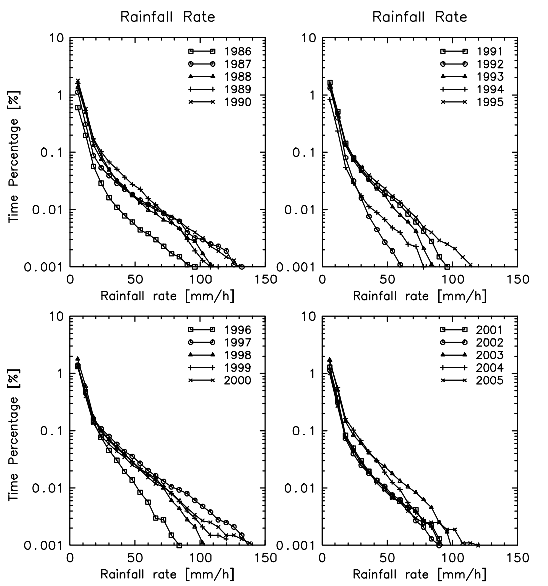

Figure 1: Yearly cumulative time percentages of rainfall rate obtained for 1986-2006.

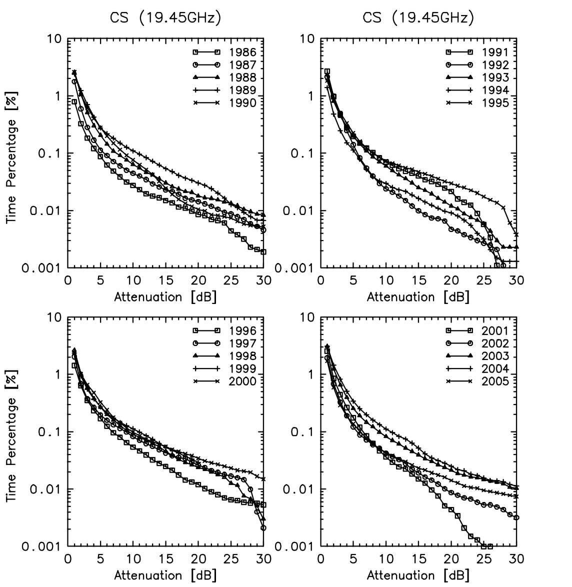

Figure 2: Cumulative time percentages of Ka-band rain attenuation obtained for 1986-2006.

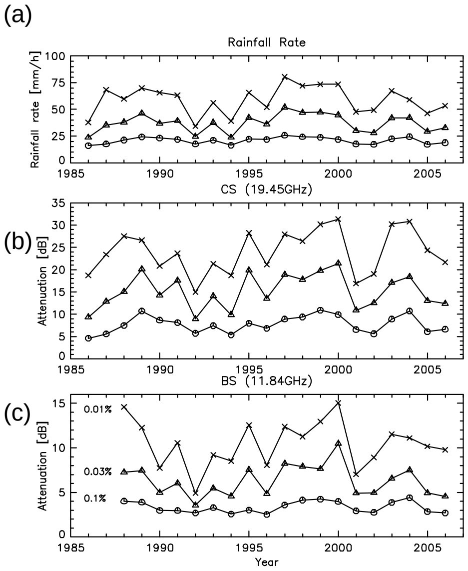

Figure 3: Equi-probability values of (a) rainfall rate, (b) Ka band, and (c) Ku band rain attenuation in each year.

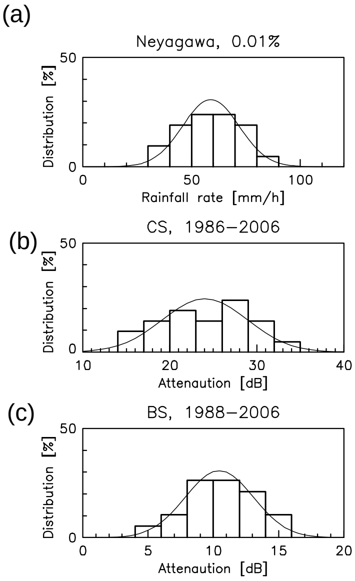

Figure 4: Distribution of 0.01% values for rainfall rate and rain attenuation.

