Radar simulation studies for measurement of precipitation from space-borne radar on GPM

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(Dated: 15 Julyl 2014)

1. Introduction

The Global Precipitation Mission (GPM) core satellite successfully launched on 28 Feburary 2014 from Japan on an H-IIA rocket. The GPM core satellite equips with a dual-frequency precipitation radar (DPR) to measure precipitation. The DPR is a radar operated at frequencies of 14GHz (Ku-band) and 35 GHz (Ka-band) and has a potential to measure more accurate rainfall rate than the space-borne precipitation radar (PR) operated at a single frequency on the TRMM satellite. The DPR is, however, a new instrument. In particular, the Ka-band radar is the first space-borne radar for measurements of precipitation. The Ka-band radar has a merit to detect weaker rain than the Ku-band radar but suffers more attenuation. In addition, there may be multiple scattering contribution in the received signals for intense rain (Battaglia et al., 2006). These effects are still unknowns. To examine theses unknowns, various ground validations of the DPR measurements of precipitation are planned by using Ka-band radar and ground-based dual-polarized radar which is capable of providing distributions of rain intensity with higher accuracy by using variables obtained by the dual-polarized radars include specific differential phase (Kdp) and differential reflectivity (Zdr) than conventional weather radar in which rainfall rate estimate using the so-called Z-R relationship. These polarimetric parameters, however, depend on various characteristics of precipitation, such as, raindrop size, shape, orientation, phase as well as rainfall rate in a complicated way (Bringi and Chandrasekar, 2001). To develop a robust algorithm for more accurate measurements of precipitation from those radars, it is needed to evaluate theoretically how micro-physical properties of precipitation link to the received signals with polarimetric parameters and to the multiple scattering contributions in the space-borne radar.

We have developed a radar simulator for multiple scattering contributions in space-borne radar and for ground-based polarimetric radar measurements of precipitation. We will present results of multiple scattering contributions and the attenuation in the DPR configurations by using our radar simulator. We will also present a method to identify the multiple contributions from simultaneous measurements with Ka-band and Ku-band radar.

2. Radar simulation model

We calculated single scattered signals from precipitation for ground-based dual-polarized radar and multiple scattered signals for space-borne radar by using generalized radar simulator (GRASIA).

For modeling ground-based dual-polarized radar signals, a lot of papers have been published (eg. Oguchi, 1981, Olsen,1982, Holt, 1984,Stapor and Pratt, 1984,Matrosov, 1991, Vivekanandan et al., 1991). The electrical field components (Es) of the scattered electromagnetic waves can be expressed as

$$\begin{bmatrix} E_{vs} \\ E_{hs} \end{bmatrix} = \frac{e^{-ikr}}{r} \begin{bmatrix} S_{vv} & S_{vh} \\ S_{hv} & S_{hh} \end{bmatrix} \begin{bmatrix} E_{vi} \\ E_{hi} \end{bmatrix} \tag{1}$$

where index s and i denotes scattered and incident electromagnetic wave, respectively. Distance of target from radar is r. k is wavelength/2 π .The matrix S (unit: [L]) is the amplitude scattering matrix which relates the incident and scattered electromagnetic waves. The components of the scattering matrix are calculated by Mie theory for spherical particles and T-matrix method for non-spherical particles of oblate/prolate (Mischchenko, 1980). Various parameters of drop size distributions, drop orientation, atmospheric properties such as temperature, components and radar configurations are easily allowed as input data for simulations (GRASIA-P).

