CHAPTER 5

RAIN ATTENUATION DISTRIBUTIONS

5.1 Introduction

This Chapter presents statistics of rain attenuation along an earth-satellite path in Southeast Asia over a three-year period of a radiometric measurement from 1 March 1992 - 28 February 1995, and a one-year period of a beacon measurement from 1 April 1997 - 31 March 1998. Data analysis comprises three years cumulative distributions, annual cumulative distributions, monthly distributions, worst month statistic, year-to-year variations and seasonal variation. Results are compared among current attenuation prediction models such as ITU-R 618-2 [1992] model, Dissanayake, Allnutt and Haidara [1997] model, CETUC [1993] model, and M. JUY [1990] model. Intensive analysis of rain attenuation includes Site-diversity, Fade-duration, and Diurnal variations of rain attenuation are described in Chapter 6, 7, 8 respectively. Fade-duration model and powerful attenuation prediction model are also present in Chapter 7 and 9.

5.2 Data Analysis

Antenna noise temperature with every 2 seconds sample interval from the radiometers and attenuation data from the beacon receiver are analyzed to obtain statistical behaviors of rain-attenuation in Southeast Asia. Rain attenuation from a radiometer can be acquired by converting antenna noise temperature (Ta) to attenuation which is described in Chapter 3. The effective medium temperature (Tm) of a radiometer in Bangkok and Si-racha were calibrated at 280° K while the Tm of Singapore and Bundung were calibrated at 290° K.

The accuracy of radiometric measurement, described in Chapter 3 section 3.2, highly relies on the estimation value of Tm and the measured value of Ta. When antenna noise temperature (Ta) increase, an error will increase. Therefore, our analysis will be limited the measured attenuation up to 12 dB.

In general, a cumulative distribution of rain attenuation is considered to be a probability distribution of measured attenuation (A) exceeding a threshold (α) in a long observation period.

$$P(A > \alpha) = 1 - P(A \leq \alpha) \qquad \text{------------------- (5.1)}$$
$$= 1 - F_R(\alpha)$$

From long-term observation period, the cumulative attenuation distribution can be obtained by:

$$P(A > \alpha) = \frac{\sum T(A > \alpha)}{T_{tot}} \quad \text{------------------(5.2)}$$

where

$\sum T(A > \alpha)$ is the total accumulation time of A exceeds the threshold (α) in seconds,

T_{tot} is the total observation time in seconds.

5.3 Cumulative Distribution of Rain-Attenuation

1) Annual Cumulative Distribution of Rain Attenuation

Figures 5.1 - 5.4 show the annual cumulative distribution for Bangkok (Figure 5.1), Si-racha (Figure 5.2), Singapore (Figure 5.3) and Bundung (Figure 5.4). The vertical axis is the probability (percentage time) of attenuation exceeding the thresholds (the abscissa). In all Figures, the solid curve, the dotted curve, and the dashed curve belong to year-1 (1992-1993), year-2 (1993-1994) and year-3 (1994-1995) respectively. Figures 5.1 - 5.2 of the ITU-R zone N, all annual distribution curves show similar curve with small year to year variation. Year-3 curves show the highest distribution whereas year-1 curves show the lowest attenuation distribution. At 0.1% of the time, Bangkok and Si-racha obtain attenuation higher than 12 dB to all three years. With 80 km site separation, annual attenuation distributions of Bangkok and Si-racha are very similar.

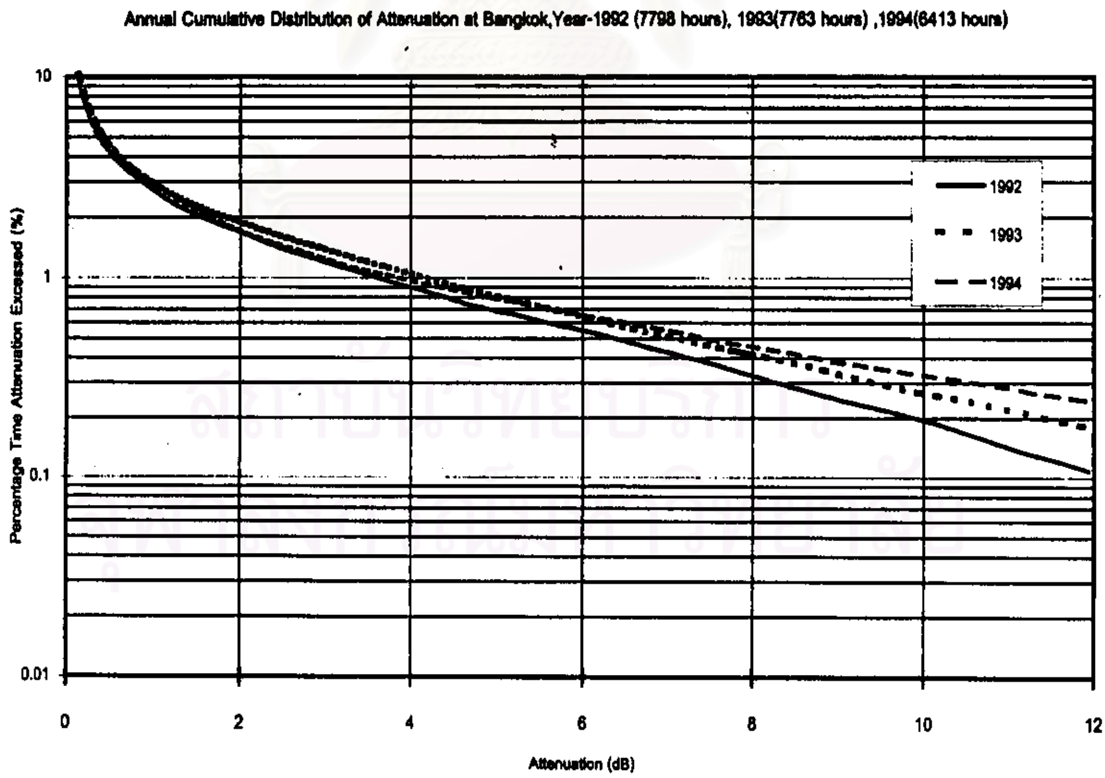

Figure 5.1 Annual cumulative distribution of rain attenuation in Bangkok, 1992 -1995 (ITU-R zone N).

