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 in the typhoon, 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 (128° 03' 50'' E, 26° 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 scanings. 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.

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.

* Corresponding author address: Yukari Shusse, Hydrospheric Atmospheric Research Center, Nagoya University, Nagoya, 464-8601, Japan; e-mail: shusse@rain.hyarc.nagoya-u.ac.jp
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 $\phi_{DP}$-$Z_{DR}$ constraint (Bringi and Chandrasekar 2001). The value of correlation coefficient between horizontal and vertical polarization signals ($\rho_{hv}$) 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.

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 $\rho_{hv}$ (< 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. 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.

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.
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 $\rho_{hv}$, 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 rises 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 $Z_h$, $Z_{DR}$, $\rho_{hv}$, $K_{DP}$, and (e) hydrometeor types. The location of the sections is indicated in Fig. 3.

3.2 Typical raindrop size at low levels

$Z_{DR}$ and $\rho_{hv}$ 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 $\rho_{hv}$ 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
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 \(\rho_{hv}\) 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-\(\rho_{hv}\) 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 Zr region of the eyewall around the 0 °C level, with the region of dry graupel overlying this. The low-\(\rho_{hv}\) layer in this region corresponds to the upper part of the wet graupel region.

Below the 0 °C level, Z DR increased with Zr. 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, \(\rho_{hv}\) values were higher than 0.98 at low levels in the region of strong Zr of the eyewall, which also supports the smaller raindrop sizes in the eyewall of the typhoon.

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 \(\rho_{hv}\) 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-\(\rho_{hv}\) 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 Zr region of the eyewall around the 0 °C level, with the region of dry graupel overlying this. The low-\(\rho_{hv}\) layer in this region corresponds to the upper part of the wet graupel region.

Below the 0 °C level, Z DR increased with Zr. 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, \(\rho_{hv}\) values were higher than 0.98 at low levels in the region of strong Zr of the eyewall, which also supports the smaller raindrop sizes in the eyewall of the typhoon.

References


