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Rain drop size distribution model for Indian climate

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Rain drop size distribution (RDSD), which varies with climatic conditions, affects microwave and mm wave propagation severely. A RDSD model for tropical Indian climate is presented. The limitations of the exponential model for RDSD, followed by CCIR, have been highlighted, and a more appropriate log-normal distribution model for tropical climate is discussed.

1 Introduction

The growing demand of communication system with higher data rate and larger bandwidth necessitates the exploitation of SHF and EHF bands. Therefore, the widespread use of microwave and mm wave technology in communication and remote sensing has resulted in an increased interest in the study of tropical rain characteristics[1-2]. At mm wavelength, rain is the primary source of signal degradation and warrants more information on the interaction between electromagnetic wave and rain drops in order to develop reliable propagation models. Enormous data are required to be analysed for predicting loss due to rain drops to provide sufficient input to a system designer. Since the wavelengths of mm wave are of the same order as rain drop sizes, the rate of attenuation is highly dependent on RDSD[3,4]. Therefore, uncertainty persists in estimating specific attenuation for accurate prediction of the limitations imposed by rain. Rainfall of the tropics, where about 60% of the global rainfall is concentrated[5], is a force of global climate change, global heat balance and global water cycle. In the tropical climate, rains are characterized by high intensity rainfall, enhanced frequency of occurrence and increased presence of large rain drops compared to temperate climate. In recent years, a few measurements have been carried out in tropical region like Nigeria[6], Brazil[3] and Malaysia[7] which follow log-normal rain drop size distribution (RDSD). Based on RDSD, log-normal distribution models have been reported for Nigeria[4,6] and Brazil[3]. However, a large data base exists for temperate region which follows exponential Laws and Parsons (LP) and Marshal and Palmer (MP) DSD models[1]. There is, in general, dearth of data on RDSD for tropical climate like that of India[8]. To meet such requirements, studies are needed for rain-induced attenuation, phase-shift and depolarization on terrestrial and earth-space propagation path for tropical regions. The accurate account of rain drops of small drop diameter is as important as for large drops to theoretically estimate the specific attenuation due to rain based on DSD and to provide a proper fade margin during the design of microwave and mm wave communication systems. For frequency below 10 GHz, large rain drops are responsible for attenuating the signal compared to smaller rain drops. As the frequency is increased beyond 10 GHz, wavelength becomes comparable to rain drop size. As a result, small rain drops become important in attenuating the signal more compared to large rain drop size[9]. Therefore, it is essential to have proper knowledge of DSD of tropical climate like that of India for the estimation of specific attenuation based on forward scattering coefficient to improve the system performance at microwave and mm wave range. In this paper, a RDSD model developed based on distrometer data collected at Dehradun is reported. It follows log-normal distribution as observed for tropical climate. The proposed log-normal RDSD model has been compared with existing log-normal RDSD models of Nigeria[6] and Brazil[3].

2 Experimental details

The RDSD is measured by an instrument called distrometer. It consists of electromagnetic sensor, processor, analyser and paper tape recorder[8]. It measures the momentum of rain drops falling on its sensor of 50 sq cm area. It distinguishes between drops with time spacings of about 1 ms. This system provides 20 different drop size class intervals from 0.3 mm to more than 5 mm drop diameter with a resolution varying from 0.1 mm for small drops to 0.5 mm for large drops. The total number of rain drops captured by distrometer sensor in 1 min time is analysed by an analyser for different drop size intervals and the counts are punched on a paper tape in the standard ASCII (American standard code for information interchange) code. Later on, the paper is read by paper tape reader and information is stored on floppy disk for further analysis. In this system, it is assumed that rain drops impacting the sensor are travelling at their terminal velocity. The processor of the system eliminates the unwanted signals such as sputtering noise of rain drops, accoustic noise due to strong winds, and surrounding noise. The accuracy of the system is ±5%. The distrometer was procured from Distromet Ltd, Switzerland. Distrometer data were collected during the rain of the year 1989. The present paper deals with the analysis of 1100 rain events of 1 min duration to develop RDSD model for tropical climate of India.

