Ground Validation of GPM DPR Precipitation Type Classification Algorithm by Precipitation Particle Measurements in Winter

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Abstract

A field observation was carried out along the coast of the Japan Sea in the 2016−2017 and 2017−2018 winter seasons, using the Ground-based Particle Image and Mass Measurement System (G-PIMMS) to evaluate the Global Precipitation Measurement Mission (GPM) dual-frequency precipitation radar (DPR) precipitation type classification algorithm. The G-PIMMS was installed at Kanazawa University and Ishikawa Prefectural University, which are about 10 km apart from each other. The G-PIMMS observations showed that the major precipitation particle type (graupel or snowflake) was different in the precipitation types classified by the GPM DPR algorithm.

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1. Introduction

The Global Precipitation Measurement Mission (GPM) core satellite was launched from the Tanegashima Space Center of the Japan Aerospace Exploration Agency (JAXA) in February 2014. It can observe not only tropical but also mid- to high-latitude areas with its orbit inclination of 65 degrees and has the objective of obtaining global homogeneous precipitation data, including solid precipitation. The core satellite carries a dual-frequency precipitation radar (DPR) which consists of Ku (13.6 GHz) and Ka (35.5 GHz) -band radars. The Ka-band radar is suitable for estimating precipitation at high latitudes because it can detect light rain and snow (Hou et al. 2014, Skofronick-Jackson et al. 2017). The dual frequency ratio (DFR), which is defined as the difference between the Ku- and Ka-band radar reflectivities, provides important information for the identification of the hydrometeor phase (Liao and Meneghini 2011).

Precipitation type classification is essential to correctly estimate the vertical profiles of latent heat release by precipitating clouds. The vertical profile of the latent heat release in a cloud differs with the precipitation type (convective or stratiform) because of different microphysical processes (Houze 1989). Schumacher et al. (2004) estimated the latent heat budget in tropical clouds from the Tropical Rainfall Measurement Mission (TRMM; Simpson et al. 1988) precipitation radar. In convective clouds, latent heat release heats the atmosphere through all layers of a cloud due to the active deposition growth of ice particles in the upper layer and condensation growth of raindrops in the lower layer. In stratiform clouds, melting of solid particles and evaporation of raindrops cool the atmosphere in the lower troposphere. Information on the precipitation type classification obtained by measurements from space, is important for a better understanding of the global-scale heat budget in clouds.

It is well known that there are remarkable differences in radar echo distributions between convective and stratiform precipitation (Steiner et al. 1995). Stratiform clouds are characterized by a bright band (BB) where solid precipitation particles begin to melt just below the 0°C level, and radar echo distributions are usually broad and uniform horizontally. On the other hand, convective clouds have a vertically-extended strong radar echoes without a BB.

The GPM DPR precipitation type classification algorithm (Awaka et al. 2016) classifies the observed precipitation profiles into convective, stratiform, or other types. The measured dual-frequency ratio (DFRm) obtained from the GPM DPR is used for the detection of BBs and precipitation type classification. In addition, for the detection of convective precipitation, an algorithm that flags pixels containing intense ice precipitation above the −10°C level is implemented (Iguchi et al. 2018).

The detection of a BB is essential for the classification of stratiform precipitation by the TRMM and GPM radars (Awaka et al. 2009). However, BBs cannot be detected in winter snow clouds because only solid precipitation occurs from the ground to the cloud top. Thus, the GPM DPR precipitation type classification algorithm needs to be validated using ground level data for winter snow clouds.

To develop precipitation type classification methods, the direct measurement of precipitation particles is essential. Upper air soundings have been conducted with a special balloon-borne instrument called videosonde (Suzuki et al. 2012, 2014, 2016a, 2018, Watanabe et al. 2014, Takahashi et al. 2017). The videosonde is a powerful tool for measuring the vertical profiles of precipitation particles in clouds, but it cannot be continuously operated for a long time and cannot measure particle weights. Suzuki et al. (2016b) developed a new low-cost instrument based on the videosonde, called the Ground-based Particle Image and Mass Measurement System (G-PIMMS), to capture precipitation particle images and to estimate their weight at the ground level.

In this study, to validate the GPM DPR precipitation type classification algorithm in winter, we conducted intensive observations using G-PIMMSs in the Hokuriku region along the coast of the Japan Sea in the 2016−2017 and 2017−2018 winter seasons.

