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POLARIMETRIC RADAR OBSERVATION OF THE EYEWALL OF TYPHOON MAN-YI

Yukari Shusse[(1)], Makoto Satake[(2)], Shinsuke Satoh[(2)], Nobuhiro Takahashi[(2)], Hiroshi Hanado[(2)], Katsuhiro Nakagawa[(2)], and Toshio Iguchi[(2)]

(1) Hydrospheric Atmospheric Research Center, Nagoya University, Japan

(2) National Institute of Information and Communications Technology, Japan

1. INTRODUCTION

Matured typhoons in the northwest Pacific are commonly accompanied by intense rainfall as well as by high horizontal winds as much as 60 m s^{-1} around their eyewalls. Microphysical structures such as hydrometeor types and their three-dimensional distributions in the eyewall are required information to understand not only formation process of intense rainfall but also the maintenance and intensification processes of whole typhoon system.

Several previous studies have been investigated the microphysical structure of tropical cyclones using in-situ data obtained from research aircrafts. For example, Black and Hallett (1986) reported the distribution of hydrometeors around the level of -5 °C in three Atlantic hurricanes. They observed supercooled drops, graupels, columns and aggregated snowflakes, and related these distributions of particles to the location of the hurricanes such as the eyewall, rainbands, stratiform area, and convective area. Recently, May et al. (2008) described microphysical structure of a tropical cyclone near coastline with a polarimetric radar. They identified the region of rain-hail mixtures in the eyewall below the 0 °C level, with a substantial volume of wet graupel overlying this. As shown by May et al. (2008), polarimetric radars can provide valuable data on three-dimensional microphysical properties of tropical cyclones. Typical raindrop sizes near the surface around the eyewall, which can be obtained by polarimetric radar information, are also useful for the rainfall estimation by conventional and/or spaceborne radars. However, there are few opportunities to observe matured tropical cyclones by ground-based polarimetric radars especially in the oceanic areas.

Typhoon Man-yi hit main Okinawa island, Japan, on 13 July 2007. The typhoon was in its mature stage with minimum sea-level pressure of 940 hPa and maximum Doppler velocity of more than 60 m s^{-1}. A C-band polarimetric radar in Okinawa (128º 03’ 50’’ E, 26º 35’ 11’’ N), which is known as “COBRA” (Nakagawa et al. 2003), succeeded to obtain the three-dimensional and high spatial resolution data of the eyewall from 0430 to 1007 LST with 360-degree multiple RHI scannings. In this study, we describe the characteristics of polarimetric radar variables, distribution of hydrometeors, and typical raindrop sizes in the eyewall of the typhoon based on the polarimetric radar observation.

* *Corresponding author address:* Yukari Shusse, Hydrospheric Atmospheric Research Center, Nagoya University, Nagoya, 464-8601, Japan;
e-mail: shusse@rain.hyarc.nagoya-u.ac.jp

2. OVERVIEW OF TYPHOON MAN-YI AND RADAR OBSERVATION

Figure 1 shows the track and the central pressure of Typhoon Man-yi, reported by the Japan Meteorological Agency (JMA). The typhoon Man-yi developed from a tropical depression near Caroline Islands at 0000 UTC on 9 July. It moved northwestward at first, and then steered in a northern direction. When the typhoon hit main Okinawa island at 0900 LST (LST = UTC + 9) on 13 July 2007, its central pressure was 930 hPa, which was the minimum value of central pressure during its lifetime. After leaving main Okinawa island, it veered away to the northeastward, and finally transformed into an extratropical cyclone at 0900 LST on 16 July over in the Pacific Ocean, east of Japan.

The eyewall of the typhoon moved into the COBRA observation area (120 km in radius during this observation) around 0430 LST. After that, operation mode of COBRA changed into a multiple RHI scanning mode, which consists of 360 RHI scans with 1-degree interval in azimuth angle. It took about 1 hour to obtain one volume scan data. However, three-dimensional data with high spatial resolution in a vertical direction could be obtained by this special observation mode. This observation was continued until 1007 LST. PPI scans at an elevation of 0.5° were also inserted about every 15 minutes.

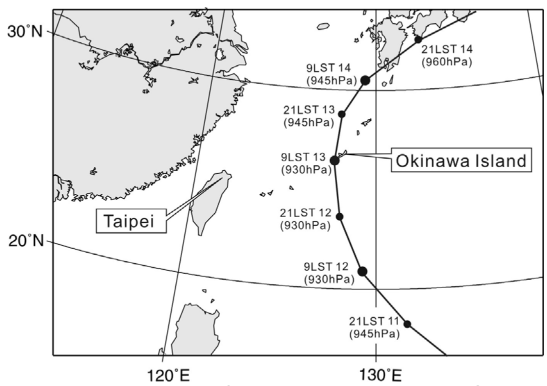

Fig. 1. The track for Typhoon Man-yi. Closed circles indicate the locations of the typhoon center every 6 hours.