3 RDSD model

Among various models employed by meteorologists for describing RDSD, the exponential model is most widely used. The LP RDSD currently used by CCIR is similar to MP RDSD negative exponential and can be written as[1]

$$N(D_i) = N_0 \exp(-\Lambda D_i) \quad \ldots (1)$$

where $\Lambda = AR^{-0.21}$, R is the rain rate calculated from RDSD data, D_i the drop diameter (mm) of the ith channel of distrometer, and $N(D_i)$ the number of drops with diameter from D_i to $D_i + \Delta D_i$ (mm) per unit volume. The coefficients N_0 and A vary with rain type and climate. For stratiform rain, $N_0 = 8000$ mm^{-1} m^{-3} and $A = 4.1$ in the temperate climate.

The tropical RDSD follows log-normal model and can be written as[3,6-8]

$$N(D_i) = \frac{N_T}{\sigma D_i \sqrt{2\pi}} \exp[-0.5\ \{(\ln D_i - \mu)/\sigma\}^2] \quad \ldots (2)$$

where N_T is the total number of drops of all sizes, μ and σ are the mean and standard deviation of $\ln D_i$. Here N_T, μ and σ are the functions of the rain rate and can be written as

$$N_T = a_0\, R^{b_0}$$

$$\mu = A_\mu + B_\mu \ln R \quad \ldots (3)$$

$$\sigma^2 = A_\sigma + B_\sigma \ln R$$

Ajayi and Adimula[4] reported that the log-normal distribution is more adequate for shower, widespread and thunderstorm rains in the tropics than negative exponential distribution[4]. It is also pointed out that Joss thunderstorm and MP distribution overestimate the number of drops. The shower/drizzle rain is a precipitation from cumuliform cloud, characterized by the suddenness of beginning and ending and by the rapid changes of intensity. The widespread/stratiform rain is long lasting with low medium intensity. These rains are generated by the sublimation-coalescence mechanism according to the Bergeron-Findeisen theory which involves the ice phase and such rains are assumed to extend up to 0°C isotherm[5]. Thunderstorm rain is a local convective rain which is usually produced by cumulonimbus cloud and is always accompanied by lightning and thunder[4,6]. Hence, rain drop size and its distribution can be used as a criterion to differentiate the shower and thunderstorm rain. Thunderstorm rain consists of larger drop sizes compared to shower rain for the same rain rate. It has much higher proportion of large rain drops than that of widespread RDSD[1,2]. Hence with the same rain rate, types of rain also affect the attenuation due to variation in RDSD.

Using distrometer data, one minute rain rate for each event can be written as[8]

$$R = 10\pi / A_1 \Sigma d_i^3 n_i \ \text{(mm/h)} \quad \ldots (4)$$

where A_1 is the area of the sensor (mm^2) and n_i is the number of drop count for the ith channel.

Hence for each corresponding rain rate, the number of drops per unit volume per diameter interval $N(D_i)$ can be written as

$$N(D_i)\Delta D_i = 10^4\, [N_i / A_1 T v_i] \quad \ldots (5)$$

where N_i is the number of drops with diameter (mm) between $D_i - 0.5\ \Delta D_i$ and $D_i + 0.5\ \Delta D_i$, and T is the integration time. Using drop terminal velocity (v_i) as followed by Medhurst (Table 1)[9], surface area as 50 sq cm and integration time as 60 s, the number of rain drops per unit volume per diameter interval can be written as[8]

$$N(D_i) = 3.33\, [N_i / (v_i \Delta D_i)] \quad \ldots (6)$$

This expression gives the DSD for each channel corresponding to rain rate R and is known as measured RDSD.

Similarly corresponding to each rain event, N_T, μ and σ^2 can be calculated by knowing total number of drops of all sizes and its related drop-size parameter of the distrometer channel using software developed. Based on 1100 rain events of 1989 and their corresponding N_T, σ, μ and R, regression analysis has been done to develop coefficients of log-normal distribution model for Dehradun and can be written as

$$N_T = 169.05\, R^{0.2937}$$
$$\mu = -0.05556 + 0.13096 \ln R \qquad \ldots (7)$$
$$\sigma^2 = 0.30042 - 0.023604 \ln R$$

This is an average log-normal RDSD model from shower to thunderstorm rain. The correlation coefficient of the RDSD model is better than 0.95 and standard error of correlation coefficient is less than 0.0015. Hence, RDSD model developed is an excellent fit to the measured RDSD data.