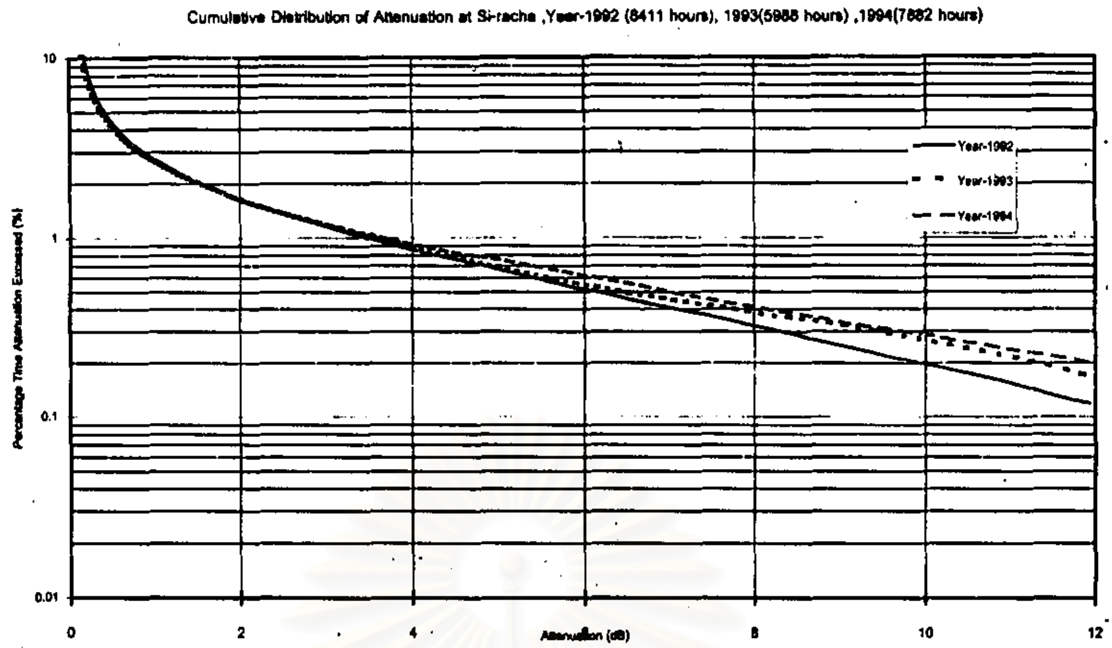

Figure 5.2 Annual cumulative distribution of rain attenuation in Si-racha, 1992 -1995 (ITU-R zone N).

Figures 5.3 - 5.4 of the ITU-R Zone P, show some differences of the two attenuation distributions. Singapore has higher distribution with small year-to-year variation than the Bundung's distribution. At 0.1% of the time, attenuation about 12 dB occupies in Singapore while attenuation about 8-9 dB occupies in Bundung. Singapore and Bundung are located in the same tropical wet region (ITU-R zone P) but the distributions are different. One expectation could be that the geographical location may influence on the attenuation statistics.

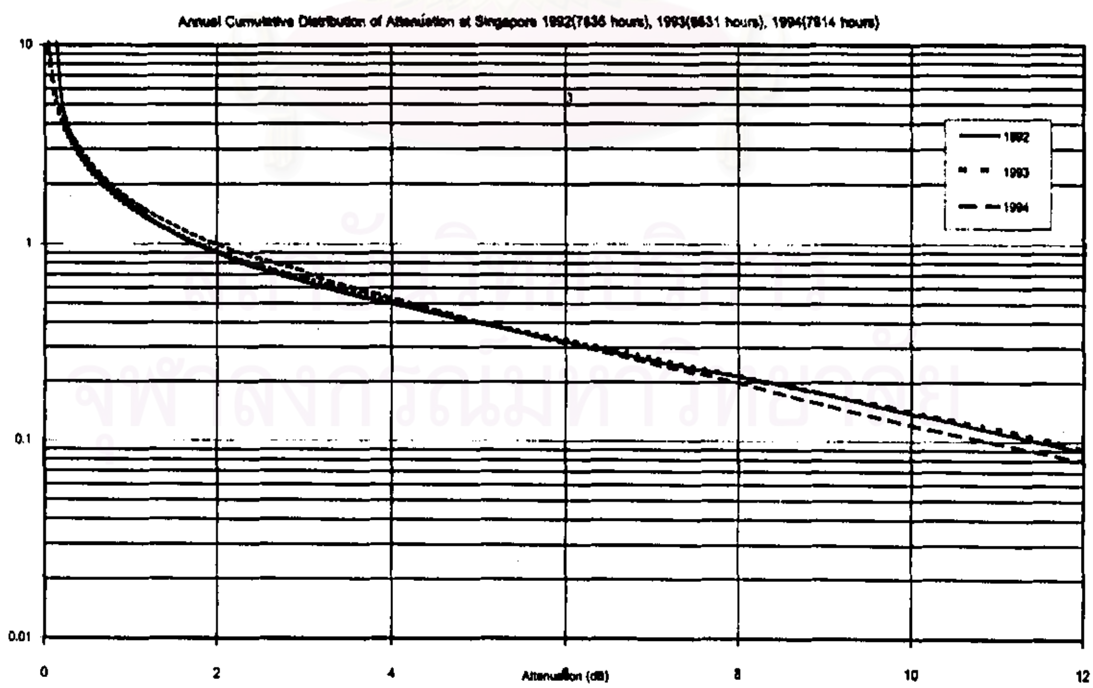

Figure 5.3 Annual cumulative distribution of rain attenuation in Singapore, 1992 -1995 (ITU-R zone P).

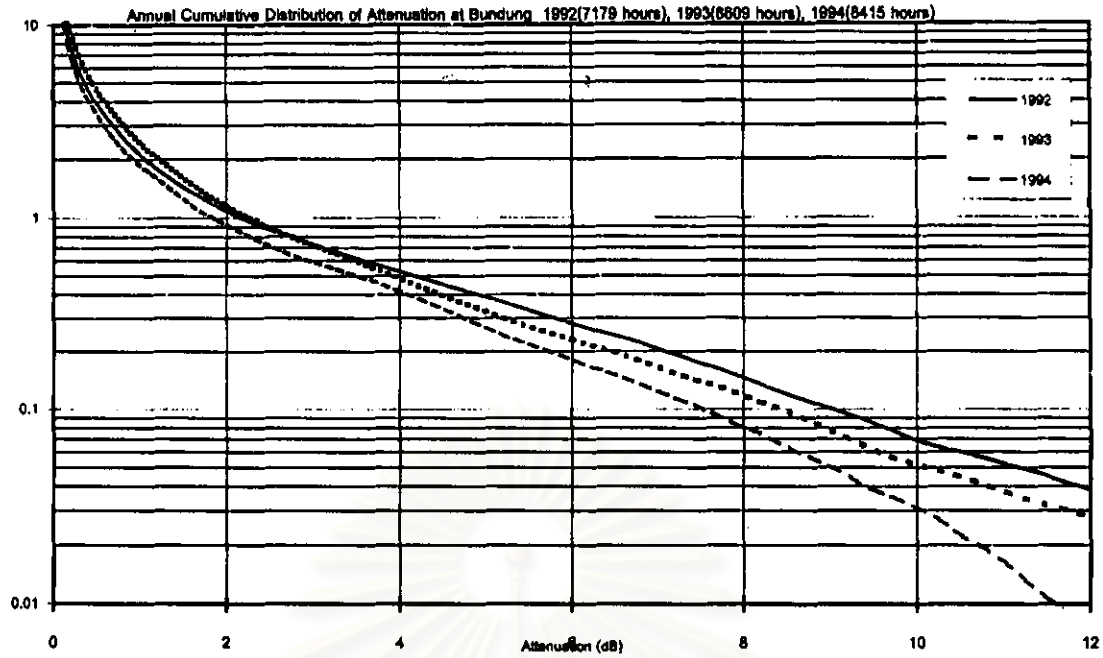

Figure 5.4 Annual cumulative distribution of rain attenuation in Bundung, 1992 - 1995 (ITU-R zone P).

