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Earth to space link

Mandeep Jit Singh, Mardina Abdullah, Baharudin Yatim,
Mahamod Ismail and Wayan Suparta
Malaysia

1. Introduction

The measurements were taken continuously from 1st January 2006 to 31st December 2008. The measured rainfall data was analyzed and presented in this chapter. Three years averaged measured rain rate and rain attenuation were compared with the cumulative probability distributions existing prediction models. Some rainfall data from selected tropical climates sites were used to make a comparison of rain rate and rain attenuation prediction.

2. The Variation of Rainfall Amount

Malaysia experiences heavy rain throughout the year and the rainfall distribution is patterned by monsoon activities. The Northeast monsoon is from October to March and the Southwest monsoon is from May to September. The Northeast Monsoon is the major rainy season in the country. The Northeast Monsoon blows from South China Sea during the months of October to March, this affects high brought rainfall to the East Coast of Peninsular Malaysia and a few other locations at Peninsular Malaysia. It was recorded by Malaysian Meteorological Department that the Northeast Monsoon has give the highest rainfall in all location in Malaysia because the wind of this monsoon blows from South China Sea without obstruction by island, peninsular and mountain. Monsoon weather systems that develop in the conjunction with cold air outbreaks from Siberia produce heavy rains, which often cause severe floods along the east coast of Malaysia. The Southwest monsoon is comparatively drier throughout the country except for the state of Sabah. During this season, most states experience monthly minimum rainfall. This is attributed to relatively stable atmospheric conditions in the equatorial region. In particular, the dry condition in Peninsular Malaysia is accentuated by the rain shadow effect of the Sumatran mountain range. During the inter-monsoon periods, winds are light and variable. Morning skies are often clear and this favours thunderstorm development in the afternoon. In the states of west coast of Peninsular Malaysia, thunderstorms contribute to a mean monthly rainfall maximum in each of the two transition period.
Figure 1 shows the monthly variation of rainfall amount at USM. A relationship between the monsoon activities and monthly rainfall amount can be studied. Based on the measurement, the total rainfall for the year 2006 was 1835 mm, for the year 2007 was 2065 mm and for the

year 2008 was 2111 mm. The total average annual rainfall at USM for three years was 2004 mm. The total average rain accumulation for the Northeast Monsoon (October – March) and Southwest Monsoon (May – September) was 1192 mm (59% of the annual averaged) and 640 mm (32% of the annual averaged), respectively. The maximum rainfall amount was in November for the year 2006 that is 274 mm, in September for the year 2007 that is 287 mm and in December for the year 2008 that is 280 mm. The minimum rainfall amount was in July for year 2006 that is 66mm, in August that is 58 mm and in May that is 5 mm. From this figure, it indicates that the rainfall amount for Northeast Monsoon is higher than Southwest Monsoon.

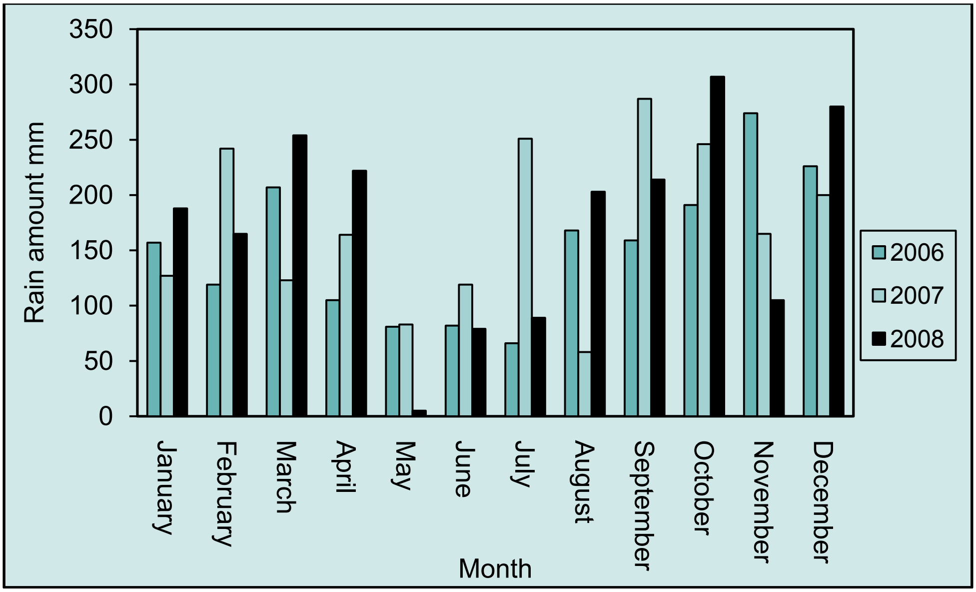

Fig. 1. Variation of monthly rainfall amount at USM for the year 2006, 2007 and 2008

3. Testing of Prediction Models

The achievement of high availability targets in advanced satellite link design requires a deep knowledge of the radio channel behavior. The effects due to different atmospheric causes, such as precipitation, clouds, atmospheric gases and tropospheric scintillation can be measured quite accurately by means of satellite beacon signals. Most prediction models of probability distribution function (pdf) of exceeding rain attenuation in slant path, based on rain rate pdf, when tested against concurrent satellite beacon measurements show large errors (Matricciani, *el at.*, 2008).

Two types of prediction tests used for this analysis:

1. The percentage error
2. The Real Mean Square (RMS) error

For certain percentage of time (from 0.001 to 1 percent of the year), for which data are available, percentage relative error, E_{rel} (percent) between the predicted value and the measured value are calculated

$$E_{rel} = \frac{A_{predicted} - A_{measured}}{A_{measured}} \times 100\% \qquad (1)$$

The mean error, μ_e and standard deviation, σ_e are used to calculate the Root Mean Square, D_e (RMS). The parameter is defined as follows

$$D_e = [(\mu_e)^2 + (\sigma_e)^2]^{1/2} \qquad (2)$$

According to evaluation procedures adopted by the CCIR the preferred prediction method is the one producing the smallest RMS values (CCIR, 1983)

4. Statistical analysis rainfall

4.1 The correlation of Rain Rate and Rain Attenuation

Fig. 2 shows a typical variation of rain rate and rain attenuation measured on a rainy day (2nd March 2008). The rapid small-scale fluctuations of the signal level are because of ionospheric and tropospheric scintillations and slower variation correspond to rain events - fade. At certain times, the decrease in the relative signal strength (attenuation) and the increase in the rain rate are coincidental, however at other times, the decrease in the signal strength was leading the increased rain rate. It is probably the result of raindrops held aloft by updrafts in the cloud, and then their time of arrival at the ground would be considerably delayed. This delay time is variable and is as long as 4–8min (Ramachandran, *et. al.,* 2004, Mandeep, 2008). In the data presented in Fig. 2, delay (corrections) time of 8 min was accounted for when investigating the correlation between rain rate and rain attenuation.

