10.208 Effect of Multiple Scattering in GPM Precipitation Radar Measurement

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1. Background

The Tropical Rainfall Measuring Mission (TRMM) satellite has been continuously monitoring precipitation on a global scale since it was launched in 1977. Following the TRMM, the Global Precipitation Mission (GPM) satellites are scheduled to launch from 2013. Dual-frequency precipitation radar (DPR) onboard the GPM core satellite will be operated at two frequencies of 14 GHz and 35 GHz, and the DPR is expected to have a potential to measure more accurate rainfall rate than the PR.

Japan Aerospace Exploration Agency (JAXA) has developed a robust algorithm for DPR data. The use of Ka-band wavelength for spaceborne radar, however, is the first attempt so that there may have some unknown factors. For example, multiple scattering may not be negligible, especially for radar signals with 35 GHz wavelength, because the size of foot print is so large in case of space-borne radar.

The main objective of this study is to examine quantitatively the effect of multiple scattering based on an approach using numerical simulation. The contribution of multiple scattering to the total received signal is discussed from the aspects of wavelength and liquid water content (LWC). In addition, the linear depolarized ratio from polarimetric radar is also considered as a parameter closely related to the degree of multiple scattering. This is a preliminary consideration for developing a method to detect and correct multiple-scattering effect for improving the accuracy of rain rate estimation from DPR data.

2. Method

In our simulator (Kobayashi et al. 2011), scattering properties are calculated for precipitation and cloud particles based on radio wave scattering (Mie or Rayleigh) theory for spherical particles, or T-matrix method for non-spherical particles (Mishchenko and Travis 1998). The multiple scattering is modeled by a forward Monte-Carlo method, and the polarized radiative transfer equation is solved.

The propagation of incident waves is modeled by the travelling of photons. The atmosphere is divided into a rectangular grid of boxes. Photons from the source (the space-borne radar) are allowed to enter the top boundary of inhomogeneous precipitation, traveling in a specified direction.

The distance of the path, along which it

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travels and interacts with a raindrop, is determined by the volume scattering coefficient. The redirection of the photon takes place at the end of its trajectory, and it is determined by the phase function in the usual way. Scattering probability to the radar antenna is based on the antenna pattern. Photons are traced until the weight of photons becomes smaller than a certain threshold. The reflectivity received is calculated from the number of photons returned to the antenna (Kunkel and Weinman 1976, Kobayashi 1998).

The processes in our code are composed of the following items:

1) Emit photons from radar to rain medium.
2) Determine the distance the photon travels until it interacts with a rain drop by the scattering coefficient.
3) Determine the scattering direction by the phase matrix.
4) Calculate the probability (I,Q,U,V) that it returns directly to the antenna.
5) Repeat until the photon goes out of radar control volume.

3. Case study

Radar signals from DPR are simulated for warm-rain cloud measurement assuming homogeneous gamma-type drop size distribution (DSD) and liquid water content (LWC) in cloud. Drop size distribution (DSD) is assumed to be the modified Gamma function.

$$N(r) = N_0 r^{\alpha} \exp(-br^{\beta})$$

α=2, β=0.5,

b (the mode radius=0.07-0.3 mm).

We assume that the DPR observes the nadir direction, and the shape of raindrop is spherical. Computations are performed for vertically uniform/non-uniform precipitation models. The vertical profile of rain-rate is produced by the WRF (Weather Research and Forecasting) model run. In configurations of DPR, the beam width is set to be 0.71 deg, and the altitude of satellite is 400 km.

4. Result

The ratio of the multiple-scattering signal to the total signal is calculated to assess the contribution by multiple scattering. Vertical variations of the contribution for W-, Ka-, and Ku-band radars are shown in Figure 1. The path length of 0 means the top of rain layer, and the value of 4 means the bottom of rain layer. In this case, liquid water content of 1 gm^{-3}, and a DSD is the modified Gamma function with the mode radius of 0.07 mm. No significant multiple scattering contribution is found in the simulation for Ku-band radar. On the other hand, the significant contribution appears for W- and Ka-band radars.

