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Rain Height Statistics from Spaceborne Radar for Satellite Communication in Malaysia

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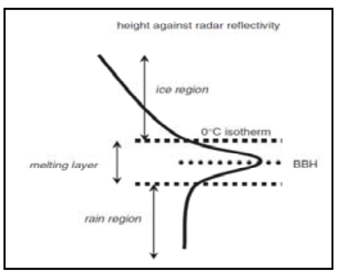

Abstract

Tropical and equatorial region exhibit significantly higher rainfall compared to the temperate region leading to higher attenuation for satellite communication links. One of the issues in radiowave propagation modeling is the different precipitation structures which play an important role in the estimation of rain fade. However, few results on rain height over Malaysian equatorial stations have been presented so far. To this aim, an investigation on rain height derived from Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) is carried out. In this paper, the bright-band heights (h_{BB}) have been analyzed to obtain monthly average values of the rain height (h_R). TRMM PR is one of the most powerful instruments able to observe vertical profiles of rainfall. The analysis covers stratiform events around peninsular Malaysia. It is well known that h_{BB}exists slightly below the 0°C isotherm height (h_0) and this may lead to the estimation of rain height (h_R). The obtained results on rain height are then compared with radiosonde observations and ITU-R Recommendation P.839-3. It is found that the bright-band height (h_{BB}) appears to vary throughout the year and will mostly lie between 4192 m and 4593 m above mean sea level. The results suggest that by carefully consider the physical information of rain height derived from the various local databases should lead to substantial improvements in the rain attenuation prediction accuracy for equatorial and tropical region.

Keywords: Rain height; bright-band height; 0°C isotherm height; TRMM PR; equatorial; tropical

■1.0 INTRODUCTION

Satellite communication links operating at frequencies above 10 GHz are affected immensely by hydrometeors such as rainfall**[1]**. Those effects become more extreme in the tropical and equatorial regions such as Malaysia as they exhibits significantly higher rainfall rate with regard to the temperate region. Therefore, information on attenuation due to rain is required in the design of earth-space links. To this aim, ITU-R recommendation provides a prediction model for long-term rain attenuation namely ITU-R P.618-10 [2]. Step by step calculation in ITU-R P.618-10 recommendation requires a number of meteorological parameters whereby one such parameter is rain height.

International Telecommunication Union (ITU) recommended a fixed value of rain height which currently estimated in relation to the 0°C isotherm level inferred from ITU-R P.839-3 for different climatology regions [3]. However, studies carried out by Mandeep [4] in Malaysia using radiosonde revealed that the 0°C isotherm height exhibits seasonal variations which shows the height of rain might vary throughout the year. In addition, rain height retrieved from ground precipitation radar near Malaysia (Singapore) was also deliberated previously by M. Thurai *et al*. [12]. It is worth mentioning that, apart from the instruments mentioned above can be employed to measure rain height, Tropical Rainfall Measuring Mission (TRMM) satellite appear as one of the alternative instrument that can be used to served such research requirement. Hence, it will be interesting to investigate the applicability of TRMM in rain height information retrieval, as well as cross validation of the radiosonde and ground radar performances.

In fact, Tropical Rainfall Measuring Mission (TRMM) satellite is considered one of the most powerful equipment for meteorological study in the tropics. The TRMM satellite is operative since 2007 and consists of five sensors on board which are Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible and Infrared Scanner (VIRS), Cloud and Earth Radiant Energy Sensor (CERES), and Lightning Imaging Sensor (LIS) [5]. The most important sensors on board TRMM satellite is Precipitation Radar (PR) where it is the first spaceborne radar that can directly observe vertical structure of rain [6].

The objectives of this paper are to analyze the variation of rain height in Malaysia throughout a year and to validate the rain height estimated from TRMM PR with measurement data from radiosonde observation and ground-based radar data.

The paper is organized as follows; Section 2 discusses on methodology where it describes the term rain height and provides rain type classification. It also explains on the parameter in relation to the rain height. Section 3 provides explanation on how analysis been carried out. Section 4 presents results and discussions on rain height variations and comparison with measurement data from radiosonde observation, ground-based radar and ITU-R Recommendation P.839-3 while Section 5 presents attenuation calculation based on ITU-R P.618-10 using different value of rain height. Finally, conclusion is drawn in Section 6.