The transmitting polarization was +45-degrees-tilt linear, and H- and V- independent digital receivers were used. The number of integration pulse was 128. The pulse width was 2 μs, and the resolution of the radar data was therefore 300 m in the radial direction. The rainfall attenuation in radar reflectivity (Z_h) and differential reflectivity (Z_{DR}) was corrected by using the combined ϕ_{DP}-Z_{DR} constraint (Bringi and Chandrasekar 2001). The value of correlation coefficient between horizontal and vertical polarization signals (ρ_{hv}) were corrected for signal-to-noise ratio (SNR) (Shusse et al. 2009). Low-SNR data of less than 15 dBZ were removed.

Figure 2 shows the PPI display of Z_h and Doppler velocity at the time the eyewall hit main Okinawa island. A circular eyewall of about 80 km diameter is clearly seen in the Z_h field. Maximum Doppler velocity of approximately 60 m s^{-1} is found in the southeast part of the eyewall. It is reasonable to say that the typhoon was in the mature stage around 0900 LST. The next section describes the characteristics of polarimetric radar variables of this matured typhoon using the multiple RHI-scan data from 0905 LST to 1007 LST.

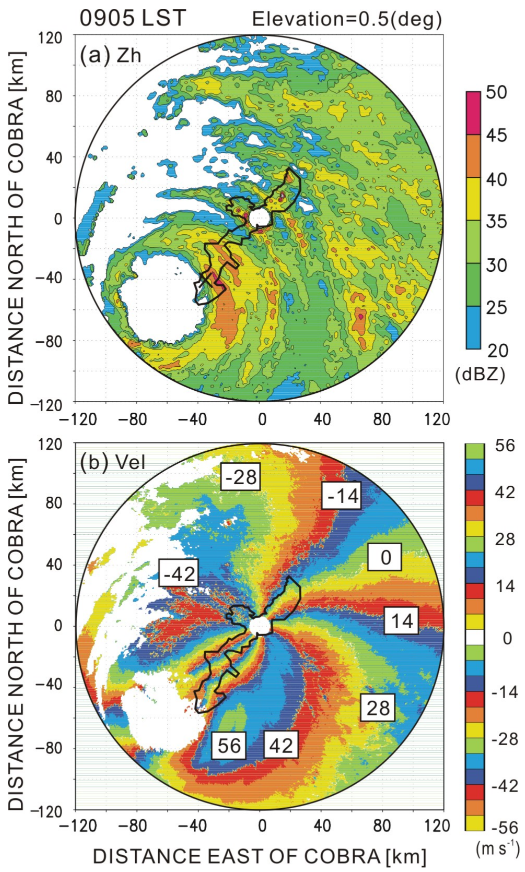

Fig. 2. PPI display of (a) Z_h and (b) Doppler velocity at an elevation of 0.5° at 0905 LST. Positive (negative) values of Doppler velocity indicate wind components toward (away from) the radar. A cross sign in (a) indicates Naha upper-air sounding site.

3. Structure of the eyewall

Figure 3 shows the horizontal distribution of Z_h at 2 km altitude calculated using multiple RHI-scan data from 0905 LST to 1007 LST. Although the observation time of the data in this figure differs according to the azimuth angle, the eyewall is still circular in shape because of its slow movement around main Okinawa island. The intense echo with Z_h larger than 40 dBZ is found in the area from south to east part of the eyewall. In this section, characteristics of polarimetric radar variables and the distribution of hydrometeors around the intense echo area of the eyewall are shown. Typical raindrop sizes at low levels are also discussed based on the polarimetric radar observation.

3.1 Characteristics of polarimetric radar variables and distribution of hydrometeors in the eyewall

Figure 4 presents the RHI display through the intense Z_h region of the eyewall and is shown as the typical vertical structure of the eyewall. The center of the typhoon is the left side of the figures. In the eyewall, intense echo of Z_h larger than 45 dBZ is found below 3 km altitude (Fig. 4a). Large K_{DP} region is also seen below 3 km altitude as seen in Fig. 4d, which indicates the region of high water content is confined in low levels in this section.