Figure 2 is the same as Figure 1 but for various liquid water contents for Ka-band radar.

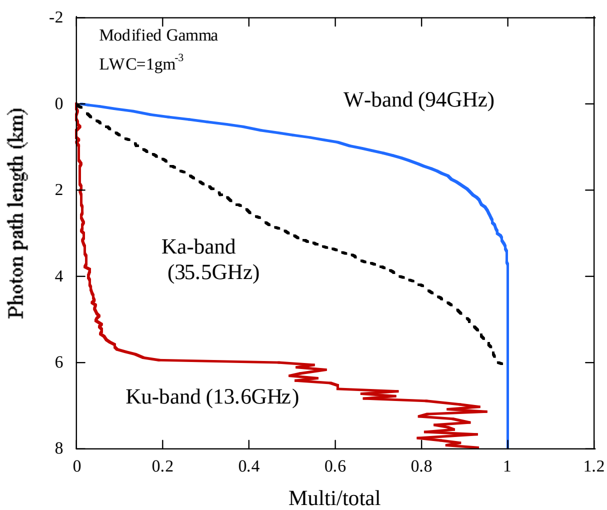

Figure 1: Vertical variations of the multiple-scattering contribution for Ku-, Ka- and W-band radars.

The multiple-scattering contribution increases with liquid water content.

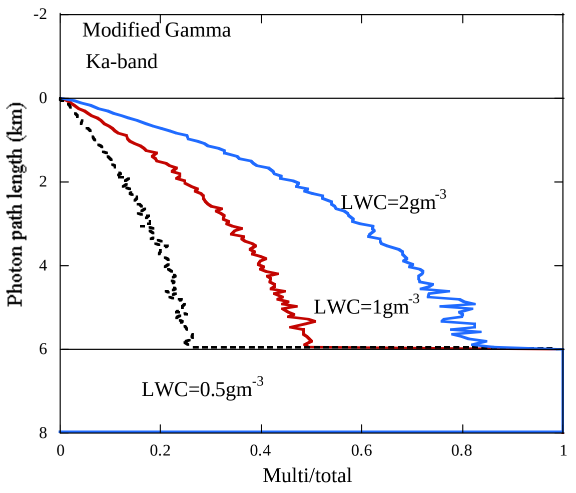

Figure 2: Multiple-scattering contribution for various liquid water contents.

Figure 3 shows the multiple-scattering contribution for vertical profile of rain-rate that is simulated with the WRF model for Ka-band and Ku-band radar. In spite of a relatively weak rain case, large multiple-scattering contribution of 20% appears. The multiple-scattering contribution increases by twice when rain-rate

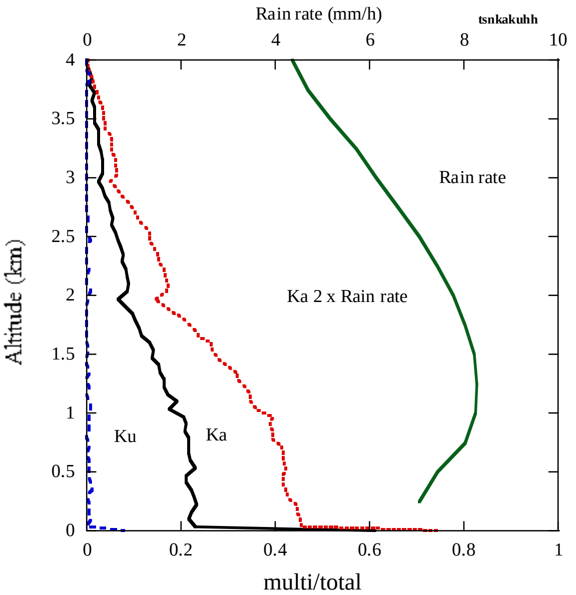

Figure 3 Multiple-scattering contribution for rain-rate profile from WRF model.

is doubled (designated as “2X” in Figure 3).

