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Raindrop size distribution and vertical velocity characteristics in the rainband of Hurricane Bolaven (2012) observed by a 1290 MHz wind profiler

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ABSTRACT

Microphysics and vertical velocity characteristics between weak and strong rainband regions of Hurricane Bolaven were investigated primarily from 1290 MHz (UHF) wind profiler measurements on 27–28 August 2012. With a focus on regions with radar reflectivities greater than 30 dBZ below a melting level, raindrop size distributions (DSDs) and related rain parameters retrieved from profiler Doppler spectra were examined. Temporal variations in vertical structure and bright band from a widespread stratiform to a relatively narrow, intense rainband were examined as the rainbands move over the land in the southern coast of Korea. Based on vertical characteristics in radar reflectivity, Doppler velocity, and vertical air motion (w) profiles, the rainbands were classified into a stratiform (S) region with a strong bright band and mixed stratiform-convective (S-C) region with a weak or non-existent bright band. The retrieved w fields showed that updrafts were dominant in the mixed S-C region and downdrafts in the S region. More broad histograms in both radar reflectivity (Z) and mass-weighted mean diameter (D_m) were found in the S period. Compared to the Z distribution, rain rate (R) was more widely distributed in the mixed S-C region than in the S region. This is largely because R values were more variable in association with stronger updrafts in this region since they depend on fall velocities of raindrops. Higher R and smaller D_m mean values were analyzed within relatively strong updrafts in the mixed S-C period compared to those in the S period. Even when the w correction is applied, the mean D_m was still slightly smaller in the mixed S-C region, indicating that there is a relatively larger number of small drops than those in the S region.

1. Introduction

During the past decades, various field campaigns using airborne radar and particle probe, ground-based radar, disdrometer, etc. have been conducted to understand kinematic and microphysical characteristics and interactions between different regimes in hurricane (Barnes and Stossmeister, 1986; Barnes et al., 1983; Gamache et al., 1993; Geerts et al., 2000; Lord et al., 1984; McFarquhar and Black, 2004; Marks, 1985; Marks and Houze, 1987; Powell, 1990). Although vertical profiles of radar reflectivity, vertical velocity, horizontal divergence, wind shear, latent heat, etc. are essential for better understanding representative kinematics and microphysics in an eyewall, rainband, or stratiform region, it is not easy to obtain these vertical profiles with accuracy, especially for vertical velocity, from field measurements (Black et al., 1996; Mapes and Houze, 1995; Marks and Houze, 1987; Marks et al., 1988; Wang et al., 2009; Xu et al., 2014). In addition, understanding characteristics about ice microphysics and raindrop size distributions (DSDs) which are central to precipitation processes above and below melting layer is still limited although they have eagerly been investigated from various *in situ* and remote sensing measurements particularly during period of landfall. DSD retrievals from 400 MHz profiler observations have been compared with those from disdrometer and polarimetric radar observations over a profiler location in Okinawa, Japan (Bringi et al., 2006, 2009). With vertically pointing profiler observations, such DSD retrievals and comparison give more insight on resolving vertical microphysical processes associated with vertical air motion although such studies of vertical DSD characteristics have been sparse in hurricane rainband regions.

Marks and Houze (1987) and Black et al. (1996) estimated vertical air motion (w) using reflectivity (Z)-terminal fall speed (V_f) relations from airborne radar measurements of Atlantic hurricanes and Kim et al. (2013) also examined vertical mean w profiles in different regimes of Typhoon Kompasu (2010) at landfall by using the similar Z-V_f formulas from wind profiler measurements. For tropical mesos-

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cale convective systems near Darwin, Australia, Cifelli et al. (2000) studied vertical properties of w and DSD parameters between convective and stratiform regions from VHF and UHF profiler Doppler spectra below melting layer and indicated that there were comparatively smaller mean drop diameters, showing an increase with decreasing height in the convective category. Rajopadhyaya et al. (1998) studied the DSD properties in tropical convective clouds from 920 MHz (UHF) profiler measurements with w magnitudes estimated from collocated 50 MHz (VHF) profiler Doppler spectra. It was shown that retrieval errors in the DSD parameters increase with w magnitudes. For stratiform rain, w effects on the retrieval of rain parameters is relatively small (Kanofsky and Chilson, 2008; Rajopadhyaya et al., 1998) but can be considerably large in convective rain. There have been many studies about errors in DSD parameters with regard to w correction, relative to those in still air (Kanofsky and Chilson, 2008; Ulbrich, 1992). Ulbrich (1992) examined errors in rain rate and liquid water content that result from inaccuracies in drop fall speed (i.e., inaccurate estimation of w) and indicated that updraft will result in larger rain rate at constant reflectivity than when there are no vertical winds. Williams (2002) retrieved vertical air motion and other parameters that describe a DSD by fitting a model spectrum to a profiler observed spectrum and tested their sensitivity to measurement uncertainties in the Doppler spectrum which cause errors in the best fit parameters.