■2.0 RAIN HEIGHT

The rain height differs based on climatic differences. It usually represents the boundary between rain region and snow region [7] and sometimes it is referred to the level at which water drop larger than 0.1 mm present [8]. The study of rain height determination is conducted by most researchers especially when involve with attenuation prediction.

Several ITU-R recommendations also use rain height as an input parameter in their step-by-step methods for evaluating the various impairments such as [7]:

1. ITU-R Recommendation P.618-10 (dealing with earth space attenuation).
2. ITU-R Recommendation P.452-14 (dealing with co-channel interference).
3. ITU-R Recommendation P.620-6 (dealing with co-ordination distances).
4. ITU-R Radio Regulation Appendix 7 (dealing with regulatory issues of co-ordination.

The physical rain height not necessarily the same as the effective rain height. It depends on the type of rain. According to Thurai *et al*. in **[7]**, stratiform rain may be assumed to extend up to 0^{o}C isotherm height. However, convective rain could extend more than the 0^{o}C isotherm height and sometimes reach more than 10 km due to strong updrafts. So, the estimation of effective rain height usually based on 0^{o}C isotherm height such as in ITU-R P.839-3. By this justification, in this paper, the effective rain height could be estimated from bright-band of stratiform rain as it clearly shows the boundary between water region and ice region.

2.1 Rain Type Classification

The classification of precipitation into stratiform or convective should lead to substantial improvements in the attenuation prediction accuracy, due to the different input parameters for the two precipitation types (typically rain height) **[9]**.

Chandrasekar *et al*. **[10]** explained on rain type classification algorithm used by TRMM PR. Two methods which are Vertical profile method (V-method) and Horizontal Pattern Method (H-method) are used. V-method detects the existence of bright-band while H-method examines the horizontal pattern of reflectivity at a given height. The algorithm is simplified as in Table 1. Further details of TRMM PR rain type algorithm are discussed in detail by J. Awaka *et al.* **[11]**.

Table 1 Simplified rain type classification algorithm

Method	Indication	Description
V-method	• Bright-band detected • Bright-band not detected and maximum Z exceeds 39dBZ	• Rain is classified as stratiform • Rain is classified as convective
H-method	• Maximum Z exceeds convective threshold • Others	• Rain is classified as convective • Rain is classified as stratiform

2.2 Bright-Band and 0^{o}C Isotherm Relation to the Rain Height

Bright-band and 0^{o}C isotherm often lie close to each other although both are indicating different parameter. As explained by M. Thurai *et al*. [12], bright-band can be detected through vertical profile of radar reflectivity. As shown in Figure 1, the occurrence of bright-band or melting layer is seen through peak value of radar reflectivity at certain height. It happens typically due to ice crystal melting into rain and it will only be detected during stratiform event [7, 10, 13]. The melting process usually started just below the 0^{o}C isotherm height. The height of maximum reflectivity will vary depending of region climatic [8].

M. Thurai *et al*. [7, 12, 14] has done various researches on the bright-band height. It is safe to assume that the bright-band height will depend on 0^{o}C isotherm height and vice versa [15]. 0^{o}C isotherm height usually lies about 200-300 m above the bright-band. It can be as high as 500 m as mentioned by J. Awaka *et al*. [13] and M. Thurai *et al*. [14]. ITU-R Recommendation P.839-3 provides yearly average data for 0^{o}C isotherm height to be used in the ITU-R Recommendation P.618-10. From the 0^{o}C isotherm height (h_0), the effective rain height (h_R) can be estimated by following equation [3]:

$$h_R = h_0 + 0.36 \text{ km} \tag{1}$$

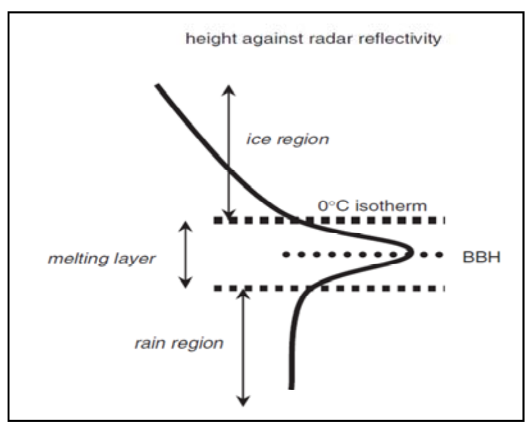

Figure 1 Typical radar reflectivity vertical profile [7]