For space-borne radar, Monte Carlo model was applied. Our Monte Carlo model was originally developed to simulate solar radiative properties for horizontally inhomogeneous atmospheres (Kobayashi, 1988, 1991) and was extended to calculate multiple scattering effects on a space-borne lidar (Kobayashi et al., 1997) and to calculate scattering of polarized radio wave (GRASIA-M). A forward Monte Carlo method is used to solve the polarized radiative transfer equation. The

Monte Carlo method directly simulates the trace of photons in the precipitation field. The atmosphere is divided into a rectangular grid of boxes. Photons from the source, that is the space-borne radar, are allowed to enter the top boundary of inhomogeneous precipitation, traveling in a specified direction. The distance of the photons until it interacts with a rain droplet is determined by the volume scattering coefficient. The redirection of the photon takes place at the end of its trajectory and is determined by the scattering matrix in the usual way. At each scattering event, scattering probability, i.e. stokes vector (I,Q,U,V), to the radar antenna which has Gaussian antenna pattern. Photons are traced until weight of photons becomes smaller than a certain threshold. The process of our code is shown by

1） Emit photons from radar to rain medium

2） Determine the distance the photon travels until it interacts with a rain drops by scattering coefficient

3) Determine the scattering direction by the phase matrix.

4） Repeat until the photon escape radar resolution.

3. Results

We calculated multiply-scattered signals from precipitation by space-born radar with the GPM configurations. Vertical profiles of rain rate were calculated by using a meso-scale numerical model with a horizontal resolution of 4km (WRF). Precipitation used in this study was the domain-averaged values for the area around Kyushu and Shikoku at around 2013/06/25 19UTC, calculated as an initial value 06/25 00UTC JMA-GSM (Japan region) in 2013. Drop size distribution N(D) (DSD) is assumed to be the M-P size distribution.

$$N(D) = N_0 \exp(-\Lambda D) \qquad (2)$$

where, D is the volume equivalent diameter (mm) of raindrops and Λ is the slope parameter. Raindrop is assumed to be oblate and the axis ratio varied with size (Beard and Chung, 1987). The DSD is calculated using the lope parameter of size distribution, number concentration and mixing ratio of water substances, and Euler gamma function （Morisson,.and Thomson,2009）. Figure 1 shows vertical variations of rainfall rate)solid line and slope parameter Λ (dotted line) in the M-P drop size distribution. Radar simulations were performed for warm rain at altitude lower than 4.5 km MSL. The Phase matrix is calculated by using the T-matrix method for given DSD and atmospheric temperature and applied to the Monte Carlo method.

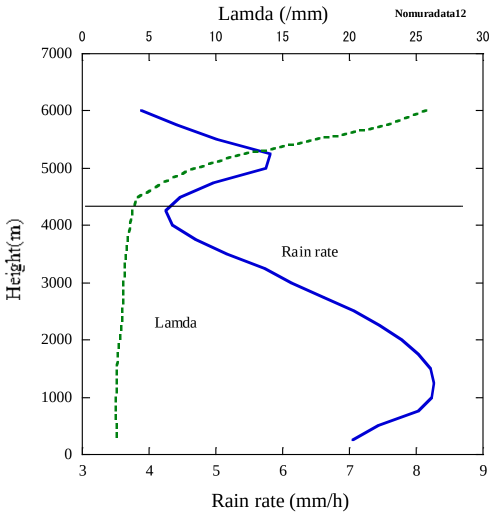

Figure 1: Vertical variations of rainfall rate (solid line) and slope parameter Λ (dotted line) in the M-P drop size distribution.

Figure 2 shows vertical variations of the ratio of the multiple scattering signals to the total signals (multiple scattering (MS) contributions) for Ku (blue dotted line) and Ka-band radar (black line) for vertical profile of rain rate shown by green line. Red line is the multiple scattering contributions for rain rate increased by two times. For Ku band radar, almost no multiple scattering contribution appears, On the other hand, although relatively weak rain, large multiple contributions of 20% appear for Ka-band radar at the lowest altitude of precipitation layer. The multiple contributions for precipitation of rain rate increases by twice as much (sign 2X in Fig.2) are almost twice of the original precipitation.

