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THREE-DIMENSIONAL CHARACTERISTICS OF POLARIMETRIC RADAR VARIABLES AND THEIR PRECIPITATION-TYPE DEPENDENCE

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1. INTRODUCTION

Understanding the characteristics of cloud microphysics in precipitation is important to enable accurate rainfall estimation through space-borne radar and microwave radiometers on satellites (e.g., TRMM, GPM, and AMSR-E) (e.g., Masunaga et al. 2002). One basic need is clarification of the differences in cloud microphysical characteristics, such as the drop size distribution (DSD), in convective precipitation and stratiform precipitation. Hydrometeor identification above an altitude of 0ºC also provides indispensable information for rain retrieval algorithms. Some previous studies have revealed the vertical profiles of DSD and hydrometeor classification using wind profiler and polarimetric radar data (Kobayashi and Adachi 2005; May and Keenan, 2005). However, few studies have described and compared the three-dimensional characteristics of cloud microphysics in various types of precipitation on the basis of observational data.

In the context of rainfall estimation through space-borne microwave radiometers, characterizing and classifying the precipitation type within an area that depends on the radiometers horizontal footprint size is also important. In the present study, we have studied polarimetric radar variables in three small areas (150 km^2) including different types of precipitation. In this study, we used observational data from COBRA (CRL Okinawa Bistatic Polarimetric Radar, C-band) which is operated on Okinawa Island (26.5N 128E), Japan (Nakagawa et al. 2003). We investigated the radar reflectivity factor (Z_{hh}), differential reflectivity (Z_{DR}), correlation coefficient ($\rho_{hv}(0)$), and the relationships between them to characterize each precipitation type rather than to reveal the detailed structure of precipitation. The horizontal variability and vertical distribution of these values in selected areas are provided as three-dimensional characteristics of the polarimetric radar variables in this study.

2. OBSERVATION AND PRECIPITATION TYPES

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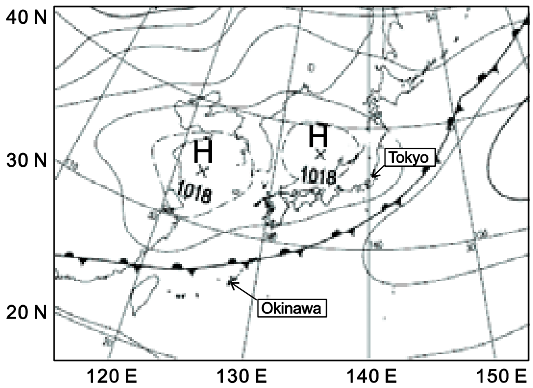

Fig. 1 Surface weather map at 1500 LST, 1 June 2004.

In May and June 2004, a field campaign to observe precipitation in Okinawa, Japan was carried out as part of the GSMaP/CREST (Global Satellite Mapping of Precipitation) and LAPS/CREST (Lower Atmosphere and Precipitation Study) programs. On 1 June 2004, the Baiu front, a significant subtropical frontal zone in East Asia, was located close to the observation area as shown in Fig. 1. Figure 2 shows the horizontal distribution of Z_{hh} at an altitude of 2 km at 1400 LST. Widespread stratiform precipitation was found in the northwestern part of the COBRA observation area. Several convective radar echoes were observed in the southeastern side of the stratiform precipitation area. In this study, we focused on the three areas shown by rectangles in Fig. 2. Each area was 150 km^2.

Area A was characterized by typical stratiform precipitation whose bright band (BB) was clearly found around an altitude of 4 km (section a-a' in Fig. 2), which almost corresponded to the level of 0ºC. Area B was characterized by isolated convective precipitation. A region with a radar echo stronger than 50 dBZ developed up to an altitude of 5 km (section b-b' in Fig. 2). This indicates that the convective precipitation was in the mature period of its lifetime. We will refer to these two types of precipitation in areas A and B as "stratiform type" and "convective type", respectively.

