Reply to the reciewer1's comments

Thank you for your kind review. My reply is written in blue characters

.

The manuscript presents a retrieval method to retrieval mass-weighted mean diameter (Dm) using satellite-based nadir pointing Doppler radar measurements. The retrieval method uses the attenuation-corrected reflectivity, measured Doppler velocity, and a constrained specific attenuation (k in dB/km). The simulated DSDs are produced with a Monte Carlo model to produce convective rain DSDs with extreme rain rates (exceeding 200 mm/hr) using a coalescence and breakup parameters. While I would like to see Dm and vertical air motion retrieved from satellite Doppler radar measurements, I believe the current manuscript is not up to the standards of Atmospheric Measurement Techniques. My specific comments are listed below.

Reply: Radar-measured Doppler velocities are reflectivity-weighted values and depend on the Drop size distribution (DSD) of rain and vertical air velocity (w_0). To estimate Dm, it is necessary to remove the both effects. In the retrieval method, the specific attenuation (K) is estimated from the measured Ze (or Z) and Vp using a look-up table (LUT) which assumes Gama DSD (DSDtable). The observed Vp is modified as Vp = Vpobs + △Vp so that the estimated K matches the observed K. This △Vp is the sum of the effect of △Vp(DSD) resulting from the difference between the actual rain DSD and the DSDtable and the effect of △Vp(air) resulting from air velocity, i.e., △Vp = △Vp(DSD) + △Vp(air). Because two effects are removed simultaneously, it is not possible to directly determine the effect of atmospheric velocity alone. This method is solely for determining Dm. Therefore, the accuracy of atmospheric velocity estimation is not discussed.

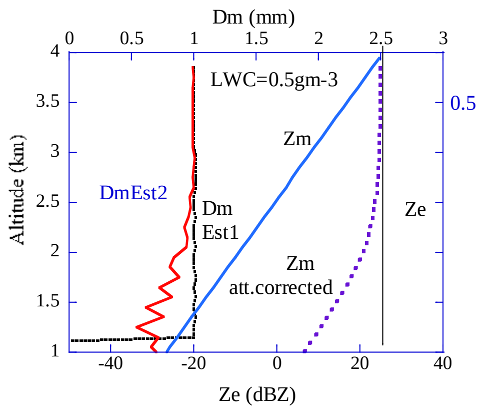
1. Since the proposed Dm retrieval method uses the measured Doppler velocity and assumes DSD gamma shape parameters, the air motion should also be retrievable. Getting the air motion correct is critical for the Dm retrieval. Why was air motion retrieval not discussed?

Reply: Again, the air motion cannot be derived from the method. Even for W_0=0, △Vp≠0. Let's look at an example of the estimation at W-band. Measured Z=24.7dBZ, Vp=2.8m/s, Dm=0.52mm, k=9.7dB/km and W_0=0m/s. The estimated K is 11.5dB/km and △Vp=0.2m/s, i.e. Vp=3m/s resulting Dmest2=0.54mm. The △Vp is not W0 (=0) because of the difference of actual DSD and DSDtable. Thus △Vp is determined by a combined effect of DSD and atmospheric velocity, and therefore cannot directly determine the atmospheric velocity. A method for estimating atmospheric velocity is described in appendix 2, but its verification is a future task.

2. The manuscript described the retrieval method for observations at Ku-band and at W-band. The retrieval at Ku-band is appropriate because Ku-band radars can observer through convective rain. However, the proposed retrieval method for radar observations in the W-band is not practical. The specific attenuation is greater than 10 dB/km at W-band for Dm between 0.5 and 2 mm (See Fig. 7). For the convective rain simulated in Section 2, with rain rates exceeding 200 mm/hr, the W-band signal will be extinguished before reaching the surface, preventing a retrieved specific attenuation using the surface return. If the manuscript wants to convince the reader that the method is possible at W-band, then the simulation needs to start with attenuated reflectivities (also known as measured reflectivities). The manuscript would need to estimate the attenuation-corrected reflectivities and then perform the retrieval.

