APPLICABILITY OF THE ITERATIVE BACKWARD RETRIEVAL METHOD FOR THE GPM DUAL-FREQUENCY PRECIPITATION RADAR

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1. INTRODUCTION

The Dual-frequency Precipitation Radar (DPR) on the core satellite of the Global Precipitation Measurement (GPM) mission will measure radar reflectivity factor (Z_m) in the Ku-band (13.6 GHz) and Ka-band (35.5GHz). There have been several methods to retrieve two parameters (N_0, D_0) of the drop size distribution (DSD) function from the Z_m in the two frequencies assuming that the DSD function is modeled by a gamma distribution function as shown in Eq. (1).

$$N(D) = N_0 D^{\mu} \exp\left[-(3.67+\mu)D/D_0\right], \qquad (1)$$

where μ is the third parameter of the DSD function, which is a known parameter in this study.

While Meneghini et al. [1] developed a retrieval method with the use of surface reference technique (SRT), Mardiana et al. [2] proposed another retrieval method without the use of SRT. However, it was pointed out that Mardiana's method (referred to as MA04 hereafter) cannot give the true solution for heavier rainfall cases [3]. The purpose of this study is to show the conditions that MA04 can give the true solution.

2. APPLICABILITY OF THE IBRM AND MA04

MA04 is a special case of the iterative backward retrieval method (IBRM), and the IBRM is equivalent to the forward retrieval method (FRM) with a constraint on D_0 (D_0-constraint) [D_0 is larger than 0.82mm in the case of μ=1]. In the FRM, a problem to retrieve (N_0, D_0) from Z_m at each range always has two solutions: the true solution and a false solution. When the true solution does not satisfy the D_0-constraint (type-0), the IBRM can never give the true solution. On the other hand, when the true solution satisfies the D_0-constraint and the false solution does not (type-1), the IBRM can always give the true solution. In other cases (type-2 and type-3), as both the true solution and the false solution satisfy the D_0-constraint, the IBRM cannot always give the true solution.

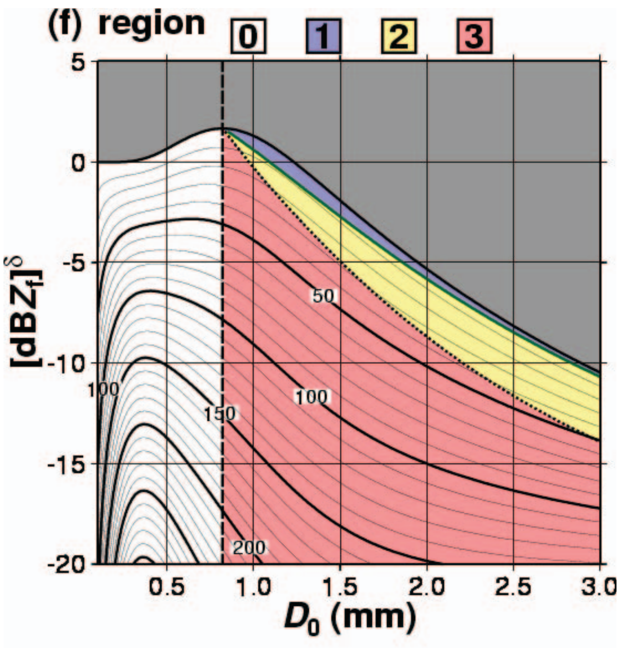

Fig. 1. Categorization into the types 0 to 3 in the case of μ=1, α=1, and L=0.25[km]. The contour shows the rain rate [mm h^{-1}]

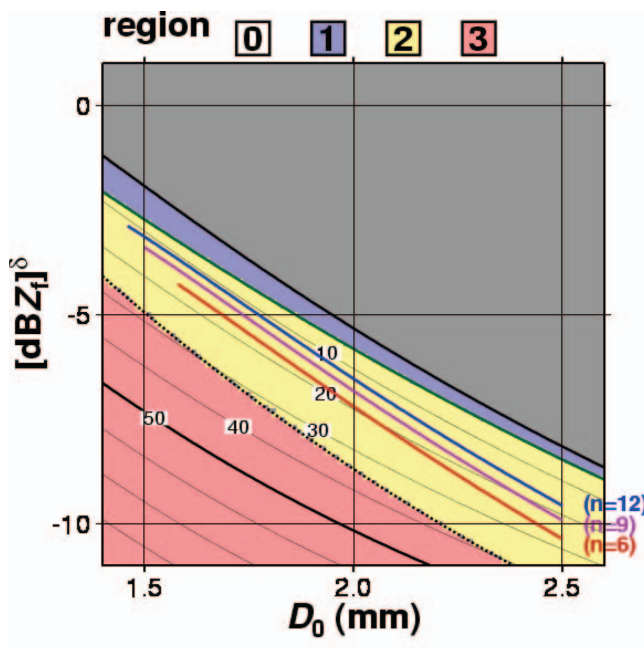

Fig. 2. The part of Fig. 1 is enlarged. The three lines indicate the upper limit of the rain rate for which Mardiana's method can be applied.