In rainfall rate estimate, single scattering signals are usually assumed. For accurate rainfall rate estimate, we need to detect the degree of multiple-scattering contribution in the received signal. One of methods is to use the linear depolarization ratio (LDR) (Battaglia et al., 2006). The LDR increases when the multiple-scattering contribution becomes large (Figure 4), indicating that he LDR can be an index of the multiple-scattering contribution.

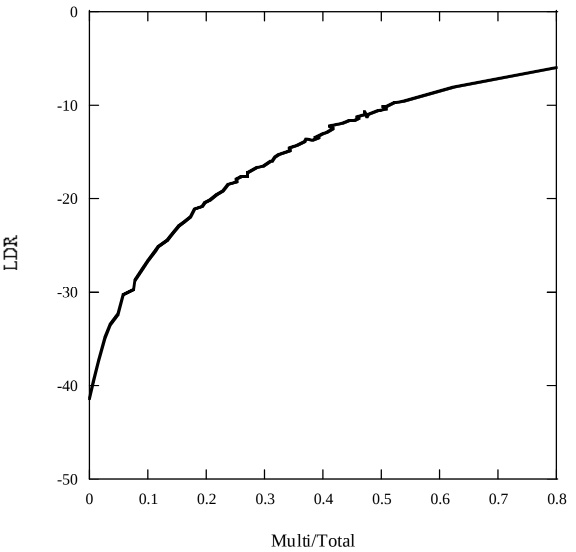

Figure 4 Linear depolarization ratio versus multiple-scattering contribution.

Figure 5 shows the LDR, the single and total signals for Ka-band radar for uniform precipitation. Abscissa is a photon path length. The LDR increases with the large discrepancies between the single and total signals. Unfortunately, the LDR will not be observed in the GPM DPR. The dependence of the LDR on the multiple scattering, however, can be used in the ground validation of the DPR.

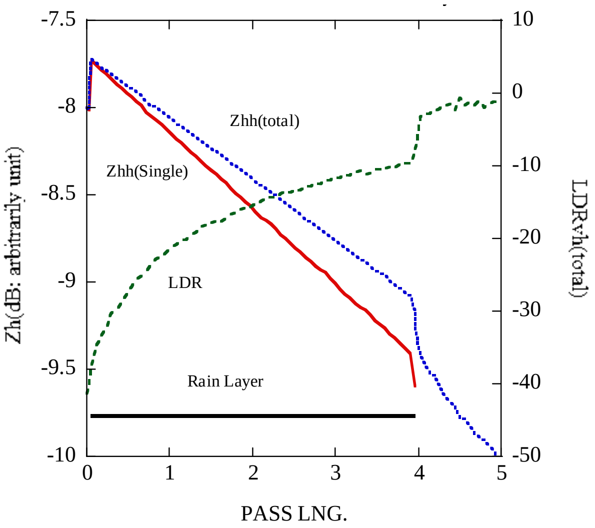

Figure 5 Linear depolarization ratio, the single and total scattered signals as a function of photon path length.

5. Summary

This study discussed on the multiple-scattering contribution in the received signal from the GPM DPR using a radar simulator developed. Sensitivity experiments also are performed by various LWCs. Results indicate that the degree of the contribution of multiple scattering depends on path-length from the cloud top and LWC, and that radar signals with 35 GHz wavelength are clearly suffered from multiple-scattering effect. The contribution of multiple-scattering to the total received signal with 35 GHz wavelength can be estimated well by the ratio of the total signal (14 GHz) to the total signal (35 GHz), which has little dependence on path-length from the cloud top.

LDR is simulated as one of polarimetric parameters, and it is a good indicator of the degree of multiple scattering. The development of quantitative correction scheme of the multiple-scattering effects is important as future research directions.

Acknowledgements

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