2. Data

The G-PIMMS developed by Suzuki et al. (2016b) has two CCD cameras, an infra-red sensor, a strobe, and an electronic...
balance inside (Figs. 1a and 1b). When a particle interrupts the infrared beam, the stroboscopic light emission provides us with the still image of the particle in the air captured by the CCD camera. The video images are recorded on a personal computer that is connected to the internet, allowing the data to be monitored remotely. The infrared sensor has the same performance of the videoconduc. The minimum performance is to completely react to a particle of 0.5 mm in diameter, which falls from 5-cm square inlet of the G-PIMMS. Sampling volume that the CCD camera can capture particle images by a strobe is 30 mm long, 30 mm wide, and 22 mm high. The weights of particles are measured at a frequency of 10 Hz by an electronic balance (minimum readability 0.1 mg). The G-PIMMS was surrounded by the nets to protect from wind (Fig. 1c). After the image processing, particles are classified into “completely melted (raindrop)”, “partially melted”, or “solid (snowflakes, graupel, and ice crystals)”, based on their transparency and shape. Figure 1d shows particle images obtained from the G-PIMMS.

In the 2016−2017 and 2017−2018 winter seasons, we installed the G-PIMMS at Ishikawa Prefectural University (36.51°N, 136.60°E, 40 m above sea level (ASL), hereafter referred to as IPU) and Kanazawa University (36.54°N, 136.71°E, 150 m ASL, hereafter referred to as KU) on the coast of the Japan Sea. At each observation site, a Micro Rain Radar (MRR web site 2018) was also installed to measure the vertical profile of K-band radar reflectivity just above the observation sites. The IPU observation site is 10.2 km apart from the KU site. The GPM DPR has a horizontal resolution of 5 km. We examined hydrometeors measured at each site in the case that the GPM DPR classified different precipitation types at the IPU and KU sites; 25 January 2017 and 4 February 2018.

3. Results and discussion

3.1 Case of 25 January 2017

The GPM DPR passed southeastward from the northwest of the observation sites at 05:23 JST on 25 January 2017. The winter monsoon was enhanced, and snow clouds developed over the Japan Sea. Surface air temperature and relative humidity at IPU and KU were −0.4°C, 84.9% and −0.8°C, 88.3%, respectively. No melting particle observed at both sites. The JMA radar echoes indicated that the propagation speed of approximately 12 m s⁻¹, and formed a line perpendicular to the coast of the Japan Sea (Fig. 2a). Figure 2b shows the precipitation type classified by the GPM DPR algorithm. It shows that the precipitation types at the IPU and KU sites were convective and stratiform, respectively.

At the IPU site, the G-PIMMS started observing solid precipitation just before the passage of the GPM DPR, and graupel with a diameter of 1 mm were dominant (Fig. 3a). The maximum diameter of the graupel was around 3 mm at 05:31 JST. A strong echo of 40 dBZ in the MRR observation appeared at an altitude of 1.2 km at 5:28 JST (Fig. 3a, bottom panel). This indicated the presence of active graupel formation in the upper layer because the G-PIMMS subsequently detected graupel with a diameter of up to 3 mm at 05:31 JST. According to the upper sounding (09 JST) at Wajima (37.38°N, 136.90°E), the altitude of −10°C level was 1.5 km.

On the other hand, the GPM DPR passed above the KU site just before the snow stopped. The G-PIMMS observed snowflakes over 4 mm in diameter (Fig. 3b). A lot of flat and irregular shaped particles were observed at the KU site in comparison with IPU (figure not shown). The radar reflectivity of the MRR at KU was weaker than that at IPU.

These G-PIMMS and MRR observations at the two observation sites confirm the different precipitation types classified by the GPM DPR.

3.2 Case of 4 February 2018

At 06:24 JST on 4 February 2018, the GPM DPR passed northeastward from the southwest of the observation sites. The JMA radar echoes indicated that the propagation speed of the
snow clouds was approximately 17 m s⁻¹, and the individual echoes had larger areas than those on 25 January 2017. Surface air temperature at KU was 0.3°C (No humidity data). At IPU site, neither data of temperature and the humidity were recorded due to instrumental trouble. At Kanazawa meteorological observatory, which is 9.4 km apart from the IPU site, surface air temperature was 1.4°C at 06:30 JST. The GPM DPR classified the precipitation type as stratiform at the IPU site and convective at the KU site (Fig. 4). Graupel was dominant in the first half of the passage of the snow system at the IPU site. The G-PIMMS detected graupel up to 5 mm in diameter from 06:08 JST, and the major hydrometeor type changed to snowflakes after 06:21 JST (Fig. 5a). No melting particle was observed at both sites. The time-height cross section obtained from the MRR showed weak reflectivity around the time of the GPM DPR passage, indicating that the snow system was dissipating. The upper sounding (09 JST) at Wajima showed that the altitude of −10°C was 1.5 km. The G-PIMMS at the KU site detected solid particles continuously from 06:20 to 06:45 JST (Fig. 5b). In the first half of the precipitation period, before and after the passage of the GPM DPR, the major hydrometeor type was graupel > 2.5 mm in diameter, which then changed to snowflakes after 06:30 JST. Five minutes before the GPM DPR passage, the MRR observed a strong echo with radar reflectivity greater than 40 dBZ around an altitude of 1 km.

