P2.15 SPATIAL STRUCTURE AND TIME EVOLUTION OF RAIN DROP SIZE DISTRIBUTIONS REVEALED FROM DISDROMETER AND POLARIMETRIC RADAR OBSERVATIONS

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1. INTRODUCTION

A better understanding of rain microphysical properties is needed for accurate rain estimation and model parameterization. Polarimetric radars measure reflectivity at horizontal and vertical polarization, differential reflectivity, specific differential phase, and copolar cross correlation coefficient that depend on cloud/precipitation physics (Cao et al., 2008; Zhang et al. 2001; Zrnic and Ryzhkov, 1999). Polarimetric radar measurements provide information about hydrometeor size, shape, orientation and phase and allow retrieval of drop size distributions (DSDs). The 2-dimensional video disdrometer (2DVD) directly measures the shape, size and falling velocity of precipitation particles, which is essential for interpreting polarization radar data.

Observations and data analysis of several rain events collected with S-band polarimetric KOUN radar and a 2DVD in Oklahoma during the period from 2005-2007 are presented in this paper. Cases studied include a convective storm, a convective-stratiform mix, and a squalline case. Storm structure and evolution were studied using the polarimetric radar and disdrometer observations and comparisons. The PPIs of Z_H, Z_{DR}, ρ_{hv} and hydrometeor classification are shown to reveal the morphology of each storm. Time evolution of DSD, mass and reflectivity distributions obtained with 2DVD are examined. The radar mesured vertical structure and time evolution of Z_H, Z_{DR} and ρ_{hv} at disdrometer site are extracted and shown. Also, raindrop size distributions (DSDs) are retrieved from polarimetric radar measurements and compared with the disdrometer measurements.

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2. DATASETS

Datasets were collected with S-band polarimetric weather radar (KOUN), OU and NCAR 2D video disdrometers. Radar data for the location of the disdrometer is an average of a 2x5 (azimuth x range-gates) box of resolution volumes from the 0.5 degree elevation scan centered on the volume located above the location of the disdrometer. The range gate spacing is 0.25 km. The disdrometer measured DSDs are sampled for 1-minute duration. NCAR disdrometer datasets were used only for the 13 May 2005 case. The disdrometer was deployed at Kessler's farm, OU test site at approximately 29 km south from KOUN. For the rest of the cases, 26 June 2007 and 28 June 2007, OU 2DVD observations were used. OU 2DVD was located approximately 65 km southwest from KOUN at Harris farm. Relative locations of the radar and the disdrometers are shown in Figure 1.

Figure 1: Relative locations of KOUN and 2DVDs

Preliminary analysis (not shown) uncovered significant instrument offsets. Radar-measured differential reflectivity values average several tenths of a dB larger than disdrometer calculations. The source of the discrepancy has been difficult to determine. The radar data are calibrated with the calculations from disdrometer measured DSDs.

3. METHODOLOGY

Fundamental information associated with rain microphysics is contained in raindrop size distributions (DSDs). Gamma distribution has been widely accepted to model rain DSDs in recent years (Zhang et al. 2001, Brandes et al. 2004). The gamma distribution has the form:

$$N(D) = N_0 D^{\mu} \exp(-\Lambda D), \tag{1}$$

where $N(D)$ denotes the DSD, N_0 $(mm^{-1-\mu}\ m^{-3})$ is the number concentration parameter, μ is the distribution shape parameter, Λ (mm^{-1}) is the slope parameter and D (mm) is the equivalent volume diameter. The fallowing constraining relation is used in this paper (Cao et al., 2008):

$$\mu = -0.0201\Lambda^2 + 0.902\Lambda - 1.718 \tag{2}$$

Thus, the gamma DSD model reduces to a two-parameter model whose parameters N_0 and Λ can be retrieved from the radar measured reflectivity at horizontal polarization (Z_H) and differential reflectivity (Z_{DR}). The dual-pol. integral equations for solving Λ and N_0 from Z_H and Z_{DR} are fallowing (Zhang et al. 2001):

$$Z_{hh,vv} = \frac{4\lambda^4}{\pi^4 |K_w|^2} \int_{D_{\min}}^{D_{\max}} |f_{hh,vv}(\pi, D)|^2\ N(D) dD \tag{3}$$

$$Z_{DR} = 10 \log_{10} (Z_{hh} / Z_{vv}). \tag{4}$$

Backscattering amplitudes are represented by $f_{pp}(\pi,D)$, where index pp denotes either horizontal (hh) or vertical (vv) polarization, λ is the wavelength, $K_W = (\varepsilon_r - 1)/(\varepsilon_r + 2)$ where ε_r is the complex dielectric constant of water. The scattering amplitudes used for the retrieval were calculated based on T-matrix method.