The 0^{o}C isotherm height often used as a reference to estimate the height of rain. For example Ajayi *et al*. [8] study on variation of 0^{o}C isotherm height to evaluate the slant-path rain attenuation, while M. Thurai *et al*. [7] used information of 0^{o}C isotherm height to estimate co-channel interference. TRMM PR 2A23 algorithm also produce the estimated freezing level height which is the same as 0^{o}C isotherm height and the value can be extracted from 2A23 product data. Table 2 shows the 0^{o}C isotherm height from various researchers and sources:

Table 2 Estimated value of 0^{o}C isotherm height from various sources and locations

Source	Location	Estimated 0^{o}C isotherm height (km)
ITU-R P.839-3 **[3]**	Malaysia	4.5
TRMM PR 2A23	Malaysia	4.5-4.7
	Roma, Italy	2.71
Ajayi *et al*. **[8]**	Cordoba, Argentina	3.7
	Dar es Salaam, Tanzania	4.65
	Kuala Lumpur	4.9-5.2
Mandeep**[4]**		
	Melaka	4.6-5.0

■3.0 METHODOLOGY/DATA ANALYSIS

To achieve the objective of the paper, the research and analysis method is presented in this section. The dataset obtained in the year 2007 consisting of 8842 stratiform rain events, was processed to obtain the bright-band height. The bright-band height occurs only during stratiform rain and can be identified by the maximum value or peak in the radar reflectivity profile. From the knowledge of bright-band height, the 0^{o}C isotherm height can be estimated as it tends to be typically 500 m higher than the height of the bright-band. The derived bright-band and 0^{o}C isotherm height is then presented by monthly distribution and comparison is made with radiosonde observation, ground-based radar and ITU-R recommendation P.839-3.

In order to complement the analysis, Orbit Viewer THOR and MATLAB are another tools required. Orbit Viewer THOR is the software required to read and visualize data of HDF format. THOR is stand for "Tool for High-Resolution Observation Review. It was developed by National Aeronautics and Space Administration (NASA). In this work, Orbit Viewer THOR is used to extract data from TRMM PR 2A23 and 2A25 product data. The product data of TRMM PR 2A23 and 2A25 are downloaded from NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) Data Groups for Project TRMM and the data are presented by graphical method using MATLAB.

■4.0 RESULTS AND DISCUSSION

4.1 Bright-Band Height Inferred FromReflectivity Vertical Profile

It is shown earlier that the rain height can be estimated based on the bright-band height. To achieve this objective, data from TRMM PR 2A25 and 2A23 product data are extracted. Vertical profile of reflectivity during stratiform may be plotted using data from 2A25.

Figure 2 shows the example of reflectivity vertical profile from three stratiform rain events on 11th June 2007.

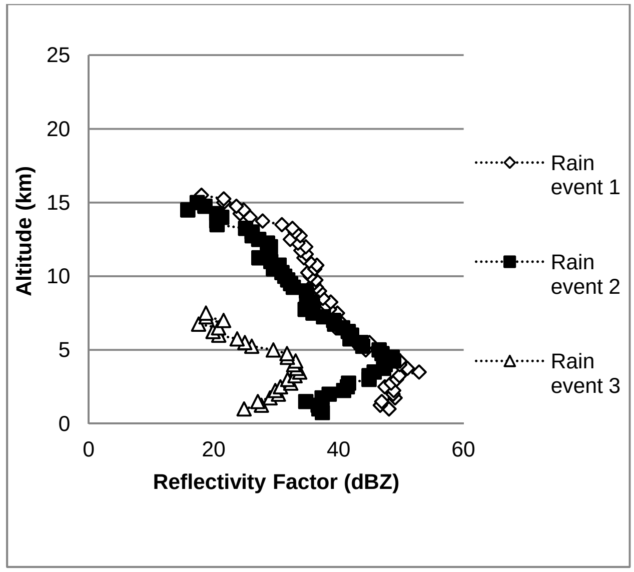

Figure 2 Reflectivity vertical profile for 3 events on 11th June 2007

Height of bright-band can be seen from Figure 2 which appears at altitude below 5km. However, to accurately estimate the bright-band height, a large number of events have to be considered. To this aim, TRMM 2A23 product data is used as the 2A23 algorithm already come up with estimation of the height of bright-band based on radar reflectivity. One year events of stratiform rain around Malaysia are considered from January 2007 to December 2007 with a total of 8842 events

