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Characteristics of the raindrop size distributions and their retrieved polarimetric radar parameters in northern and southern China

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ABSTRACT

The characteristics of raindrop size distributions (RSDs) and polarimetric radar parameters retrieved by T-matrix for stratiform and convective precipitation in Beijing and Zhangbei (northern China), and Yangjiang (southern China) are studied and compared based on RSD data observed with PARSIVEL disdrometers in these three different climatic regions. The effects of observed and fitted RSD on scattering simulation are also discussed. The conclusions further confirm the obvious variation of RSDs in different climatic regions and rain types. There is significant regional difference in rainfall microphysical parameters for convective precipitation, and small regional difference for stratiform precipitation, instead. Convective precipitations from Beijing and Yangjiang both have higher mass-weighted mean diameter D_m and $\log_{10}N_w$ (N_w: normalized intercept parameter) values than stratiform precipitations. The averaged RSDs from both rain types in Beijing and Yangjiang are in good agreement with gamma distribution while those in Zhangbei cannot be well fitted either by gamma or M–P (Marshall–Palmer) distribution. It is essential to take into account the effect of air density on raindrop fall velocity in highlands far away from sea level, such as Zhangbei. The μ–Λ relation varies with location. For a given Λ value, the fits to the data in the three regions have higher μ values than Florida relation (Zhang et al., 2003). It is robust to retrieve polarimetric radar parameters by T-matrix. There is an exponential relationship between differential reflectivity Z_{DR} and radar reflectivity factor Z_H, as well as the relation between specific differential phase K_{DP} and Z_H. The variation of the relations in different climate regions and rain types results from RSD's sensitivity to climatic regions and rain types. Observed RSD is superior to the fitted one in retrieving polarimetric radar parameters.

1. Introduction

Raindrops are created by the interaction of dynamical and microphysical processes. Information about raindrop size distribution (RSD) is the fundamental microphysical property of precipitation. Therefore, observation of RSD is essential for the understanding of formation and microphysical structure of precipitation, radar estimation of precipitation, improvement of microphysics parameterization in numerical weather prediction models, and effect evaluation of artificial precipitation.

Raindrop size distribution is affected by many physical factors, including collision-coalescence, breakup, condensation, evaporation, updraft, downdraft, and horizontal wind shear and so on, which contribute to RSD variation both spatially and temporally (Bringi et al., 2003; Tokay and Short, 1996; Ulbrich, 1983). The effect of these factors on RSD is

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complex, and RSDs vary not only within a climatic regime but also within a specific rain type (Nzeukou et al., 2004). The microphysical characteristics of the drop size distributions from various climatic regimes and rain types have been demonstrated by numerous studies using the observed disdrometer data (Atlas and Ulbrich, 2006; Bringi et al., 2003; Chang et al., 2009; Chapon et al., 2008; Chen et al., 2013; Lee et al., 2009; Martner et al., 2008; Marzano et al., 2010; Moumouni et al., 2008; Niu et al., 2010; Tapiador et al., 2010; Tokay et al., 2008). Chen et al. (2013) showed that characteristics of DSDs observed in Nanjing (a big city in eastern China) during the Meiyu season are different from those observed in some other tropical or subtropical locations even though eastern China is situated in a similar latitudinal belt, which is likely due to local atmospheric aerosols and/or moisture. The variability of mass-weighted mean diameter D_m and normalized intercept parameter N_w in stratiform and convective rain in different climatic regimes was analyzed by Bringi et al. (2003). The distribution of RSD parameters in the D_m–N_w plane at different latitudes seems to follow prescribed criteria (Marzano et al., 2010).

In the retrieval of polarimetric radar parameters with observed RSDs, the scattering feature of hydrometeors should be computed under certain assumptions to get relatively realistic situation of precipitation particles. For hydrometeors, the scattering characteristics are related to the distributions of size, shape, composition, and spatial orientation of the particles. T-matrix is one of the most powerful and widely used methods for accurately computing scattering features of nonspherical particles, based on directly solving Maxwell's equations, which is also known as the extended boundary condition method (Mishchenko et al., 1996). For a given nonspherical particle, the T-matrix only needs to be computed once and then can be used any number of times for computing the amplitude and phase matrices for any directions of the incident and the scattered beams. Relative to other methods (e.g. finite difference time domain), the T-matrix method is extremely convenient and efficient. Besides, considering that most hydrometeors are nonspherical particles with spatial orientation, the T-matrix is more preferable in scattering simulation of hydrometeors, because it can easily take into account their size, shape, composition and spatial orientation.