Reply: At the W band, significant attenuation apear in rain as the reviewer mentioned, Therefore, the retrieval of Dm is limited to relatively weak rain. Figure A1 shows vertical profiles of Ze, Zm, Zm' (attenuated corrected Zm) and estimated Dm for vertically uniform rain of Gamma DSD of LWC=0.5g/m3, and Dm=1mm. It can be seen that Dmest2 can be accurately estimated above an altitude of 2.5km.

The W-band radar cannot detect PIA for intense rain as the reviewer pointed out but detect PIA for weak rain. Whether the PIA is detectable or not depends on the rain rate and the radar sensitivity. We found many observed data of PIA up to 60dB/km for rain in the initial CPR data. We estimated Dm for the EarthCARE CPR data. Figure A2 shows the observed Ze(Zm), Vp, and the estimated Dm. Peaks of Ze appears at an altitude of 4 km and then decreases sharply due to the attenuation. It can be seen that estimation is possible for near top of rain layer. At around 3 km in altitude, Dms cannot be estimated due to missing Vp due to the folding error. Note that the estimated Dms are not correct because the no attenuation corrected reflectivity and Vp without correcting Doppler folding error were used for the estimation. We have just made the estimation to examine the potential of the retrieval method for W-band radar because we also had the same concern as the reviewer. More accurate estimation will be performed in the future.



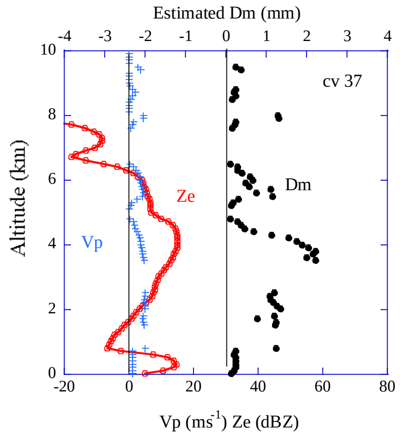


Fig.A1 simulated vcertical profiles of Ze, Zm and Dm

Fig.A2 Estimated Dm for CPR data of

3. There are several assumptions that need to be removed, or accounted for, before this retrieval method can be taken seriously. Specific assumptions:

a) Attenuation-corrected reflectivity Ze assumed to be known beforehand. (Line 339)

b) Look-up table (LUT) is based on a fixed mu and a gamma shaped distribution.

Reply: The above assumptions are usually used in the rain-rate estimate algorithm in radar measurements. In the Z-R relationship, $R=aZ^b$, the coefficients a and b are determined from statistical relationships between Z and R. This means that the shape of DSD is assumed. In the GPM observations, gamma shaped DSD is also assumed in the rain-rate estimate module. In addition, attenuated corrected values of Z are applied in the estimation. Attenuation corrected reflectivity is calculated in another module before estimation of rain rate. The present method applied similar procedure to the current radar algorithms for rain measurements.

c) The Ze vs. Doppler velocity curve with the over-plotting of the k and Dm grid (Fig. 8) are based on fixed mu gamma distribution, and the retrieval accuracy depends on selecting the correct LUT (Line 418).

Reply: The shape of DSD is a key point in radar measurements. Appropriate assumptions on DSD are necessary. To reduce the uncertainties in the estimation, attenuation is used in the method. For Ku-band, attenuation is almost insensitive to the shape of DSD and therefore different technique is needed as shown in 4.3. For W-band, the effects of DSD are reduced to some degree.

4. Line 418. “This figure suggests that selection of appropriate LUT is critical for accurate estimation.” How is the appropriate LUT going to be determined? If we knew the DSD shape, then the retrieval would be trivial.

Reply: Selection of appropriate shape of DSD is a key point in radar measurements of precipitation. Conventional radar sometimes suffers significant errors in the estimated rain due to insufficient Z-R relationship. Most advantage of the present method is to reduce the uncertainties resulted from inappropriate selection of DSD using attenuation which is sensitive the shape of DSD and is useful to correct the effect of DSD in the retrieval of Dm for W-band. For Ku-band, attenuation is almost insensitive to the shape of DSD and therefore different technique is needed as shown in 4.3.