Ajayi and Olsen reported the log-normal RDSD model for Nigeria whose equation for N_T, μ and σ^2 can be written as[6]

$$N_T = 108\, R^{0.363}$$
$$\mu = -0.195 + 0.119 \ln R \qquad \ldots (8)$$
$$\sigma^2 = 0.137 - 0.013 \ln R$$

Similarly, Maciel and Assis developed log-normal RDSD model for Brazil whose equations for N_T, μ and σ^2 can be written as[3]

$$N_T = 0.859\, R^{1.535}$$
$$\mu = -0.023 + 0.116 \ln R \qquad \ldots (9)$$
$$\sigma^2 = 0.805 - 0.15 \ln R$$

4 Results and discussion

Figures 1 and 2 depict the variation of measured $N(D_i)$ between shower and thunderstorm rain for 48.4 and 46.9 mm/h rain rate respectively at Dehradun. It is observed that thunderstorm rain contains rain drops of larger sizes as compared to shower rain. The drop size where maximum $N(D_i)$ is present is called mode diameter D_m and the corresponding $N(D_i)$ is called $N_{\max}(D_m)$. It is also observed from both the figures that $N_{\max}(D_m)$ will be greater for shower rain than for thunderstorm rain for the same rain rate but D_m will be less for shower rain. Hence it

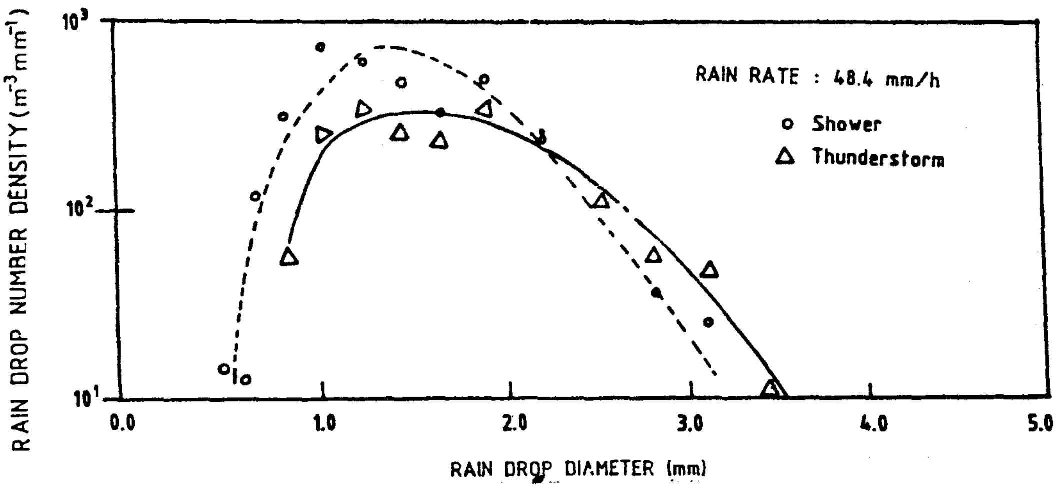

Fig. 1—Comparison of measured RDSD of shower and thunderstorm rain at 48.4 mm/h rain rate.

