Rain Attenuation Factor in the Earth-Space Links of Tropical Regions

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***Abstract*— Rain attenuation is an important factor to be considered in the Earth-space communication link budget, especially for regions that receive heavy rainfall, e.g. tropical regions. Inaccurate estimation of rain attenuation may result in broken or intermittent Earth-space links. The estimation of rain attenuation depends on many other factors. One of the important ones is the height from sea level within which raindrops is assumed present, i.e. *rain height*. International Telecommunications Union (ITU) recommends the ITU-R P.839-4 (09-2013) method for predicting rain height, and the ITU-R P.618-13 (12-2017) method for determining rain attenuation. Recently, some works claimed inaccuracy of these methods in the tropical regions, and proposed some modified methods. This paper aims to clarify the doubts. We determine the possible causes of inaccuracy, and then assess the impact of inaccurate estimation of rain height onto rain attenuation. As compared to the modified methods, we found that the rain height values calculated from ITU-R P.839-4 make more sense. It is likely that incorrectly represented formulas were used in some related works. Moreover, rain attenuation values obtained from ITU-R P.618-13 are resilient to the changes in rain heights. As a result, we advocate the use of the ITU-R P.839-4 and ITU-R P.618-13 methods in the tropical regions.**

***Index Terms*— Attenuation; Radio Propagation; Radio Propagation Meteorological Factors; Rain.**

I. INTRODUCTION

Climate change poses a serious threat to the world, bringing catastrophes to modern civilizations. Modern infrastructures like telecommunication systems are seriously affected. Unpredicted thunderstorms and heavy rains severely impair the qualities of terrestrial and Earth-space telecommunication systems, especially in tropical regions that receive heavy rainfall. Rain attenuation refers to the propagation loss on an Earth-space path due to rain. It is an important parameter in the calculation of Earth-space link budget. Due to the lack of recent and updated measurement data, rain attenuation needs to be predicted and modeled accurately. The discrepancy between the predicted and actual values may be costly to the Earth-space link budget calculation.

The International Telecommunications Union (ITU) recommends the following methods for incorporating rain attenuation in the link budget calculation.

1. **Recommendation ITU-R P.618-13 (12-2017)** documents the propagation data and prediction methods required for the design of Earth-space communication systems [1]. It provides an estimate of the long-term statistics of rain attenuation. To be specific, it calculates the predicted attenuation exceeded for 0.01% of an average year, $A_{0.01}$ dB. This Recommendation itself relies on the use of the following methods.
2. **Recommendation ITU-R P.837-7 (06-2017)** gives the characteristics of precipitation for propagation modeling [2]. To be specific, this method is used for obtaining the rainfall rate ($R_{0.01}$) exceeded for 0.01% of an average year. Such data varies with latitudes and longitudes.
3. **Recommendation ITU-R P.838-3 (03-2005)** gives specific rain attenuation model for use in prediction methods [3]. To be specific, it provides the frequency-dependent coefficients to be used in calculating the specific attenuation, γ_R.
4. **Recommendation ITU-R P.839-4 (09-2013)** gives the rain height model for prediction methods [4]. Rain height is defined as the height from sea level within which raindrops is assumed present.

Recently the accuracy of rain attenuation predicted using the Recommendation ITU-R P.618 has been questioned [5-8]. In predicting rain attenuation, the first step is to determine the rain height [1]. The rain height, followed by rain attenuation, was regarded as an underestimation in [5]. The actual rain height was considered to be higher [6]. But there were conflicting reports [7-8], which claimed that there were overestimations in both rain height and attenuation. This creates confusion that requires further investigation and clarification.

On the other hand, different methods of predicting rain height have been presented, e.g. radiosonde [5], space borne precipitation radar [6-9], ground radar [8, 10], etc., each claimed to be of high accuracy. They resulted in different rain heights. We critically review these studies to (1) find out if there is a better alternative to the ITU-R P.839-4 (09-2013) method [4], and (2) assess the impact of different rain heights on the accuracy of rain attenuation. Our findings show that: (1) It is unnecessary to come up with a different rain attenuation model that is meant for tropical regions. The ITU methods should apply well for these regions. (2) The impact of rain height on the estimation of rain attenuation has been exaggerated. Inaccurate estimation of rain height does not result in large variation of rain attenuation value.