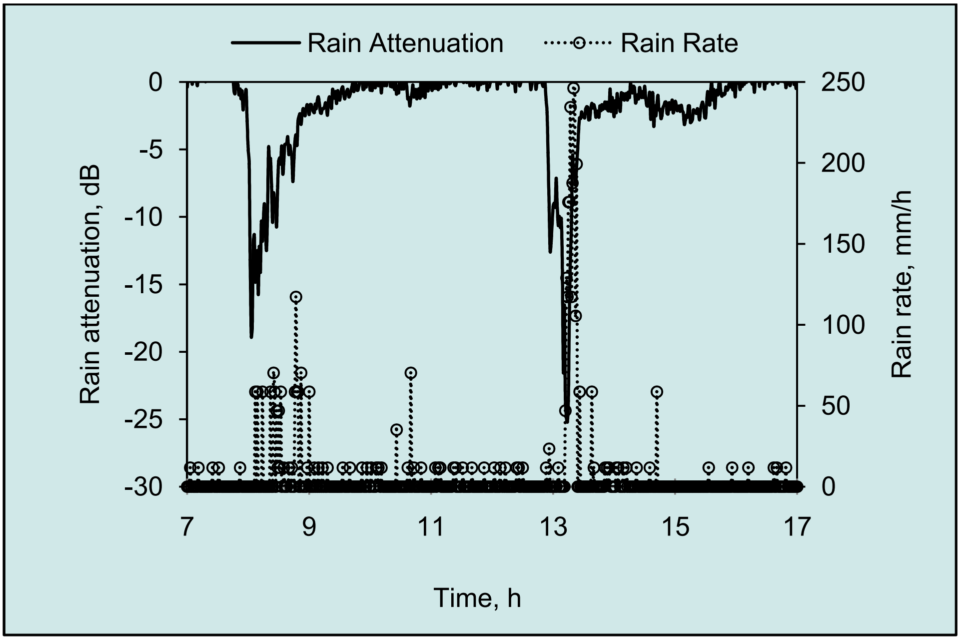

Fig. 2. Time series record of attenuation and rain rate

To determine the nature and strength of the relationship between rain rate and rain attenuation, correlation analysis has been done to indicate the strength of the relationship between rain rate and rain attenuation is high. Fig 3 shows the relation between rain rate and rain attenuation. Form that figure, the dots are obtained by straightforwardly plotting rain attenuation versus rain rate and the solid line is the best fit curve obtained by fitting rain attenuation versus rain rate. The R- square is 91.39%. It indicates that the correlation between rain rate and rain attenuation is high.
The attenuation for the site was a logarithmic function of rain rate and can be simplified as:

$$A\ (\text{dB}) = 0.054R^{1.2315}$$

where A denotes as attenuation and R denotes as the site rain rate, mm/h. This empirical equation would be helpful to system designer to determine the link margin at the site. Calculating by using this empirical equation, a threshold of 19.6 dB is considered as the economical limits.

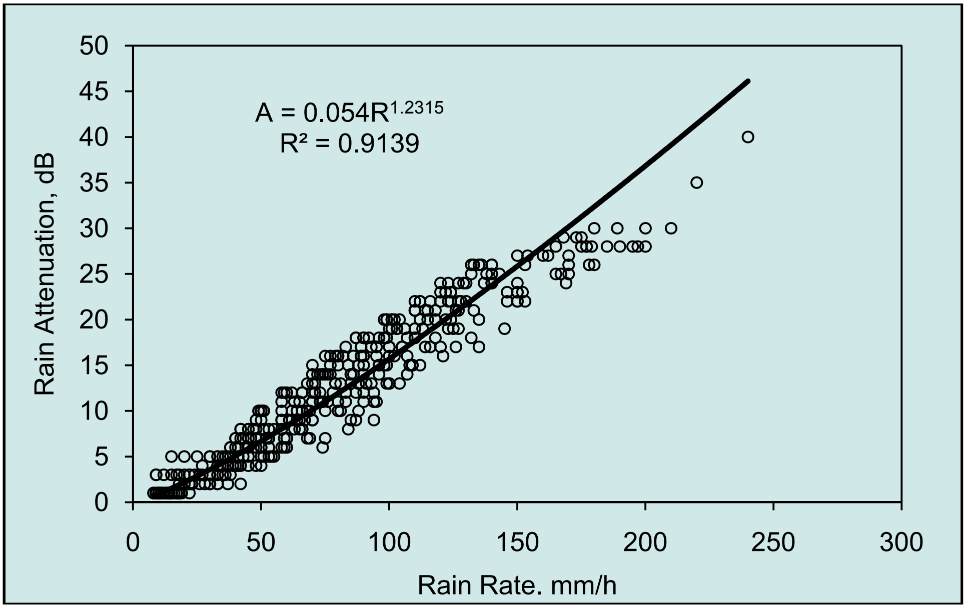

Fig. 3. The correlation between rain rate and rain attenuation

4.2 Statistical Confidence Level and Interval of the Measured Data

In statistics, a confidence interval (CI) is an interval estimate of a population parameter. Instead of estimating the parameter by a single value, an interval likely to include the parameter is given. Thus, confidence intervals are used to indicate the reliability of an estimate. How likely the interval is to contain the parameter is determined by the confidence level or confidence coefficient. The end points of the confidence interval are referred to as confidence limits. Increasing the desired confidence level will widen the confidence interval. For analysis purpose, a 95% confidence level was used because it is recommended by many statistical analysts. By using Minitab software, the confidence limits for 95%

confidence level were calculated. Fig 4, 5 and 6 show the confidence level of cumulative distribution of measured rain rate data in the year 2006, 2007 and 2008, respectively. In any statistical investigation, the variations of values in a measured data are due to random and systematic errors. The measured rain rate data for the year 2006, 2007 and 2008 lie in between the 95% confidence limits. The R-square is 99.7%, 99.2%, 97.8%, respectively. Therefore, these rain rate data are suitable to be used for comparison with models.