Figure 1 shows categorization into the four types on (D_0, $[\mathrm{dB}Z_f]^\delta$) plane. $[\mathrm{dB}Z_f]^\delta$ is the difference of $[\mathrm{dB}Z_f]$ between the Ka-band and the Ku-band, and $[\mathrm{dB}Z_f]$ at a discrete range bin is defined as Eq. (2).

$$[\mathrm{dB}Z_f] \equiv [\mathrm{dB}Z_e] - \alpha \times 2 \times [k] \times L, \qquad (2)$$

where $[\mathrm{dB}Z_e]$ is the effective radar reflectivity factor (in decibel), $[k]$ is the attenuation coefficient, L is the width of the range bin (=0.25km), and α is a parameter. The second term of the right-hand side of Eq. (2) indicates the attenuation occurred inside the range bin (called "internal attenuation" in this study). The value of α should be larger than 0 and smaller than 1, but α is set to be 1 in this study as well as in the previous studies such as [1], [2], and [3]. Therefore, $[\mathrm{dB}Z_f]$ of a range bin can be determined only by (N_0, D_0) of the range bin. In Fig. 1, the contour indicates rain rate of the range. The rain rate for which the IBRM can always give the true solution is less than 10 mm h^{-1} (depending on D_0).

Figure 2 enlarges a portion of Fig. 1. The three lines show the upper limit of the rain rate for which MA04 can give the true solution according to [3]. It is shown that MA04 can give the true solution not only for type-1 but for part of type-2, where path integrated attenuation (PIA) of the true solution is smaller than that of the false solution. As MA04 tends to select the solution with the smallest PIA when the IBRM has multiple solutions, it can give the true solution for part of type-2. However, if the number of range bins (n) is large, false solutions with a smaller PIA than that of the true solution emerge because of the accumulation of numerical error, and it becomes difficult for MA04 to select the true solution.

3. APPLICATION OF MA04 TO SIMULATED DATASET

To check the applicability of MA04 under realistic conditions, a simulated DPR observation dataset was produced based on the TRMM standard product 2A25 (version 6) as follows.

(1) In 2A25, range bins with liquid precipitation (from node-D and clutter free bottom) are taken.

(2) k can be calculated by $k=aZ_e^b$ (a, b, Z_e are given in 2A25)

(3) As k/Z_e is a function of D_0, D_0 can be retrieved, and N_0 is also retrieved by substituting D_0 into k or Z_e. According to the 2A25 standard algorithm, μ=3 is assumed. The physical temperature of rain drops (T) is set as 0°C at node-D and increases by 1.5°C per range bin.

(4) From D_0, N_0, and μ(=3), Z_e and k in the two frequencies of DPR are calculated.

(5) Z_m is calculated by assuming α=1. No attenuation above the top of node-D and no attenuation by non-precipitating particles are considered.

(6) Where Z_m in the Ka-band is less than 12dB, the range bin and lower range bins are excluded from simulation data.

The simulated dataset was produced for one month (July 2001). The categorization explained in Sec. 2 is applied to the dataset. If all the range bins in a pixel is categorized into the same type, the pixel is called a uniform type pixel, otherwise it is called a mixed type pixel. Almost half of the rain pixels are uniform type pixels. Among uniform type pixels, type-1 is dominant, and type-0 is second dominant in terms of the number of pixels, but type-2 and type-3 are more dominant than type-0 in terms of total amount of rainfall.

MA04 is applied and the retrieved rain rate at the lowest range bin is evaluated. Figure 3 shows the results for uniform type pixels. In most cases of type-0, retrieved rain rate is underestimated. On the other hand, in most cases of type-1, retrieved rain rate is very close to the true value. In type-2, there is severe underestimation particularly when the number of range bins is large. When the number of range bins is 1 to 4, the results are pretty good. In type-3, regardless of the number of range bins, the retrieved rain rate is mostly underestimated. These results correspond well to the discussion in sec. 2; MA04 can give the true solution in type-1 and par t of type-2 (when the number of range bins is small).

