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Vertical profile of rain: Ka band radar observations at tropical locations

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SUMMARY

Information of vertical rain structure is important for accurate quantitative precipitation estimation from weather radars and space-borne radars. In this paper, some characteristics of the vertical rain structure observed using a Ka band Micro Rain Radar at three tropical locations in India are presented. The average vertical structure is studied in terms of drop size distribution (DSD), fall velocity, rain rate, liquid water content and radar reflectivity profile. The changes in vertical rain structure with rain rate is observed to be significant only above 20 mm/h in Ahmedabad and Trivandrum, although, in Shillong, significant variation is observed starting from 2 mm/h. Results show a significant negative slope of the fall velocity of rain drops and Ka band radar reflectivity up to melting layer height for rain rate above 20 mm/h indicating a shift in the drop size distribution (DSD) toward lower size at all sites. The near ground measurements show strong variation of rain structure for all rain rates. The mean DSD near ground (<1 km) indicates the dominance of smaller drops during rain rates below 2 mm/h, but significant increase in drop size in rain rate above 20 mm/h. The findings suggest using different retrieval techniques for near ground rain estimation than the rest of the height profile as well for high rain rate events.

1. Introduction

Radar provides a unique tool to measure the precipitation with a large aerial coverage. However, the space borne-radars as well ground based weather radars do not always represent the surface rain characteristic accurately (Peters et al., 2005; Thurai et al., 2003; Kirstetter et al., 2013). The major source of this inaccuracy is due to vertical variation of radar reflectivity, especially near the melting layer. The bias in the vertical profile of reflectivity (VPR) also arises due to the assumptions of constant reflectivity up to melting layer height from the surface. The evolution of rain drops via melting, coalescence, break up and evaporation are primarily responsible for this variation of VPR. The change in drop size distribution (DSD) along the vertical direction may have a significant effect in the estimated rain rate profile. Studies using radars have been performed in the past to address this issue, notably in relation to the Tropical Rainfall Measuring Mission (TRMM) (Peters et al., 2005; Thurai et al., 2003; Cluckie et al., 2000). However, due to lack of experimental measurements of actual VPR, most studies concentrated on adjusting bias in the ground precipitation estimation of radar data by using ground based instruments (Koistinen and Michelson, 2002; Bellon et al., 2007; Seo et al., 2000).

A very limited number of radar observations are reported which studied the variation of VPR in connection with the change in DSD spectrum over the height and how this variation influence the rain retrieval (Kirstetter et al., 2013; Cluckie et al., 2000). Peters et al. (2005) showed a significant shape transformation of DSD and Z-R relation from the ground to the melting layer for strong rain around the Baltic Sea in temperate regions. Strong variation of VPR in convective rain was also observed by Thurai et al. (2003) during radar campaign in Singapore in equatorial region. Similar observations are also reported by Das et al. (2010a,b) from Ahmedabad in tropical region. Zipser and Lutz (1994) reported contrasting features of VPR in mid-latitude and tropical continental locations with that of the tropical oceanic region. The seasonal variation of Z-R using ground based DSD measurements are also studied by various researchers (Rao et al., 2001; Kozu et al., 2006). Seasonal variations of vertical Z-R relation are also observed to be significant over Kolkata in tropical region (Das et al., 2011a,b). The characteristic difference of VPR between convective and stratiform rain was also reported by many researchers from these regions (Das et al., 2010a,b; Rudolph and Friedrich, 2013; Thurai et al., 2003).

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The previous results highlight significant vertical variation of the reflectivity profile during various phases of the precipitation (Bellon et al., 2005) as well as between different regions. The most significant variation is observed due to presence of melting layer in stratiform rain. The regions below the melting layer are assumed to be uniform. Most of the results suggest that the N_o adjustment technique (Thurai et al., 2003) is generally acceptable for rain rate estimation from radar data during stratiform precipitation below melting layer. However, for convective systems, these assumptions are no longer valid and multi-frequency measurements are suggested. The Global Precipitation Mission (GPM) satellite are having dual frequency radar in Ku and Ka band to improve the rain fall estimation from space.

In view of GPM satellite, further investigation on this topic is expected, especially from the regions where very limited or no information of VPR is available. In addition, rain observations in the Ka-band are also an important consideration due to heavy rain attenuation in this frequency band. Moreover, the variation of VPR near ground (<1 km) and above up to the melting layer is usually assumed to be similar which may need a closer examination since the instantaneous ground rain rate is more important for flood warning and other related early warning systems.

In this paper, we report some statistical observations of vertical rain structure obtained using a vertical looking Micro Rain Radar (MRR) in Ka band frequency at three tropical locations in India, namely, Trivundrum (8°29′N, 76°57′E), Ahmedabad (23°04′, 73°38′), and, Shillong (25°34′N, 91°53′E,), during 3 years (2006–2008) of the measurement period. The VPR and associated rain DSD are investigated for different rain rate regimes with a special emphasize on the lowest 1 km region to address these questions.