The above two types of precipitation in areas A and B are provided as simple and extreme examples of stratiform and convective precipitation. However,

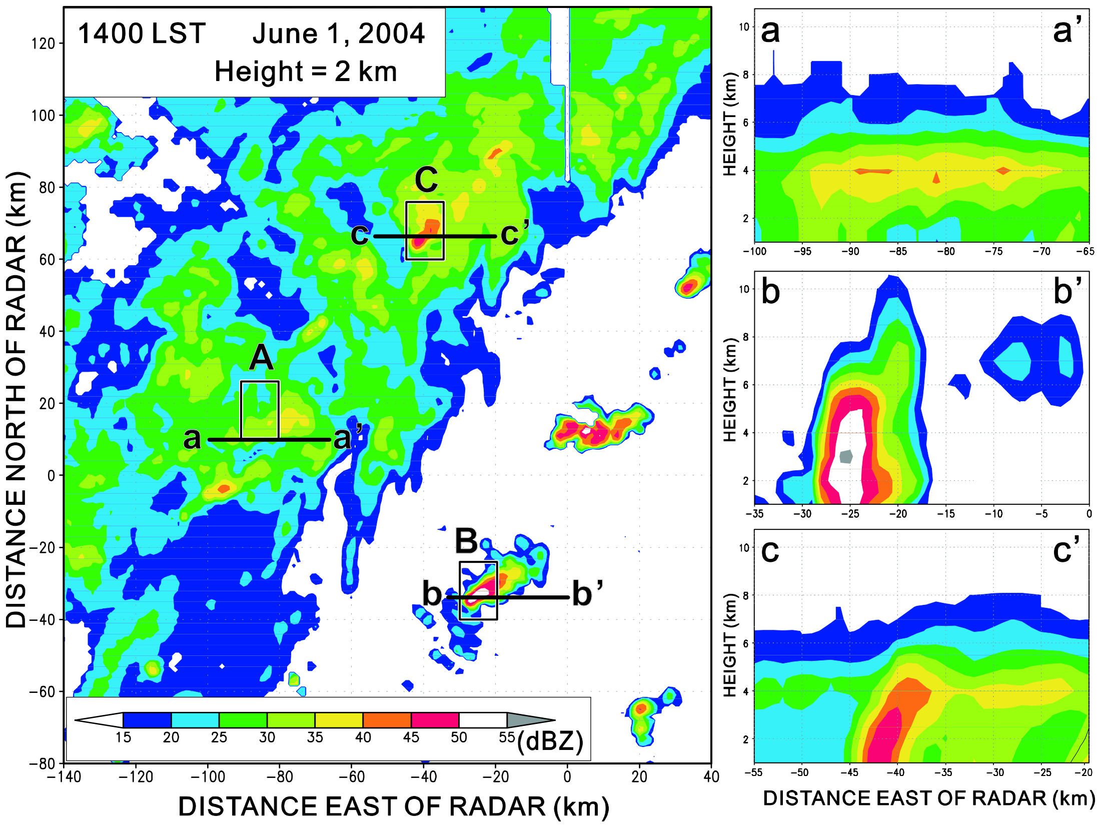

Fig. 2 (Left) Horizontal and (Right) vertical distribution of radar reflectivity factor (Z_{hh}) at 1400 LST on 1 June 2004. The locations of the vertical sections are indicated in the left figure.

stratiform precipitation and convective precipitation often coexist within a small region. An example is the precipitation in area C, where convective precipitation was embedded in stratiform precipitation. The convective precipitation in area C was less intense than that in area B, but its maximum Z_{hh} reached 50 dBZ. A BB was also found at an altitude of about 4 km (section c-c' in Fig. 2). The precipitation in area C will be referred as "embedded type".

In the next section, we describe the values of three-dimensional polarimetric radar variables corresponding to these three precipitation types. PPI scan data were used in the following analysis. COBRA was operated in PPI scanning mode for less than 6 minutes at elevation angles of 0.5, 0.9, 1.4, 2.0, 2.6, 3.4, 4.3, 5.5, 6.8, 8.5, 10.5, 13.0, 16.1, and 20.0º. Transmitting polarization is +45 degrees linear, and H and V independent digital receivers are used. The rainfall attenuation was corrected by the ZPHI method (Bringi and Chandrasekar 2001).

3. THREE-DIMENSIONAL CHARACTERISTICS OF POLARIMETRIC RADAR VARIABLES

3.1 *Stratiform Type*

Figure 3 shows vertical distributions of the relationships between (a) Z_{hh} and Z_{DR}, (b) Z_{hh} and $\rho_{hv}(0)$, and (c) Z_{DR} and $\rho_{hv}(0)$ for the stratiform type of precipitation. As Figs. 3a and 3b show, Z_{hh} ranged from 20 to 40 dBZ below the BB. In the BB, a general increase in Z_{hh} is obvious. Above the BB, Z_{hh} decreased with height.