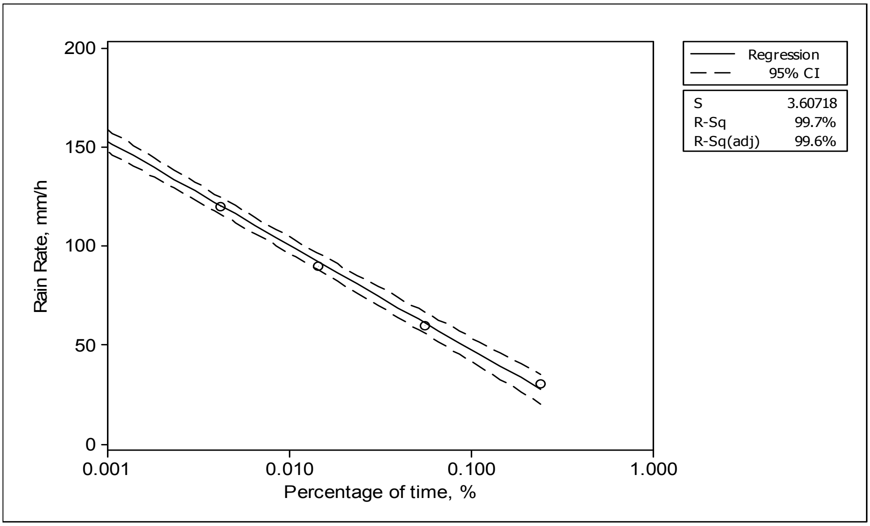

Fig. 4. The confidence level of cumulative distribution of measured rain rate data in year 2006

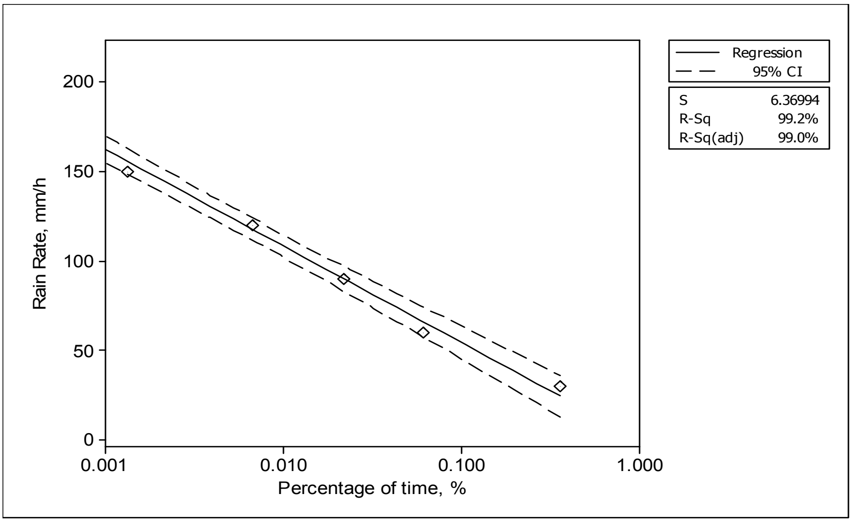

Fig. 5. The confidence level of cumulative distribution of measured rain rate data in year 2007

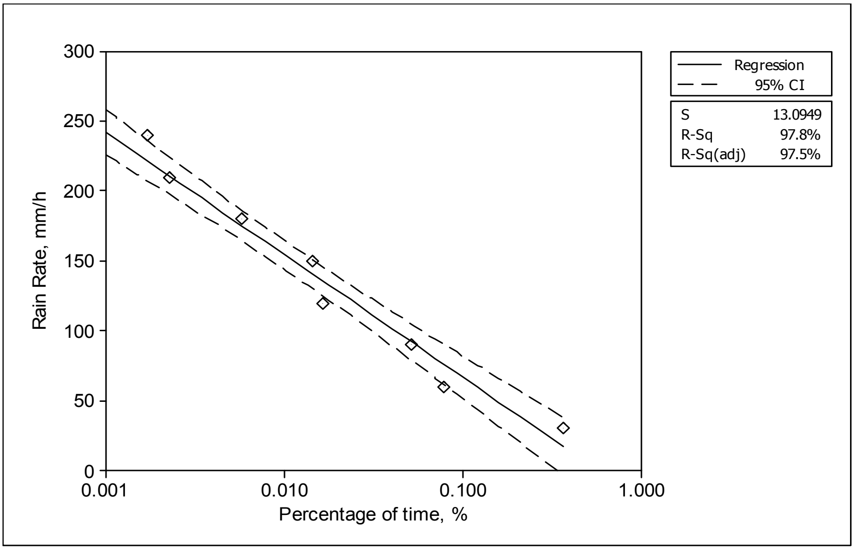

Fig. 6. The confidence level of cumulative distribution of measured rain rate data in year 2008

To calculate the confidence limit, having drawn a random sample and calculated the mean and standard deviation, the lower confidence limit (LL) is found by

$$LL = \bar{X} - z\left(\frac{\alpha}{2}\right) s_{\bar{x}} \tag{3}$$

In a similar way, the upper confidence limit (UL) is found by

$$UL = \bar{X} + z\left(\frac{\alpha}{2}\right) s_{\bar{x}} \tag{4}$$

where a is the significance level. At 95% confidence level, $z\left(\frac{\alpha}{2}\right)$ is equal to 1.96 and $s_{\bar{x}} = \frac{s}{\sqrt{N}}$, where s is the standard deviation and N is the sample size.

By using equation (3) and (4), the confidence limits were calculated for 95% confidence level. The confidence limits are calculated for the rain attenuation data in year 2006, 2007 and 2008 data are shown in Fig 7, 8 and 9. The measured rain attenuation data lies in between the 95% confidence limits for the entire measurement time. Hence, these rain attenuation data are suitable to be used for comparison with models.

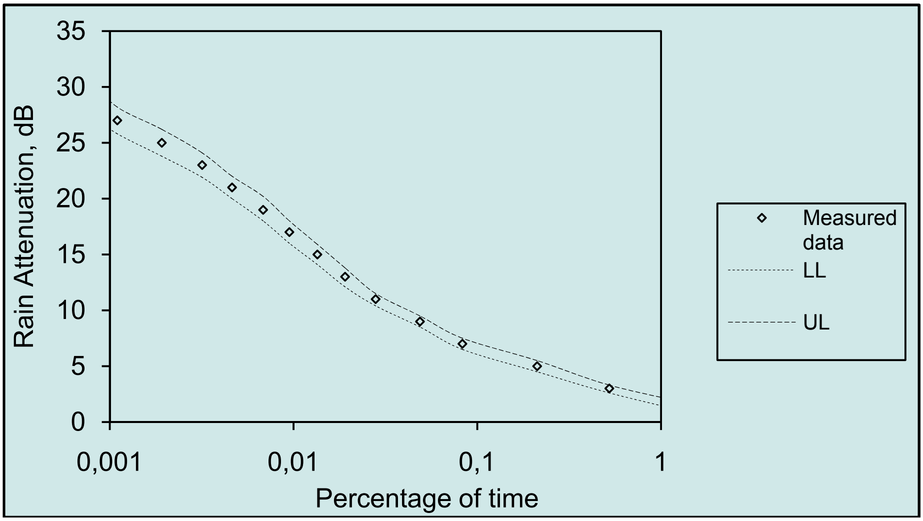

Fig. 7. The confidence level of cumulative distribution of measured rain attenuation data in year 2006