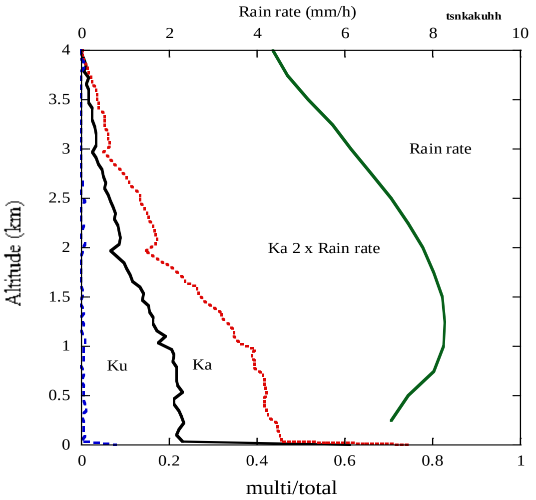

Figure2: Vertical variations of multiple scattering contributions for Ku (blue dotted line) and Ka-band radar (black line) for vertical profile of rain rate shown by green line. Red line is the multiple scattering contributions for rain rate increased by two times.

As shown in Fig.2, the multiple scattering contributions may not be neglected for Ka-band radar in intense rain. However, the Ka-band radar suffers significant attenuation for such intense rain and may not able to detect enough signals from rain and therefore cannot measure precipitation. In particular, precipitation in lower altitude above which intense rain exists, cannot able to be measured by the Ka-band radar. Figure 3 shows vertical profiles of equivalent radar reflectivity Ze at radar frequency of 14 (left figure) and 35GHz (right figure) calculated with GRASIA-P. Five rain models of rain rate multiplied by one to five are adopted, as shown by 1x,2x,3x,4x and 5x in Fig.3. For Ku-band radar, attenuation is negligible. For the Ka-band radar, however, significant attenuation appears. The Ka-band Radar data is difficult to use at lower altitude than 2 km for 5x models associated with the minimum detectable level of Ze of 10dB in the GPM Ka-band radar..

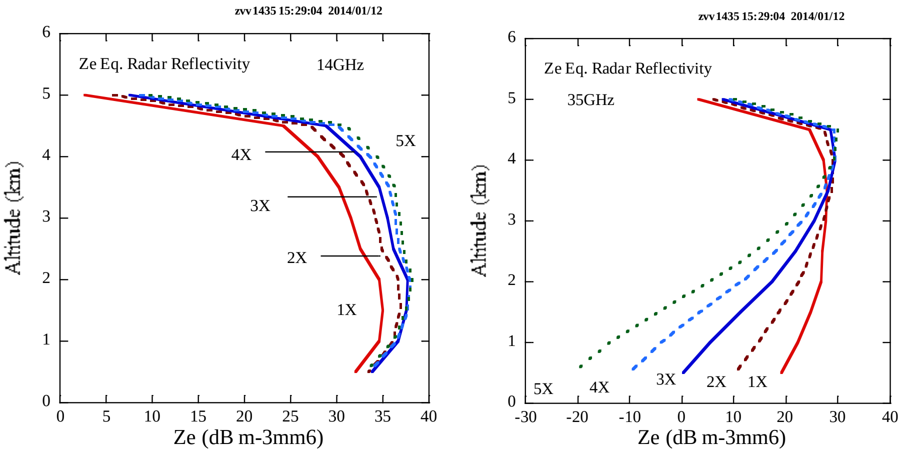

Figure3: Vertical profiles of Ze for Ku-band radar (left figure) and Ka-band radar (right figure). Five rain models of rain rate multiplied by one to five are adopted, as shown by 1x,2x,3x,4x and 5x.

