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Modelling of rain decay parameter for attenuation estimation at a tropical location

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Abstract

Owing to the wide rain variability of the tropical region, the Simple Attenuation Model (SAM) estimated rain attenuation values are often found to exhibit substantial deviation from the actual measurements over the location, Kolkata (22°34′N, 88°22′E). This is due to the variability in rain cell sizes resulting from the diverse rain characteristics of the region. Thus, an attempt has been made to model the rain decay parameter in SAM on the basis of the tropical rain characteristics. A model of rain decay parameter in terms of rain rate is proposed which accounts for different types of rain at the present location. The incorporation of the model of decay parameter provides a better estimation of rain attenuation than the existing SAM and ITU-R model.

Keywords: Simple Attenuation Model; Rain decay parameter; Rain attenuation; Tropical region

1. Introduction

The troposphere, being the lowermost layer of the atmosphere, introduces significant signal impairments in earth-space propagation of radio wave signals at frequencies above 10 GHz (Crane, 1996; Ippolito, 1986). The study of the tropospheric propagation characteristics can be utilized for channel modelling of Ka-band or higher frequency bands in view of the future development of radio-wave communication systems. Rain attenuation is the most dominant propagation effect, causing signal degradation in microwave and millimeter wave bands. The tropical region experiences intense raining conditions prevailing both in pre-monsoon and monsoon months with diverse rain structure and distinguishable rain characteristics. The rain attenuation, that often leads to significant signal fading, has been studied under different rain conditions at the present tropical location Kolkata (22°34′N, 88°22′E) (Maitra et al., 2007, 2009; Chakravarty and Maitra, 2010; Adhikari et al., 2011; Maitra et al., 2012; Bhattacharya et al., 2013; De et al., 2016). This type of situation calls for proper fade mitigation technique based on the tropical rain characteristics. Most of the available rain attenuation prediction models like ITU-R, SAM (Simple Attenuation Model), Global Crane Model and DAH (Dissanayake, Allnutt, Haidara) models (ITU-R P.618-12, 2015; Crane, 1982; Dissanayake et al., 1997) exhibit significant deviations while estimating tropical fade margin (Chakravarty and Maitra, 2010; Suryana et al., 2005; Maitra and Chakravarty, 2005). Thus the existing models require some modifications in view of the distinct tropical rain characteristics. Various studies of rain structure has been done by utilizing space borne and ground based measurements manifesting distinct rain characteristics prevailing at the tropical region (Das et al., 2010; Das and Maitra, 2016;

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Schumacher and Houze, 2003; Rakshit and Maitra, 2016). Moreover, it is easier to have rain records rather than having propagation measurements at a location. The present study demonstrated a method of rain attenuation estimation at a tropical location utilizing ground-based rain rate measurements. SAM is an effective model for predicting rain attenuation in the tropical region, which utilizes point rainfall rate, decay parameter and elevation angle of the earth-space path. However, SAM often overestimates the rain attenuation at the present tropical location (Adhikari and Maitra, 2011; Maitra et al., 2012). One of the major concerns in this regard is the characterization of the rain-cell size in tropical regions, which particularly varies with rain rate and type (Goldhirsh, 1983). In the present study, the rain decay parameter has been modelled in terms of rain rate under varying rain conditions. The model of the decay parameter is incorporated in SAM to estimate rain attenuation from rain rate measurements. The estimated attenuation is compared to the actual measurements to indicate the efficacy of the model.

2. Experimental set-up

The Ku-band satellite signal of frequency 11.172 GHz has been continuously monitored from the geostationary satellite, NSS-6, at the University of Calcutta, Kolkata (Maitra et al., 2006; Maitra and Chakravarty, 2009; Chakravarty and Maitra, 2010; Adhikari and Maitra, 2011, Adhikari et al., 2011). The horizontally polarized Ku-band satellite signal is first received with an offset parabolic antenna of 60 cm diameter and then down-converted to an L-band signal. The L-band signal of frequency 1.4215 GHz is subsequently fed into a spectrum analyzer having a post-detection bandwidth of 10 Hz. A data logger stores the video filter output of the spectrum analyzer with a sampling rate of 1 Hz. An optical rain gauge (ORG), collocated with the Ku-band receiving system, measures the ground-based rain rate with a time constant of 10 s. However, to explore the fine structures of rain, the output of ORG is sampled at 1 s interval. The performance specifications of ORG are summarized in the Table 1.

In this study, the Ku-band propagation data and the rain rate data pertaining to the period of 2008–2009 have been utilized to propose the rain attenuation model. The proposed model is validated with the data of the year 2010.

Table 1
ORG specifications.

Performance specification	Digital output
Rain dynamic range	0.1–500 mm/h
Rain accumulation	0.001–999.999 mm
Rain accuracy	5% accumulation
Rain resolution	0.001 mm
Time constant	10 s

3. Theoretical background

The focus of the present study is to obtain a model of rain decay parameter of SAM on the basis of the tropical rain characteristics. The model yielded results are further compared with the existing SAM and ITU-R model estimated values. A theoretical backgrounds of SAM and ITU-R rain attenuation model are given in the following sub-sections.

3.1. Simple Attenuation Model (SAM)

The Simple Attenuation Model (SAM) (Stutzman and Dishman, 1982; Stutzman and Yon, 1986), a well-known model for attenuation prediction, utilizes the point rainfall rate (R_0) at the ground to calculate the attenuation time series. According to SAM, the rain rate profile can be given by:

$$R(z) = R_0 \quad R_0 \leqslant 10 \text{ mm/h} \tag{1}$$

$$R(z) = R_0 \exp[-\Gamma \ln(R_0/10)z] \quad R_0 > 10 \text{ mm/h} \tag{2}$$

where z is the horizontal distance along the path and Γ is the decay parameter controlling the rate of decay of the rain profile. Thus, the decay parameter can be defined as the rate at which the point rain rate of a location is decaying with increasing radial distance on either side of the rain cell from the study location (Stutzman and Dishman, 1982).

According to the model the effective rain height is given by the relations:

$$H_r = H_0 \quad \text{for} \quad R_0 \leqslant 10 \text{ mm/h} \tag{3a}$$

$$H_r = H_0 + \log(R_0/10) \text{ km} \quad \text{for } R_0 \geqslant 10 \text{ mm/h} \tag{3b}$$

Thus, the slant-path length within the rain cell is:

$$L_s = \frac{H_r - H_0}{\sin\theta} \tag{4}$$

Here, H_0 is the 0° isotherm height of the present location. As revealed from the local radiosonde data, H_0 is taken as 5 km and the total attenuation can be obtained from the point rainfall rate R_0 using the following expressions:

$$A = \gamma L_S \quad \text{for} \quad R_0 \leqslant 10 \text{ mm/h} \tag{5}$$

$$A = \gamma \left[\frac{1 - \exp[-\alpha\Gamma \ln(R_0/10) L_S \cos\theta]}{\alpha\Gamma \ln(R_0/10)\cos\theta}\right] \text{ for } R_0 \geqslant 10 \text{ mm/h} \tag{6}$$

where L_S is the slant path length and $\gamma = kR_0^\alpha$ is the specific attenuation due to the rain rate R_0, Γ is the rain decay parameter and θ is the elevation angle of the earth-space path. Now, if attenuation A and point rain rate R_0 can be measured, the rain decay parameter (Γ) can be obtained by numerically finding the roots of relation (6).

3.2. ITU-R model

The rain height (H_r) and the rain cell dimensions are some important parameters in estimating rain attenuation

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