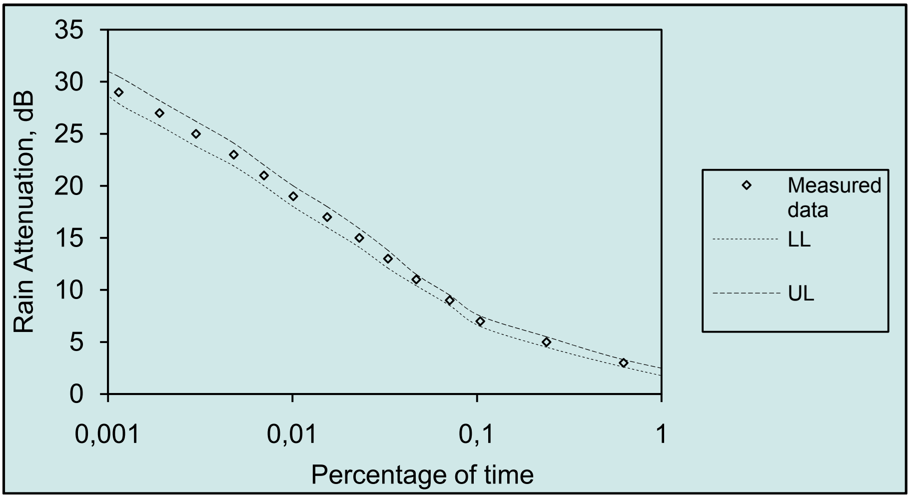

Fig. 8. The confidence level of cumulative distribution of measured rain attenuation data in year 2007

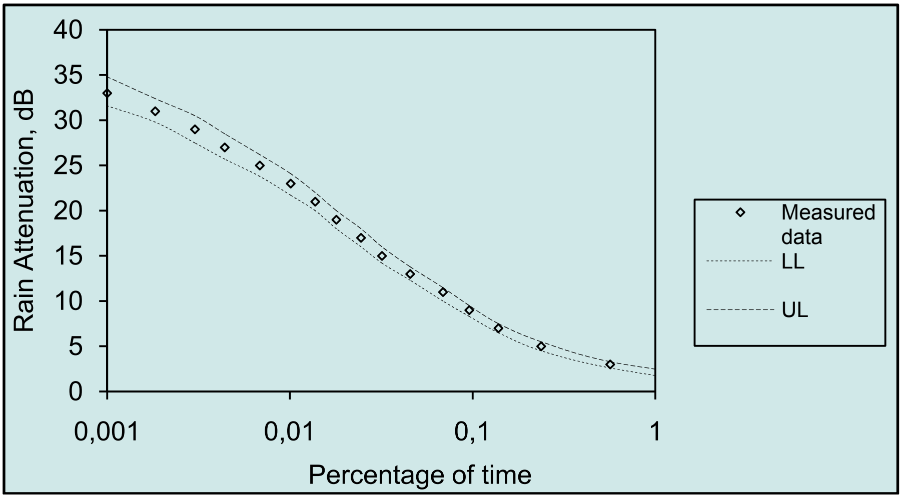

Fig. 9. The confidence level of cumulative distribution of measured rain attenuation data in year 2008

5. Rain Rate, Rain Attenuation Analysis

Communication systems operating at frequencies beyond 10 GHz in tropical and equatorial climates are subjected to many fade occurrences due to heavy rain. The information on rain rate and attenuation statistic is useful in link budget design. The considerable average worst month from year to year and within individual years is important in the planning of satellite earth-link design.

Rain rate is the volume of liquid water that falls through a unit area per unit time period. Rain attenuation is the depletion of electromagnetic energy during propagation through rain, caused by raindrop scattering and absorption. Worst month distribution of rain rate and attenuation is defined as the highest rain rate and attenuation, respectively within a set of individual monthly distributions of rain rate and attenuation for a year.

Best fit lines of the annual cumulative distribution of measured rain rate and rain attenuation for these three years have been used to make the comparison.