We observed the same snow system at the KU and IPU sites (Fig. 4). This suggests that, in the front of the snow system, active graupel formation through the riming process was likely enhanced by an updraft, while the aggregation of ice crystals formed snowflakes due to the weaker updraft in the posterior of the snow system.

### 3.3 Validation of GPM DPR precipitation type classification

Winter snow cloud, in which solid hydrometeors dominate from the ground through to the cloud top, mostly has no melting layer, so radar observations cannot identify the BB and stratiform clouds cannot be distinguished from convective clouds.

One indicator for the precipitation type classification is the existence of updraft in the cloud. Houze (1994) defined a strati-
form as a precipitation process in which the updraft in the cloud is smaller than the terminal velocity of falling ice particles. From the cloud microphysical point of view, the updraft is strongly related to differences between the hydrometers of clouds. In general, the existence of a strong updraft in the cloud indicates that it uplifts the supercooled droplets that are necessary for the riming growth of graupel. On the other hand, different precipitation processes occur at small scales with the vertical air motion, in which ice particles with small densities fall and aggregate to form snowflakes. Consequently, the different hydrometeors observed at the two observation sites in the present study showed different precipitation types.

In the GPM DPR algorithm V05 classification (CSF) module, new items were added for a decision on winter convective precipitation. One of the changes from the previous version is the flag for the heavy ice precipitation (flagHeavyIcePrecip; Iguchi et al. 2018). The flagHeavyIcePrecip is defined as precipitation consisting of ice particles by strong radar reflectivity above the −10°C level. If flagHeavyIcePrecip and large DFRm above the −10°C level are detected near the footprint, the precipitation is classified as convective (Iguchi et al. 2017). In the case of 4 February 2018, at the KU site, the cross section of the MRR showed that strong radar reflectivity was observed around −10°C level 5 minutes before the passage of the GPM DPR as shown in Fig. 5b. Considering the propagating speed, 5 minutes was equivalent to a distance of 5.1 km. In the results, flagHeavyIcePrecip was detected at neighboring footprints, and the precipitation at the KU site was classified as convective by the algorithm V05 (Fig. 4). Videosonde observations in the tropics and sub-tropics showed graupel in the upper level in convective clouds but graupel was rarely observed in stratiform clouds, in which the BB is detected by radar remote sensing (Suzuki et al. 2014, 2016a, 2018). Thus, the flagHeavyIcePrecip is effective for precipitation type classification of winter snow clouds, and the hydrometeor measurements in the present study confirm that the precipitation type classification by the GPM DPR algorithm V05 is reasonable.

4. Summary

Solid hydrometeors dominate throughout the winter snow cloud, and there is no melting layer, which is detected by the radar
as a BB. For the ground validation of the GPM DPR precipitation type classification algorithm, we carried out ground-based precipitation particle measurements along the coast of the Japan Sea in winter. We observed different solid hydrometeors at the KU and IPU sites, which are located approximately 10 km apart from each other. Then, the GPM DPR classified precipitation at each observation site into different types (convective and stratiform). From the viewpoint of microphysics, the existence of graupel suggests the presence of updraft in the cloud, and the existence of snowflakes suggests the aggregation of ice crystals falling through the cloud.

We examined only two cases because of limited simultaneous observations by the satellite remote sensing and the ground-based hydrometeor measurement, but we could confirm the results of the GPM DPR precipitation type classification. For the further enhancement of validation accuracy for the precipitation type classification, spatial information of hydrometeor distribution obtained from a polarimetric radar (e.g., Kouketsu et al. 2015), using hydrometeor information provided by G-PIMMS as reference, will be useful. Direct hydrometeor observations are essential for the precipitation type estimation by the remote sensing technique, so it is expected that the result of this study will help improvement of the future algorithm.

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