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Investigation of the Unified Rain Attenuation Prediction Method With Data From Tropical Climates

A. Y. Abdulrahman, T. A. Rahman, Islam Md. Rafiqul, B. J. Olufeagba, T. A. Abdulrahman, J. Akanni, and S. A. Y. Amuda

Abstract—The semi-empirical method recently proposed by Silva Mello and Pontes (SMP) for the prediction of rain attenuation in slant paths is investigated in this letter. The SMP method uses the simplified model of equivalent rain cell and the concept of an effective rain rate. However, substantial deviations were observed in SMP predictions when compared to the rain cell diameters derived from experimental data. The measured rain rates and attenuations were obtained from three tropical climates (Australia, and USM and IIUM both in Malaysia). The measured rain attenuation complementary cumulative distributions (CCDs) were also compared to SMP and the Rec. ITU-R P. 618-11. The test results show that the ITU-R model performs much better compared to SMP method in the three tropical climates.

Index Terms—Correction factor, effective rain height, ITU-R 618-11, rain attenuation complementary cumulative distribution (CCD), rain cell diameter, Silva Mello and Pontes (SMP) method, tropical climates.

I. INTRODUCTION

A TRANSMITTED radio signal from GEO satellite to ground stations can be absorbed, depolarized, and scattered by rain at frequencies above 10 GHz [1]. These can cause signal attenuation, thereby reducing the reliability, availability, and performance of the communications link [1], [2]–[4]. The previous versions of the ITU-R model were originally based on data collected from temperate climates, and therefore did not perfectly predict rain attenuation complementary cumulative distribution (CCD) when applied to tropical and equatorial climates [5]–[7]. However, thunderstorms are more frequent in tropical and equatorial climates due to atmospheric instability caused by heat and moisture [5]. This has motivated

the campaign to collect rain attenuation data on slant paths in tropical and equatorial climates.

In the ITU-R methods, the attenuation is predicted using the measured rainfall rate $R_{0.01}$ exceeded at 0.01% as the principal input data. For other percentages of time, the attenuation is obtained using an extrapolation function. More so, a constant rain height is assumed in the Rec. ITU-R P. 839-3 [8], depending on the 0°C isotherm height above mean sea level. This assumption may result in inadequacy, as rain height actually varies with rainfall intensity in tropical and equatorial climates [1]. Detailed procedures for calculating slant path attenuation can be found in Rec. ITU-R P. 618-11 [9, pp. 5–7]. Some previous efforts to modify and improve accuracy of the ITU-R method can be found in [10] and [11].

The major aim of this letter is to compare the recently proposed Silva Mello and Pontes (SMP) method [10] to the latest version of the ITU-R method [9] in terms of performance accuracy using data from three tropical climates.

II. ANALYSIS

The slant path attenuation A_p (dB) exceeded at $p\%$ of time is given by

$$A_p = kR_p^\alpha L_{\text{eff}} \quad (1)$$

where L_{eff} (km) is the effective slant path, R_p (mm/h) is the rain rate exceeded at $p\%$ of time, and k and α are parameters whose values can be obtained from the ITU-R 838-3 [12], depending on frequency and wave polarization. Note that L_{eff} can be written in terms of effective rain height H_R (km), station mean altitude above the sea level H_S (km), slant path L_S (km), and link elevation θ (degrees) as follows:

$$L_{\text{eff}} = L_S \cdot r_h = \frac{H_R - H_S}{\sin \theta} \cdot r_h. \quad (2)$$

The reduction factor r_h accounts for the nonuniformity of the rain rate in the horizontal direction, while H_R accounts for the effects of the nonuniform vertical structure of rainfall. As earlier mentioned, a constant H_R is assumed in the ITU-R method, i.e., $H_R = 0.36 + H_0$; whereas in reality, H_R varies with rainfall rate, as expressed in the following equation [10]:

$$H_R = 4.5 + 0.0005 R^{1.65}. \quad (3)$$

L_{eff} and r_h were computed from the experimental data using (1) as follows:

$$L_{\text{eff}} = \frac{A_p}{kR_p^\alpha}. \quad (4)$$

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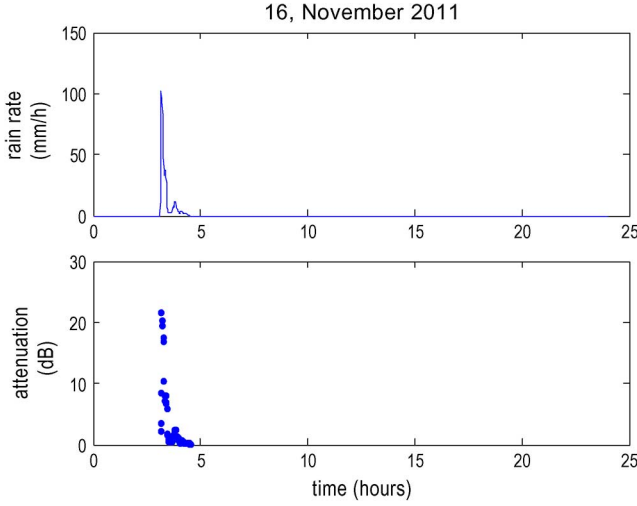


Fig. 1. Correlation of rainfall rate and attenuation time series.

Therefore

$$r_h = \frac{L_{\text{eff}}}{L_S}. \quad (5)$$

According to the SMP method, r_h can be simplified to [10]

$$r'_h = \frac{1}{1 + L_0 \cos \theta / L_0} \quad (6)$$

where

$$L_0 = 119 R_p^{-0.244}. \quad (7)$$

L_0 represents the effective real rain cell diameter in kilometers, and it may be extracted from experimental data by combining (5) and (6) as follows:

$$L'_0 = \frac{L_S \cos \theta}{1r - 1}. \quad (8)$$

The effective rain rate was also computed according to the following expression [2]:

$$R_{\text{eff}} = \left(\frac{A_p}{k L_{\text{eff}}} \right)^{1/\alpha}. \quad (9)$$

III. RESULTS AND DISCUSSIONS

The long-term rain rate CCDs and attenuation measurement data used for Darwin, Australia, Universiti Sains Malaysia (USM), and Islamic International University of Malaysia (IIUM) were extracted from published results reported in [5], [6], and [13], respectively. For the measurements conducted at IIUM, the monitoring signal is 20.5 dB above noise floor level during clear-sky events as indicated by the spectrum analyzer. This corresponds to nearly 0.01% of the time. The sampling rate is one sample every 10 s (i.e., 10-s intervals) and averaged about 1 min. The analyzer could not monitor the signal level at heavy rain rates (>100 mm/h), as the noise level became so high and masked the received signal. In this kind of climate, a huge receiver margin is required, which

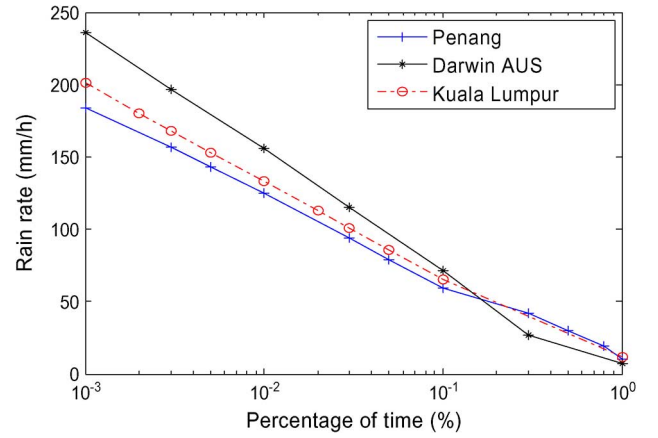


Fig. 2. Rain rate CCDs.