2) Monthly Cumulative Distributions of Rain Attenuation

A monthly cumulative distribution is also important for the system design to estimate the suitable margin for the communication link. It gives more extensive information at more specific time than the yearly cumulative distribution. All useful 48 Figures, including 144 monthly distribution curves for all four locations in Southeast Asia are illustrated in Appendix C. In addition, Table C.1 - C.4, corresponding to the ITU-R format, providing a very useful of all cumulative distribution information for the system design in Southeast Asia are also given in Appendix C.

The monthly distribution curves of Bangkok and Si-racha show a relatively large variation than the monthly distribution curves of Singapore and Bandung. Singapore and Bundung have the smallest year-to-year variation of the curves. In addition, the monthly curves of Singapore tend to show a similar shape that persist higher percentage time to all months.

3) Three Year Cumulative Distribution of Rain Attenuation

Figures (5.5) - (5.6) indicate a three-year average of the measured attenuation distributions of the ITU-R zone N (Bangkok, Si-racha) and the ITU-R zone P (Singapore, Bundung) associated with the predicted attenuation distributions. As shown in Figures 5.5 - 5.6, attenuation distributions in Bangkok, Si-racha, Singapore, (the coastal areas) show longer percent of fading time than Bundung's distribution (the mountainous area).

3-Year Cumulative Attenuation Distribution, Bangkok, Si-racha Thailand
Log-normal Fits (mean = -3.7, std= 2.2)

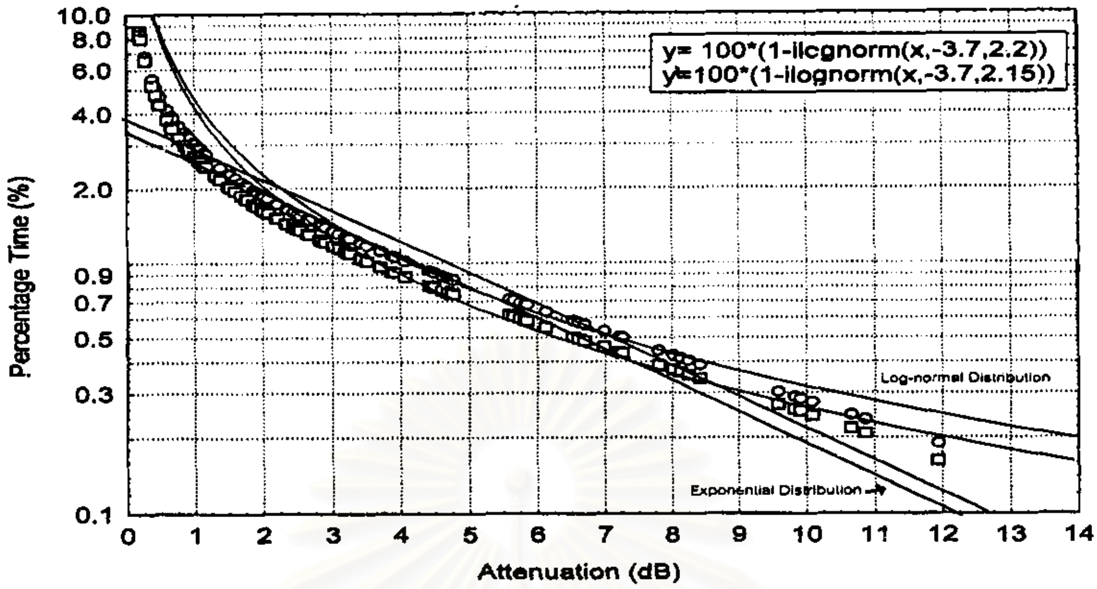

Figure 5.5 Comparison between measured attenuation distribution with Log-normal and exponential distributions.

A power-law distribution, an exponential distribution, and a log-normal distribution are used to test the statistical distribution of rain attenuation distributions. It is found that the exponential distribution is underestimated the measured distribution especially lower than 1 dB and above 10 dB thresholds. The log-normal distribution is found more better fit than the exponential distribution. However, it shows overestimation of the measured distribution higher then 10 dB, but due to radiometer's limitation, attenuation higher than 12 dB can not be observed.

3-Year Cumulative Distribution, Singapore, Bundung Indonesia
Log-normal Fit

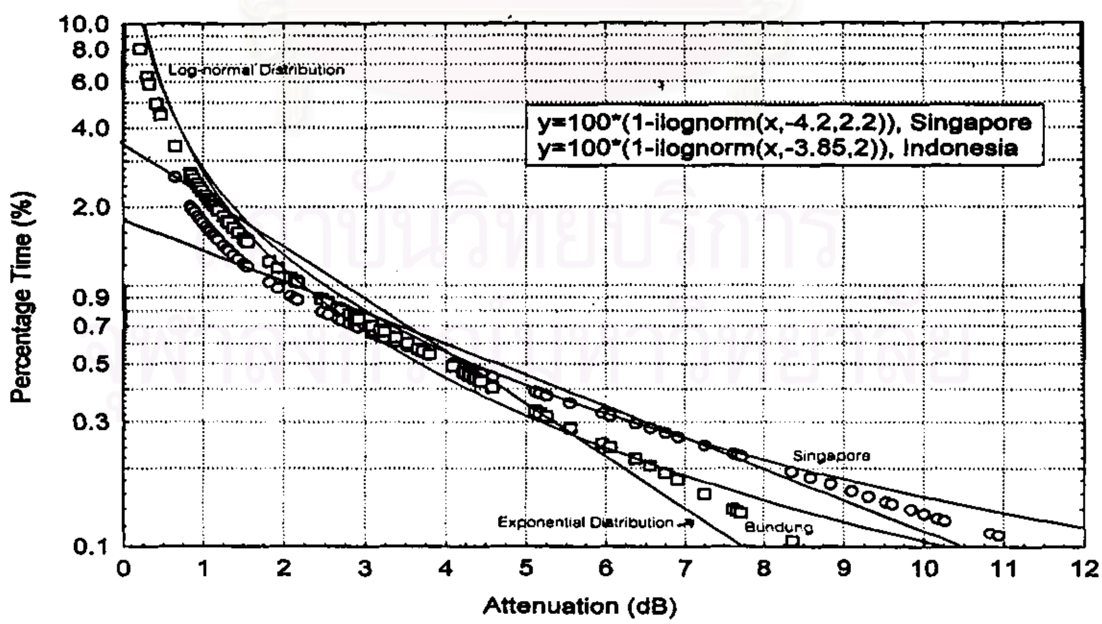

Figure 5.6 Comparison between the measured attenuation distribution with the Log-normal and the exponential distributions.