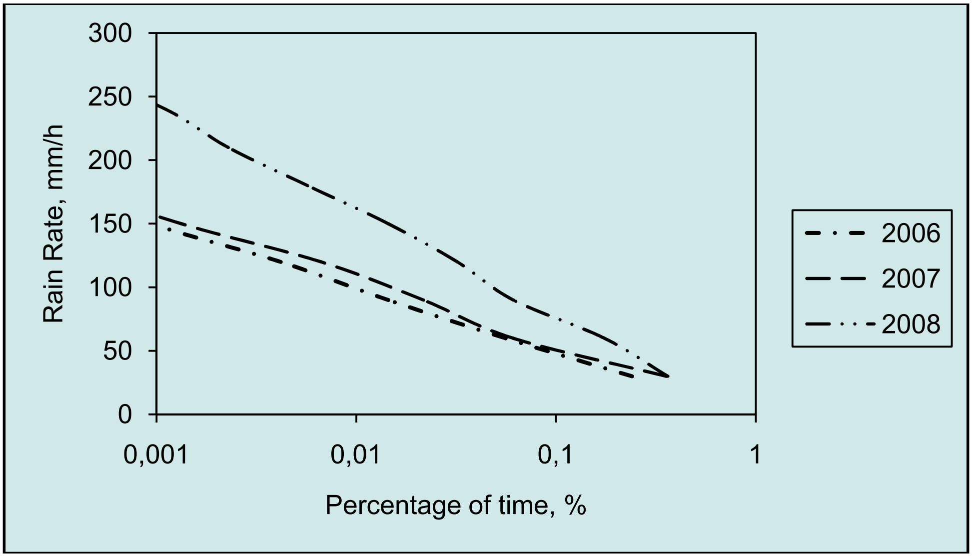

Fig. 10. Cumulative distribution of measured rain rate

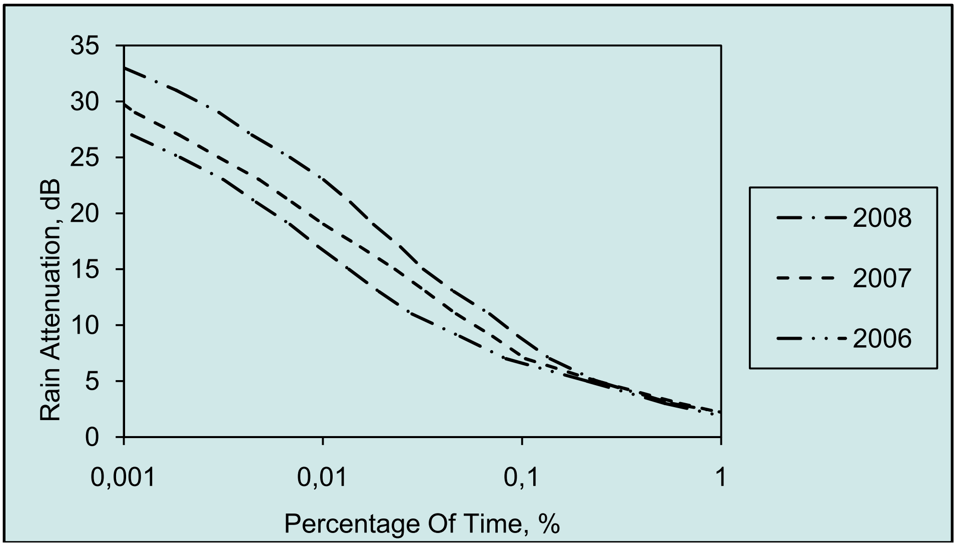

Fig. 11. Cumulative distribution of rain attenuation

Fig 10 and Fig 11 show the annual cumulative distribution of rain rate and rain attenuation for three years (2006-2008), respectively. Table 1 shows the record of rain rate and rain attenuation at point 0.01% of time and maximum point for the year 2006, 2007, 2008.

Year	Rain Rate. mm/h		Rain Attenuation, dB	
	At point 0.01%	Maximum	At point 0.01%	Maximum
2006	100	180	17	29
2007	110	210	18	31
2008	160	270	28	31

Table 1. The record of rain rate and rain attenuation at point 0.01% of time and maximum point for the year 2006, 2007, 2008

6. Worst Month Statistics

Worst month distribution of rain attenuation is defined as the highest rain attenuation within a set of individual monthly distributions of rain attenuation for one year. Rain attenuation data for year 2006, 2007 and 2008 at USM was analyzed.

In planning of the design of reliable communication systems, the required statistics of propagation effects is relevant to the worst month reference. On the other hand, the reference statistics for several propagation prediction methods are the long term average annual distribution. Therefore, the conversion of the yearly statistic to the worst month is important. The annual and worst-month rain attenuation exceedance curve is shown in Fig.12, Fig 14 and Fig 16 for year 2006, 2007 and 2008, respectively. The worst month for 2006, 2007 and 2008 were November, October and March, respectively. The Q factor as a function of annual percentage of exceedance for Ku-band rain attenuation is shown in Fig.13, Fig 15 and Fig 17 for year 2006, 2007 and 2008, respectively.

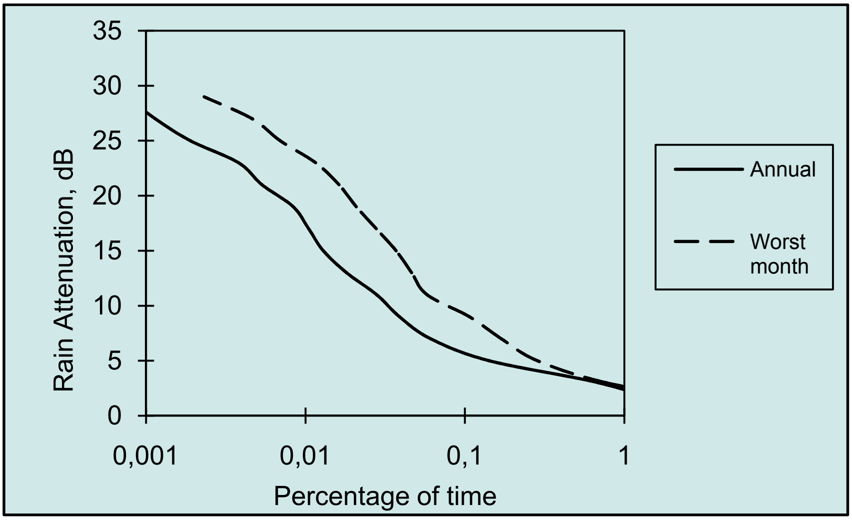

Fig. 12. The annual and worst-month rain attenuation exceedance curve at Ku-band for year 2006

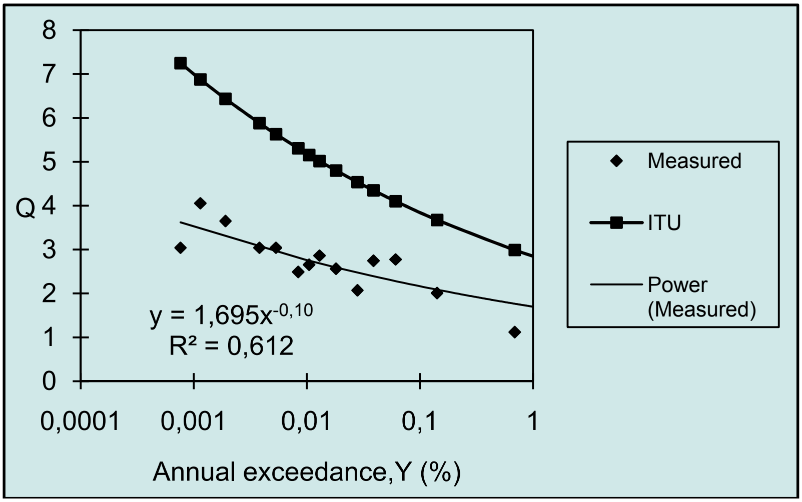

Fig. 13. The Q factor as a function of annual percentage of exceedance for rain attenuation at Ku-band for year 2006

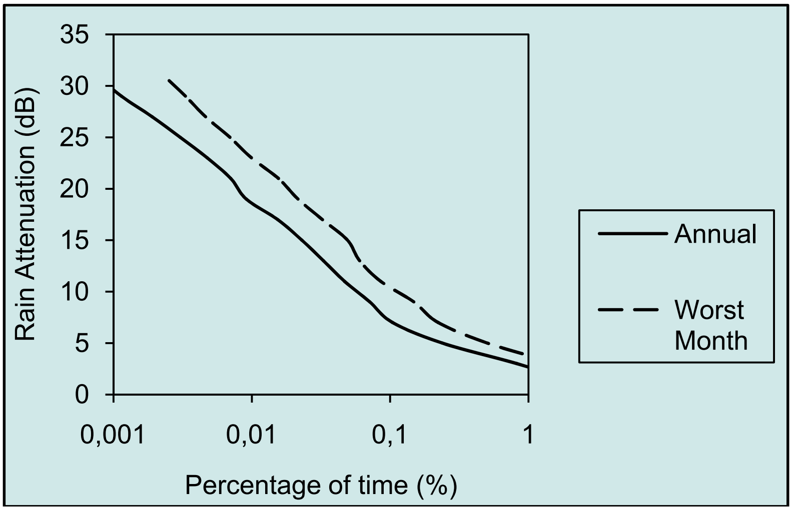

Fig. 14. The annual and worst-month rain attenuation exceedance curve at Ku-band for year 2007

