Studies on Rain Structure Based on Ground Based Dropsize Distribution and Rain Attenuation Measurements over an Earth Space Path

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Abstract

The drop size distribution (DSD) of rain in tropical region shows the characteristic features of different types of rain, namely, stratiform, transitional and convective. This is also indicated in behaviors of the rain decay parameter, obtained from the measurements of rain rate and attenuation over an earth-space path. The DSD parameters and rain decay parameter give similar clustering indicating the feature of convective and stratiform rain. To predict rain attenuation from rain rate, the decay parameter is modeled for different rain rate regions that provides a good matching between the predicted and measured values.

1. Introduction

The rain structures, both in horizontal and vertical direction, vary in a complex manner and play an important role in determining the types of rain at tropical locations. Also, to understand the micro structure of rain, it is necessary to have the knowledge of the variation of rain drop size distribution (DSD) during rain events. DSDs are usually modeled in terms of three-parameter functions namely, gamma and log-normal distribution. The variations of the distribution parameters with rain rate can indicate the type of rain during rain events [1, 2].

On the other hand, the prediction of rain attenuation over an earth-space path has remained a major issue in implementing the fade mitigation technique for the satellite signal. It is convenient to consider the Simple Attenuation Model (SAM) [3] to estimate rain attenuation over an earth-space path from the ground based rain rate information. In this model the horizontal structure of rain is indicated through an exponential relation of rain rate with rain rate decay parameter. However, the relation of the decay parameter with rain rate varies with the rain type. In the tropical region, even during a single rain event, the type of rain can vary from convective to stratiform for which we have to consider the different models of the rain decay parameter.

In this paper, disdrometer measurements are utilized to study the evolution of the DSD spectrum at the ground level. Also, the rain attenuation measurements of Ku-band signal over earth-space path have been utilized to indicate the horizontal extent of the rain cell. The information of the rain rate decay parameter is used to predict the rain attenuation over an earth-space path.

2. Data

A Joss-type disdrometer (model: Distromet RD-80) has been used to measure DSD at Kolkata (22°34' N, 88°29' E), India, since June 2004. The disdrometer is capable of sensing dropsizes in the range of 0.3 to 5.5 mm with an accuracy of 5% and a minimum integration time of 30 sec. In the present study, the measurements are taken with an integration time of 1 min. At the same site an optical raingauge has been operated to measure rain rates with a sampling interval of 10 sec. Also, the Ku-band signal at 11.172 GHz transmitted from the satellite NSS-6 (geostationary at longitude 95°E) has been received to carry out propagation measurements over an earth-space path

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over Kolkata. The elevation of the satellite signal is about 63^0. The satellite signal has a fade margin of 20 dB. The rain attenuation data have been used in the present study.

3. Theoretical Consideration

DSD measurements are modeled using the method of moments in terms of three-parameter gamma function, namely,

$$N(D) = N_o D^{\mu} e^{-\Lambda D} \tag{1}$$

Here N_0 is known as the intercept or offset parameter, μ and λ are the shape and slope parameter respectively. The type of rain also controls the rain attenuation of microwave radio signal propagating over an earth-space path. The horizontal structure of rain that depends on the physical processes associated with the precipitation can be indicated by the decay parameter (γ). The change of rain rate over a rain cell can be characterized by an exponential variation of rainfall namely,

$$R(l) = R_o \exp[-\gamma \ln(Ro/10)\, l] \tag{2}$$

Here R_0 is point rain rate and l is the path length. γ indicates the extent of rain cell at a particular rain rate. Again, the rain attenuation over the earth-space path can be obtained from SAM [3] from the following relation.

$$A_S(R_0) = kR_0^{\alpha} \frac{1-\exp[-\alpha\gamma\ln(R_0/10)Ls\cos\theta]}{\gamma\alpha\ln(R_0/10)\cos\theta} \tag{3}$$

Here R_0 is the point rainfall intensity, L_s the slant path length, θ the elevation angle and γ the decay parameter in the exponential distribution of spatial rainfall, k and α are the constants at a satellite signal frequency and used to obtain the specific attenuation using the relation:

$$A_{Specific} = kR_0^{\alpha} \tag{4}$$

A numerical solution of equation (3) for γ is obtained from the experimental measurements of rain rate (R_0) and rain attenuation (A_S). γ is modeled in terms of R_0 for different types of rain and used to predict rain attenuation from the ground based rain rate measurements.

4. Results and Discussion

The variations of N_o, μ and Λ with rain rate (R_0) during a rain event are given in Fig. 1. The scatter plots of the different parameters show the clustering of points at different rain rate regions, namely, 1-4 mm/h, 4-20 mm/h

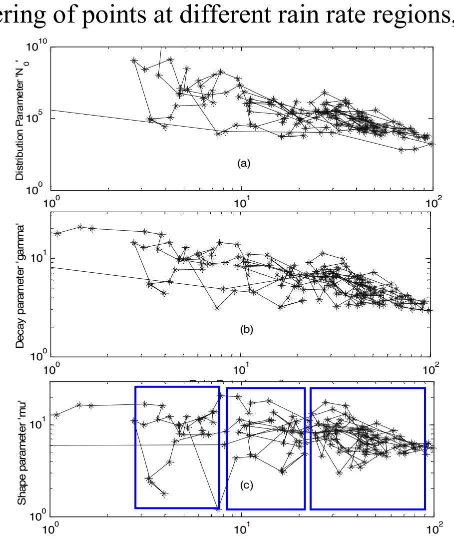

Fig 1: Variation of DSD parameters with rain rate: (a) N_0 (b) γ (c) μ

and 20-100 mm/h, indicating different types of precipitation. A lower value of N_0 indicates the dominance of larger drops in the drop size distribution [4] which occurs at higher rain rates and is associated with the convective rain. The small drops dominate at low rain rate pertaining to the stratiform rain and the intermediate range of rain rates belongs to a transitional case between the convective and stratiform rain.

