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Convective–stratiform separation using video disdrometer observations in central Oklahoma – the Bayesian approach

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ABSTRACT

Application of 2-Dimensional Video Disdrometer (2DVD) data, collected in central Oklahoma, to the problem of convective-stratiform rain separation is presented. The partition into convective (CO) and stratiform (ST) periods is achieved by applying a multi-variable Bayesian classification algorithm to the 2DVD dataset. It turns out that the CO-ST separation methods developed for measurements with one type of disdrometer may not work optimally on measurements with a different type of disdrometer. Similarly, single/dual parameter, or simple threshold separation methods may not be able to adequately separate CO and ST rain types. The corresponding shape-slope (μ-Λ) relations of the constrained gamma distribution are derived for these two rain classes. These constrained gamma relations are then used for rain drop size distribution (DSD) retrievals, and the results are compared with those obtained from the exponential distribution and the unified μ-Λ constraint previously proposed. It is demonstrated that the results based on the convective-stratiform separation yield more accurate DSD retrievals with respect to the exponential distribution and moderate improvements in comparison to unified μ-Λ constraint.

1. Introduction

To achieve a better understanding of the rain microphysics and improve the accuracy of quantitative precipitation estimation (QPE), precipitation is often separated into convective and stratiform regimes. Then, proven quantitative relations to estimate the amounts are used. For example, the National Weather Service applies the *Z-R* relation (*R* – rainfall rate, *Z* – reflectivity factor) $Z = 300R^{1.4}$ (Woodley et al., 1975) in summer convection and $Z = 200R^{1.6}$ (Marshall et al., 1955) in stratiform precipitation. This is because different microphysical mechanisms dominate the hydrometeor growth in convective and stratiform clouds, yielding different hydrometeor distributions, and hence different *Z–R* relations. Initial drop growth in convective clouds is by condensation, followed by collision, coalescence, and breakup. In the higher sections of the stratiform clouds, ice crystals grow at the expense of water vapor (deposition), whereas in lower portions aggregation and riming occurs. Particles become larger due to aggregation, and fall after melting as relatively large raindrops (Houze, 1993; Tokay and Short, 1996) in comparison to small/medium drop sizes in convection for the same rainfall rate. In addition, considerably different latent heating profiles of convective-CO and stratiform-ST systems lead to diverse atmospheric circulation patterns (Tao et al., 2010). Clearly, different microphysical mechanisms govern convective and stratiform precipitation.

In recent years, several studies emphasize the necessity for the convective-stratiform separation (Tokay and Short, 1996; Schuur et al., 2001; Atlas and Ulbrich, 2006; Islam et al., 2012, etc.). Tokay and Short (1996) elaborate on the importance of distinguishing rain as convective or stratiform in observational, modeling, and remote sensing studies; microphysical processes

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affect kinematic fields through differing latent heating vertical profiles, and influence cloud modeling parameterizations and radar rainfall estimations due to different CO-ST DSDs. Schuur et al. (2001) in their 2-Dimensional Video Disdrometer – polarimetric radar study have found that $R(Z)$ and $R(K_{DP})$ relations (K_{DP} is the specific differential phase) underestimate rain rate when the DSD is dominated by small drops and overestimate rain rate when the DSD is dominated by large drops. Therefore, there is a need for classification of different rain types associated with different DSDs in polarimetric rainfall estimation. Islam et al. (2012) argue that CO-ST discrimination is important in precipitation retrievals, weather modification and forecasting.

To address these microphysical differences, numerous radar-based classification algorithms separating the convective from the stratiform rain had been proposed (Churchill and Houze, 1984; Steiner et al., 1995; DeMott et al., 1995; Rosenfeld et al., 1995; Biggerstaff and Listemaa, 2000; Mesnard et al., 2008; Bringi et al., 2009; Thurai et al., 2010, etc.). These approaches came as a consequence of the radars' large spatial coverage. However, use of polarimetric radar data in microphysical retrievals/studies hinges on DSD models which are usually derived from the instruments that can directly measure DSDs. Thus the disdrometer, or some similar type of the instrument that can directly measure DSD, is needed for inferring the appropriate DSD model.

