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RETRIEVAL OF RAINDROP SIZE DISTRIBUTION USING C-BAND POLARIMETRIC RADAR MEASUREMENTS

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1. Introduction

The raindrop size distributions (DSD) are important in the parameterizations of cloud microphysical processes hereby the numerical cloud models. In addition, the DSD information is also important for the estimation of rainfall amount by radar or other remote sensing techniques. For rain rate measurements using radar, it is well known that R-K_{DP} relations estimate more accurate rain rates than Z-R relations, over a critical rain rates, because of advantages such as insensitivities to DSD variations. It is thought, however, that the rain rate directly integrated from DSD are more accurate than by other relations, because the rain rate are given by the integration of DSD.

In the present study, we retrieve the gamma DSD parameters from C-band polarimetric radar measurements. The retrieved DSD parameters are compared with disdrometer data. And then the rain rate are estimated from the retrieved DSD, and compared with several rain gauges rain rate.

2. Data and processing

The Japan Australia Tropical Mesoscale Experiment (JATMEX) was carried out in Darwin, Australia, during 1998 to 2000 (Iwanami et al., 1999). Among the four radars during the JATMEX, we used the data observed by C-band polarimetric radar (C-POL, frequency of 5.625 GHz) of BMRC, Australia. The C-POL radar measures Z_{HH}, Z_{DR}, and differential propagation phase shift Φ_{DP} (Keenan et al., 1998). The calculation of the specific differential phase shift K_{DP} and the correction for the attenuation of Z_{HH} and Z_{DR} were accomplished using a 13-gate filtered Φ_{DP} field (Carey et al., 2000). A Z_{DR} bias caused by power loss during JATMEX was corrected by adding a bias of 0.88 dB, which was obtained by comparing radar data with disdrometer data during weak rain rate less than about 5 mm/hr.

A Joss-Waldvogel type disdrometer DSD data recorded at an azimuth of 203^{o} and at a range of 23 km from the C-POL site were utilized for comparisons with the radar retrievals. The DSD parameters every minute were fitted to the modified gamma DSD (1) (Ulbrich, 1983) by the least square fitting scheme,

$$N(D) = N_0 D^{\mu} \exp(-\Lambda D)\,, \qquad (1)$$

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where the DSD parameters N_0($mm^{-1-\mu}m^{-3}$), μ, and Λ(mm^{-1}) are the intercept, shape and slope parameter, respectively. Median volume diameter D_0 was calculated from Λ and μ.

Several rain gauges located within observable range of the C-POL were used for comparisons with radar rain rate.

3. DSD retrieval method

Consider a cost function *J* consisted of variances between theoretical and observed radar measurements, and deviations (Δ) between retrieved N_0-μ and an empirical N_0-μ relation,

$$J = \iiint [\, w_{HH}(Z_{HH} - Z_{HH}{}^{obs})^2 + w_{DR}(Z_{DR} - Z_{DR}{}^{obs})^2 + w_{DP}(K_{DP} - K_{DP}{}^{obs})^2 + w_{N_0-\mu}\Delta^2 \,]\, d\Lambda\, dN_0\, d\mu\,, \qquad (2)$$

where Z_{HH}, Z_{DR}, and K_{DP} are theoretical values, and the *obs* denotes radar observed value. The *w* denotes the weighting factor which determines the contribution with respect to *J*. The fourth term in the right hand is a constraint term, which adjusts the retrieved N_0 and μ to an empirical N_0-μ relation.

The gamma DSD parameters in (1) can be determined by minimizing *J*. The necessary conditions that *J* be a minimum are that the partial differential equations with respect to the each parameter must be zero simultaneously. However, since it is difficult to derive the partial differential equations, we used a similar method to the algorithm presented by Seliga and Bringi (1976). Fig. 1 shows the variations of the theoretical values Z_{DR}, Z_{HH}/N_0, and K_{DP}/N_0 with Λ and μ for the C-POL wavelength. These values were calculated by T-matrix with conditions of temperature of 20^{o}C, maximum drop diameter of 8 mm, antenna angle of 0^{o}. An axis ratio of raindrop was calculated from the equation of Andsager et al. (1999), and Gaussian distribution with mean of 0^{o} and standard deviation of 10^{o} was supposed for consideration of drop canting angle. These conditions were adopted for all simulations in this study.

Using the data shown in Fig. 1, some $(\Lambda,\mu)_i$ pairs corresponding to an observed Z_{DR} can be determined. And then N_{0i} corresponding to the pairs can be obtained from an observed Z_{HH} using Fig. 1(b). Among these selected $(\Lambda, \mu, N_0)_i$ pairs, the solution of the DSD parameters for the observed radar measurements are determined by selecting a pair minimizing function *J*.

4. Results

(1) DSD retrievals

To test the performance of the proposed DSD retrieval method, some experiments were carried out using simulated radar measurements from the fitted DSD parameters of the disdrometer data recorded during 06-13 UTC, Jan. 15, 1999. An N_0 -m relation, $Log(N_0)= 3.11+0.51\mu$ was derived during this time. The results of experiments were quantified by the mean relative error(MRE),

$$MRE(\%) = \left[\sum_{i=1}^{N} \left((X_i - Y_i)/Y_i \right)^2 / N \right]^{0.5}$$

where X and Y denote the retrieved and the disdrometer DSD parameters, respectively.

