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On the seasonal variability of raindrop size distribution and associated variations in reflectivity – Rainrate relations at Tirupati, a tropical station

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ABSTRACT

Three years of continuous OTT Parsivel disdrometer measurements made at Tirupati (13.6°N, 79.4°E), a tropical station near the foothills of Nallamala mountains, have been used to examine the climatological seasonal differences in bulk rainfall parameters, gamma parameters, raindrop size distributions (DSDs) and reflectivity – rainfall (*Z–R*) relationships. These relations are derived for both stratiform and convective rain during southwest and northeast monsoon (SWM and NEM) seasons, the two primary rainfall seasons for this region. The probability distribution functions for bulk rainfall and gamma parameters during the SWM and NEM suggest the dominance of evaporation and drop sorting during the SWM. The seasonal variations are also clearly apparent in DSD with fewer big drops and more small drops during the NEM than in SWM. These differences are seen more prominently at smaller *R*. As a result, the retrieved *Z–R* relations are found to be distinctly different during the monsoon seasons. The seasonal variations in *Z–R* relations are not only observed for the total data but also for the rain type-segregated data. The prefactor of the *Z–R* relation is found to be larger for SWM and also for stratiform rain, consistent with earlier reports from southeast India, indicating that these features are robust and representative of southeast India. The observed differences in *Z–R* relations are discussed in the light of microphysical differences between the seasons and rain types.

1. Introduction

Weather radars are potential tools for providing high-resolution quantitative precipitation estimates (QPE) continuously over a large area, information crucial for a variety of meteorological and hydrology applications. Nevertheless, single-polarization radars that depend on traditional reflectivity-based QPE algorithms, "so-called *reflectivity factor* (*Z*)-*rain rate* (*R*) relations" suffer with several sources of errors, including both technical and geophysical problems. The former includes, calibration issues, beam blockage due to mountains and high-rise buildings, ground-clutter, beam broadening, attenuation of radio signal (severe for high-frequency radars), etc., and the later includes variability of rainfall from observational height to ground, contamination due to hail and radar bright band (Krajewski and Smith, 2002 and references therein). In addition, these radars depend on an empirical relation of the form $Z = AR^b$ for converting radar measured *Z* to more commonly used *R*. Unfortunately, the coefficients of the above relation are not unique rather depend heavily on the raindrop size distribution (DSD), which varies widely with rain type and climatic regime. The selection of a single *Z–R* relationship increases the probability of under- or over-estimating the precipitation rates and accumulations (Ulbrich and Lee, 1999; Sánchez-Diezma et al., 2001). To overcome this, rain- and region-specific *Z–R* relations have been retrieved from DSD measurements with disdrometers and radar-rain gauge combinations (Rosenfeld and Ulbrich, 2003; Bringi et al., 2003; Ochou et al., 2011; Amarjyothi and Rao, 2012 and references therein). Given its importance both in fundamental research and operational applications, understanding the variability of DSD and *Z–R* relations remains a subject of un-exhausted interest even after many years of study.

A myriad of *Z–R* relations has been reported by several authors ever since Marshall and Palmer (1948)'s seminal study (See Battan, 1973; Rosenfeld and Ulbrich, 2003; Gosset et al., 2010; Amarjyothi and Rao, 2012; Bamba et al., 2014 and references therein). In addition to the variability in DSD owing to changes in rain type and climatic regime, the coefficients in *Z–R* relations also suffer with

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the uncertainties in the measurements of DSD (due to limited sampling volume and limited data in many cases) and the procedures adopted for deriving the relationships (Jameson and Kostinski, 2001; Campos and Zawadzki, 2000). Furthermore, the relations are derived empirically and therefore are statistical in nature. To compensate the above problems, more data are required to obtain statistically robust relations.

Although rain-specific relations were derived separately for stratiform and convective rain, neither the coefficients nor their trends (i.e., higher/lower values of coefficients for a particular type of rain) remain the same. One set of relations shows larger values of prefactor (A) for convective rain than stratiform rain (Yuter and Houze, 1997), while the other shows the opposite (i.e., larger A for stratiform rain than for convective rain) (Tokay and Short, 1996; Atlas et al., 1999; Rao et al., 2001; Reddy and kozu, 2003; Maki et al., 2005; Islam et al., 2012; Amarjyothi and Rao, 2012). These differences are attributed to the natural variations of DSD in those regions and also to the differences in stratiform/convective classification schemes adopted in those studies (Atlas et al., 1999; Ulbrich and Atlas, 2002). Ochou et al. (2011) and Bamba et al. (2014) argued that all the above sets of relations can exist at the same location, but in different precipitating systems occurring in different atmospheric conditions. They have shown 3 squall line cases in which the coefficients show opposite behavior from stratiform to convective types of rain.