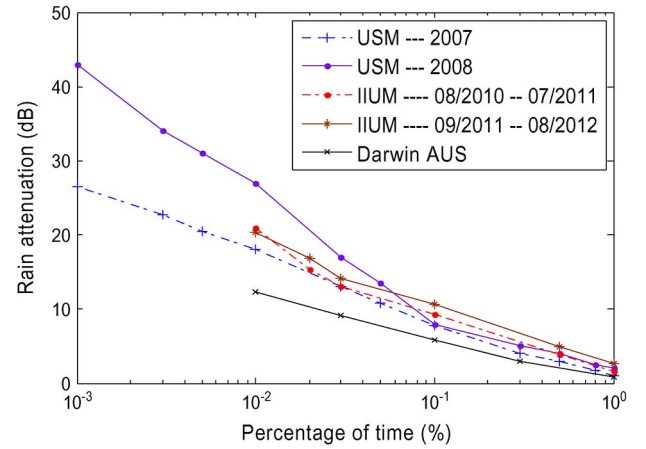


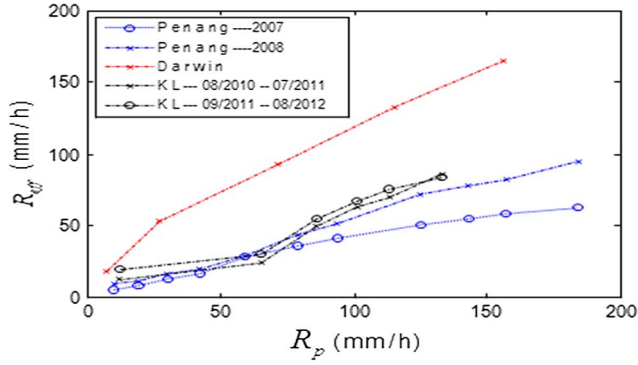
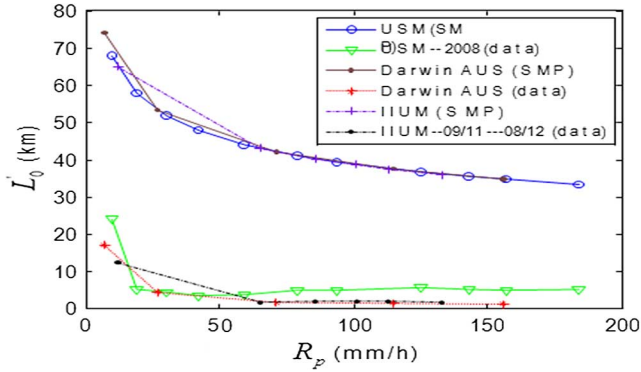
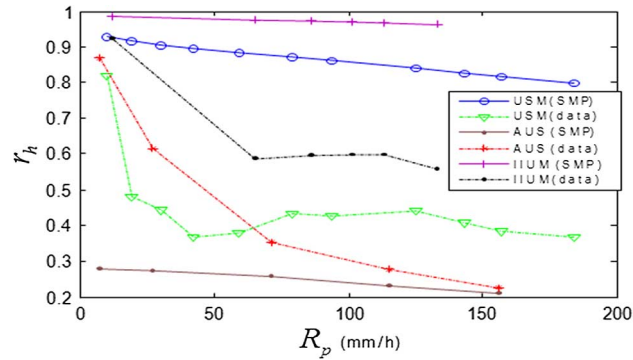
Fig. 3. Rain attenuation CCDs.

TABLE I
SITE PROPAGATION CHARACTERISTICS

Site	IIUM, Kuala Lumpur, Malaysia	USM, Penang, Malaysia	Darwin Australia
Longitude	101.7° E	100.4° E	130.83° E
Latitude	3.3° N	5.17° N	12.4° S
Altitude (m)	22.0	57.0	30.0
Elevation (V)	77.4°	40.1°	60.0°
Frequency (GHz)	10.982	12.255	11.1

is very difficult to obtain by using a spectrum analyzer. For this reason, the attenuations at percentages of time ($<0.01\%$) could not be measured in this study. Raining events are determined manually based on 0.2-mm tipping bucket rain gauge data, which is time-synchronized with an attenuation data logging system.

Details of the experimental setup are available in [13]. As an example, the correlation of rainfall rate and rain attenuation time series for one rainy day is presented in Fig. 1. The site propagation characteristics are also shown in Table I. The long-term measured rain rate CCDs for USM, AUS, and IIUM are shown in Fig. 2, while those of measured attenuation are shown in Fig. 3.

Fig. 4. Plots of R_{eff} against measured R_p .Fig. 5. Plots of L'_0 versus R_p .Fig. 6. Plots of r_h against R_p .