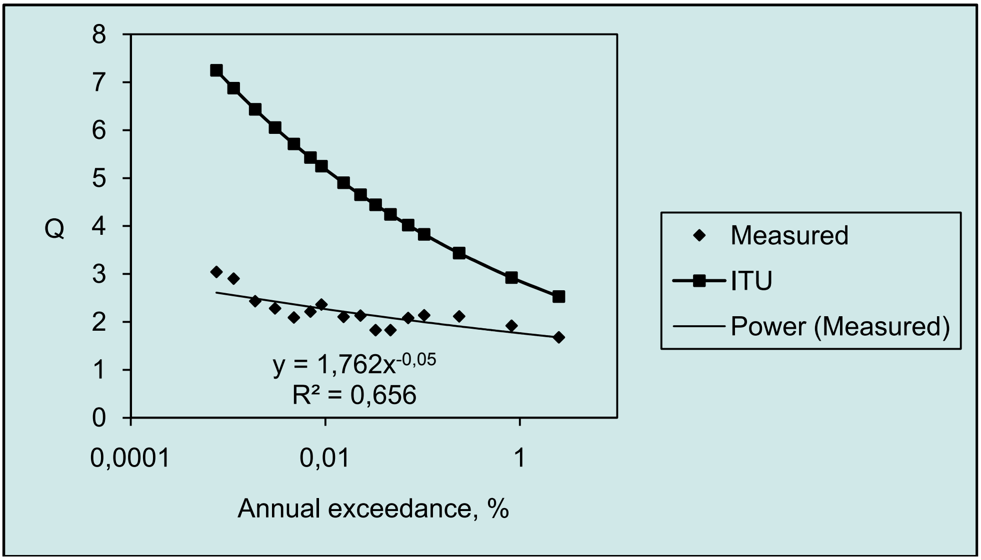

Fig. 15. The Q factor as a function of annual percentage of exceedance for rain attenuation at Ku-band for year 2007

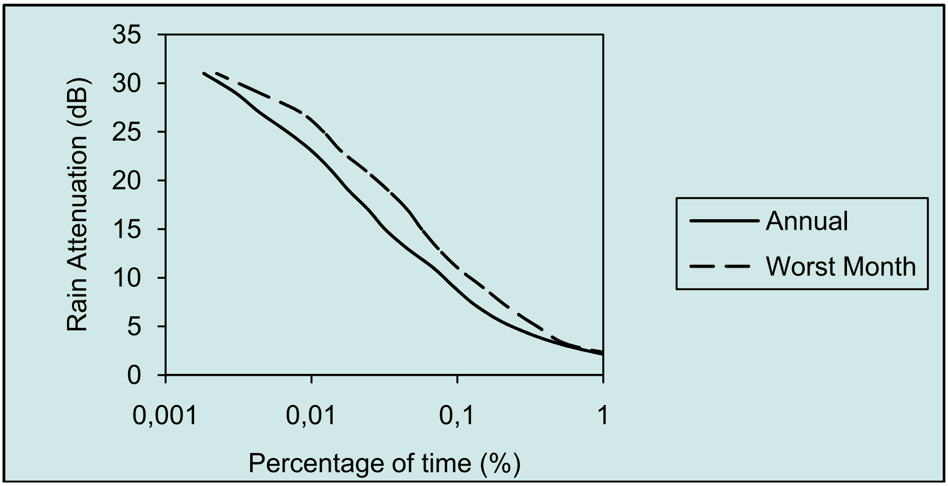

Fig. 16. The annual and worst-month rain attenuation exceedance curve at Ku-band for year 2008

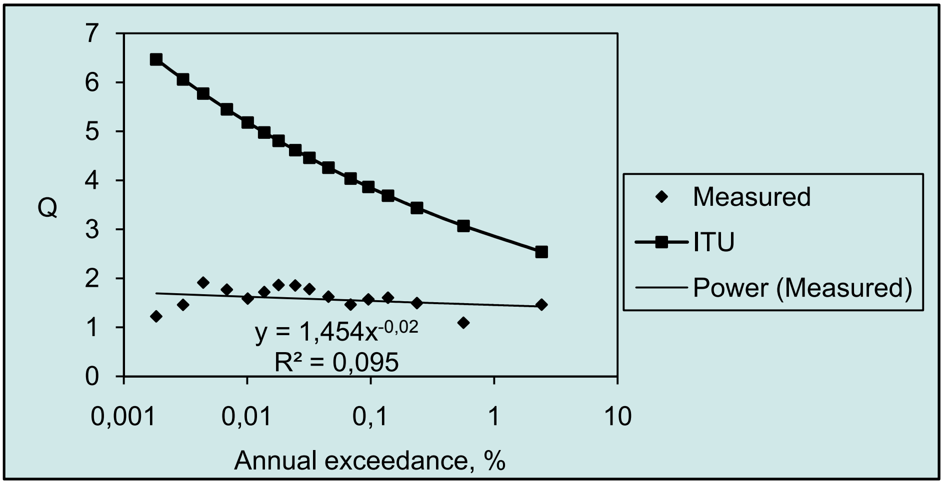

Fig. 17. The Q factor as a function of annual percentage of exceedance for rain attenuation at Ku-band for year 2008

The Q factor for rain attenuation was found to follow the power law of the form $Q=AY^{-\beta}$. Table 2 shows the parameter A and β for year 2006, 2007 and 2008.

Year	A (Proposed by ITU-R = 2.82)	B (Proposed by ITU-R = 0.15)
2006	1.6953	0.106
2007	1.7624	0.055
2008	1.4547	0.024

Table 2. The parameter A and β for year 2006, 2007 and 2008

For global rain rate applications, the ITU P.841-4 has recommended values of **A** = 2.82 and β = 0.15 for tropical, subtropical and temperate climate regions with frequent rain. The percentage of time for worst month distribution of rain attenuation is significantly higher than annual distribution of rain attenuation. There is a large difference between the A and β values obtained for tropical area with the ITU proposed. It shows that the ITU values are not suitable for use in worst-month analysis for tropical area. This indicates that the Q factors are climatic dependant. The worst month curve was strongly influenced by the Northeast Monsoon during which the highest levels of attenuation occurred. Worst month attenuation statistics are very important for the study of the performance of a communication system during periods of up to 31 days.

Ku-band TV services are affected by outages for time-critical transmission such as real-time news and sports broadcasting. Service providers need to consider the use of appropriate forward error correction codes, the choice of modulations, and the range of uplink power controls to use during severe rain fade periods in the overall design of their communications networks (Pan, *et al*, 2008). These techniques can be used to provide a significant improvement in both performance and availability for worst month attenuation.