Figure 3c shows that Z_{DR} of the stratiform type of precipitation mainly ranged from 0.5 to 2.5 dB at all heights. As shown in Fig. 3a, Z_{DR} was positively correlated with Z_{hh} below the BB. In and above the BB, Z_{DR} showed no significant relationship with Z_{hh} at any level, while Z_{hh} and Z_{DR} slightly decreased with height. Z_{DR} larger than 2 dB was observed even in the region where Z_{hh} was weaker than 30 dBZ.

$\rho_{hv}(0)$ also showed no significant relationship with Z_{hh} in the BB (Fig. 3b). Above the BB, $\rho_{hv}(0)$ below 0.9 was observed in the region where Z_{hh} was weaker than 25 dBZ (Fig. 3b). Low $\rho_{hv}(0)$ values at upper levels were not significantly correlated with Z_{DR} (Fig. 3c).

3.2 *Convective Type*

Figure 4 shows the vertical distribution of the relationships between (a) Z_{hh} and Z_{DR}, (b) Z_{hh} and $\rho_{hv}(0)$, and (c) Z_{DR} and $\rho_{hv}(0)$ for the convective type of precipitation. The maximum value of Z_{hh} at each

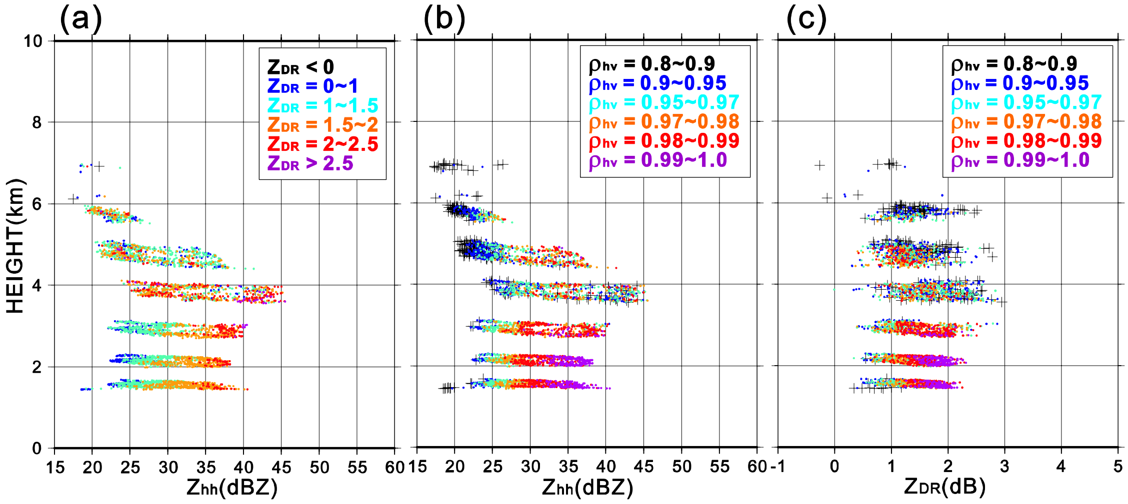

Fig. 3 Vertical distribution of the relationships between (a) Z_{hh} and Z_{DR}, (b) Z_{hh} and $\rho_{hv}(0)$, and (c) Z_{DR} and $\rho_{hv}(0)$ for the stratiform region.

