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Long-term Rain Attenuation Statistics and Variations in Ku Band Satellite Communications

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***Abstract* - Long-term rain attenuation statistics and variations are discussed using Ku band satellite signal observations conducted at Osaka Electro-Communication University in Neyagawa, Japan, from 1988 to 2015. The yearly cumulative time percentages of Ku band attenuation indicate fairly large 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 sufficiently explained by that of rain height, but rather related to the rain types which frequently appear in summer time and have much larger cloud sizes. Also, the equivalent path length tends to increase further for the last 10 years since 2006, and this tendency seems to be related to the overall increase of the average ground temperature in rain time of each year.**

***Index Terms* — Rain attenuation, Long-term statistics, Ku band, Satellite communications.**

1. Introduction

It is well known that rain attenuation effects become significant in satellite communications using frequency of higher than 10 GHz. Rain attenuation statistics are usually predicted by rainfall rate statistics observed on the ground for a long period. Typical statistical values used in the predictions, such as the ITU-R recommendations, are rainfall rate with a yearly time percentage of 0.01% and average 0℃ height [1],[2].

In this study, long-term rain attenuation statistics and variability are discussed using Ku band satellite signal observations conducted at Osaka Electro-Communication University in Neyagawa, Japan, from 1988 to 2016. The deviations of 0.01% values of rainfall rate and rain attenuation around their mean values are presented for the entire observational period, and their large yearly variation is pointed out. Also, a yearly variation of equi-probability values between rainfall rate and rain attenuation and its relationship with equivalent path length are investigated in relation to the rain types which frequently appear in summer time.

2. Yearly Variations of Rain attenuation Statistics

First, yearly statistics of rainfall rate and rain attenuation are presented for the entire observational period of nearly thirty years from 1988 to 2015. In these periods, the Ku-band attenuation has been observed using the signal of Japan's Broadcasting Satellite (BS). The frequency is 11.84 GHz, the elevation angle is 41.4°, and the polarization is right-hand circular. The dynamic range of the BS signal receiver is about 20 dB, using a level meter dedicated to IF signal output from the down converter. Figure 1 depicts equi-probability values of (a) rainfall rate and (b) 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 1988 to 2015. The rainfall rate statistics include the years of 1986 and 1987. Thus, Fig.1 clearly shows fairly large variations of rainfall rate and attenuation in the Ku band. Also, these yearly fluctuations basically depend on the amount of rainfall in each year [3].

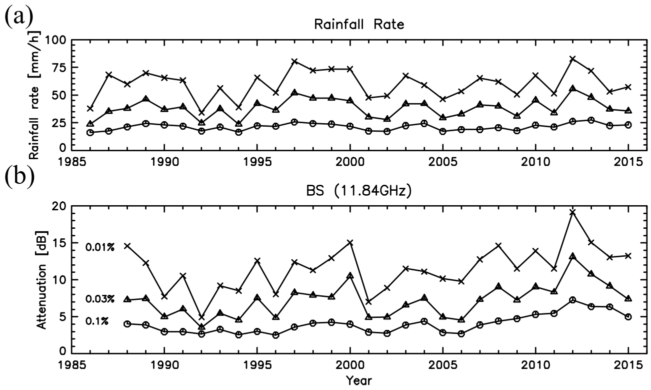

Fig. 1. Equi-probability values of (a) rainfall rate and (b) Ku-band rain attenuation for three specified cumulative time percentages.

3. Yearly Variations of Equivalent Path Length

In this chapter, the yearly equi-probability values of rainfall rate and rain attenuation shown in Fig.1 are compared, and yearly average equivalent path lengths of the Ku band satellite signal are estimated using the specific attenuation α [dB/km] [2] for rainfall rates of greater than 20 mm/h. Figure 2 shows the results of (a) Ku-band satellite signal attenuation, together with (b) the ground temperature averaged over the rain time from May to October when the rainfall is primarily observed in each year. In addition, Fig. 3 depicts scatter plots of the yearly equivalent path lengths of Ku-band rain attenuation against the ground temperature in the rain time from May to

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October. It is found from Figs.2 and 3 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. 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.3. The fitted lines in Fig.3, 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.