7. Specific Attenuation Analysis

The measurement ran continuously from 1st January 2006 to 31st December 2008. Three years of cumulative distributions are obtained. The measurement ran continuously from 1st January 2006 to 31st December 2008. Three years of cumulative distributions are obtained. The relation between rain attenuation and rain rate in year 2006, 2007 and 2008 were shown in Fig. 18, 19 and 20. In these figures, the symbols × are obtained by directly plotting the rain attenuation against rain rate and the solid line is the best-fit curve obtained by fitting the rain attenuation against rain rate. The effective path length, L_{eff}, is a function of rain rate and has a direct correlation with the measured rain rate. The effective path length has been found by using equation 2.5 and 2.6 and shown in Fig. 21. The effective path length for the site is a power-fitting function of rain rate and can be simplified as

$$L_{eff}\,(km) = 13.367\ R^{-0.21} \tag{5}$$

The L_{eff} is obtained from the equation 5 is used to divide the total attenuation to obtain specific attenuation, γ at different rain rate. Fig. 22, 23 and 24 show the relation between specific attenuation, γ and rain rate in the year 2006, 2007 and 2008.

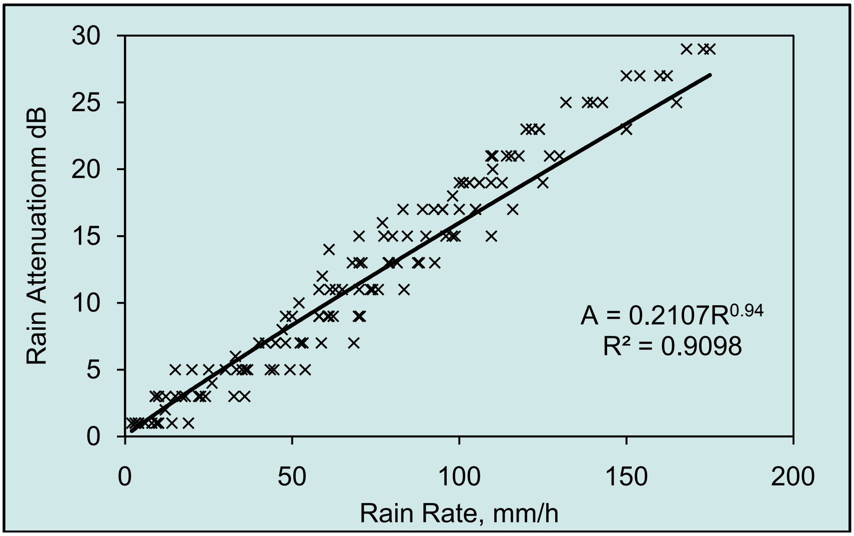

Fig. 18. The correlation between rain attenuation and rain rate in year 2006

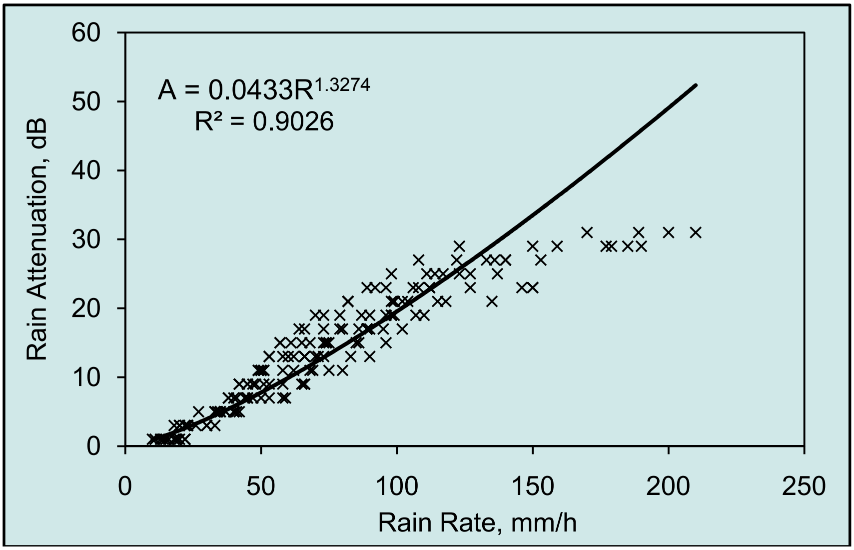

Fig. 19. The correlation between rain attenuation and rain rate in year 2007

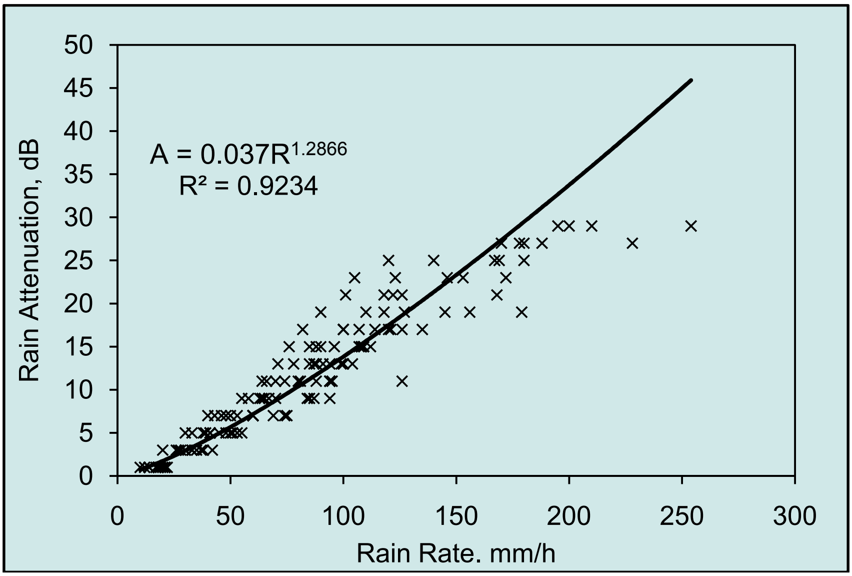

Fig. 20. The correlation between rain attenuation and rain rate in year 2008

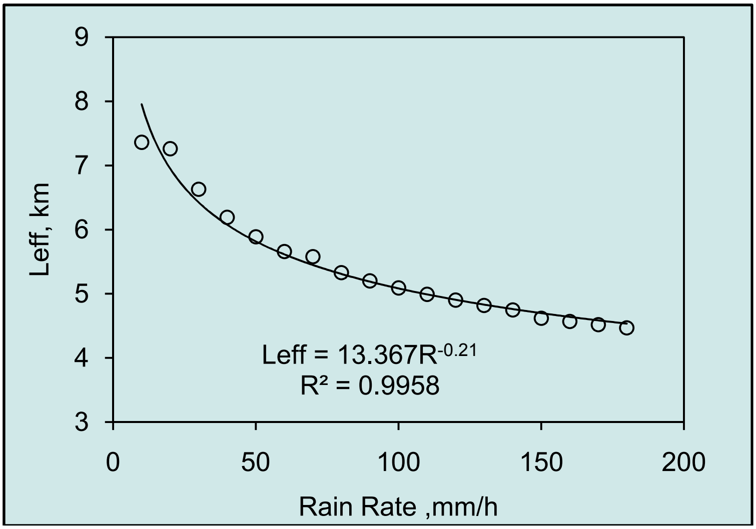

Fig. 21. The correlation between the effective path length and rain rate.