The experiments were undertaken by changing the weighting factors in (2). In all experiments, the weighting facors for Z_{DR} and Z_{HH} were fixed as 1, because $(\Lambda,\mu)_i$ pairs are directly determined from Z_{DR}, and then N_{0i} corresponding the $(\Lambda,\mu)_i$ pairs are calculated from Z_{HH}. According to the results of experiments, in which the weighting factors of K_{DP}(w_{DP}) and N_0 -mrelation($w_{N0\text{-m}}$) were changed 0 to 1, the best agreements were obtained in the case using K_{DP} together with the N_0 -mrelation (w_{DP}=1, $w_{N0\text{-m}}$=0.01). The factor of $w_{N0\text{-m}}$=0.01 implies a consideration of the variance of the N_0 -m relation. The worst results were derived in the case using K_{DP} alone. This suggests that the K_{DP} values are too small to retrieve the DSD parameters.

Fig. 2 shows the retrieved DSD parameters where w_{DP}=1 and $w_{N0\text{-m}}$=0.01. The MRE(%) for Λ, D_0, $Log(N_0)$, and μ are 14.1, 11.1, 5.7, and 280.9, respectively. The relatively large MRE for μ is due to negative values of μ itself. As shown in the figure, the retrieved DSD parameters show good agreement with the disdrometer data for Λ and $Log(N_0)$ smaller than about 10 and 6. It is thought that the deviations in the large Λ values occurred because the distinction of $(\Lambda,\mu)_i$ pairs corresponding to a given Z_{DR} is not clear in the region of low Z_{DR} (large Λ) as shown in Fig. 1(a). In the case of D_0, some differences are shown at about 1.6 mm in the disdrometer data. These large retrieved D_0 values, compared to the disdrometer data were obtained at small Λ values. Since a small Λ means a gentle slope in DSD, the D_0 differences are ascribed to the increased effects of large drops (5-8 mm) when D_0 is calculated by integration to D_{max}.

Fig. 3 shows the retrieved DSD parameters from the observed radar measurements during 06-13 UTC, Jan. 15, 1999. The radar data interpolated to a height of 500 m above the disdrometer were compared with averaged disdrometer data (averaged over 3 minutes from 1 minute later than the starting time of new volume scan of the radar which was a 10 minutes interval). To consider the Z_{DR} measuring error, we used all $(\Lambda,\mu)_i$ pairs in the range ±0.2 dB of a given Z_{DR} value. As shown in Fig, 3, the variations of the retrieved gamma DSD parameters are agree well with the disdrometer data during 08-11 UTC. It is thought that the differences prior to 0730 UTC were caused by a few convective cells passing over the disdrometer site. In the case of D_0, the large differences were not derived, because D_0 were calculated from both small Λ and μ.

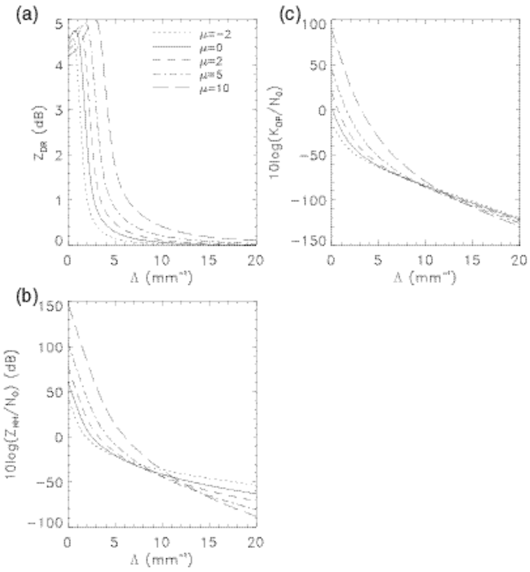

Fig. 1. Variations of the simulated Z_{DR}, Z_{HH}/N_0, and K_{DP}/N_0 with L *and* m

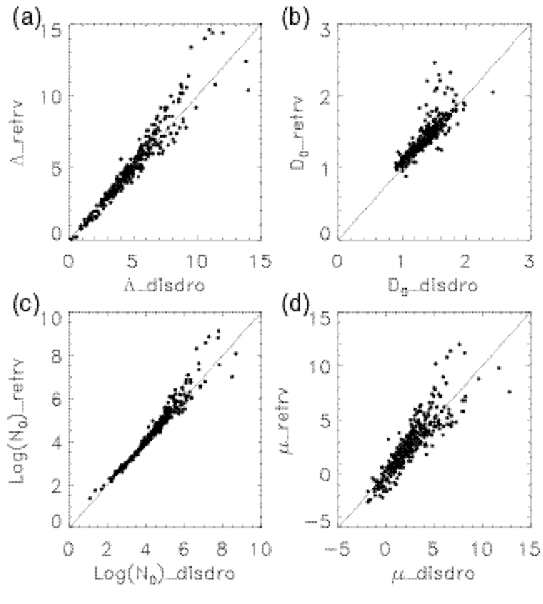

Fig. 2. Comparisons between the DSD parameters obtained from the disdrometer and retrieved from the simulated radar measurements.