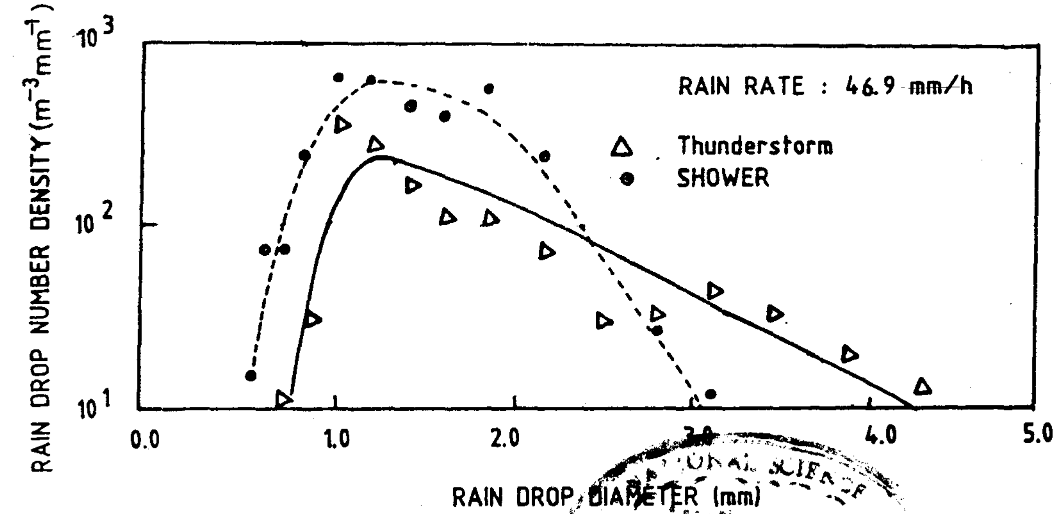

Fig. 2—Comparison of measured RDSD of shower and thunderstorm rain at 46.9 mm/h rain rate.

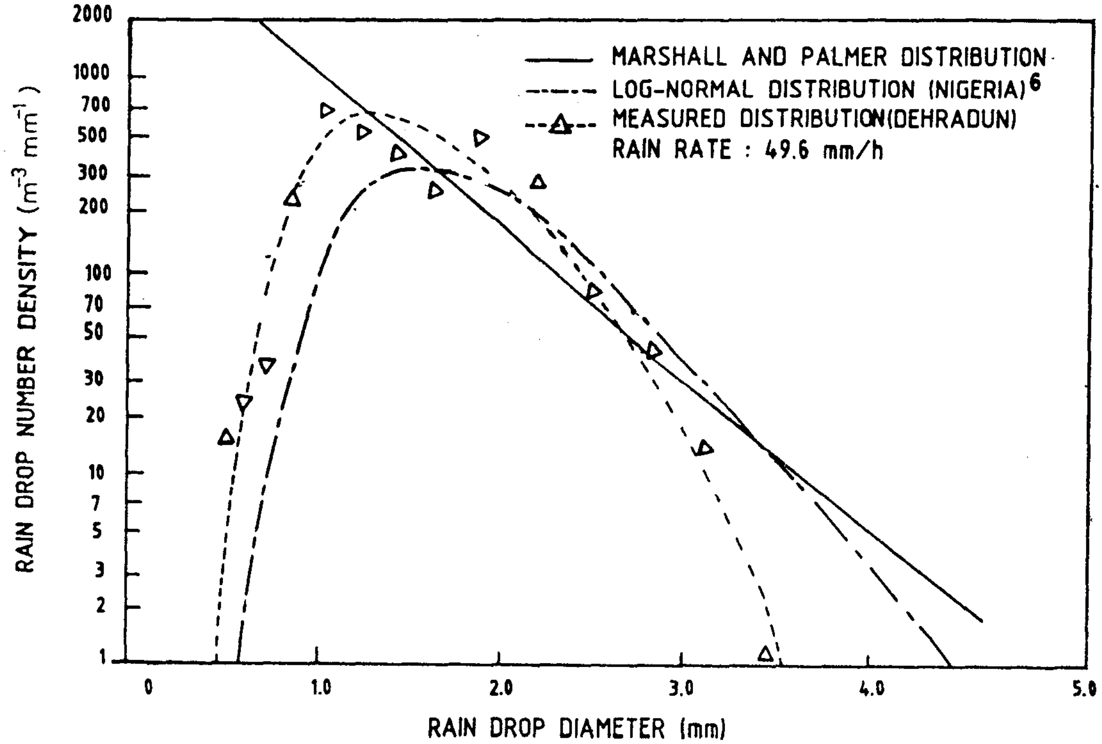

Fig. 3—Comparison of measured RDSD at Dehradun with MP model and log-normal model[6] at 49.6 mm/h rain rate.