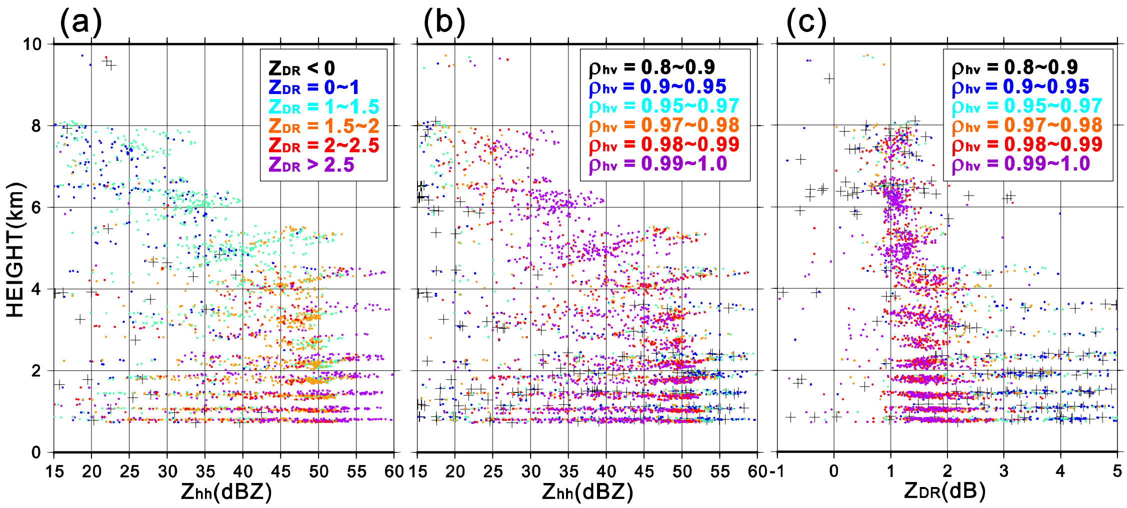

Fig. 4 As in Fig. 3, but for the convective region.

level was nearly constant from the surface up to an altitude of 4 km, and generally decreased with height at higher altitudes (Figs. 4a and 4b). Below 4 km, Z_{DR} tended to become larger with Z_{hh} (Fig. 4a) and ranged widely, reaching up to 5 dB (Fig. 4c). Z_{DR} generally decreased with height and mainly ranged from 1 to 1.5 dB above an altitude of 4 km (Figs. 4a and 4c).

As Figs. 4b and 4c show, $\rho_{hv}(0)$ higher than 0.99 was observed up to an altitude of 8 km, although such high values for the stratiform type of precipitation were confined to the altitude below the BB (Figs. 3b and 3c). Note that no values of $\rho_{hv}(0)$ higher than 0.99 were observed around the region of maximum Z_{hh} at the lower levels (Fig. 4b). This is because $\rho_{hv}(0)$ was not very high around the echo core. There were only scattered values of $\rho_{hv}(0)$ lower than 0.9 in the convective region even at the upper levels (Figs. 4b and 4c).

Most values of $\rho_{hv}(0)$ higher than 0.99 had corresponding Z_{DR} values ranging from 1 to 2.5 dB at lower levels and from 1 to 1.5 dB at upper levels (Fig. 4c). Note that Z_{DR} and $\rho_{hv}(0)$ were slightly inversely correlated at low levels (Fig. 4c).

3.3 *Embedded Type*

Figure 5 shows the vertical distribution of the relationships between (a) Z_{hh} and Z_{DR}, (b) Z_{hh} and $\rho_{hv}(0)$, and (c) Z_{DR} and $\rho_{hv}(0)$ for the embedded type of precipitation. The maximum Z_{hh} was observed at an altitude of about 2 km (Figs. 5a and 5b). The maximum Z_{hh} at each level generally decreased with height.

Below an altitude of 4 km, Z_{DR} was positively correlated with Z_{hh} (Fig. 5a). At an altitude of about 4

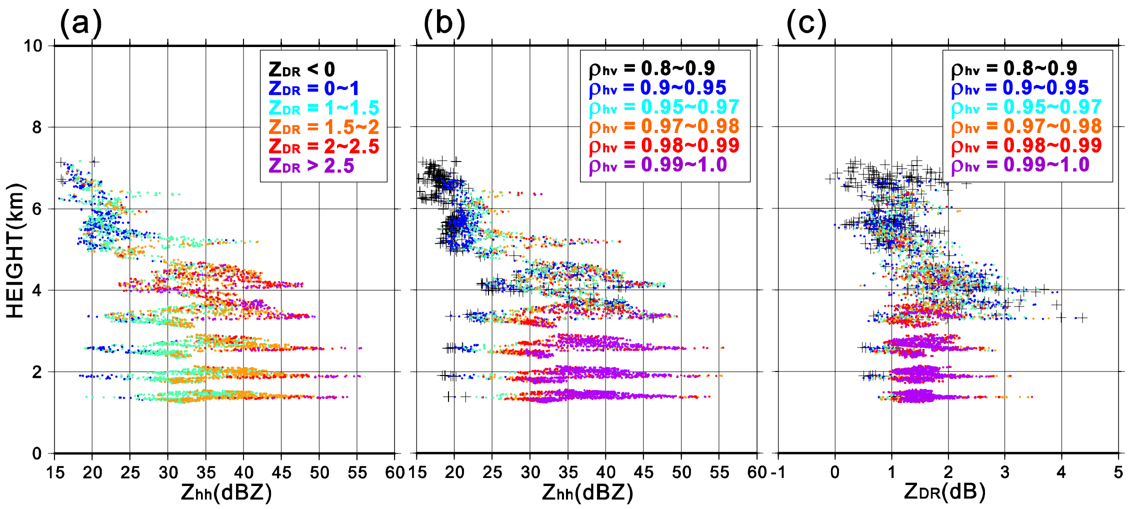

Fig. 5 As in Fig. 3, but for the embedded region.

km, corresponding to the level of the BB, Z_{DR} and $\rho_{hv}(0)$ were not significantly related to Z_{hh} (Figs. 5a and 5b). Above the BB, $\rho_{hv}(0)$ lower than 0.9 was also observed (Figs. 5b and 5c). These characteristics are similar to those of the stratiform type.