The log-normal distribution that fits with the measured data can be expressed by:

$$P(A \geq \alpha) = F_A(\alpha)$$
$$= F(10\log(a_i))$$
$$= [1/(\sigma\sqrt{2\pi})] \int_{\alpha}^{\infty} \exp[-(x - m)^2/2\sigma^2]dx \qquad \text{------(5.3)}$$

where

A = 10log(a) in dB

m is the mean,

σ is the standard deviation

Bangkok, Si-racha, Singapore and Bundung have m = -3.7 dB, -3.7 dB, -4.2 dB, and -4.0 dB while σ = 2.2, 2.15, 2.2, 2.0 respectively. Method of obtaining the mean and standard deviation are shown in Appendix C.

The measured results of the cumulative distribution of rain attenuation from the beacon at Si-racha and Songkla from April 1997 - March 1998 is shown in Figure 5.7. It is remarkably indicated that the power-law distribution is well fitted to both Si-racha and Songkla data. Songkla is located in the tropical wet climate (ITU-R zone P) having high rainfall accumulation of about 2035 mm/yr and the attenuation exceedance probability is higher than Si-racha. The fitted power-law distribution can be expressed by:

$$P(A > \alpha) = (x)A^{-(y)} \qquad \text{------ (5.4)}$$

where

x, y are constants

Table (5.1) shows the parameters "x" and "y" that well fitted with the measured data.

Table 5.1 Parameters "x" and "y" and correlation coefficient (COR)

Name	"x"	"y"	Correlation Coefficient
Si-racha	3.4996	-1.2094	0.9978
Songkla	4.0469	-0.8324	0.9631

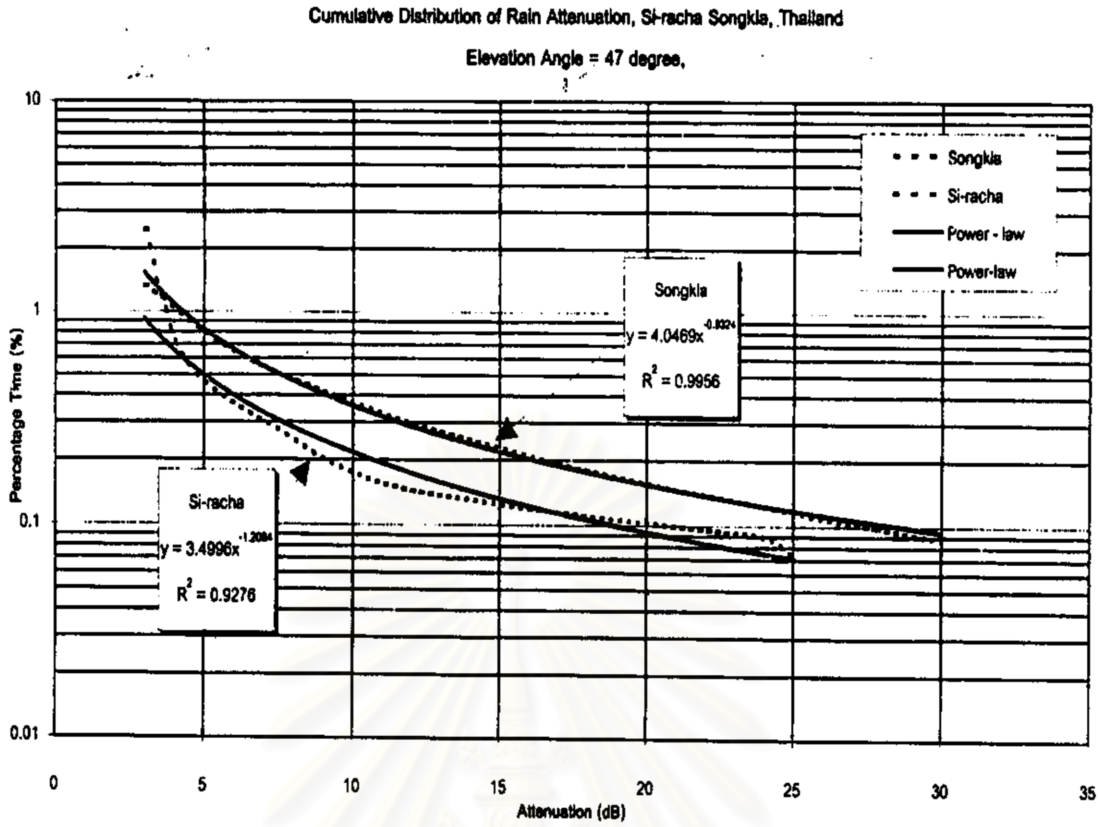

Figure 5.7 Comparison between measured attenuation distribution with power-law distributions, in 1997, Si-racha (ITU-R zone N) and Songkla (ITU-R zone-P).

5.4. Year-to-Year Variability

A year-to-year variation of rain attenuation is one of the useful information to describe an instability of the rain attenuation distribution varying from year-to-year. System design can further estimate the effects of long-term rain attenuation statistics. As shown in Figures 5.1 - 5.4, at percentage time > 0.1%, year-to-year variation of rain attenuation show relatively small variation. Singapore shows the smallest year-to-year variation followed by Bundung, Si-racha, and Bangkok. Table 5.2 summarizes values of attenuation exceeding above each percentage time of 0.1%, 0.2%, 0.3%, and 1% of each year.

5.5 Diurnal and Seasonal Variations

Intensive analysis of the diurnal variation of rain attenuation is described in Chapter 8 and will not be presented in this section. The seasonal variations are illustrated in Figures 5.8 - 5.9. It shows the cumulative distribution taken in the rainy season (May - October) and the cold and dry seasons (November - April) of every year. In Figure 5.8, it is remarkably indicated that attenuation distributions of Bangkok and Si-racha is highly dependent on the season. Rainy season has longer attenuation than the cold and dry seasons. At 0.1% of the time, more than 5 dB attenuation difference from the rainy season and the cold-dry seasons.

Table 5.2 Measured attenuation (dB) exceeding 0.1%, 0.2%, 0.3% and 1%, the maximum deviation (Max Diff.) of the attenuation value in each year, and percent average year-to-year-variation.