Convective, mixed, or stratiform rain type can be separated in various ways such as DSD characteristics, bright band signature, vertical Doppler velocity and reflectivity profiles, and so on (Cifelli et al., 2000; Tokay et al., 1996, 1999; Thurai et al., 2016; Williams et al., 1995). Thurai et al. (2016) tested the ability of a 2-dimensional video disdrometer with X-band Doppler profiler measurements for the classification of convective and stratiform precipitation through different inverse relations between intercept parameter and median volume diameter. Tokay et al. (1999) classified rainfall type by applying different algorithms to disdrometer and profiler observations and indicated that compared to profiler classifications, disdrometer is relatively more feasible to misclassify stratiform rain as convective or vice versa due to time-height ambiguity mostly associated with advection of drops while falling to the ground. Since a profiler measures Doppler shifts vertically, it is natural for profiler measurements and retrievals to be more susceptible to the w effect, compared to disdrometer and even scanning radar measurements. If there are downdrafts or updrafts, Doppler spectra at vertical incidence can be smeared. For a given spectrum, updrafts can overestimate rain rate and underestimate mass-weighted mean diameter since updrafts shift a hydrometeor spectrum to a small drop diameter range (vice versa for downdrafts) (Hauser and Amayenc, 1981; Rajopadhyaya et al., 1998). In a reversed way, the shifted Doppler spectrum can be used to retrieve w magnitudes and quantify the w effects on DSD parameters (Kim et al., 2009).

Profiler measurements and DSD retrievals in hurricane rainbands over the southern coast of Korea have been rare. This study investigates properties of DSD parameters and their relationship with w from 1290-MHz wind profiler observations in the rainband of Hurricane Bolaven on 28 August 2012. This paper is organized as follows. In Section 2, instruments used in this study are introduced. Methods for DSD and w retrievals are described in Section 3. S-band radar observations and profiler DSD characteristics with regard to w in different regimes of Bolaven are investigated in Section 4. A summary and conclusions follow in Section 5.

2. Instrumentation

On 28 August 2012, wide rainbands of Hurricane Bolaven were observed by a Sumitomo L-28 wind profiler operating at 1290 MHz (UHF) and a Parsivel disdrometer collocated in the National Center for Intensive Observation of severe weather (NCIO, 34.7∘N, 127.2∘E), Boseong, near the southern coast of Korea (see Fig. 1(a)). The 1290 MHz wind profiler is more sensitive to Rayleigh scatterers such as raindrops and ices than Bragg scatterers. Radial velocities along a vertical and four off-vertical beams tilted 15 degrees from the zenith are used to measure horizontal winds at each range gate height. Three moments of signal-to-noise ratio, Doppler velocity, and spectral width are calculated from measured Doppler spectra along each beam. Only the Doppler spectra observed along the vertical beam are used to retrieve DSDs and parameters in this study. Dwell time for each beam is about 30 s. Time and height resolution is 1 min and 100 m, respectively. At high mode, the maximum height is 9.0 km above ground level (AGL). The details of the profiler parameters are listed in Table 1.

Parsivel disdrometer measures ice and liquid particle size, fall velocity, radar reflectivity, precipitation rate, and so on by using laser-optical properties (640 nm wavelength) on the ground. During heavy rain, the Parsivel disdrometer tends to underestimate the number of small drops and overestimate drop diameter >2.0 mm (Tokay et al., 2014). Radar reflectivities measured from the Parsivel disdrometer are used for calibrating both profiler Doppler spectra and reflectivities in this study.

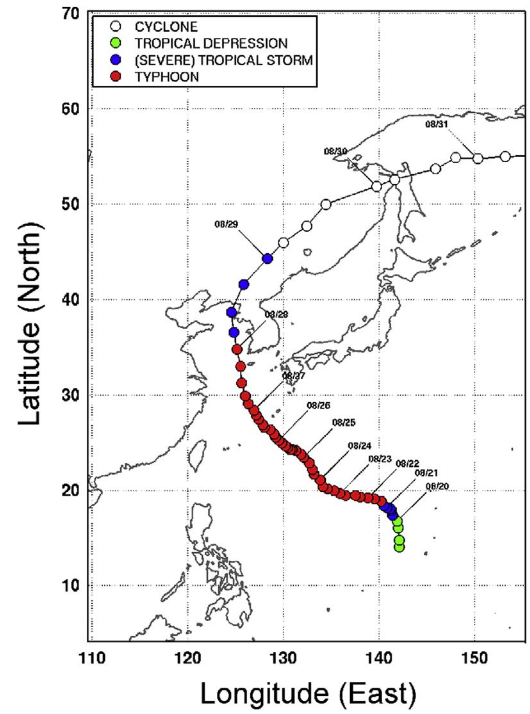

Fig. 1. Track of Bolaven with change in intensity during its lifetime.

Table 1
Operating parameters of the 1290-MHz wind profiler (high mode).

Parameters	
Frequency	1290 MHz (23 cm)
Beam width	5°
Inter Pulse Period	80000 ns
Pulse width	666 ns
Number of coherent integrations	2
Number of spectral averages	18
Number of FFT points	128
Height resolution	100 m
Number of range gates	90