4.2 Distribution of Bright-band over Malaysia

Based on Figure 3, average bright-band heights occur at altitude between 4192 m and 4593 m. Variation of bright-band height displays monthly basis. It also shows that the lowest height occurs during January and September which are the end month of Northeast and Southwest monsoon respectively. These results also suggest the seasonal dependence effect to the bright-band height.

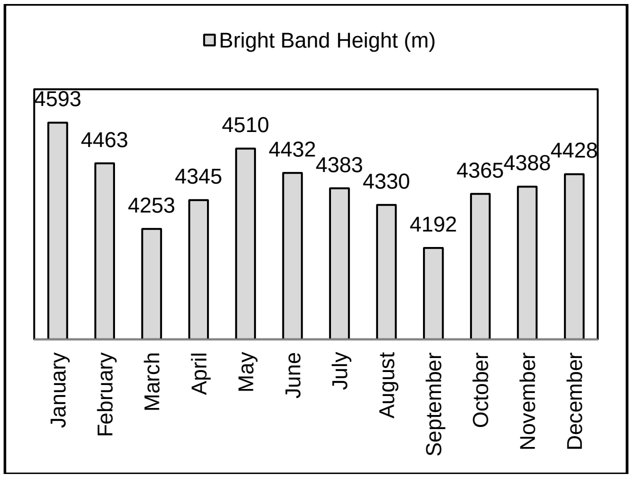

Figure 3 Monthly average variation of bright-band height

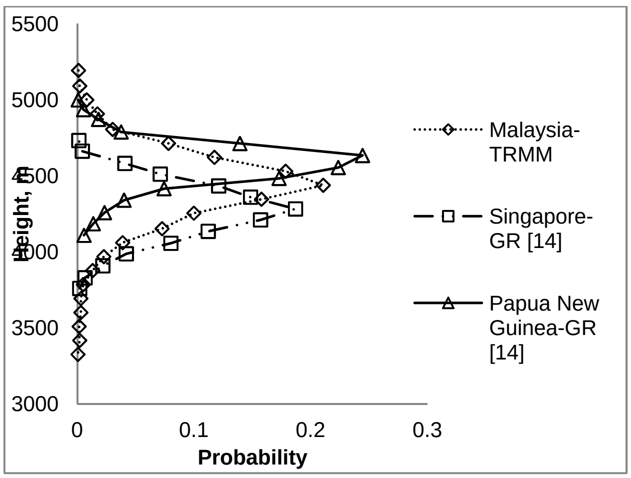

Figure 4 Comparison of bright-band height distribution from TRMM PR (in Malaysia) and ground-based radar data (in Singapore and Papua New Guinea)

Figure 4 shows that the bright-band height distribution in Malaysia, Singapore and Papua New Guinea mostly laid between 4000 m and 5000 m above mean sea level. Note that distribution of bright-band height in Malaysia is taken from TRMM PR measurement while Singapore and Papua New Guinea are using ground-based radar observation. Although the measurements are taken using independent equipment, it shows almost similar pattern of distribution. These results have validated the measurement of bright-band height by TRMM PR and vice versa.

4.3 Comparison of Monthly Average 0^{o}C Isotherm Heights

Figure 5 shows the comparison of 0^{o}C isotherm height from TRMM PR with measurement data from radiosonde observation and ITU-R P.839-3. The 0^{o}C isotherm height by TRMM PR is computed by assuming that it lies 500 m above the bright-band [13, 14]. Measurement data from radiosonde**[4]** are taken at 3 different locations; Kuala Lumpur, Terengganu and Melaka. Based on the result in Figure 5, the 0^{o}C isotherm height will also vary on monthly basis. Result from TRMM PR shows almost similar pattern with that of radiosonde measurement. In term of validation, these results show good agreement to each other even though the measurements are taken using two independent equipments. Furthermore, it shows that the bright-band height not only vary by monthly basis, but also locally. This result shows that different location may result in the different bright-band height. So, it suggests that locally measurement on rain height to determine the attenuation is highly required.