There have been fewer radar-disdrometer and disdrometer-only classification attempts (e.g., Tokay and Short, 1996; Atlas et al., 1999; Zhang et al., 2001; Bringi et al., 2003; Caracciolo et al., 2006). Tokay and Short (1996) used the number concentration parameter N_0 of gamma distribution to separate convective from its stratiform counterpart with the same rain rate. Atlas et al. (1999) exploited variability in several integral and microphysical parameters along with the gamma distribution shape parameter μ to produce *Z*–*R* relations for convective, transition and stratiform rains. Both studies used the RD-69 (Joss and Waldvogel, 1967) impact disdrometer. Bringi et al. (2003) computed DSDs from measurements by two types of disdrometer, two-dimensional video disdrometer and RD-69 impact type disdrometer, and compared these with polarimetric radar retrievals in a statistical approach to distinguish between CO and ST rain. Caracciolo et al. (2006) derived a theoretical relation between μ and Λ parameters of the gamma DSD. They utilized the 4th, 5th and 6th moments in an attempt to mitigate underestimation of small drops (D < 0.5 mm, where D is the drop diameter), which is a limitation of the RD-69 disdrometer. In this algorithm the line $1.635\Lambda - \mu = 1$ in a μ-Λ space serves as the discriminator; the stratiform events are indicated above the line and convective below.

The goal of this study is to develop a 2DVD-based multi-parameter algorithm to classify the convective and stratiform portions of rain events in order to more accurately characterize microphysical properties associated with the two types of precipitation. Subsequently, the newly derived constraining CO-ST relations could be utilized for polarimetric radar DSD retrievals and QPE improvements. The Bayesian approach looks very promising for separating CO and ST rains. It combines statistical knowledge about the initial processes (*a priori*) with the knowledge of how these processes change and evolve (conditional probabilities), leading to the final outcome (*a posteriori*).

The paper is organized as follows: In Section 2, the data sets, acquisition of these, and processing are described. The theoretical background for Bayesian approach and guidelines for the practical implementation are in Section 3, whereas the classification results are presented in Section 4. Comparison between several DSD retrieval methods are depicted in Section 5, and the summary and the discussion are at the end.

2. Datasets

2.1. Disdrometer data collection and processing

Observations and data, collected from June 2006 to May 2012 with the University of Oklahoma (OU) low-profile 2DVD in central Oklahoma, are presented. Polarimetric radar data, collected with the S-band polarimetric KOUN radar are used mainly for 2DVD CO-ST separation verification. Specifically, Steiner et al. (1995, herein SR) method is used as primary verification tool. The SR method was applied to the Constant Altitude Plan Position Indicators (CAPPI's) data, constructed from KOUN volumetric scans at 1.5 km altitude with respect to the 2DVD ground level. The outcome of the SR method directly above the 2DVD location served for validation. The temporal evolutions of vertical profiles of Z_H (reflectivity at horizontal polarization, dBZ), Z_{DR} (differential reflectivity, dB), and ρ_{hv} (copolar correlation coefficient), extracted from the volumetric scans directly above the 2DVD location, are used as additional source of information, providing an aid in verification (mostly for the timing of prominent CO and ST features).

For most of the observations, the disdrometer was located at the Kessler Atmospheric and Environmental Field Station (KAEFS), an OU test site approximately 29 km in range and 191.4° in azimuth from KOUN. The site is 350 meters above sea level. From 24 April to 9 July 2007, the 2DVD was located at the Harris farm, 65 km southwest from KOUN. From 4 February to 3 June 2010, the 2DVD was in Oklahoma City, ~26 km northwest of KOUN. The lowest beam elevation angle for the first location was ~250 meters above the 2DVD site and for the latter two locations ~560 m and 220 m, respectively. The disdrometer measured a total of 54681 DSDs, each sampled over a 1-minute duration. To avoid under sampling from the 2DVD, 1-minute measurements with drop number count less than 150 per minute (herein min^{-1}) were excluded from the dataset, reducing the total number of DSDs to 32282. Although the threshold of 150 min^{-1} seems high, mean and median rainfall rate of the excluded samples were 0.27 and 0.11 mm h^{-1}, indicating that only light rain was affected by the threshold. This step was necessary to preserve the representativeness of DSDs. Horizontal resolution of the 2DVD is approximately 0.2 mm while vertical resolution depends on the terminal velocity of the particles and ranged from 0.1–0.2 mm for hydrometeors. The drops observed by 2DVD were partitioned into 41 size bins having 0.2 mm width each, with central diameters ranging from 0.1 to 8.1 mm. For a detailed description of the 2DVD, the reader is referred to Kruger and Krajewski (2002) and Schönhuber et al. (2008).

2.2. Subjective data separation for training and testing

In an attempt to reduce subjectivity in the training set for convective – stratiform discrimination, we employed a method