4. SUMMARY AND FUTURE STUDIES

The limitation of applicability of MA04 has been pointed out by previous studies, and the conditions on which MA04 can give the true solution is discussed objectively and is tested by using a simulated DPR observation dataset in this study. In near future studies, more realistic simulated dataset including solid and melting layers and with observation errors should be used to test actual applicability of MA04, and MA04 should be modified to have no underestimation.

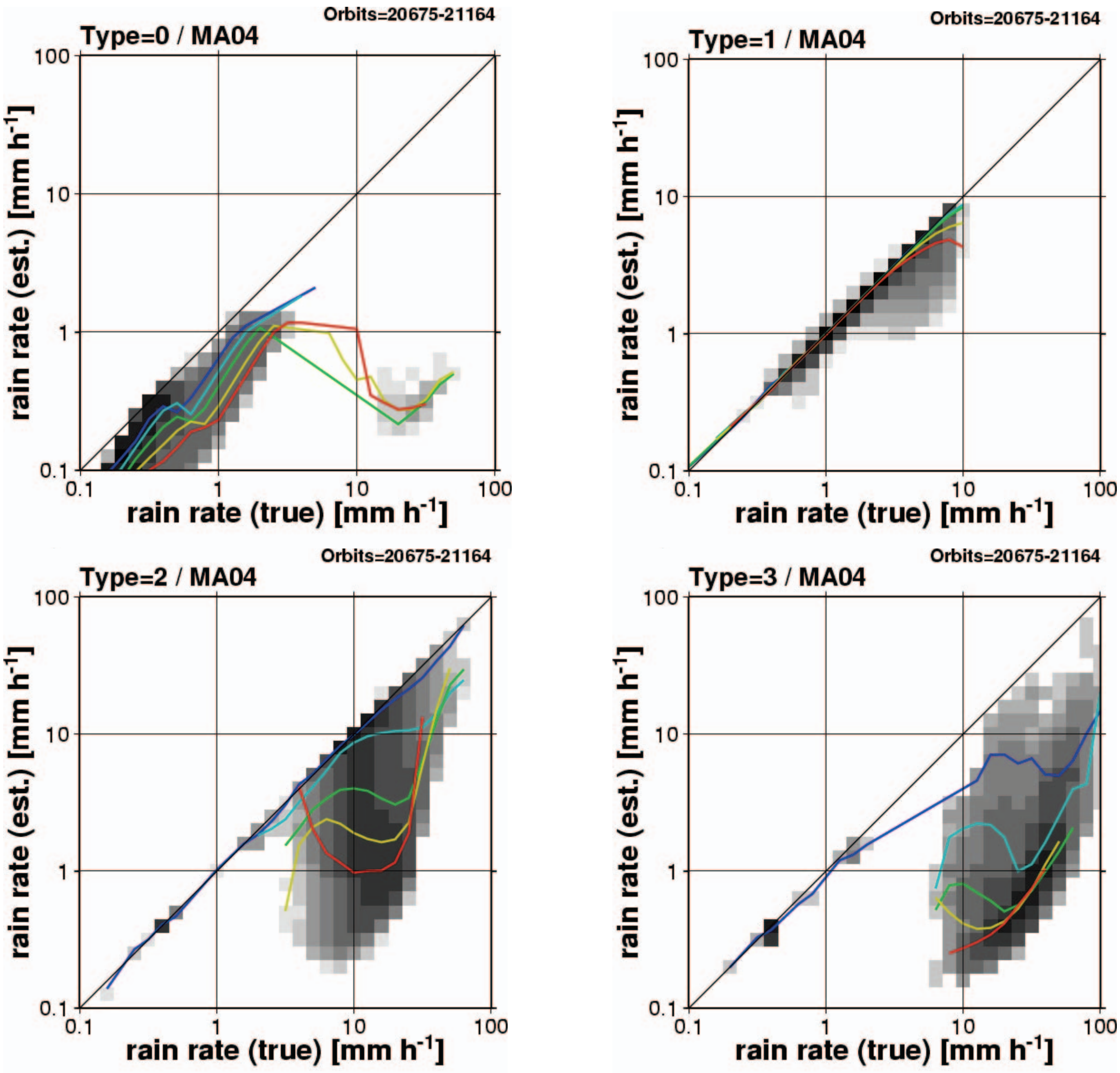

Fig. 3 The evaluation of MA04 for type-0 through type-3 (uniform pixels). The horizontal (vertical) axis is the true (retrieved) rain rate at the lowest range bin. Dark (light) shade indicates the large (small) population of pixels. Colored lines show the average of retrieved rain rate (the number of range bins is 1-4 for blue, 5-8 for light blue, 9-12 for green, 13-16 for yellow, and 17-20 for red).

REFERENCES

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