4. Can we detect MS effects?

Rainfall rate estimate is usually made on the assumption of single scattered radar signals. It is, therefore, needed to examine how the multiple scattering contribute the radar received signals in particular for radar at 35 GHz. Generally, MS contribution cannot be known. As mentioned earlier, MS contribution is negligible for Ku-band radar in contrast to significant contribution for Ka-band radar. MS contribution depends on range and microphysical properties of precipitation among which scattering coefficient of rain is essential to determine MS contribution. This is because the photon path until it interacts with raindrops is determined by the scattering coefficient. Scattering coefficient depends on DSD, refractive index, shape of raindrops and radar frequency complicatedly. Changes in scattering coefficient with radar frequency are significant. However, ratio of the scattering coefficient at 35 GHz and 14GHz may not change so much. Under this condition, the ratio of the single scattered radar reflectivity does not also change significantly. Consequently, different MS contributions between 14 and 35GHz signals can be used to estimate MS contributions. Figure 4 shows MS contribution versus the ratio of total signals at 35 GHz and 14GHz for homogeneous rain. Almost same relationships are obtained for different range. Figure 5 shows MS contribution versus the ratio of total signals for various altitude and rain rate for vertical profile of rain as shown by Fig 1. Attenuation corrected values are used for Ka-band radar. This figure suggests that MS contribution is closely related to the ratio and can be identified from the ratio.

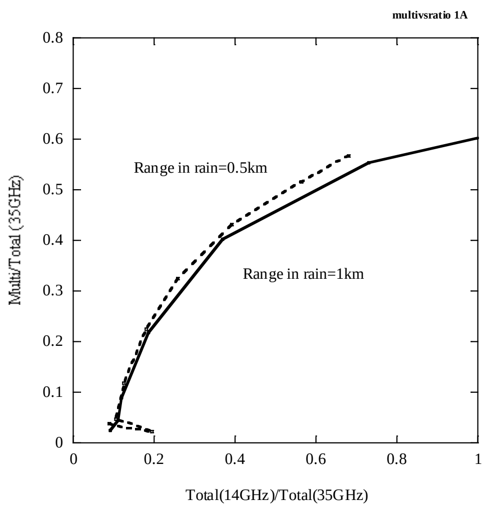

Figure 4: MS contribution versus the ratio of total signals at 35 GHz and 14GHz for vertically homogeneous rain at range of 0.5 and 1km.

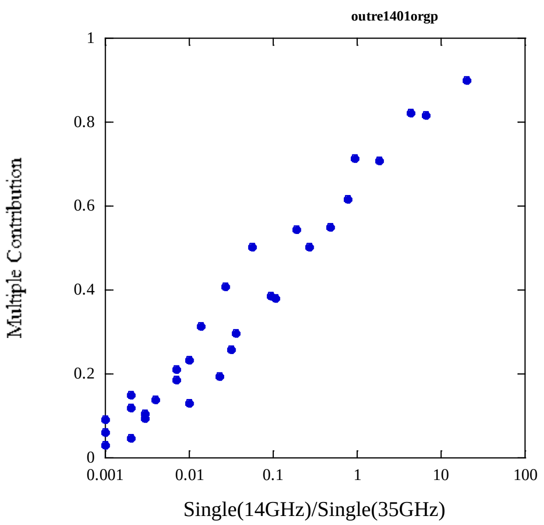

Figure 4: MS contribution versus the ratio of total signals at 35 and 14GHz for rain profile shown in Fig.1. Data of various ranges and rain rates are plotted.

5. Conclusions

We simulated scattered signals from rain for the GPM DPR configurations. The multiple scattering contribution likely occurs in the Ka-band radar for intense rain. For such intense rain, however, Ka-band radar signals are significantly attenuated and undetectable. Therefore, the multiple scattering effects may be so serious in the measuring of heavy rain in the GPM. The degree to which the multiple scattering affects the rainfall rate estimate depends on the microphysical properties of precipitation. Identifying multiple scattering affected signals is essential for accurate measurements of precipitation. The ratio of Ku-band to Ka-band signals is closely related to the multiple scattering contributions and can be used to identify the multiple scattering contributions.

Acknowledgement

This study was partially supported by the PMM project conducted by the Japan Aerospace Exploration Agency (JAXA).

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