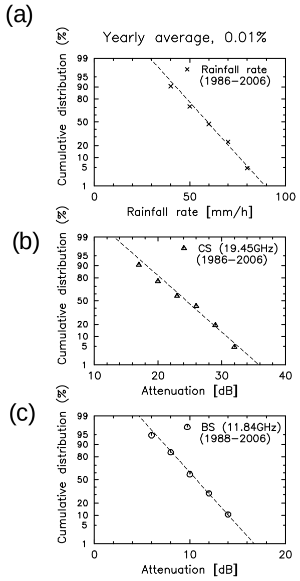

Figure 5: Cumulative distribution for 0.01% values.

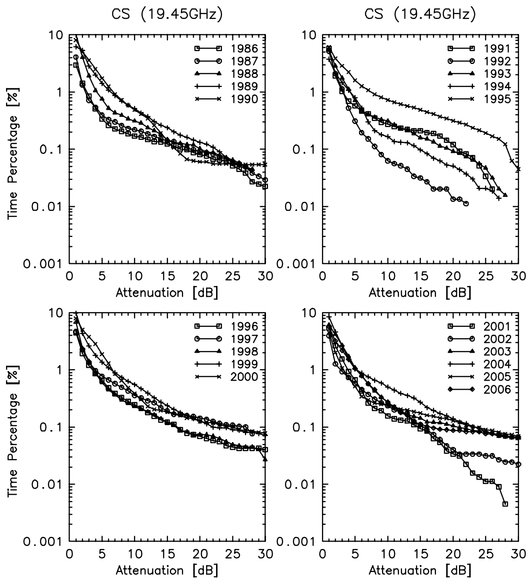

Figure 6: Worst month statisitcs of Ka-band rain attenuation obtained for 1986-2006.

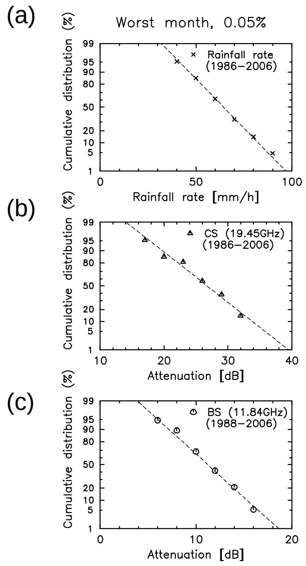

Figure 7: Cumulative distribution for worst month statistics (0.05%).

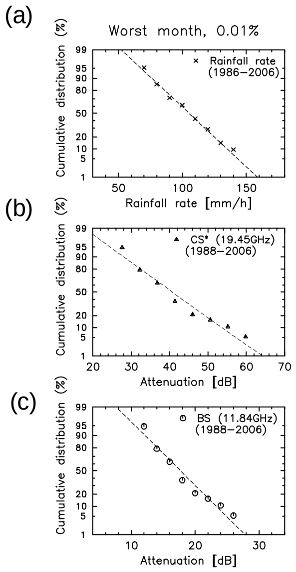

Figure 8: Cumulative distribution of for worst month statistics (0.01%).

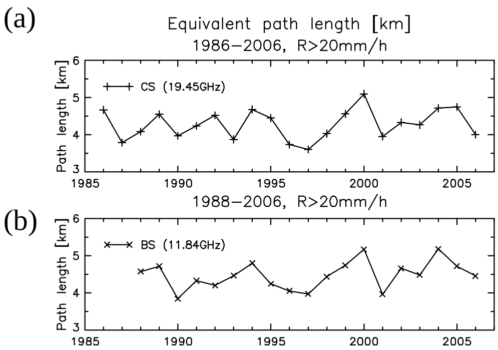

Figure 9: Equivalent path length for (a) Ka and (b) Ku band attenuation in each year.

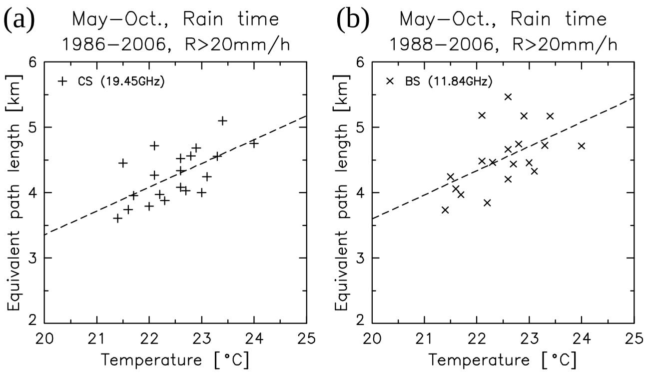

Figure 10: Scatter plot of yearly equivalent path length against ground temperature in rain time.