4. CASE STUDIES

Several cases have been studied as follows: a convective-stratiform mix happened on 26 June, 2007, a convective storm occurred on 28 June, 2007, and a squall-line case on 13 May, 2005.

4.1 A convective stratiform mix on 26 June, 2007

The event started around 0700 UTC with light convective rain at disdrometer site (65 km southwest from KOUN). In the beginning stage, storm was more convective (from 0700-1100 UTC), while in the later stage of its development, storm was mainly stratiform with embedded convection regions. Storm motion relative to the 2DVD and KOUN was from southwest to northeast. PPI of Z_H, Z_{DR}, ρ_{hv} and hydrometeor classification for 1200 UTC is shown in Fig. 2.

In this stage, as it can be seen from Fig. 2, the storm was mostly stratiform with embedded convective regions. In stratiform part, values of Z_H varied between 30 to 40 dBZ while in convective regions they went up to 45-50 dBZ. Z_{DR} values were between 0.7 to 1.5 dB in stratiform part and >1.5 dB in convective regions. Hydrometeor classification with 10 classes of scatterers has been made, using Z_H, Z_{DR} and ρ_{hv} as independent variables. The classes used in classification are: GC/AP- ground clatter/anomalous propagation (pink), BS- biological scatterers (dark green), DS- dry snow (cian), WS- wet snow (navy blue), CR- cristals (dark blue), GR- groupel (lite green), BD- big drops (violet), RA- rain (orange), HR- heavy rain (red) and HA- hail (yellow).

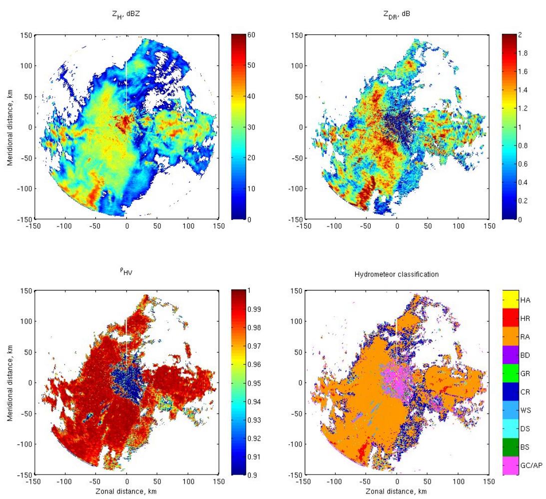

Figure 2: PPI of Z_H (top left), Z_{DR} (top right), ρ_{hv} (bottom left) and hydrometeor classification (classis are explained in text, bottom right), time: 1200 UTC

The rain (RA, orange) coincides with stratiform regions while heavy rain (HR, red) coincides with convective regions with enhanced convection (east and southwest from KOUN). Also, we can see an area of GC/AP close to radar, spreading radially aproximatelly 20 km from KOUN.

Evolution of DSD, mass, Z_H and Z_{DR} distribution measured from 2DVD is shown in Fig. 3. Measurements from the disdrometer show that in the beginning stage of development, at least at the 2DVD

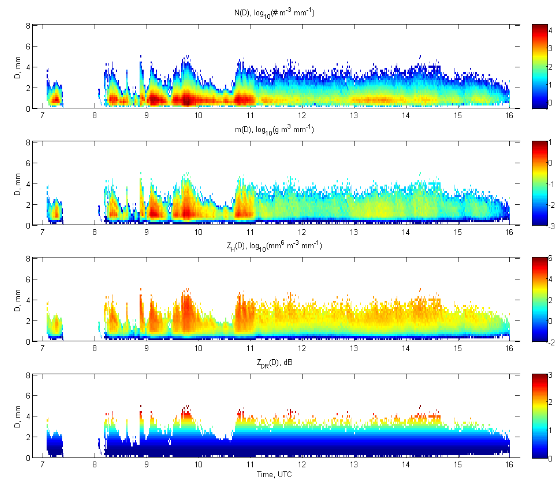

Figure 3: Evolution of DSD, mass, Z_H and Z_{DR} distribution (from top to bottom, respectively) measured with 2DVD.