(2) Rain rate estimation

We estimated the rain rate R(DSD) from the retrieved DSD parameters through integration to D_{max}. Fig. 4 shows the rain rate $R(Z_{HH})$, $R(K_{DP})$, and R(DSD) for the observed radar data during 06-13 UTC, Jan. 15, 1999. The $R(Z_{HH})$ and $R(K_{DP})$ were obtained from the following Z-R and R-K_{DP} relation,

$$Z_{HH} = 549.8R^{1.1}$$

$$R(K_{DP}) = 31.48K_{DP}^{\ 0.916},$$

which were derived from comparisons between the simulated Z_{HH} and K_{DP} and the rain rate from the disdrometer data. The R(Gauge) denotes the rain rate recorded by gauges positioned within 40 km range from the C-POL site.

As shown in the Fig. 4, $R(Z_{HH})$ show relatively better agreement with gauges rain rates than $R(K_{DP})$ in weak rain rates less than about 10 mm/hr. In contrast, in the intensive rain rates more than 20 mm/hr $R(K_{DP})$ indicate better agreements than $R(Z_{HH})$. These results accord with previous study on comparison between $R(Z_{HH})$ and $R(K_{DP})$ (Ryzhkov and Zrnic, 1995). In the case of R(DSD), better agreements with gauges rain rates than $R(Z_{HH})$ and $R(K_{DP})$ are shown in the entire range of rain rate.

5. Conclusions

The radar measurements Z_{HH}, Z_{DR}, K_{DP}, and an empirical N_0 -m relation were utilized to retrieve the modified gamma DSD parameters. The basic concept of the retrieval method is to minimize sum of variances between the theoretical and observed polarimetric radar measurements. An empirical N_0 -mrelation was added as a constraint that adjust the retrieved N_0 and μ to the empirical relation. It is thought that the retrieval method presented in this study is an useful one for retrieval of the gamma DSD parameters from radar measurements.

In the further, we have a plan to analyze the microphysical processes in the topical precipitation systems based on the estimation of the DSD parameters.

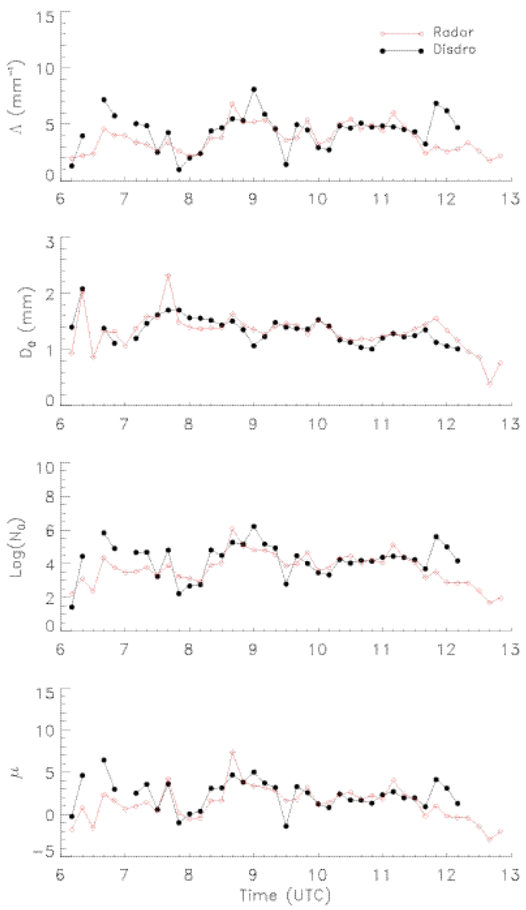

Fig. 3. Comparisons between the time variations of DSD parameters obtained from the disdrometer and retrieved from the observed radar measurements.

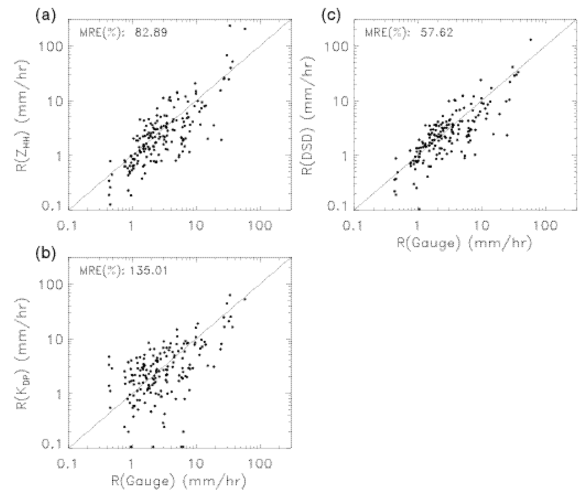

Fig. 4. Comparisons of gauge rain rate with radar rain rate derived from (a) $R(Z_{HH})$, (b) $R(K_{DP})$, and (c) R(DSD) integrated from the retrieved DSD parameters.

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