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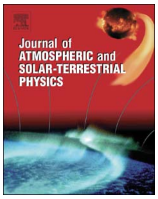

Dependency of rain integral parameters on specific rain drop sizes and its seasonal behaviour

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ABSTRACT

This paper investigates the variability of raindrop size distribution (DSD) and rain integral parameters at Ahmedabad, a tropical location, in relation to the radar estimation of rainfall. Rain DSDs for the years 2006–2007 at Ahmedabad (23°04′N, 72°38′E) have been measured using a disdrometer. Variability of DSD is evaluated for different seasons and its effect on the integral rain parameters like radar reflectivity, rainfall intensity and attenuation are examined. A percentage contribution of different drop diameters on rain integral parameters is studied to understand the seasonal behaviour of rain attenuation and radar reflectivity. It is observed that drops with diameter around 3 mm contribute maximum to the radar reflectivity while drops having a diameter around 2 mm contribute the maximum to the rainfall intensity for the present location. The critical diameter range responsible for the maximum contribution in rain attenuation found to shift towards large drops with an increase in rain rate for a fixed frequency. Linear and non-linear regression analysis between radar reflectivity and rainfall intensity show significant variations in different seasons but does not differ much for different regression techniques. Results point to the necessity of considering the seasonal variability of rain DSD in radar remote sensing and will be helpful for better characterizing of rain parameters from radar measurements.

1. Introduction

Meteorological or climate studies nowadays rely heavily on remote sensing of precipitation systems, either from space-borne or using ground-based radars. Use of high frequencies, such as X (8–12 GHz), Ku (12–18 GHz) or Ka (18–40 GHz) band as radar signals, improve the capability of detection of very small rain rates (Das et al., 2015; Thurai and Bringi, 2008). An excellent example of improved capability of high-frequency signals in radars is the precipitation radars onboard Global Precipitation Mission (GPM) satellite, one at Ku band (13.6 GHz) and another in Ka-band (35.5 GHz) (Hamada and Takayabu, 2016).

Radar reflectivity factor is an important parameter for quantitative estimation of rain rate using radar. It is completely independent of the radar electronics and dependents only on the raindrop size distributions (DSD) (Uijlenhoet, 2001). However, high frequencies used in space-borne radars as well conventional meteorological radars used for characterization of hydrometeors like rain, snow, hail or cloud are affected by the atmospheric phenomena to a great extent (Crane, 1996; Iguchi et al., 2009). Particularly, rain severely attenuates millimeter and microwave signals. This is also a crucial factor determining the link availability in high-frequency satellite communication (Sarkar et al., 2014; Das et al., 2010). Since drops concentrations are not same for all drop sizes, the rain attenuation (as well the rain rate and radar reflectivity factor) will be primarily influenced by a specific drop size, known as the critical diameter (Lakshmi et al., 2007; Adetan and Afullo, 2013, 2014; Lee et al., 2007). Hence, for proper functioning and correct estimation of weather conditions, it's important to know the correspondence between the DSD, radar reflectivity factor, and rain attenuation.

The drop size distribution is not unique to any place and it also varies from season to season and time to time (Tokay and Short, 1996; Bringi et al., 2003; Thurai and Bringi, 2008; Das and Maitra, 2010). For example, high rain rates associated with convective activities are much more frequent in tropical regions than the temperate regions which mostly have the stratiform type of rain. It is, therefore, of utmost importance to understand the features of raindrop size distribution for improving radar estimation of rainfall for any location. Besides, the study of DSD is of practical importance in a variety of research areas such as satellite meteorology, microwave communication, cloud physics, soil erosion, telecommunication and broadcast areas and so on (Caracciolo, 2012; Tokay et al., 1996; Das et al., 2010).

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In this paper, the variability of rain DSD and its impact on integral rain parameters during different seasons are investigated at Ahmedabad, a tropical location in India. Variations of specific attenuation, rain rate and radar reflectivity factor with rain drop diameter for different seasons have been studied to understand the seasonal variability. The effects of variations in DSD and regression techniques on the relationship between radar reflectivity and rainfall rate are also examined for different seasons.

2. Data

Data was collected from a Joss-Waldvogel Disdrometer (Disdromet, RD-80) at Space Applications Center, Ahmedabad (23°04′ N, 72°38′E) during the years 2006–2007. The average rain characteristics of the measurement period are given in Table 1.

Disdrometer converts the momentum of a raindrop falling on the sensitive surface into an electric pulse whose amplitude is a function of drop diameter. The terminal velocity estimated from the momentum measurement is then converted to the rain drop diameter using Gunn-Kinzer relation (Gunn and Kinzer, 1949).

Disdrometer can distinguish 127 classes of drop sizes, however, regrouped further into 20 bins in the range of 0.3–5 mm in order to reduce the amount of data. The instrument was operated with a 30 s integration time. The data point has been discarded if the instantaneous rain rate is found to be less than 0.01 mm/h as a precautionary measure.