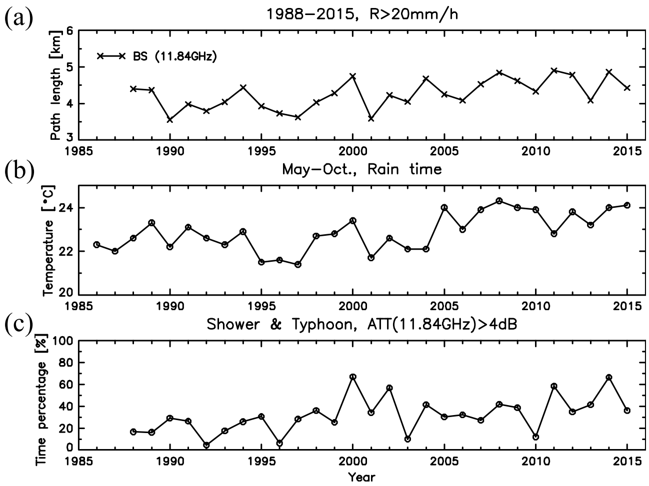

Fig. 2. Equivalent path lengths of (a) Ku-band attenuation (b) the ground temperature averaged over the rain time from May to October, and (c) time percentages of attenuation caused by typhoon and thunderstorm in summer.

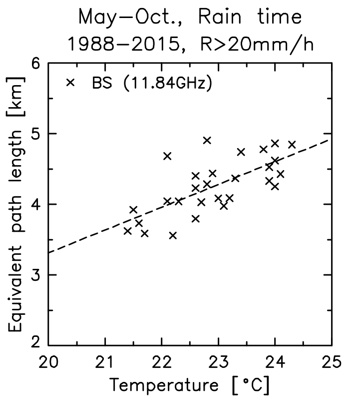

Figure 3. Scatter plots of the yearly equivalent path lengths of Ku-band rain attenuation against the ground temperature in the rain time from May to October.

Next, Fig.4 shows scatter plots of the yearly equivalent path lengths of Ku-band rain attenuation against the time percentages of Ku-band rain attenuation of more than 4 dB which is caused by typhoon and thunderstorm in summer time of each year. The yearly variations of these time percentages are also shown in Fig.2 (c). Thus, Fig.2 (c) and Fig.4 indicate a close relation of the equivalent path length with the yearly time percentages of the typhoon and thunderstorm in summer time. It is indeed shown in our previous study [3] that the equivalent path lengths of the Ku-band attenuation are increased up to about 5 km for the rainfall rates from 20-60 mm/h in typhoon and thunderstorm rainfall events, while they are decreased down to 4 km for the same rainfall rate range in warm, cold, and stationary front rainfall events. Also, the equivalent path length tends to increase further for the last 10 years since 2006, and this tendency seems to be related to the overall increase of the average ground temperature in rain time of each year.

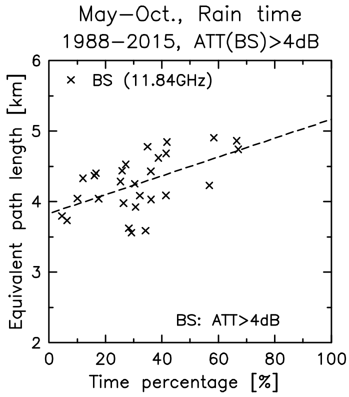

Figure 4. Scatter plots of the yearly equivalent path lengths of Ku-band rain attenuation against the time percentages of Ku-band rain attenuation of more than 4 dB caused by typhoon and thunderstorm in summer.

4. Conclusions

The long-term rain attenuation statistics and variations are obtained from Ku band satellite signal observations conducted in Neyagawa, Osaka, from 1988 to 2015. Besides the yearly rainfall rate statistics, these variations seem to be caused by difference in the equivalent path length in each year. The increase of the equivalent path length is shown to be closely related to the rain types which frequently appear in summer time with much larger cloud sizes. For the past ten years from 2006 to 2015, the equivalent path lengths seem to increase further possibly due to the overall increase of the ground temperature in rain time, suggesting a further study on the estimation of rain height in ITU-R prediction methods.

References

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