It is important and necessary to study and analyze the RSD data and obtain the characteristics of RSD from different rain types and climatic regions of China because of RSD's natural variation both temporally and spatially which was demonstrated by many RSD studies and China's specific climate from other regions. Attention has been paid to the development of X-band dual-polarimetric radar in China in recent years (He et al., 2009a, b, 2010; Zhao et al., 2012). However, the related theoretical and applied research is still far from complete, especially the study of the effect of RSD on retrieving polarimetric radar parameters via scattering simulation. It is essential for further understanding the microphysical characteristics of precipitation, and study of quantitative precipitation estimation and RSD parameters' retrieval with dual-polarimetric radar.

The purpose of the present paper is to study the characteristics of RSDs and polarimetric radar parameters retrieved by T-matrix in rain types and different climatic regions of China. The data sources and analysis method are presented in Section 2. The results of analysis and comparison of the characteristics of RSDs from different climatic regions and rain types are shown in Section 3. Section 4 examines polarimetric radar parameters retrieved by T-matrix in different climatic regions and rain types, and the effect of observed and fitted RSD on retrieved polarimetric radar parameters. The major findings are summarized in Section 5.

2. Data and analysis methods

2.1. PARSIVIEL disdrometer

RSDs analyzed in this study were collected with a PARSIVEL precipitation particle disdrometer manufactured by OTT Messtechnik, Germany. Löffler-Mang and Joss (2000) provided a detailed description of this instrument. Briefly, the instrument is a laser-based optical disdrometer for simultaneous measurement of particle size and velocity of all liquid and solid precipitation. The core element of the instrument is an optical sensor that produces a shallow and broad horizontal radiation band. Hydrometeors falling through the measurement area cause variations in the radiation intensities. The amplitude of the signal deviation is a measure of particle size, and the duration of the signal allows an estimate of particle fall velocity. The instrument can measure the amount (rate) of precipitation and the size distribution and velocity of particles, and also indentify the type of precipitation and provide precipitation code. Additionally, radar reflectivity and visibility are derived. All results can be transferred to the personal computer and data storage in real time, and then analyzed with radar data, which can improve quantitative precipitation estimation. It can operate in any climate weather regime and the incorporated heating device minimizes the negative effect of freezing and frozen precipitation accreting critical surfaces on the instrument. Like other measurement of a physical process, disdrometer measurements are affected by noise and sampling effects (Jaffrain and Berne, 2011).

Particles with diameters between 0.125 mm and 24.5 mm and fall velocities between 0.05 m s^{-1} and 20.8 m s^{-1} can be detected by PARSIVEL. The particle size and velocity are each subdivided into 32 size and velocity bins, respectively, with different bin widths.

The shape of a falling raindrop in still air is determined by a balance of three types of forces, hydrostatic pressure, surface tension and aerodynamic pressure. A small drop has a spherical shape, whereas a larger drop tends to have an oblate spheroid shape with a flatter base. This means that the particle sizes directly derived by the instrument (i.e. $2a$) frequently overestimate the large raindrop diameter. To minimize the potential instrument error, the observed raindrop diameter should be corrected (Yang et al., 2012). The drop axis ratio $r = b/a$ (here vertical axis b divided by the horizontal axis a) is well approximated with

$$r = 0.9971 + 0.2193D_{eq} - 3.5105D_{eq}^2 + 5.0746D_{eq}^3 - 2.3559D_{eq}^4 \quad (1)$$

where D_{eq} is the equivalent-volume drop diameter in cm. Eq. (1) is fitted based on the data of the experimental fit line shown in Fig. 2 of Brandes et al. (2004) due to obvious difference between their fitted relation and experimental data. Equivalent-volume drop diameter D_{eq} can be calculated by a combination of Eq. (1) and $D_{eq} = 2a^{2/3}b^{1/3}$. After shape correction, raindrop diameter is