The features of different types of rain are also evident in the nature of variation of γ with rain rate as shown in Fig. 2. The clustering of γ values has a similar pattern as that of the clustering of DSD parameters, indicating that

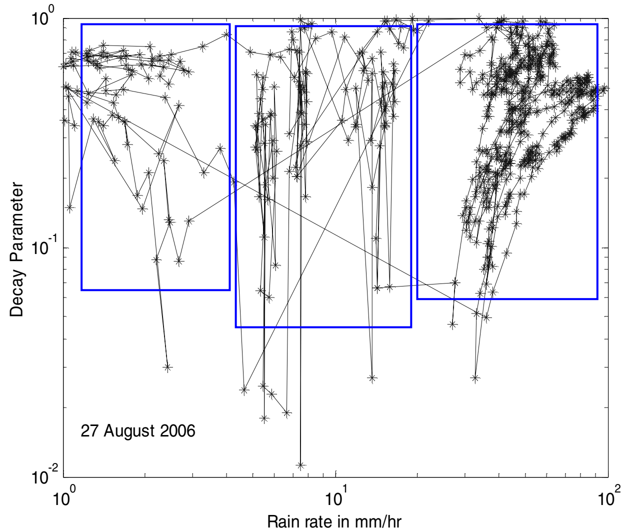

Fig 2: The variation of decay parameter (γ) with rain rate (R) showing clusters.

the decay of rain is much faster at high rain rates which usually pertain to the convective type of rain dominated by the larger drops. The convective rain settles down to the stratiform type when large drops break down into small ones and result in lower rain rates with a large spatial coverage revealed by small values of γ.

For the purpose of predicting rain attenuation from ground based rain rate measurements, γ is modeled in terms of rain rate for two rain rate regions, namely, convective and non-convective (stratiform and transitional case). Fig. 3 shows the scatter plot between γ and R_0 and the fitted power-law curve for the two rain rate regions, namely, 1-20 mm/h and 20-100 mm/h.

The resultant power-law curves are as follows:

$$\gamma_{low} = c_l R_0^{d_l} \qquad 1\ \text{mmh}^{-1} \le R_0 < 20\ \text{mmh}^{-1} \qquad (5)$$

$$\gamma_{high} = c_h R_0^{d_h} \qquad R_0 \ge 20\ \text{mmh}^{-1} \qquad (6)$$

The above models of γ have been used to predict the rain attenuation over earth-space path during the rain event occurring on 27 August 2006. A comparison of predicted and measured values is shown in Fig. 4 and a reasonably good agreement is observed except for some regions where very high rain rates occur. High rain rates pertain to the convective type of rain with small and varying spatial coverage and any small discrepancy will cause an appreciable error in attenuation prediction.

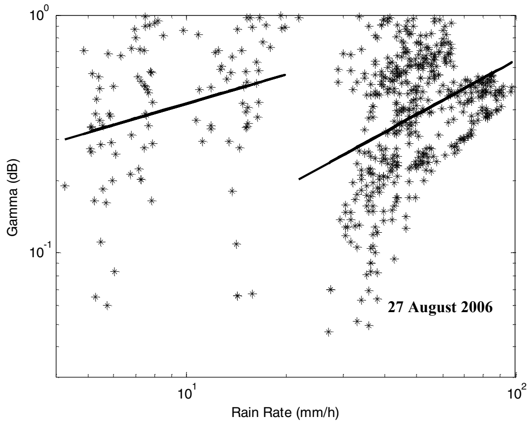

Fig 3: Variation of rain decay parameter (γ) during a rain event

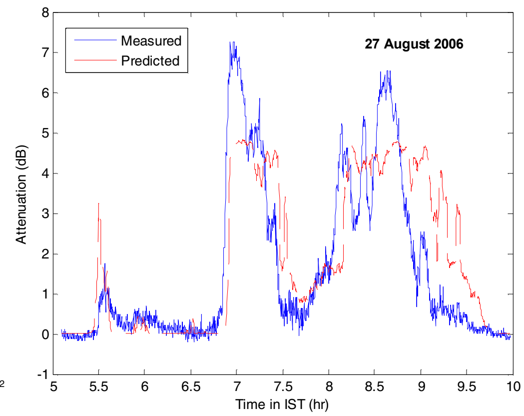

Fig 4: Comparison of predicted and measured attenuation during a rain event

5. Conclusion

The DSD of rain in tropical region prominently shows the characteristic features of different types of rain, namely, stratiform, transitional and convective. The clustering of DSD parameters and rain decay parameter give similar figures indicating the feature of convective and Stratiform rain. The distinctive features can also be noticed by the rain decay parameter, indicative of horizontal extent, which can be revealed by the rain attenuation measurement over an earth-space path. The convective rain has small and varying spatial coverage and associated with high rain rates whereas the stratiform type has large spatial extent with relative smaller rain rates. The modeling of rain decay parameter for different types of rain enables rain attenuation prediction over an earth-space path from ground based rain rate measurement with reasonable success. Long term data are required to have a reliable model of decay parameter for more consistent prediction of rain attenuation, particularly at high rain rates.

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