The rest of the paper is organized as follows. Section II discusses various "rain heights" that are available in the literature, and the methods of predicting it. Section III discusses the validities of rain attenuation models presented in Recommendation ITU-R P.618-13 (12-2017) and [5]. In Section IV, we investigate the extent of which rain height affects the calculated rain attenuation value. Finally, we conclude our findings in Section V.

II. RAIN HEIGHT

In this section, we list down the various methods used to determine rain height.

A. Recommendation ITU-R P.839-4 (09-2013) [4]

According to [4], the mean annual rain height above mean sea level, h_R, is given by

$$h_R = h_0 + 0.36 \text{ km}, \quad (1)$$

h_0 is the mean annual 0°C isotherm height above mean sea level (i.e. altitude at which the temperature of the atmosphere is 0°C). h_0 is available as part of the Recommendation. The resolution of the data is 1.5° latitude by 1.5° longitude.

B. Radiosonde Observations [5]

An alternative method of determining h_R is based on the radiosonde data collected by the National Oceanic and Atmospheric Administration (NOAA) / Earth System Research Laboratory (ESRL) [5]. Since a different form of data was collected, an alternative method of determining h_R was presented in [5]. The calculated h_R values were actually higher (as shown in Table 4 of [5]).

C. Tropical Rainfall Measuring Mission (TRMM) [6-9]

The TRMM satellite was launched in 1997. A precipitation radar (PR) onboard detects the *bright-band* layer which gives the highest reflectivity to the radar. The bright-band height, h_{BB}, was considered to be 200 to 300 m below h_0 [6]. In another report [9], 95% of the differences between h_0 and h_{BB} fell between 0 and 600 m, and the mean value was 304 m. This was consistent with that was documented in [6]. The TRMM PR data collected using the 2A23 algorithm for two years in Nigeria was analyzed in [7-8] to obtain h_{BB}. Again h_{BB} were reported to be lower than h_0.

D. Ground Radar [8, 10]

Instead of space borne radar, h_{BB} can also be determined using ground radar. For example in [8], a vertical pointing micro rain radar (MRR) was installed for the study. It covered a height up to 4.8 km, and the operating frequency was 24.1 GHz. They reported a close match between the h_{BB} results obtained using MRR and TRMM PR 2A23. In [10], a 3D bistatic ground radar was used. Similarly, h_{BB} were reported to be lower than h_0.

E. Comparison and Analysis of Rain Heights

h_{BB} is not equivalent to h_R. Some of the aforementioned methods determine only h_{BB} but not h_R. Both h_{BB} and h_0 vary with locations (local conditions) and seasons (dry and wet months). It is inappropriate to fix a difference value between the two. For example, it is inappropriate to assume that $h_0 = h_{BB} + 0.5$ km as in [6].

Predicting h_R worldwide requires global data as the inputs. It cannot rely only on studies conducted on some specific locations within specific periods. It has to be based on information collected from as many locations as possible, over a long period. As of now, Recommendation ITU-R P.839-4 (09-2013) [4] is perhaps the most reliable source.

Table 1 lists down the h_R values calculated using the ITU-R P.839-4 (09-2013) method [4] for five locations studied in [5], i.e. Universiti Sains Malaysia (USM), Malaysia; Institut Teknologi Bandung (ITB), Indonesia; King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand; Ateneo de Manila University (AdMU), Philippines; and University of South Pacific (USP), Fiji. The calculated h_R values are compared with those reported in [5], which are doubtful since it was the same value (4.86 km) for four different locations. Different h_R values calculated by ITU-R P.839-4 make more sense.

Table 1
h_R Values

Location	Calculated by ITU-R P.839-4 [4] (km)	Reported in [5] (km)
USM (5.17°N 100.4°E)	4.9544	4.86
ITB (6.5°S 107.4°E)	4.9693	4.86
KMITL (13.7°N 100.8°E)	5.0935	4.86
AdMU (14.7°N 121.1°E)	5.1179	4.86
USP (18.1°S 178.3°E)	4.8615	3.36

Note that the values of h_R vary with latitudes and longitudes. But [5] reported the same h_R value for four different geographical locations, which does not make sense. One possible cause is that inappropriate formula had been used. Those h_R values calculated using the ITU-R P.839-4 are more sensible.

h_0 and h_R vary with latitudes, longitudes, and seasons. One wonders about the impact of their variations on the estimation of rain attenuation. In Section IV, we investigated the impact of varied rain heights on rain attenuation. Before that, Section III briefly discussed the rain attenuation models.