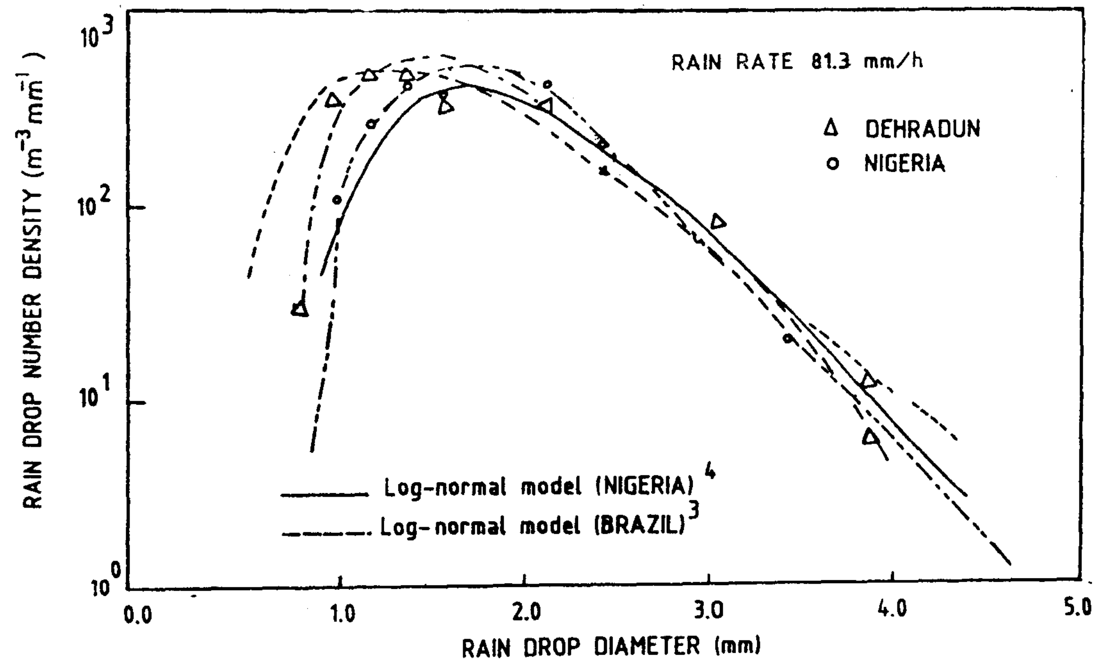

Fig. 4—Comparison of measured RDSDs of Dehradun (India) and Nigeria with log-normal models of Nigeria and Brazil.

is found that $N(D_i)$ also varies with the type of rain. Hence, the pattern of RDSD measured varies with the kind of rain process and also follows log-normal distribution of $N(D_i)$.

Figure 3 depicts the variation of $N(D_i)$ with rain drop sizes measured at Dehradun for 49.6 mm/h rain rate. This theoretical curve of $N(D_i)$, based on log-normal RDSD model of Nigeria and MP RDSD model, has been plotted for comparison with the measured $N(D_i)$ of Dehradun. It is observed that a large number of small drops are present at Dehradun compared to those in Nigeria DSD and they follow log-normal RDSD instead of MP RDSD which is not suitable for tropical climates as observed.

Figure 4 depicts the variation of measured

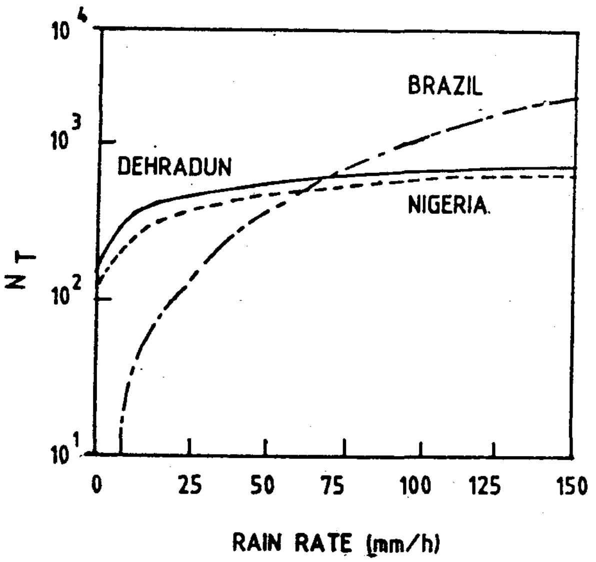

Fig. 5—Variation of N_T with rain rate for log-normal models of Nigeria, Brazil and Dehradun (India).