The effective rain rate is first computed and compared to measured rain rate as shown in Fig. 4. L'_0 , r_h , and L_{eff} are empirically derived from experimental data depending on the long-term point rainfall rate measured in the region. These results are then compared to those predicted by the SMP method, as shown in Figs. 5 and 6, respectively. More so, the corresponding plots of correction factors (r'_h) against the effective real rain cell diameters (L'_0) are compared and presented in Fig. 7.

The comparisons of measured attenuation CCDs to the predictions of SMP and ITU-R methods are shown in Figs. 9–11 for USM, AUS, and IIUM, respectively. The overall expression given by Silva Mello and Pontes [see (11)] [10] was used to compute the attenuation CCDs for all the three stations.

For USM (as shown in Fig. 9), the ITU-R predictions matched measurements perfectly for nearly all %p, while

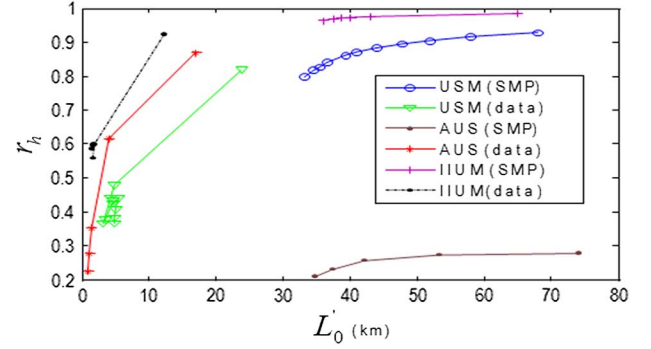
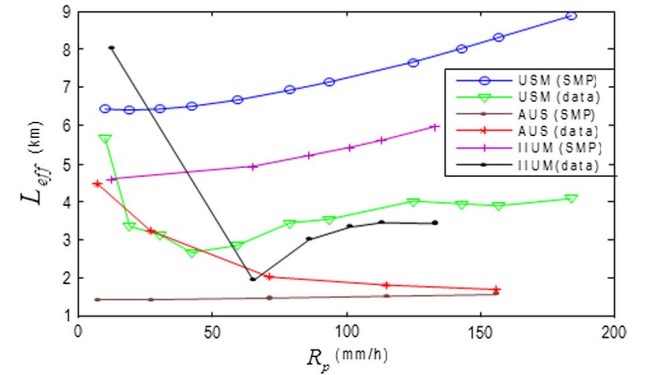
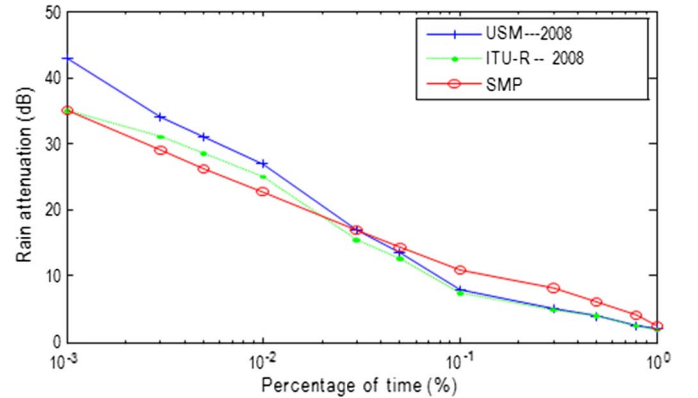
Fig. 7. Plots of r_h against L'_0 .Fig. 8. Plots of L_{eff} versus R_p .

Fig. 9. Comparison of rain attenuation CCDs for USM.

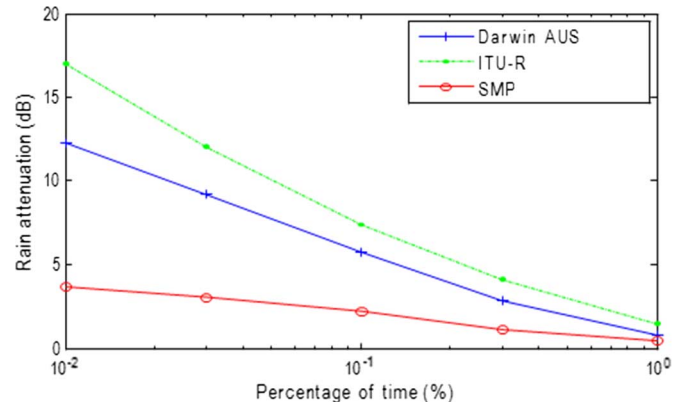


Fig. 10. Comparison of rain attenuation CCDs for Darwin.