site, storm had convective character. Later in mature stage, there was a transition to a stratiform type. DSDs varied more in convective part with the highest values for N from D = 0.4 to 1.7mm. DSD distributions were the broadest at the peaks of convection and as convective cells started to decay, DSDs shrank. In stratiform part, DSDs were less variable with highest N for D~0.8 to 1.2mm. For the highest values of N, the difference between convective and stratiform part was at least one order of magnitude. The similar pattern was recognized for evolution of mass distribution where the droplets with diameters between D~0.5 to 3 mm contributed the most. Also, broadening and shrinking was present, coinciding with convective maximums and minimums. In stratiform part mass distribution was almost uniform, with the droplets between D~0.4 to 2 mm contributing the most to the distribution. Similar conclusions can be drawn for evolution of reflectivity and differential reflectivity distribution. Raindrops with larger diameters contribute the most to the distribution, with higher values of Z_H and Z_{DR} for the same value of D in convective part of the storm.

Time plot of vertical profiles over the disdrometer

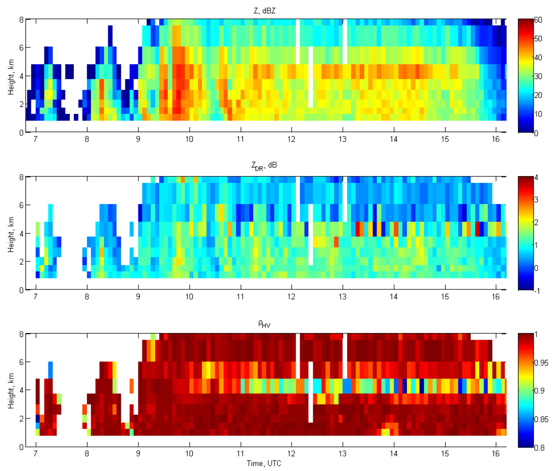

Figure 4: Evolution of vertical profiles of Z_H, Z_{DR} and ρ_{hv} (from top to bottom, respectively) measured with KOUN at 2DVD site.

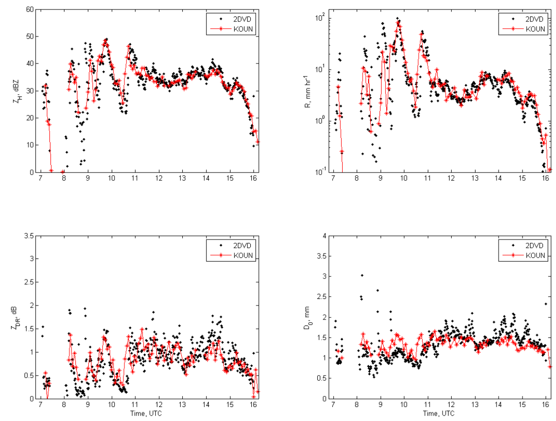

Figure 5: Comparison of Z_H (top left), Z_{DR} (bottom left), rainfall rate (top right), and median volume diameter (bottom right) obtained from radar DSD retrieval (KOUN) and disdrometer, time series for 0.5° KOUN elevation angle

site of radar variables Z_H, Z_{DR} and ρ_{hv} is shown in Fig. 4. Correlation between evolutions of profile of reflectivity factor measured with radar and reflectivity distribution at the ground measured with 2DVD is high. Peak in the Z_H value profile over the 2DVD site has occurred at about 0945 UTC (Fig. 4), which coincided with the highest values of N. Bright band signature is clearly distinguished in stratiform stage of the storm. It was located at height of ~ 4km. Sudden increase in Z_H and decrease in ρ_{hv} values along with the delineation of higher and smaler values in Z_{DR} is obvious (Fig. 4).

Next, we'll look at the radar-disdrometer comparison. Disdrometer data are considered as a ground truth and lately, often used as verification of the radar measurements, in this case variables R and D_0 obtained from DSD retrieval. DSD retrieval is based on Z_{DR} -Λ and Z_H -N_0 -Λ dependence as shown in Eqs 3-4.