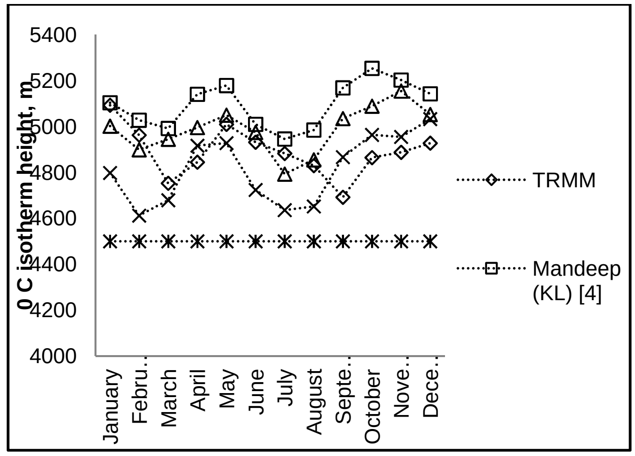

Figure Annual distribution of monthly average 0^{o}C isotherm heights from TRMM PR, radiosonde measurement and ITU-R P.839-3

5.0 ATTENUATION PREDICTION EXCEEDED FOR 0.01% OF AN AVERAGE YEAR

ITU-R P.618-10 provides a step by step method to estimate the predicted attenuation exceeded for 0.01% of an average year. The effective rain height recommended is from ITU-R P.839-3. The effective rain height will be varying to see the effect to the attenuation prediction. For this case, the effective rain height will be computed from the value of bright-band based on the result and discussion about the bright-band height above. Calculation is carried out based on MEASAT 3 satellite downlink. Table 3 shows the parameter used for the calculation.

Table 3 Parameters for rain attenuation calculation

Parameter	Value
Latitude of the earth station, □	1.48^o
Altitude of the earth station, h_s	0.03 km
Point rainfall rate for 0.01% of an average year, $R_{0.01}$	120 mm/h
Elevation angle, □	75.52^o
Frequency, f (GHz)	12GHz
Polarization angle, ζ	0^o

Calculation of 0.01% attenuation exceeded is computed using MATLAB and the value of effective rain height is varying based on bright-band height in the range between 4 km until 5 km. So, from Eq. (1) the effective rain height will vary from 4.86 km up to 5.86 km (calculation based on assumption that 0^{o}C isotherm height lies 500 m above the bright-band). Table 4 shows the calculated value of 0.01% rain attenuation exceeded for several value of rain height between the considered ranges.

The purpose of these calculations is to show the effect of rain height to the estimation of rain attenuation. Based on the result, the difference of attenuation may reach up to 1.85 dB if the difference of rain height is 1 km. These calculations clearly suggest how important it is to accurately estimate the rain height for attenuation prediction in the design of satellite communication system.

Table 4 Attenuation for 0.01% exceeded of a year

Rain height (km)	Attenuation for 0.01% exceeded (dB)
4.86	17.29
5.0	17.57
5.3	18.13
5.6	18.68
5.86	19.14

■6.0 CONCLUSION

The statistics of rain height over Malaysian equatorial station derived from spaceborne radar have been presented. Good agreement is obtained between TRMM PR measurement and radiosonde observation and also between TRMM PR and ground-based radar. The results show variability of the rain height on monthly basis throughout a year and also locally dependent. Variation of rain height demonstrated to affect the attenuation statistics prediction using ITU-R P.618-10.

Furthermore, rain height values estimated from ITU-R P.839-3, if compared to the height measured by the TRMM satellite and radiosonde observation will cause an underestimation of the attenuation prediction in Malaysia. Therefore, accurate information of rain height can significantly improve the reliability of the attenuation estimation, especially for tropical/equatorial regions.This information could be very useful for high speed broadband applications using satellite where high availability system is required. However, further studies are required for detail understanding on the behaviour of the rain height. For future improvement, study on rain height could be focused on the variability by diurnal, rain type and/or rainfall rate.

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