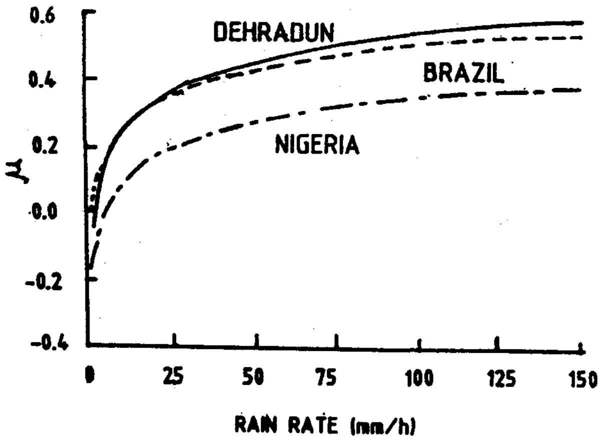

Fig. 6—Variation of μ with rain rate for log-normal models of Nigeria, Brazil and Dehradun (India).

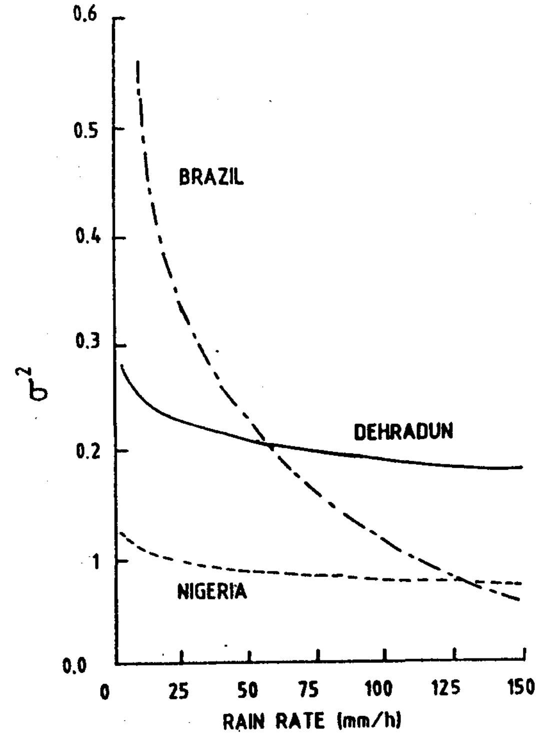

Fig. 7—Variation of σ^2 with rain rate for log-normal models of Nigeria, Brazil and Dehradun (India).

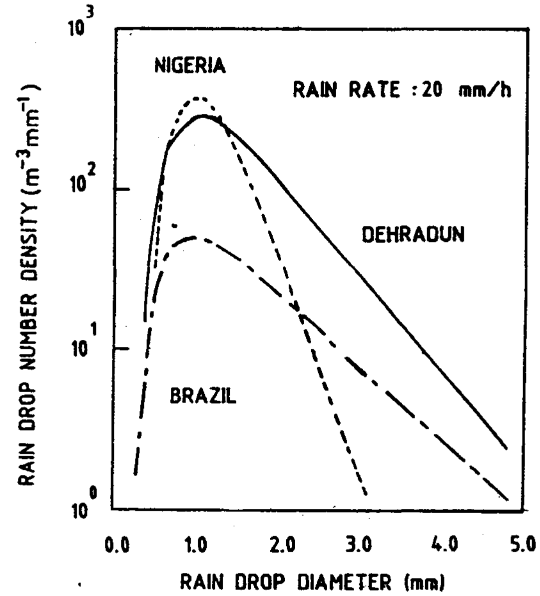

Fig. 8—Comparison of log-normal RDSD models at 20 mm/h rain rate.

$N(D_i)$ of Dehradun and Nigeria at 81.3 mm/h rain rate along with theoretical RDSDs based on log-normal RDSD of Nigeria and Brazil. It is observed that mode diameter (D_m) lies between the values of D_m evaluated for Nigeria and Brazil RDSD models and follows log-normal distribution observed in a tropical climate. Here, $N_{\max}(D_m)$ value observed at Dehradun was also found close to those of log-normal distributions observed at Nigeria and Brazil.