Name	1%	0.3%	0.2%	0.1%	% average variation
BK 92	3.6	8.23	9.82	12.2	
BK 93	4.13	9.43	11.3	n/a	
BK 94	3.85	10.55	n/a	n/a	
Max Diff	0.53	2.32	1.48	n/a	1.43%
SR 92	3.46	8.29	9.91	n/a	
SR 93	3.54	9.43	11.30	n/a	
SR 94	3.66	9.74	11.93	n/a	
Max diff	0.2	1.45	2.02	n/a	1.3%
SP 92	1.73	6.26	8.35	11.5	
SP 93	1.77	6.40	8.35	11.6	
SP 94	2.05	6.23	8.0	10.93	
MAX diff	0.32	0.17	0.35	0.67	0.37%
DB 92	2.50	6.30	7.50	9.45	
DB 93	2.26	5.20	6.44	8.4	
DB 94	1.88	4.78	5.80	7.6	
Max diff	0.62	1.52	1.70	1.85	1.28%

As shown in Table 5.6, Bangkok has the largest variation whereas Singapore shows the smallest variation with average year to year variation between 0.37% - 1.43%.

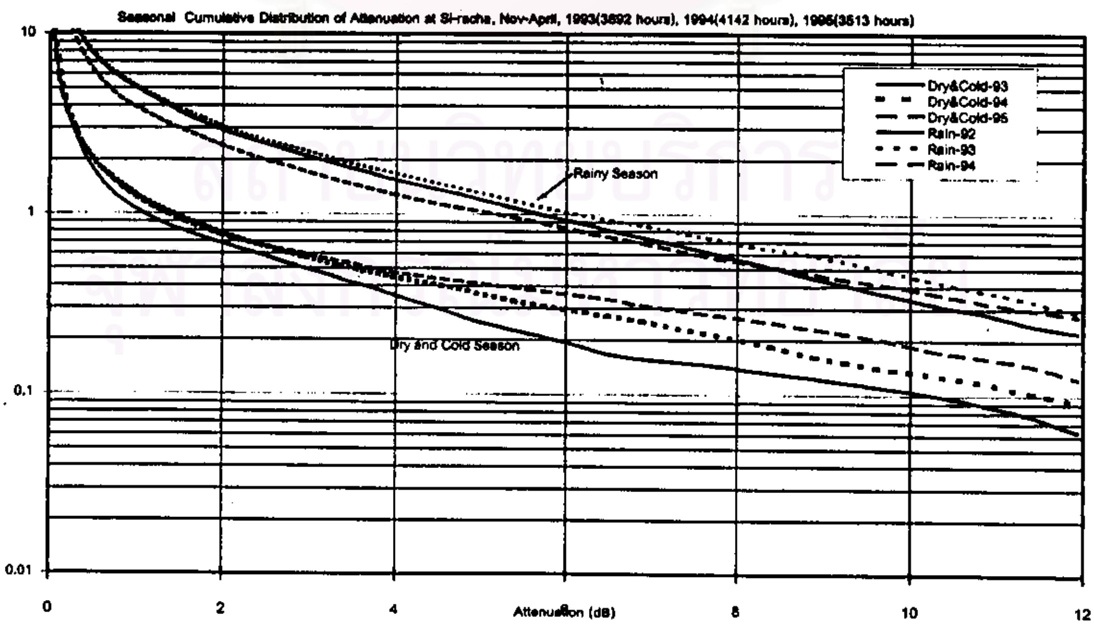

Figure 5.8 Seasonal cumulative distribution of rain attenuation at ITU-R zone-N, 1992-1995

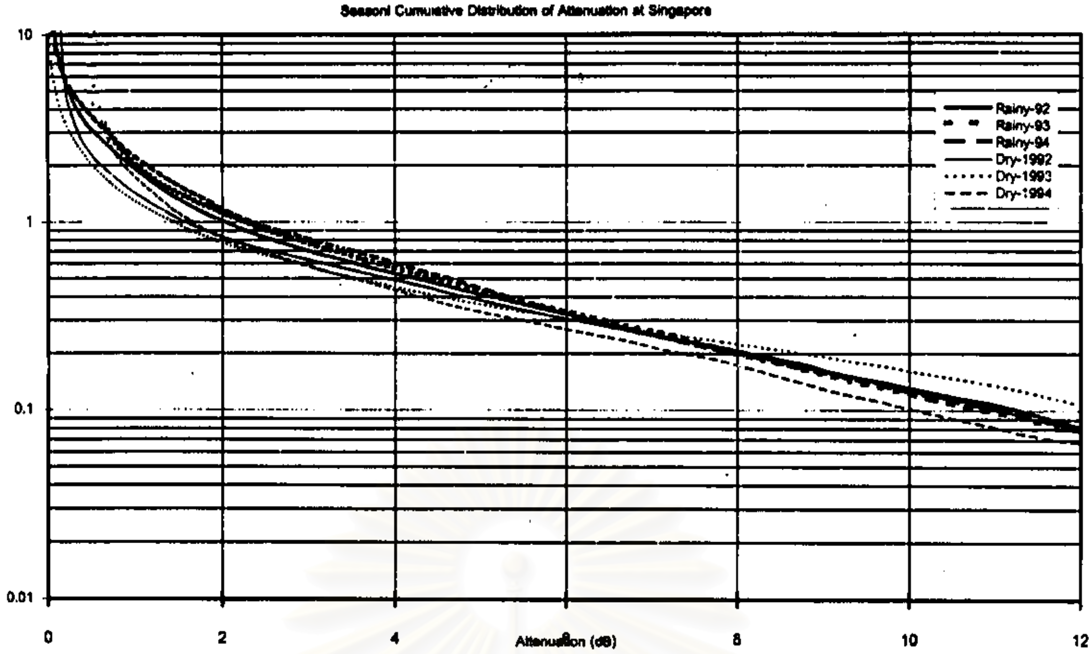

Figure 5.9 Seasonal cumulative distribution of rain attenuation at ITU-R zone-P, 1992-1995

Figure 5.9 shows the curves of the seasonal distribution of Singapore and no large variations between the two seasons. It is clearly indicated that the seasonal variation has no influence on the attenuation distribution in Singapore (the equatorial).

The attenuation distribution of the ITU-R zone N (Bangkok, Si-racha) is highly dependent upon the season. To operate more efficient satellite link, it is possible to operate lower link margin in the cold and dry seasons than in the rainy season. In the ITU-R zone P, there is no seasonal benefits for the satellite system.