A bright band is not obvious around the 0 °C level (5.7 km altitude) in Z_h field (Fig. 4a). However, layers of large Z_{DR} (> 1dB) and low ρ_{hv} (< 0.98) are obvious around the 0 °C level in the eyewall (Figs. 4b and 4c). These polarimetric features indicate the existence of a melting layer as described in previous

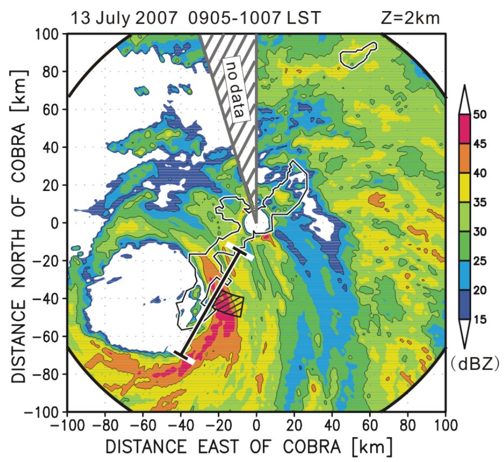

Fig. 3. Horizontal distribution of Z_h at 2 km altitude calculated using multiple RHI-scan data from 0905 LST to 1007 LST. The arrow indicates the location of the vertical sections in Fig. 4. The area with slant lines indicates the domain of data in Fig. 5.

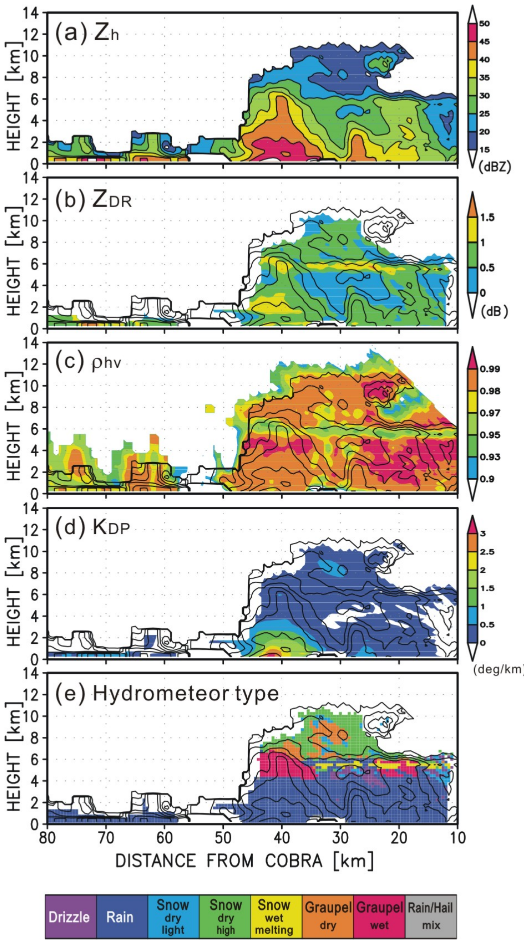

Fig. 4. RHI displays of (a) Z_h, (b) Z_{DR}, (c) ρ_{hv}, (d) K_{DP}, and (e) hydrometeor types. The location of the sections is indicated in Fig. 3.

studies (e.g. Brandes and Ikeda 2004). Using the method of Shusse et al. (2007), which detects the melting layer from the vertical profile of ρ_{hv}, the detection of melting layer and its height was conducted for all RHI scans of the volume data. Figure 5 shows the horizontal distribution of the melting layer. The melting layers were detected in the colored area, while they were undetected in the gray area. Color shades indicate the height of melting layer. As seen in Fig. 5, the melting layer is observed not only at the location of Fig. 4, but also in the wide area of the eyewall. The level of the melting layer in the outer region of the eyewall is approximately 5.5 km altitude. In the eyewall, the level of the melting layer is generally higher than that in surrounding areas and rised up to 7 km altitude in the intense Z_h region.

Figure 4e shows the result of the hydrometeor classification based on the approach of Keenan (2003). Input parameters are Z_h, Z_{DR}, ρ_{hv}, K_{DP}, and a vertical profile of temperature. The temperature was obtained by an upper-air sounding launched at Naha

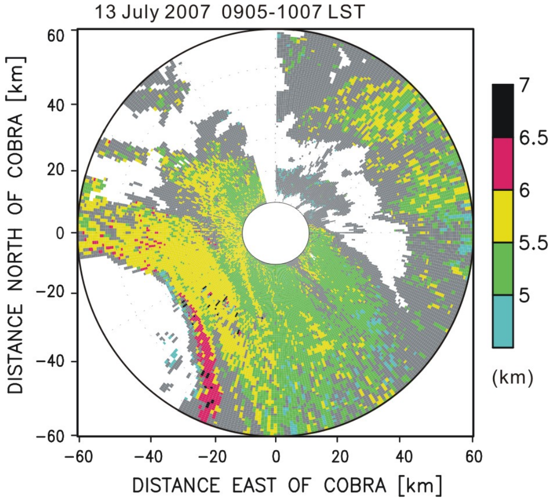

Fig. 5. Horizontal distribution of the level of melting layer from 0905 LST to 1007 LST.