3. Methodology

The shape of the DSD has a pivotal role in varied attenuation of microwave signals and radar reflectivity for different rain rates and locations. DSD not only depends on rain rate but also on rain types. DSD is usually represented by $N\ (D_i)$ (in $\mathrm{m}^{-3}\ \mathrm{mm}^{-1}$) and is estimated from the disdrometer measurements as follows,

$$\mathrm{N(Di)} = \frac{n_i}{F.\ t.\ v(D_i).\ \Delta D_i} \tag{1}$$

where, n_i is the number of drops measured in i^{th} class during time interval t, D_i (in mm) denotes the average diameter of i^{th} class, F is the size of the sensitive surface of the disdrometer (here, F=0.005 m^2), $v\ (D_i)$ (in m/s) is the fall velocity of a drop with diameter D_i, and ΔD_i is the diameter interval of i^{th} drop size class.

Rain rate, R (in mm/h), is estimated from the DSD as follows,

$$R = \frac{\pi}{6} * \frac{3.\ 6}{10^3} * \frac{1}{F.\ t} * \sum_{i=1}^{20} n_i D_i^3 \tag{2}$$

Radar reflectivity factor, Z (in mm^6 m^{-3}) can be estimated as,

Table 1
Yearly average rain event features of different months.

Month	Rain-minutes (m)	Peak rain rate (mm/h)	Longest event (m)
Jan	107.5	68	14.5
Feb	243.5	57.55	17
March	1602	52.9	296
April	1000	120.4	101
May	517.5	88.56	100
June	2595.5	51.27	210.5
July	4225.5	86.37	200
August	5503	62.86	470.5
Sept	4179.5	90.39	908.5
Oct	1334.5	64.09	244.5
Nov	2515	37.77	113
Dec	645	34.23	149

$$Z = \frac{1}{F.\ t} \sum_{i=1}^{20} \left(\frac{n_i}{v(D_i)} * D_i^6 \right) \tag{3}$$

Specific attenuation, A (in dB/km), can be estimated from DSD as

$$A = 0.0434 * \int_0^{\infty} n(D) Q_{ext} dD \tag{4}$$

where Q_{ext} (in mm^2) is the total extinction cross section estimated using Mie scattering theory.

To study the rain DSD characteristics during different seasons and for different rain rates, the percentage contribution of different rain drops in total drops is examined. The seasons are defined as pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and winter (December– February). The raindrops are categorized into five groups, such as very small ($D < 0.6$ mm), small ($0.6 \le D < 1$ mm), medium ($1 \le D < 3$ mm), large ($3 \le D < 5$ mm) and very large ($D \ge 5$ mm). The data are further classified into four broad categories based on the rain rate, namely drizzle ($R \le 5$ mm/h), widespread ($5 < R \le 10$ mm/h), shower ($10 < R \le 40$ mm/h) and thunderstorm ($R > 40$ mm/h). The details of rain categories for different seasons are presented in Table 2. It can be noticed from Table 2 that maximum data is obtained during monsoon season and least data is contributed by the winter season. Further, it is observed that high rain rate events are less in numbers and the majority of the samples is coming from the drizzle.

4. Results

4.1. DSD characteristics

In Fig. 1, the average rain DSDs are shown for different rain types. We can see that for drizzle, the drop density reaches a maximum value at drop diameter 0.5 mm. However, the DSD is bimodal in case of widespread rain and the two peaks are obtained at diameter around 0.6 mm and 1.12 mm. The DSDs of shower and thunderstorm are uni-modal and the peaks are further shifted towards the large drop diameter.

The drop evolution process via break-up and coalescence is the primary reason for the existence of peaks at different drop sizes (Porcùa et al., 2014). The drop evolution is dependent upon the atmospheric condition. In the case of Ahmedabad, drop coalescence is the dominant mechanism in the convective rain, whereas drop break-up is the main mechanism in the stratiform rain (Das et al., 2010). It can be observed from the Fig. 1 that the presence of small drops ($0.6 \le D < 1$ mm) is maximized for lower values of rain rates. For higher intensity rain, the presence of large drops is comparatively greater than the low rain rate events. Low rain rates usually correspond to the stratiform type of rain whereas high rain rates are associated with convective rain. The existence of peak concentration at the lower drop diameter at low rain rates and at a higher drop diameter in high rain rates is the consequence of this fact. The bi-modal distribution of DSD in the medium rain is indicative of the fact that both types of rains are associated with this rain rate range.

4.2. Seasonal variations of DSD

Fig. 2 shows the percentage contribution of different drop sizes for different rain rate ranges for the pre-monsoon season. It can be seen that contribution of very small drops in total drops is maximum in case of drizzle. However, the contribution of small size rain drops is also significant in this type of rain. As rain rate