The natural variations in DSD from region to region are caused by the differences in microphysical processes due to geography of the region (for ex., continental, coastal, orography, etc.). Therefore, the DSD and Z–R relations can be linked to climatological characteristics of a region. Several studies tried to link the coefficients of Z–R relation to the region, like continental, oceanic, coastal, orography, etc., and the dominant microphysical processes occurring in those regions (see Rosenfeld and Ulbrich, 2003; Bringi et al., 2003 for a review on region-specific relations). The bulk rain parameters (R, Z and mass-weighted mean diameter, D_m) or DSD model parameters (intercept (N_0), slope (Λ) and shape (μ) of the gamma distribution) are generally used to describe climatological conditions and therefore are employed to link with Z–R relations. Nevertheless, the inverse problem, i.e., microphysical interpretation of coefficients or obtaining microphysical parameters from the coefficients, is much more complex, because it entails more parameters to be estimated from less number of observations (Steiner et al., 2004).

As mentioned above, the DSD and, thereby, Z–R relations will be different for different types of rain and climatic zones therefore, system (rain type)- and region-specific relations are proposed in the literature (Battan, 1973; Yuter and Houze, 1997; Atlas et al., 1999; Rao et al., 2001; Rosenfeld and Ulbrich, 2003; Bringi et al., 2003). However, a few studies have shown that the DSD's vary not only with rain type and region but also with the season, even at the same location, for ex., at Gadanki (a rural station surrounded by hillocks) and Cuddalore (a coastal station) (Fig. 1) (Roy et al., 2005; Rao et al., 2001; 2009; Reddy and Kozu, 2003; Kozu et al., 2006). They noted predominant occurrence of smaller drops during the northeast monsoon (October–December, hereafter referred to as NEM) compared to the southwest monsoon (June–September, hereafter referred to as SWM). The seasonal differences are clearly apparent even in rain rate-stratified DSD and at all R, although the differences are more prominent at smaller R. These seasonal differences are observed not only in seasonal rainfall, but also in cyclonic rainfall (Radhakrishna and Rao, 2010). Detailed analysis reveals that these seasonal differences are due to the differences in microphysical processes, like evaporation, occurring during those seasons (Radhakrishna et al., 2009). Nevertheless, it is not clear whether the observed seasonal differences in DSD are localized (pertaining to Gadanki and Cuddalore) or a common a feature in southeast India. Further, earlier studies used Joss–Waldvogel disdrometer measurements at Gadanki, which underestimates smaller drops during the heavy rain. Therefore, it is not clear from earlier studies, whether the near-absence of seasonal differences in DSD at high rain rates is due to the limitations in the instrument or a real atmospheric feature.

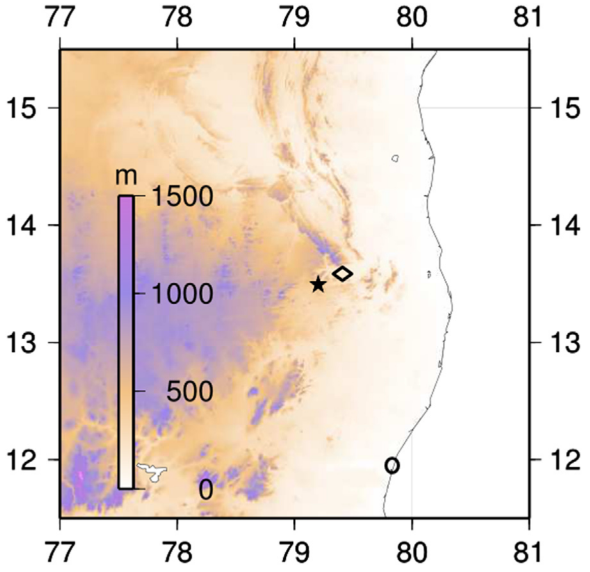

Fig. 1. The topography (in shading) surrounding the experimental site, Tirupati (diamond). Earlier studies on the seasonal variation of DSD in southeast India were made based on the measurements from Gadanki (star) and Cuddalore (circle).

Recently, a 2nd generation Parsivel disdrometer was installed at Sri Venkateswara University (SVU), Tirupati (13.6°N, 79.4°E). The location is about 30 km from Gadanki and is also close to the foothills of Nallamala Hills (in the range of Eastern Ghats), which partly influences the rainfall over that region (Fig. 1). The present study, therefore, aims to address the above issues by studying the seasonal differences in DSD over Tirupati, a different meteorological setting as the station is located near to the foothills, at different rain rates using a different DSD-measuring instrument (Parsivel disdrometer). The other objective of the study is to derive system-specific (rain type) Z–R relations during both monsoon seasons. The system description and method of data analysis are detailed in Section 2. The gross seasonal differences in DSD are studied in Section 3 with the help of probability distributions functions (PDFs) for bulk-rainfall parameters (R, Z and D_0) and DSD-describing gamma parameters (N_0, μ and Λ). Appropriate Z–R relations are also derived in this section and discussed in light of existing relations. In Section 4, the conclusions of the present study are presented.

2. Description of system and data

For the present study, DSD measurements obtained from the optical Parsivel disdrometer have been employed. The variability and robustness of local Z–R relationships, as well as their level of dependency on the storm type (stratiform and convective) and season are studied.

2.1. OTT Parsivel disdrometer

OTT PARSIVEL is a laser-based optical Disdrometer for simultaneously measuring the Pasticle size and velocity of all types of hydrometeors (solid and liquid phase) during the precipitation (Löffler-Mang and Joss, 2000). It can identify many precipitation