4. DISCUSSION

Here we discuss how the characteristics of polarimetric radar variables depend on the precipitation type and signals which can be used to classify precipitation types.

4.1 *Stratiform Type*

The existence of a BB generally indicates that snow particles are dominant at upper levels. In the present study, the snowfall region above the BB was characterized by weak Z_{hh} and low $\rho_{hv}(0)$. In the BB, Z_{DR} and $\rho_{hv}(0)$ were not significantly related to Z_{hh}. This indicates that the shapes and size distribution of melting snow particles are very complicated. In BB detection, this characteristic of the polarimetric radar variables seems to be a very useful signal. Strong positive correlation between Z_{hh} and Z_{DR} below the BB is a reasonable characteristic in the rainfall region.

4.2 *Convective Type*

The general increase in Z_{DR} with Z_{hh} below the altitude of 0ºC indicates that the dominant hydrometeor near the surface was rain in the observed convective type of precipitation. The decrease in $\rho_{hv}(0)$ around the echo core of Z_{hh} can be considered evidence of existence of extremely large rain particles.

A characteristic particular to the convective type was that $\rho_{hv}(0)$ larger than 0.99 was observed even at levels higher than the altitude of 0ºC. However, the data whose $\rho_{hv}(0)$ was higher than 0.99 above 0ºC revealed a slightly different property from those below 0ºC. First, their Z_{hh} values were generally weak in the upper levels (Fig. 4b). Their Z_{DR} values were also slightly lower in the upper levels (Fig. 4c). It is difficult to characterize these differences in polarimetric variables as a difference of hydrometeors. Detailed consideration of cloud microphysics through an analysis of a three-dimensional structure of the polarimetric variables and wind fields in the convective type of precipitation is needed to reveal information regarding the vertical distribution of hydrometeors.

4.3 *Embedded Type*

The characteristics of the radar variables for the embedded type included characteristics of both stratiform precipitation and convective precipitation. A general decrease in Z_{hh} just under the BB was not seen because of the existence of embedded convective precipitation. The BB was not detected only by the maximum Z_{hh} level. The BB was detected from the relationship between Z_{hh} and Z_{DR} and that between Z_{hh} and $\rho_{hv}(0)$; that is, from the fact that there was no significant relationship between these parameters. $\rho_{hv}(0)$ values larger than 0.99 was confined to the levels below the BB as in the stratiform type. Low $\rho_{hv}(0)$ and weak Z_{hh} values above the BB are also features seen in the stratiform type, although the embedded convective precipitation in this type was fairly intense and its maximum Z_{hh} reached 50 dBZ near the surface. From the viewpoint of cloud microphysical characteristics, it may be necessary to recognize this embedded type of precipitation as a new type of precipitation rather than as a simple combinations of stratiform and convective precipitation.

5. SUMMARY

Polarimetric radar variables within three small areas (150 km^2) of different types of precipitation (stratiform, convective, and embedded) were studied using COBRA observational data obtained on 1 June 2004 during a field campaign in Okinawa, Japan.

This study clearly shows that the three-dimensional characteristics of polarimetric radar variables provide useful information for characterizing the type of precipitation in selected area. For example, Z_{DR} and $\rho_{hv}(0)$ have no significant relationship with Z_{hh} in a bright band in the stratiform type of precipitation. In the convective type of precipitation, $\rho_{hv}(0)$ larger than 0.99 was observed even at levels higher than an altitude of 0ºC. In the embedded type of precipitation, characteristics of both stratiform and convective precipitations were observed.

The areal size of 150 km^2 was used in the present study to enable extraction of the basic features of simple stratiform and convective precipitation. Any dominant characteristic of the polarimetric radar variables should be closely related to areal size. It is necessary to examine how the characteristics of polarimetric radar variables and the meaningful classification of the precipitation type depend on the areal size as the next step.

6. REFERENCES

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