III. RAIN ATTENUATION MODEL

Table 2
$R_{0.01}$, γ_R, $A_{0.01}$, Values

Parameters		USM	ITB	KMITL	AdMU	USP
Frequency (GHz)		12.255	12.247	12.74	12.255	11.6
Antenna elevation		40.1°	64.7°	54.8°	58.8°	68.7°
Earth station height above sea level (km)		0.057	0.700	0.040	0.080	0.017
Years of measuring $R_{0.01}$ and $A_{0.01}$		2007-2010	2002-2004	2004-2005	2000-2002	2002-2003
$R_{0.01}$ mm/h	ITU-R P.837-7	99.85	91.10	95.62	95.67	99.58
	Reported in [5]	127	122	90	98	58
γ_R dB/km	ITU-R P.618-13	5.42	4.63	5.33	4.96	4.64
	Reported in [5]	6.41	6.09	4.49	4.74	4.35
$A_{0.01}$ dB	ITU-R P.618-13	18.42	13.07	16.01	14.34	12.34
	Reported in [5]	23.5	18	12	18.1	9.2

"ITU-R P.837-7" refer to those values calculated using the ITU-R P.837-7 (06-2017) method.
"ITU-R P.618-13" refer to those values calculated using the ITU-R P.618-13 (12-2017) method.

The Recommendation ITU-R P.618-13 (12-2017), subsection 2.2.1.1 describes a method of calculating long-term rain attenuation statistics [1]. The important intermediate values found by the method are (1) the rainfall rate that exceeds for 0.01% of an average year, $R_{0.01}$ mm/h, and (2) the specific attenuation, γ_R dB/km. The ultimate values to be found are (1) the predicted attenuations exceeded for 0.01% and p% of an average year, denoted by $A_{0.01}$ and A_p dB respectively. Table II lists down these values found for the five sites in [5]. A comparison is then made with those values reported in [5].

In what follows, we explain the possible causes of discrepancies between the values calculated using the ITU methods and those reported in [5].

A. Possible Cause 1: Limitations of measured data

In [5], $R_{0.01}$ (mm/h) and $A_{0.01}$ (dB) were measured data collected in short periods. The longest is a 4-year period (2007-2010), whereas the shortest are only 2 years (2004-2005, 2002-2003). Measured data is not accessible to the public. Thus one cannot check their validity. Moreover, data collected over a short period may not reflect its long-term average. ITU-R P.837-7 (06-2017) recommends that local measurements that are used should be collected over a long period (typically more than 10 years) to ensure statistical stability. The values of $R_{0.01}$ (mm/h) are to be substituted into the formulas recommended in ITU-R P.618-13 (12-2017) in order to calculate $A_{0.01}$ (dB) and γ_R dB/km. Consequently, inaccurate $R_{0.01}$ (mm/h) will result in inaccurate $A_{0.01}$ (dB) and γ_R dB/km.

B. Possible Cause 2: Mistakes in the formulas used

[5] proposed a new rain attenuation model for tropical regions by modifying some of the formulas presented in the ITU-R P.618-13 (12-2017) documents, and reusing some of them. Some of the formulas used may have been inaccurately represented, because they were different from the original ones.

Equation (2) in [5] was incorrectly represented as follows,

$$v_{0.01} = \frac{1}{1+\sqrt{\sin\theta\left(31\left(1-e^{-(\theta/1+\chi)}\right)\left(\sqrt{L_R\gamma}/f^2\right)-0.45\right)}} \quad (2)$$

The correct one [1] should be

$$v_{0.01} = \frac{1}{1+\sqrt{\sin\theta}\left(31\left(1-e^{-(\theta/(1+\chi))}\right)\left(\sqrt{L_R\gamma}/f^2\right)-0.45\right)} \quad (3)$$

On the other hand, Equation (9) in [5] was incorrectly represented as

$$\gamma = k[R(\text{mm/h})]\alpha \quad (4)$$

The correct one [1] should be

$$\gamma_R = k[R_{0.01}(\text{mm/h})]^{\alpha} \quad (5)$$

With $R_{0.01}$ (mm/h) values different from those calculated by ITU-R P.837-7 being substituted into incorrectly represented formulas, the γ_R dB/km values presented in Table 3 of [5] were different from those calculated by ITU-R P.618-13.