Figures 5-7 depict the variations of N_T, μ and σ^2 with rain rate for RDSD models of Nigeria, Brazil and Dehradun (India). The values of N_T at Dehradun increase with rain rate and follow closely with those of Nigeria model. Similarly, the values of μ at Dehradun increase with rain rate and follow closely with those at Brazil. The values of σ^2 decrease with rain rate, and the rate of decrease for Brazil is large compared to those for Dehradun and Nigeria models. It is observed that the variations of N_T, μ and σ^2 are different for the same rain rate due to change in geographic locations, however it follows the same pattern. The variations in RDSD are due to changes in their coefficients of the models of N_T, μ and σ^2.

Figures 8-10 depict the comparison of the variation of $N(D_i)$ with drop size based on log-nor-

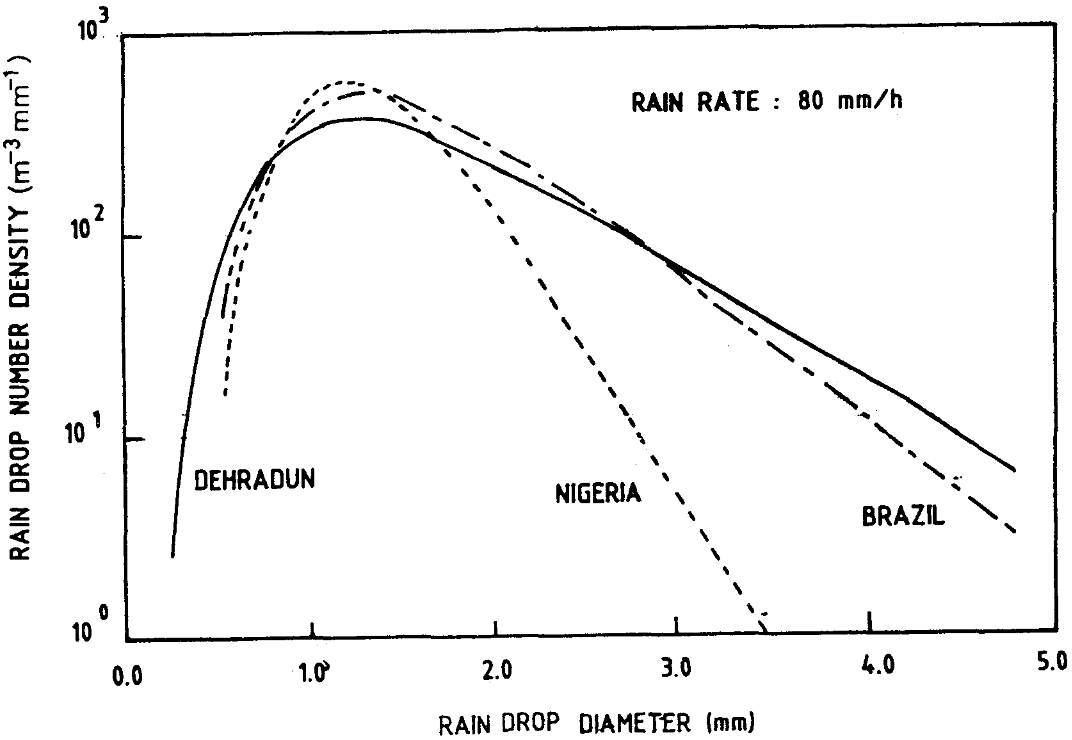

Fig. 9—Comparison of log-normal RDSD models at 80 mm/h rain rate.