5.6 Worst Month Distribution

The worst month statistic of rain attenuation is essential for the design of the satellite system especially for the design of a broadcasting satellite service which required the links to maintain within a specific outage in the worst month. Generally, the percent outage time less than 1% is allowed for some the satellite designs. The ITU-R P.814 [1990] recommended that the worst month distribution can be obtained by compiling a monthly distribution component curves at each threshold level and selecting the highest excess probability. ITU-R 723 [1990] proposed the equation to obtain the worst month distribution from the annual cumulative distribution by applying the following equation:

$$Q = Pw/Py \qquad \text{------------------ (5.5)}$$

where

Pw is the average worst month probability, Py is the annual cumulative distribution of attenuation,

Q is the ratio factor of Pw and Py

In addition, Q can be modeled by the ITU-R 723 [1990]:

$$Q = (\phi)Py^{(-\theta)} \quad \text{------------------------} \ (5.6)$$

where

ϕ and θ are constants,

ϕ is between 1.2 -3.30

θ is between 0.167 - 0.074

For the global planning, ITU-R suggested the value of ϕ = 2.85 and θ = 0.13 and substitutes value of ϕ, θ into equation (5.5)

$$Pw/Py = 2.85^{*}\ Py^{-0.13} \quad \text{--------------} \ (5.7)$$

$$Pw = 2.85^{*}Py^{\ 0.87} \quad \text{--------------} \ (5.8)$$

The measured worst month distribution are shown in Figure 5.10 for ITU-R zone N and Figure 5.11 for the ITU-R zone P. The month of September is the worst month of Bangkok and Si-racha having the highest excess probability. The monthly distributions of Singapore and Bundung do not show the significant indication to represent the worst month distribution. It is due to rain tends to fall throughout the year. Rainfall and high percent attenuation distributions tend to occur during the northeast monsoon and the ITCZ moves to the southern region (November - May).

Three year results can be concluded that the ITU-R zone N shown in Figure 5.10 has the highest excess probability than the ITU-R zone-P (Figure 5.11). The uppermost curve represents the ITU-R worst month curve obtained by the global model in equation (5.7) with ϕ = 2.85 and θ = 0.13. The dotted curve represents the measured worst month distribution while the dashed curve belongs to the modified ITU-R global model. The lowermost curve shows an average annual cumulative distribution curve. It is clearly shown that the modified global model with the modified parameter ϕ = 1.8 for ITU-R zone-N and ϕ = 0.7 for ITU-R zone P are well fitted with the measured data.

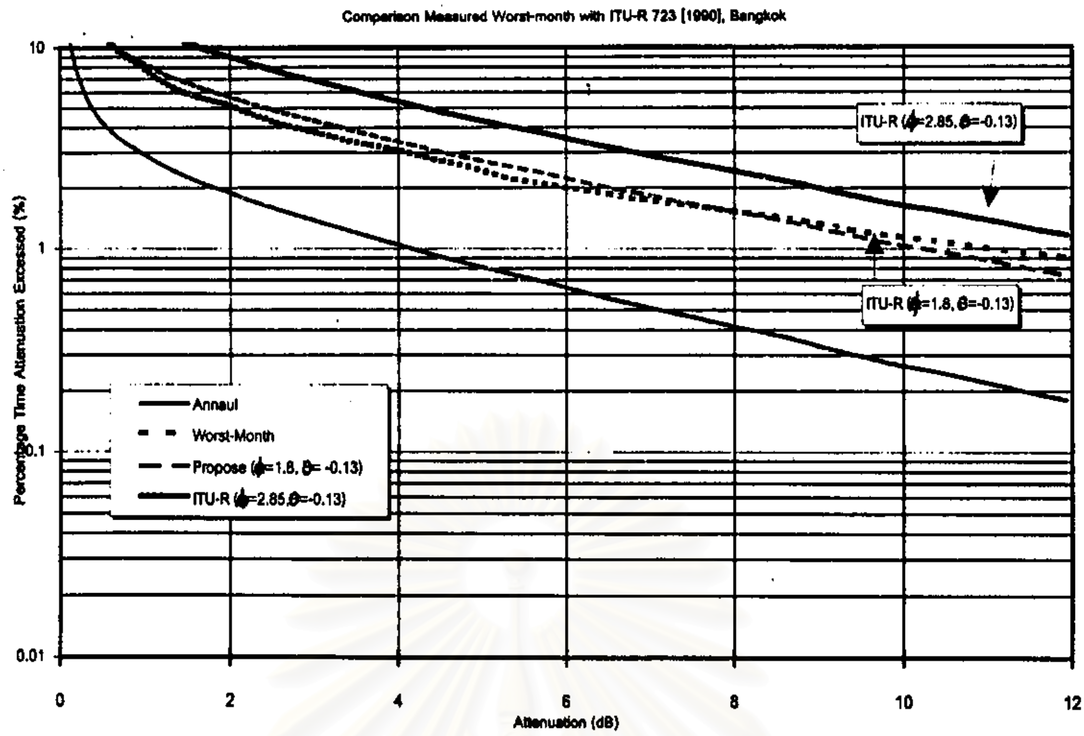

Figure 5.10 Measured worst-month distribution in Bangkok (zone-N) compared with the global model in ITU-R 732 [1990], and the modified ITU-R parameter (ϕ).

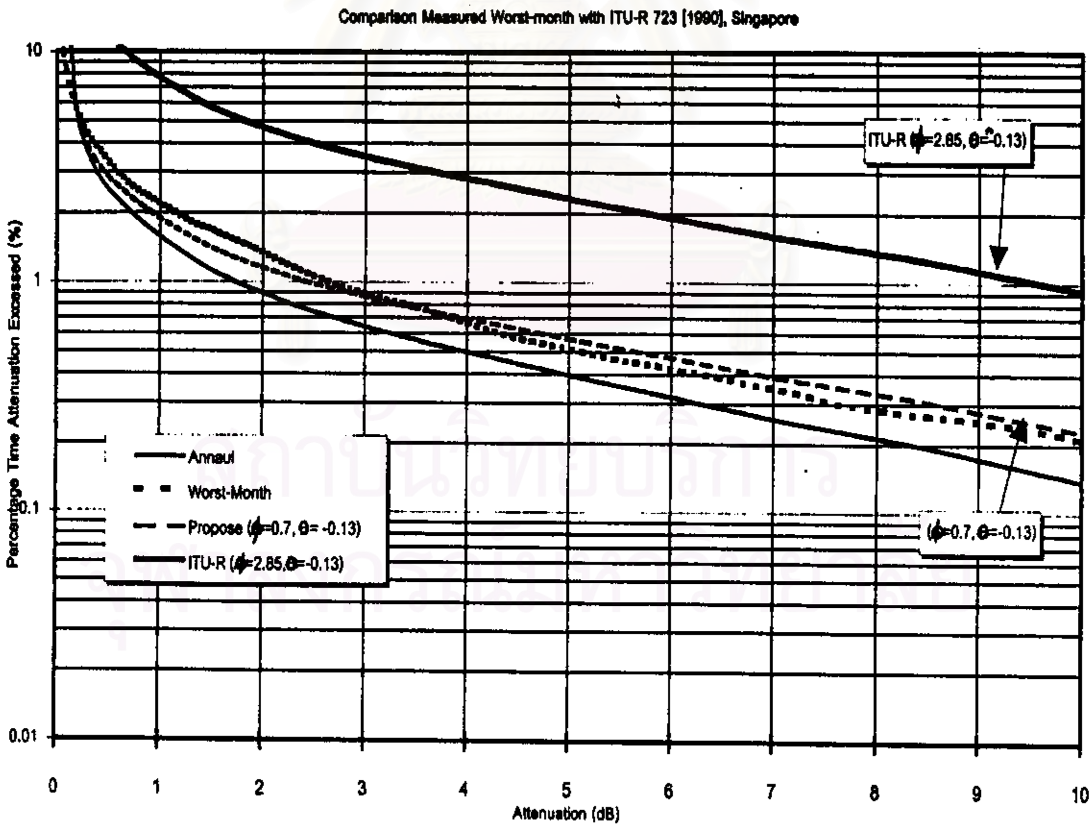

Figure 5.11 Measured worst-month distribution in Singapore (zone-P) compared with the global model in ITU-R 732 [1990], and the modified ITU-R parameter (ϕ).