2. Instrument description and data

2.1. Site specifications

MRR data has been collected from three locations in the Indian region during the year 2006–2008. These three locations have different rain climatology. Trivundrum is situated in the southern peninsular region of India. Annual rainfall in this location is ~1800 mm and received rainfall during both south-west (SW) and north-east (NE) monsoon. According to Köppen–Geiger classification (Peel et al., 2007), Trivandrum has tropical wet and dry savanna climate. On the other hand, Ahmedabad is situated in the relatively dry location in western India with approximately

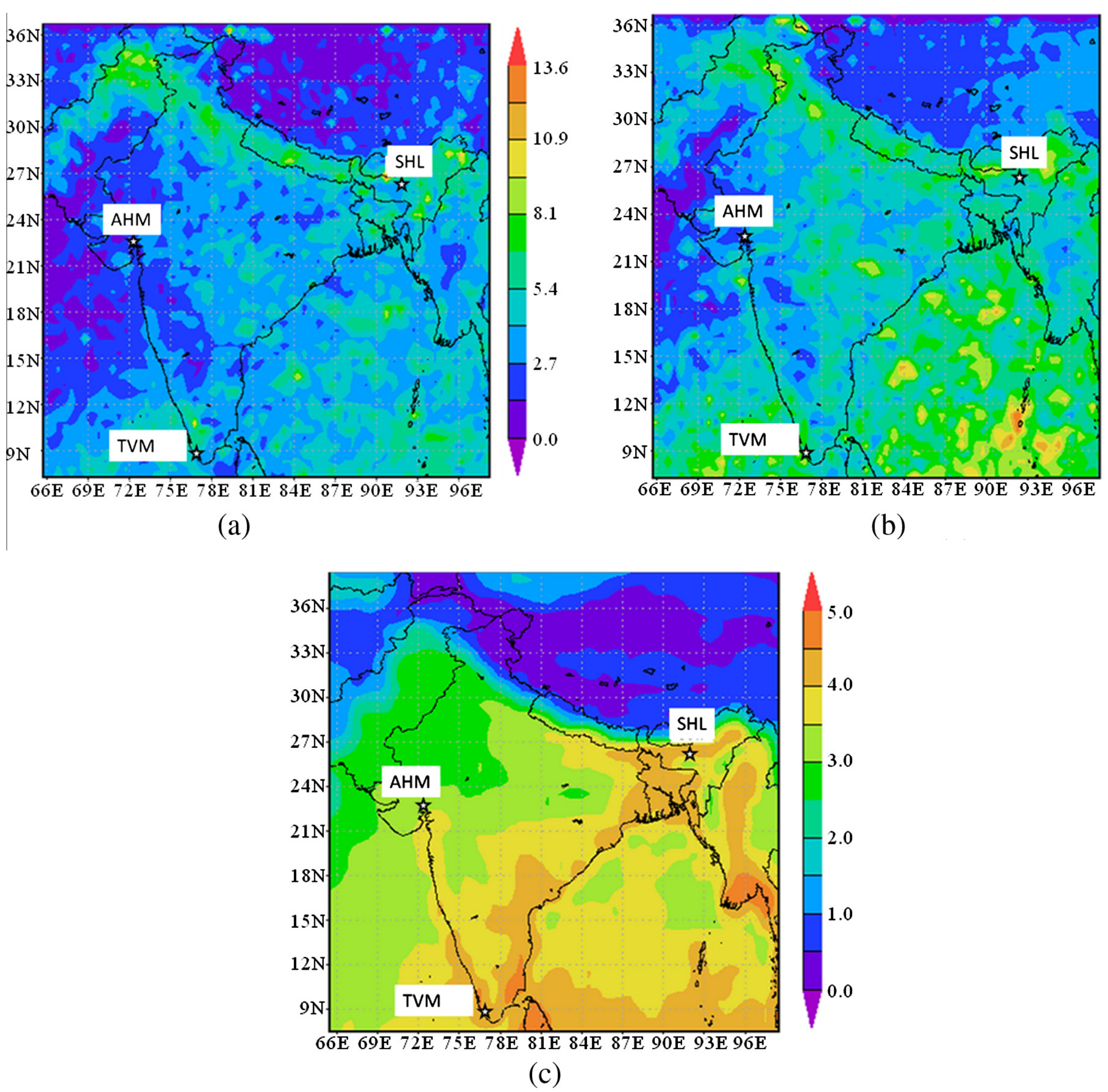

Fig. 1. Climatology of the experimental sites (a) average convective rain rates (mm/h), (b) average stratiform rain rates (mm/h) and (c) average water vapor (cm). Rain rate information is obtained from TRMM and water vapor data is obtained from AQUA-MODIS satellite.