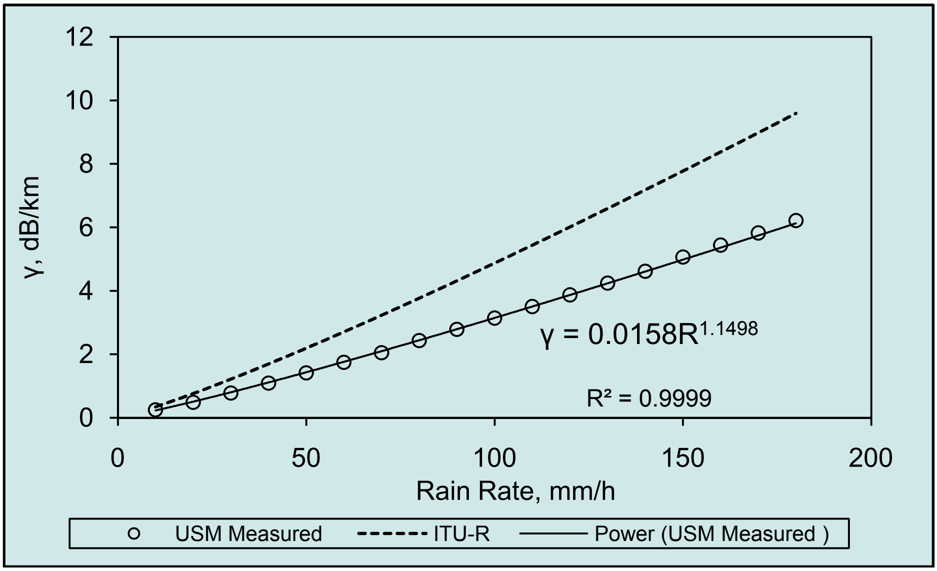

Fig. 22. Relationship between specific attenuation and rain rate compared with ITU-R in year 2006

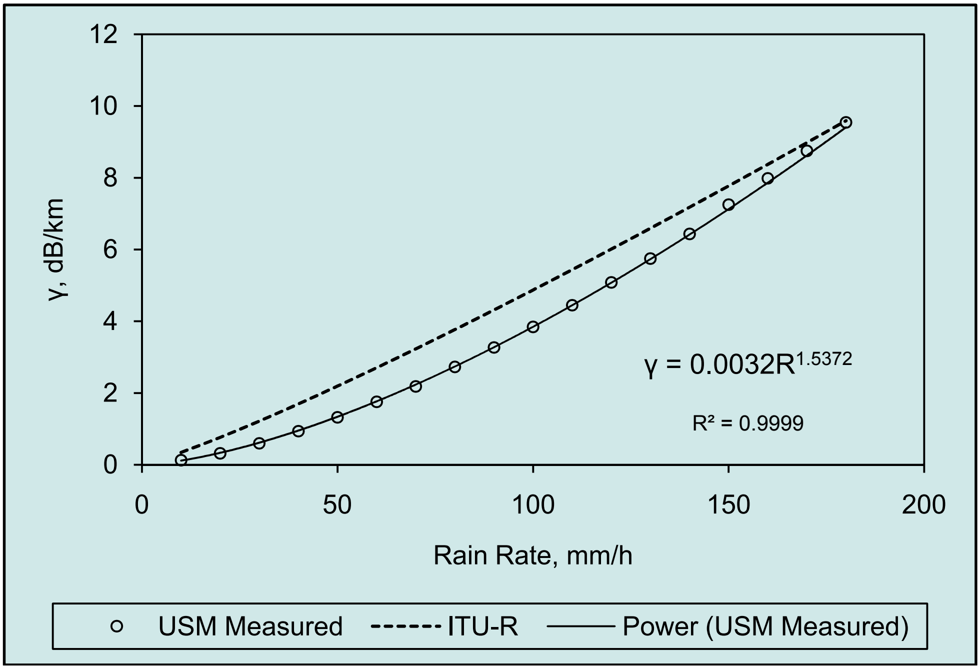

Fig. 23. Relationship between specific attenuation and rain rate compared with ITU-R in year 2007

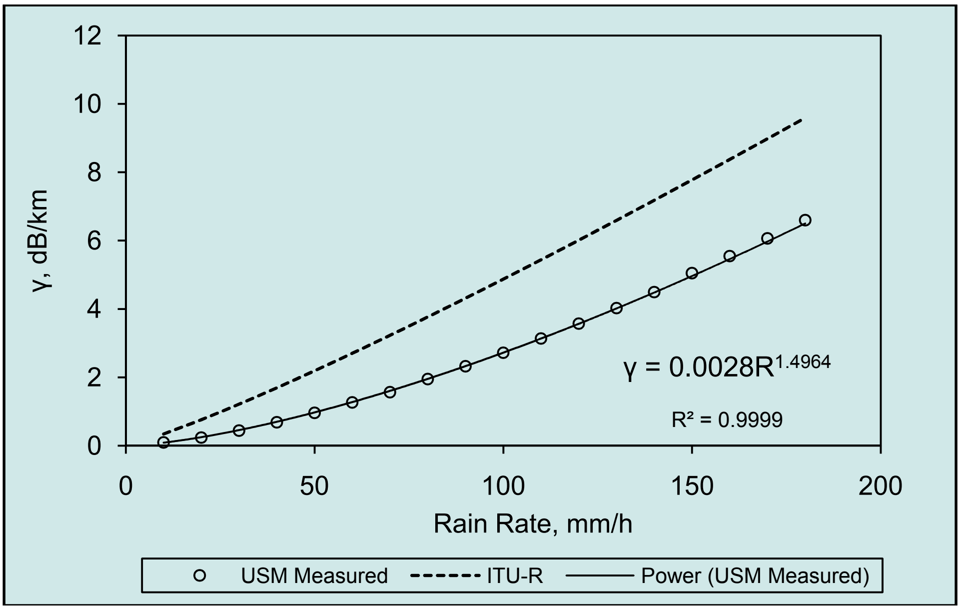

Fig. 24. Relationship between specific attenuation and rain rate compared with ITU-R in year 2008