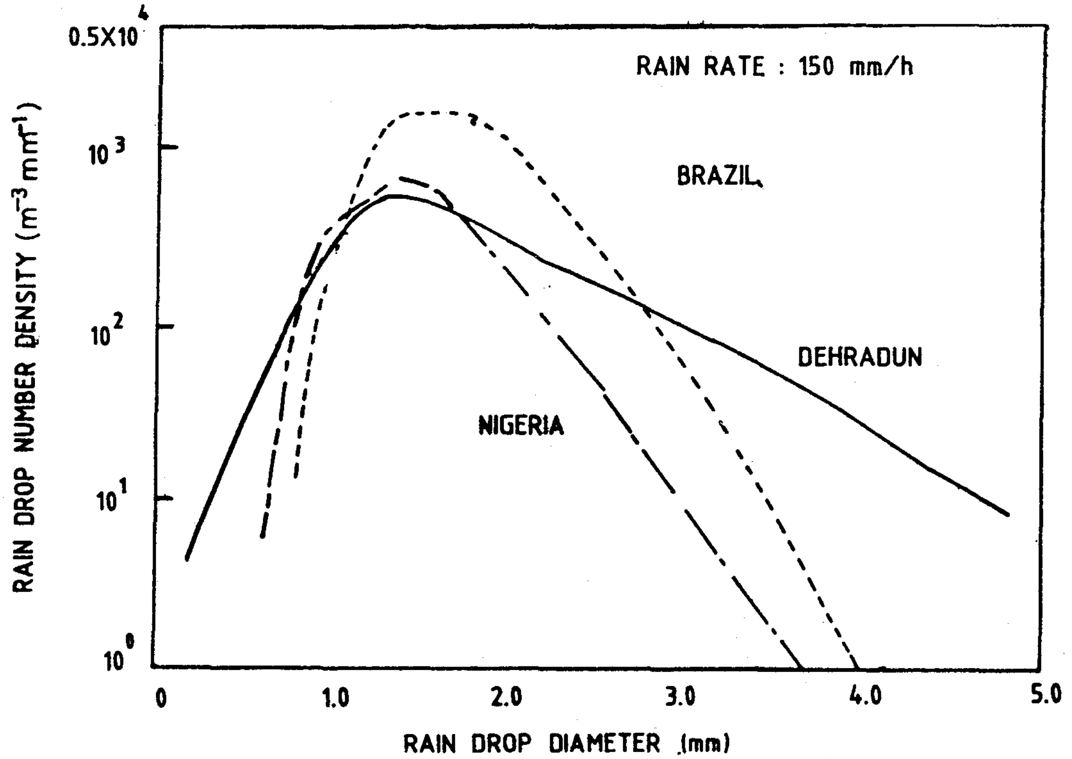

Fig. 10—Comparison of log-normal RDSD models at 150 mm/h rain rate.

mal distribution model of Nigeria, Brazil and Dehradun (India) at 20, 80 and 150 mm/h rain rate respectively. It is observed that a large number of small and large rain drop sizes are present for Dehradun compared with those for the climates of Nigeria and Brazil from low to high rain rates. $N(D_i)$ will be maximum for the climate of Nigeria for mode diameter $N(D_m)$ for 20 mm/h and 80 mm/h rain rates. Due to different DSDs for the same rain rate, their effect in attenuating the signal will be different for Dehradun, Nigeria and Brazil. For higher frequencies, the effect of small rain drop size becomes important for absorption of signal[9] and large drops take part in scattering of signal. When radiowave passes through rain drops, part of its energy is absorbed and transformed into heat and another part is scattered in all directions. Scattering predominates when the wavelengths are comparable to the drop sizes. In the mm wave range, drop size more than 0.15 cm contributes more to scattering and smaller rain drops to absorption. Due to this reason, mm wave region more than 70 GHz may cause less attenuation for higher rain rate in Indian climate compared with LP and MP DSDs[3].

5 Conclusions

The knowledge of RDSD model in the calculation of rain-induced attenuation at frequency above 10 GHz is a fundamental parameter for both terrestrial and space-to-earth path communications. Generally, Laws and Parsons RDSD model or negative exponential function proposed by Marshall and Palmer is suitable for temperate climate which overestimates both small as well as large rain drops. In this paper, log-normal RDSD model based on distrometer data measured at Dehradun (India) has been compared with log-normal RDSD models of Brazil and Nigeria. It is observed that the pattern of RDSD agrees closely with existing models but their coefficients vary. The results presented indicate that log-normal distribution seems to be more appropriate for tropical climate like that of India. Specific attenuation derived from the proposed RDSD model can have significant role in the design of terrestrial and earth-satellite radio links especially at frequency above 10 GHz and more so for a tropical region like India.

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