at 0900 LST (see Fig. 2a for the location). In the eyewall (x = 35-45 km), the region of wet graupel is dominant around the 0 °C level, while a layer of wet snow is seen in the outer area (x = 10-35 km). The region of wet graupel is found along the intense Z_h region of the eyewall around the 0 °C level (not shown). This implies the existence of supercooled water around the 0 °C level in the eyewall. The presence of the supercooled water would have the potential to release the latent heat when ice particles are seeded from the upper part. The dry graupel area covers the wet graupel region as seen in Fig. 4e. Dry aggregates spread at upper levels. The melting layer signatures of low ρ_{hv} and large Z_{DR} in Figs. 4b and 4c correspond to the upper part of the region of wet graupel.

3.2 Typical raindrop size at low levels

Z_{DR} and ρ_{hv} at low levels (from 2 to 3 km altitudes) of the intense Z_h region of the eyewall are plotted against Z_h in Fig. 6. Z_{DR} increases with Z_h in Fig. 6a. This indicates that the long-axis direction of raindrops in the lower parts of the eyewall is averagely near horizontal even in the region of high horizontal wind of 60 m s^{-1} or more. The maximum value of Z_{DR} is approximately 1.2 dB in this region. Using the relationship between Z_{DR} and the median volume diameter (D_0) in Bringi et al. (2006), corresponding maximum value of D_0 is about 1.88 mm. This size is not so large as compared with that in the rainy season in Okinawa (Shusse et al. 2009). In Fig. 6b, most values of ρ_{hv} are higher than 0.98, and do not show a significant descent in the region of strong Z_h. This indicates that the large raindrops which can cause the resonance effect are not contained (Ryzhkov and Zrnić 2005). Large raindrops with several millimeter in diameter would easily breakup in the condition of high horizontal

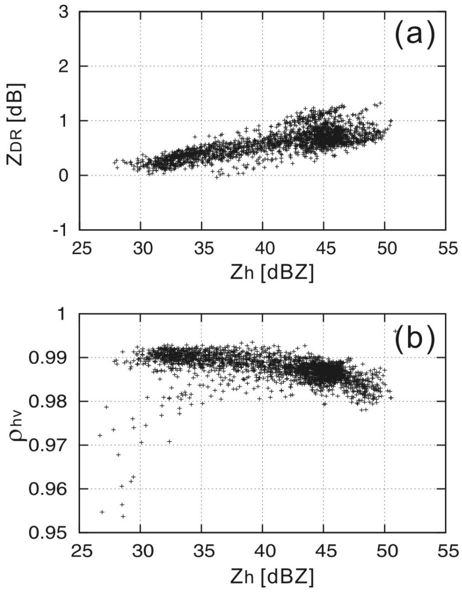

Fig. 6. (a) Z_{DR} and (b) ρ_{hv} versus Z_h from 2 km to 3 km altitudes in the eyewall. The domain of plotted data is indicated in Fig. 3.

wind in the eyewall.

5. SUMMARY

Typhoon Man-yi hit main Okinawa island, Japan, on 13 July 2007. The typhoon was in its mature stage with maximum Doppler velocity of more than 60 m s^{-1}. A C-band polarimetric radar in Okinawa, which is known as “COBRA”, succeeded to obtain the three-dimensional and high spatial resolution data of the eyewall with 360-degree multiple RHI scannings. This study describes the characteristics of polarimetric radar variables and presents the microphysical structure such as the distribution of hydrometeors and typical raindrop sizes in the eyewall of the typhoon.

Around the 0 °C level (5.7 km altitude), layers of low ρ_{hv} and large Z_{DR} were observed in a large area of the eyewall, which indicates the existence of melting layers. The levels of the low-ρ_{hv} layers in the eyewall were generally higher than those in surrounding areas and rised up to 7 km altitude. Hydrometeor-type classification was conducted using a fuzzy logic scheme. In the eyewall, the region of wet graupel was found along the intense Z_h region of the eyewall around the 0 °C level, with the region of dry graupel overlying this. The low-ρ_{hv} layer in this region corresponds to the upper part of the wet graupel region.

Below the 0 °C level, Z_{DR} increased with Z_h. This indicates that the long-axis direction of raindrops in the lower parts of the eyewall is averagely near horizontal even in the eyewall region with horizontal gale wind of 60 m s^{-1} or more. The maximum value of Z_{DR} was approximately 1.2 dB. This size is not so large as compared with that in the rainy season in Okinawa. In addition, ρ_{hv} values were higher than 0.98 at low levels in the region of strong Z_h of the eyewall, which also supports the smaller raindrop sizes in the eyewall of the typhoon.

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