5.7 Comparison of Measured Distribution with the Rain Attenuation Prediction Models

Recently many researchers found the well-known ITU-R attenuation prediction model i.e. P.618-2 [1992] using the uniform structure of a stratiform rain showing well prediction of rain attenuation in temperate regions. In the tropics, it fails to accurately predict the rain attenuation. It is due to the characteristic of rain in the tropics which is different from the temperate climates.

Many research studies are concentrated on the modification of the existing ITU-R prediction model to be able to apply to the tropical regions. Some researchers apply the non-uniform structure of rainstorm both horizontal and vertical structures. i.e. the Dissanayake model [1997] modifying the vertical factor. Some modify an effective rain height and an effective path-length i.e., the CETUC Model [1993]. Some introduce empirical parameters to adjust the ITU-R model using a log-square distribution i.e., the M.JUY [1990] model.

"In the mean time, a lot of rain attenuation models have been developed. Therefore, we are not trying to develop any additional rain attenuation models, but our research is mainly concerning data analyses that are the most fundamental tools to understand rain attenuation behavior in Southeast Asia and useful for the satellite system design. In Chapter 9, we initiate the statistical model to predict more intensive rain attenuation using the knowledge of daily rainfall patterns that have never been reported in open literature."

In this section, the measured data are compared among the rain attenuation model for the tropical regions including the CETUC model, the Dissanayake and Allnutt model, the ITU-R 618-2 model, the M. JUY model.

Figures 5.12 - 5.15 show the comparison of measured rain attenuation distributions with four models. As shown in Figure 5.12, the Dissanayake and Allnutt model seriously underestimates the Bangkok distribution while the other three models all underestimated the measured data. The M.Juy model seems to show a good agreement with the measured data followed by the ITU-R and the CETUC model.

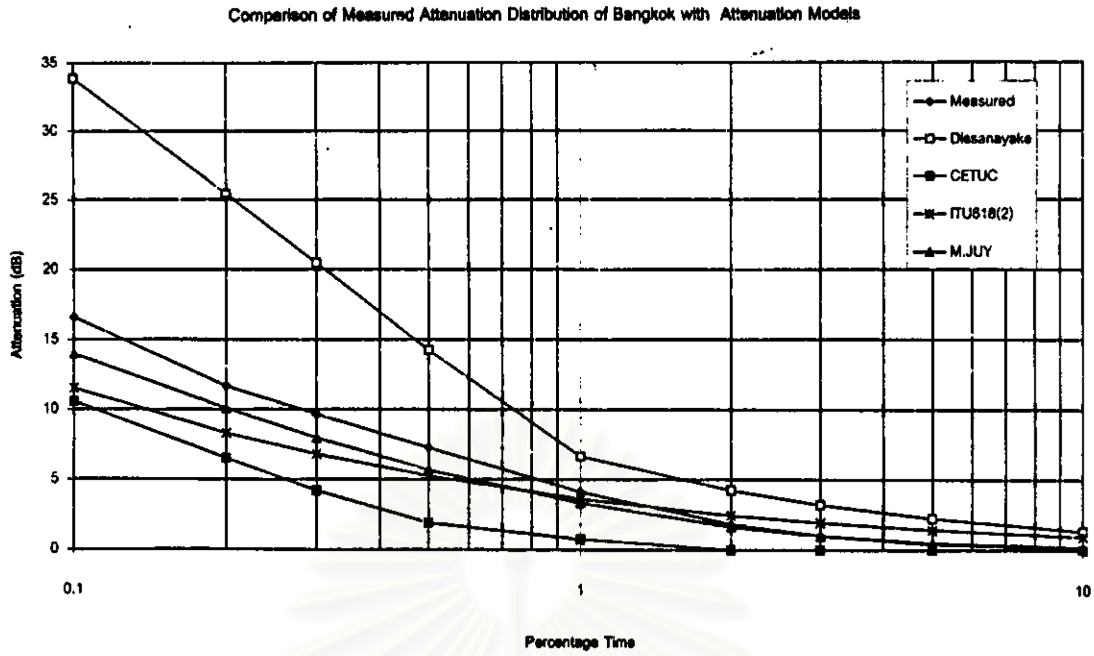

Figure 5.12 Comparison of measured attenuation distribution in Bangkok with attenuation models.

Figure 5.13, again the Dissanayake and Allnutt model seriously overestimates the measured data of Si-racha while the other three models are still underestimated and no model is well predicted.

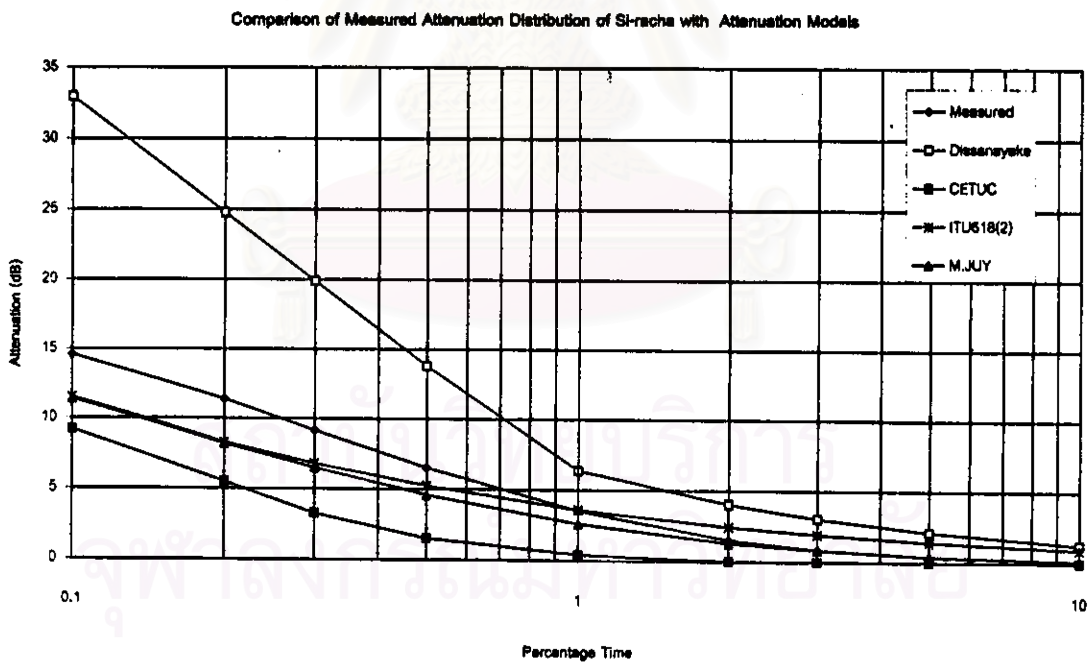

Figure 5.13 Comparison of measured attenuation distribution in Si-racha with attenuation models.