5. Fig. 9 and 11. Both figures show the first and final Dm estimates are underestimated relative to the model Dm. As an example of numbers from Fig. 11, it looks like Dm_est ~ 1.25 mm and Dm_model ~ 1.5 mm for Est 2. We can use Fig. 10 to see the change in Doppler velocity for Dm changing from 1.25 to 1.5 mm is about 1 m/s, for all three models assuming mu = 1, 3, or 12. This is a very large error in vertical air motion. And this is in a rain region assumed to have zero air motion (see the text on Line 396, “The vertical velocities of the atmosphere are zero for most data.”) This suggests that the air motion is not being removed correctly from equation (3) and the error is not only in Dm but for the air motion estimate, also.

Reply: The reason for the underestimation at large Dm is that the DSD changes significantly at large Dm (figs. 10, 12) which is different from the DSDtable. As shown in fig. 6, the Dm-Ze relationship changes when Dm > 1.5. The significant difference from the gamma distribution, as seen in Fig. 4 (1 km altitude DSD), is considered to be the reason for the underestimation. This may not be serious because such DSDs are not so many (Fig.6). Most DSDs are not so different from the Gamma DSD which is the reason that the estimated rain rates from the GPM are in good agreement with the observed values.

6. How does the retrieval work for the profiles with upward vertical air motion of 10 m/s? If the Dm were 1 mm, the zero air motion Doppler velocity would be about 5.5 m/s downward (see Fig. 9), and the measured Doppler velocity (Vp) would be about +4.5 m/s upward, and off the axis of Fig. 9.

Reply: Cloud droplets ascend within updraft region in which raindrops have not yet been formed; therefore, this is not shown in the figure.

7. Can the manuscript provide a scatter plot retrieved air motions vs. modeled air motions?

Reply: Air motion cannot be estimated directly in the retrieval as shown above.

8. In step 3 of the retrieval algorithm (Line 370), it states "If estimated k differs from the measured value, estimate Dm and k again …" How is the "measured k" determined in this manuscript from the simulated DSDs? How is the method used in this manuscript different than how the satellite algorithm would estimate k from PIA?

Reply: Yes. The measured (model) k is determined from the simulated DSDs using the Mie theory. In the satellite algorithm, k is determined such as the method by Meneghini and Nakamura, (1990). I am not sure current method in the GPM and EarthCARE algorithm.

9. In Fig. 2 shows that the simulation produces convective rain rates of 200 to 400 mm/hr. What is the specific attenuation at Ku- and W-bands for these extreme rain rates? What are the LWCs for these extreme rain rates? How representative are the specific attenuations shown in Fig. 7 for LWC = 1 g/m^3 when the simulated rain rates are over 200 mm/hr?

Reply: Figure 2 shows all data from the generated DSDs. For Dm estimation, only data with KuZe < 50 dBZ and W at 25 dBZ are used. Circles have been added to the figure to indicate this data. For w at z < 40 dBZ, k is the maximum of 20dB/km and rain rate is less than 30mm/h for LWC=1 g/m3.

10. From the description of the retrieval algorithm (Lines 366 to 374), it appears that the red dots shown in Fig. 8 are not used in the retrieval algorithm. Is that correct? A more appropriate figure would be one without the red dots, because the iterative procedure is moving around the Dm vs. k grid box using Ze, Vp, and an unknown measured k. Please clarify this for the reader because as shown, the reader may think the red dots are used in the retrieval.

Reply: The red dots in the figure indicate the observed Vp and Ze data. In the estimation, k' is determined from these red dots. Next, Vp is corrected by comparing it with the observed k, and Dm is determined. The red dots indicate the observational data that allow for the initial estimation of k; they are included to demonstrate that the figure's range encompasses the observational data. I have added an explanation regarding this point.

11. Line 759. In the summary section, “For Ku-band, the effects of air motion were well removed, …” I do not think the manuscript showed that air motions were well removed. The manuscript did not present any figures showing the accuracy of retrieving air motion.

This sentence will be removed in the revised manuscript.

12. At Ku-band, specific attenuation has been shown to be a good estimate of rain rate. So, can this method be described as a modified Z-R-Vp method?

Reply: May be Z-k-Vp method?.