The main motivation of [5] proposing an alternative rain attenuation model was the discrepancy between the results calculated using the ITU methods and the measured data. But, we found that the main reasons of discrepancy could attribute to (1) limited applicability of measured data, (2) inappropriate h_R values had been used, and (3) incorrect formulas had been used in calculating $A_{0.01}$ (dB) and γ_R dB/km.

Based on the results presented in Table 1, one cannot conclude that the ITU-R P.618-13 method gives underestimations for some sites, overestimations for others. One must bear in mind that the measurements reported in [5] were done a long time ago (more than ten years in some cases). New measurement results are unavailable. Old measurement data may become obsolete in the face of climate change. On the other hand, the ITU-R P.618-13 (12-2017) method [1] is found on the latest available and trustable data.

After taking into account of the aforementioned points, we concluded that it is unnecessary to propose an alternative rain attenuation model for tropical regions. The ITU recommended methods should work fine in these regions.

IV. Impact of Variation in Rain Height

Step 1 of the Recommendation ITU-R P.618-13 is to determine h_R, which varies with latitudes, longitudes, and seasons. When h_R varies, what is the impact on the calculated rain attenuation? In the following, we run a 'stress' test. Given certain magnitude of variation in h_R, we determine the amount of variation in $A_{0.01}$. For the five locations listed in [5], we vary the h_R values obtained from the ITU-R P.839-4 method by ±20%, and observe the corresponding variations in $A_{0.01}$. To exclude the effect given by different operating frequencies, we apply the same frequency, 12.255 GHz, for all 5 locations in the calculations. Figure 1 shows the results.

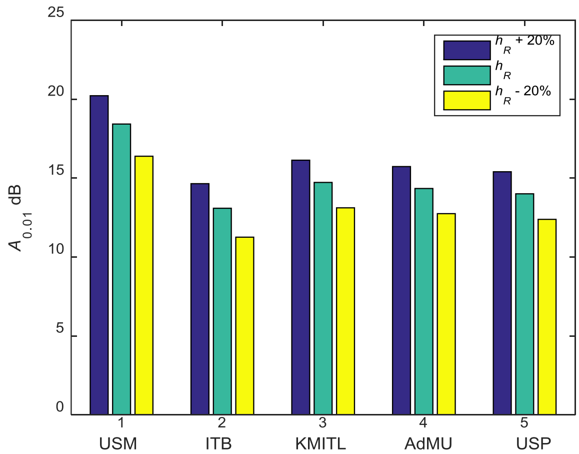

Figure 1: $A_{0.01}$ dB calculated for five different locations. h_R varies by ±20%

We found that the variations in $A_{0.01}$ are not as severe as expected. The magnitudes of variations are only between 9% and 14%, although h_R has varied by ±20%. We concluded that $A_{0.01}$ is not severely affected by inaccurate h_R. In real life, h_R varies with locations, seasons, and the methods used to estimate it. But in terms of determining the attenuation caused by rain, the impact of having varied h_R may not be as high as expected.

V. Conclusion

Rain attenuation is a critical impairment to the quality of Earth-space links, especially in tropical regions that have high precipitation. Rain related measurement data may only be available to the national meteorological departments but not the general public. Hence, modeling and estimating rain attenuation is very important, which relies on accurate predictions of many contributing parameters. One of the important ones is rain height. This paper has surveyed the recent works of determining rain height and rain attenuation, and made the following conclusions:

(1) Data measured over short periods has limited applicability.
(2) h_R values obtained from the ITU-R P.839-4 method make more sense than those presented in the literature.
(3) In some of the related works, there is a high probability that incorrectly represented formulas were used to determine rain related parameters.
(4) Rain attenuation values obtained from the ITU-R P.618-13 method are quite resilient to the changes in the h_R values. As a result, inaccurate estimation of h_R may not cause disastrous error in rain attenuation value.

Due to the lack of large-scale and recent measurement data to prove otherwise, we advocate that (1) Recommendation ITU-R P.839-4 (09-2013) [4] is the reliable method of predicting rain height, and (2) Recommendation ITU-R P.618-13 (12-2017) [1] is the reliable method of determining rain attenuation, even in the tropical regions. There is an additional merit to the ITU-R P.618-13 method, i.e. the rain attenuation value obtained is not severely affected by the variation in rain height. Thus, we need not be too worry about inaccurate estimation of rain height.

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