TABLE II
ERROR, MEAN, STANDARD DEVIATION, AND % RMS VALUES FOR EACH PERCENTAGE OF TIME

Prediction models	Exceedance probability (%)						μ_V	σ_V	% ρ_V
	0.01	0.03	0.1	0.3	0.5	1.0			
ITU-R P. 618-11	-0.0411	-0.1233	-0.1457	-0.0073	-0.0072	-0.0061	-0.0551	0.1109	5.16
SMP	-0.6789	-0.1795	-0.0859	0.0055	0.0028	0.0035	-0.1554	0.2550	19.42

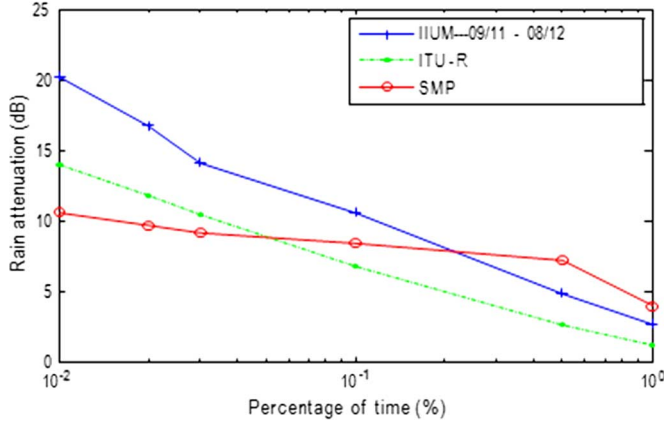


Fig. 11. Comparison of rain attenuation CCDs for IIUM.

underestimating the measured attenuation at $p < 0.05$. The SMP method overestimated measurements at low rain rates, while underestimating them at $p < 0.03\%$. When $p = 0.03\%$, the two methods predicted approximately 17.0 dB, which perfectly matched the measured attenuation. For Darwin, the ITU-R predictions overestimated measurements, while SMP method underestimated them for all $\%p$ as shown in Fig. 10. For IIUM, the ITU-R predictions underestimated measurements for all $\%p$, while SMP method overestimated measurements at $p > 0.5\%$ and underestimated them at $p < 0.1\%$ as shown in Fig. 11. The performance of each of the prediction models is also tested against measured attenuation using the Rec. ITU-R P. 311-13 [14] as presented in Table II. The ratio of predicted attenuation, A_p (dB) to measured attenuation A_m (dB) is

$$S_i = \frac{A_p}{A_m}. \quad (10)$$

The test variable is

$$V_i = \begin{cases} \ln S_i \left(\frac{A_m}{10} \right)^{0.2}, & \text{for } < 10 \text{ dB} \\ \ln S_i, & \text{for } \geq 10 \text{ dB.} \end{cases} \quad (11)$$

The mean μ_V , standard deviation σ_V , and root mean square (RMS) value ρ_V of the test variables (V_i values) for each percentage of time are presented in Table II

$$\rho_V = (\mu_V^2 + \sigma_V^2)^{\frac{1}{2}} \quad (12)$$

SMP method gave the higher values of the test variables for most of $\%p$. The ITU-R method gave the lower mean and RMS errors (being -0.0551 and 5.16% , respectively).

IV. CONCLUSION

The performances of the recently proposed SMP method for the prediction of rain attenuation in slant paths have been investigated and compared to the latest version of the ITU-R method using data from three tropical climates. The test results have shown that the ITU-R seems to yield accurate predictions, compared to SMP method in the three tropical climates. These results further support the tests on the DBSG3 database. Substantial deviations observed in the SMP method might be due to the year-to-year variability in the rain attenuation statistics.

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