Figure 5.14, the Dissanayake and Allnutt model seems to show some good predictions of Singapore data operating at high elevation (39.4 degree), but it still overestimates the measured data. The other three models are again under-prediction. The ITU-R model shows seriously underestimation at high elevation angle operation.

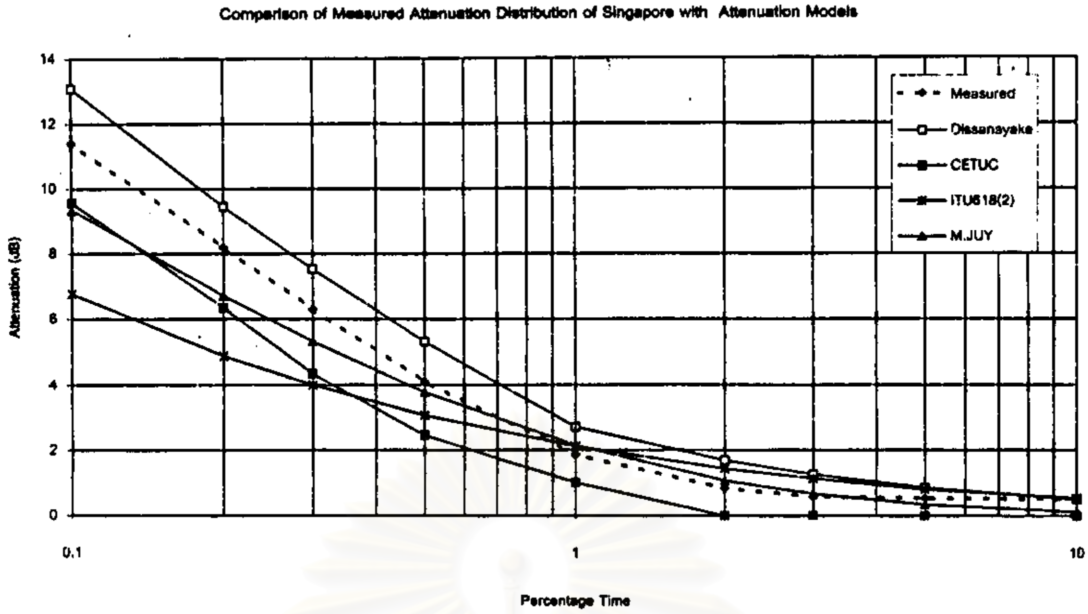

Figure 5.14 Comparison of measured attenuation distribution of Singapore with attenuation models.

Figure 5.15, the Dissanayake and Allnutt model seriously underpredict of the measured distribution in Bundung (low elevation angle operation). But all three models seem to work well especially the ITU-R model and M. Juy model developed from the measured data of Indonesia.

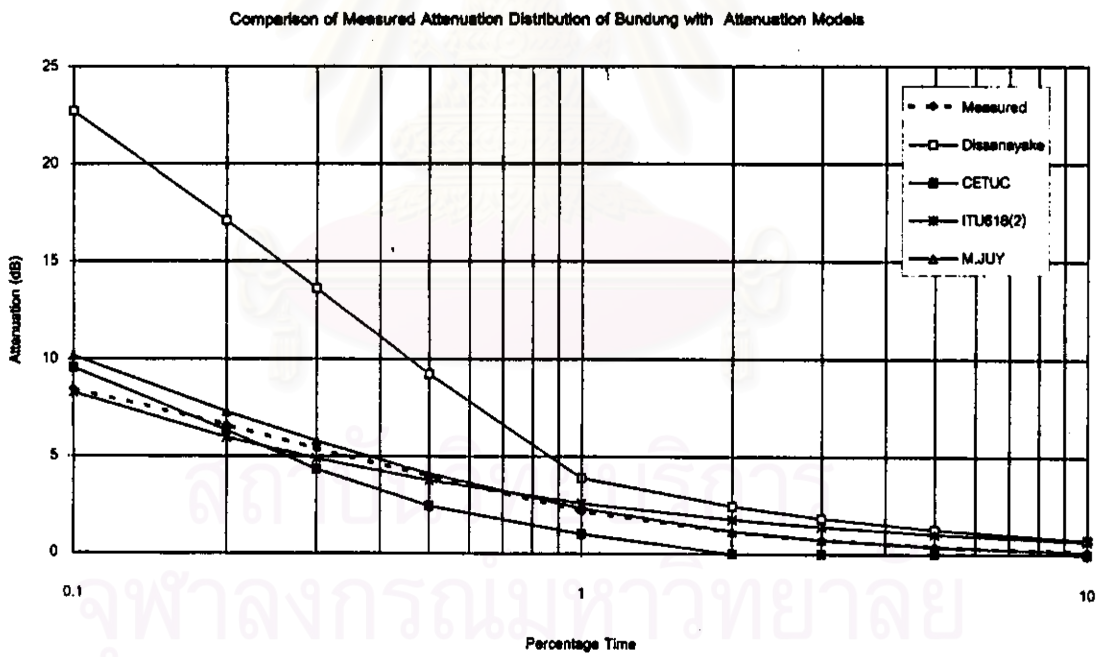

Figure 5.15 Comparison of measured attenuation distribution of Bundung with attenuation models.

No available model is well predicted to the rain attenuation in Southeast Asia especially when operating at low elevation angle. One estimation could be concluded that all models are developed from a single raincell, but the low elevation angle operation introduces more than a single raincell and it affects to rain attenuation statistics.

5.8 Concluding Remarks

In this chapter, various analysis of rain attenuation were presented. It can be concluded that rain attenuation at 12 GHz in Southeast Asia is relatively severed. No available statistical model is well representing the cumulative distribution of attenuation at four locations in Southeast Asia. The log-normal distribution presents some reasonable fits to the measured data lower than 10 dB, but it overestimates attenuation higher than 10 dB. The power-law distribution is found to be well fitted to the one-year cumulative distribution of high attenuation (3 - 30 dB) in Si-racha and Songkla. There is a small year-to-year variation on the annual attenuation distributions. The attenuation distribution in the ITU-R zone N varies with the seasons whereas the distribution in the ITU-R zone-P does not change with the seasons. Finally, attenuation prediction models were tested with the measured distributions, but no prediction model was well-fitted to the measured data.