Comparisons between radar Z_H, Z_{DR}, and DSD retrievals (rainfall rate, R, and median volume diameter, D_0) and 2DVD measurements, are shown in Fig. 5. After adjusting radar measured Z_{DR} (removing the -0.36 dB bias), results are in good agreement. The reason for Z_{DR} adjustment probably lies in radar miss-calibration. In the initial stage of convection, for the first three convective cells over 2DVD site (from 0700-0930 UTC), peak of the radar Z_H was 4-5 dBZ lower then 2DVD measurements. In that period, DSDs were narrow (Fig. 3). Also convective cells were weak, which we can see from vertical profile at the time (Fig. 4). Because of averaging of radar data and differences in resolution of sampling volumes, small numbers of big drops detected with 2DVD are harder to be seen with radar, especially if the convective updraft/downdraft occurred in small area around the 2DVD site. Later stages of convection agree well while in stratiform part, radar measurements tend to be slightly lower (~2 dBZ). The similar pattern is seen for Z_{DR} with slightly higher values in convective part and lower in stratiform part.

Radar retrieved median volume diameter is slightly overestimated for convective part (except for a few time periods in the beginning of the event when 2DVD measured small number of huge drops, which radar couldn't see because of averaging and sampling volumes issues) and slightly underestimated for stratiform part of the storm comparing to the 2DVD values. Regarding the rainfall rate, radar estimation is in fair agreement for convective part (the same kind of issues as for D_0) and in very good agreement for stratiform part. Local peaks in the rainfall rate coincide with the peaks in convection, as expected.

4.2 A convective storm on 28 June, 2007

For this event, focus was set on convective cell which passed over 2DVD site (65 km southwest from KOUN) during the time period from 0900-1540 UTC. In advance of the cold front, which was approaching from the west, convective cell develop with motion from south to north relative to 2DVD and KOUN. Four hours after convective cell decayed, stratiform system with embedded convection passed over 2DVD site.

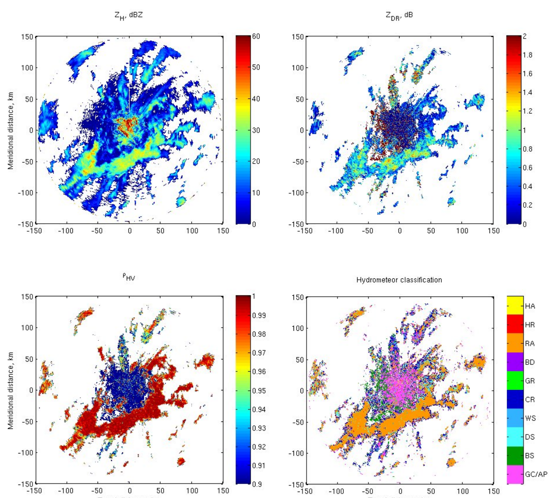

Figure 6: PPI of Z_H, Z_{DR}, ρ_{hv} and hydrometeor classification, as in Fig.2, time: 1230 UTC

PPI of Z_H, Z_{DR}, ρ_{hv} and hydrometeor classification for 1230 UTC (the time of convective peak at 2DVD site) is shown in Figure 6. Concidering the values of Z_H (~35-45 dBZ), convecton was weak in region of rain. Values of Z_{DR} were typically between 0.7 and 1.3 dB while ρ_{hv} values were close to 1. From classification PPI, we can see that only the rain class was present in whole domain (enhanced values of Z_H). Also, an area of GC/AP is located close to radar, spreading radially aproximatelly 25 km from KOUN, while BS are seen in front of the rainband.

Evolution of DSD, mass, Z_H and Z_{DR} distribution measured from 2DVD is shown in Figure 7. The DSDs are broadest at the time of the highest development of convective cell. The highest values of N were found for D within a range of ~0.7-1.3 mm. As soon as convective cell started to decay, N became narrower. Similar conclusion is valid for mass distribution except that range for D is little bit higher, from ~ 0.9-1.5 mm. The highest values of Z_H distributions were found for the range of D from ~0.9-2.6 mm. Regarding the Z_{DR} distribution, larger the diameter, higher the Z_{DR} distribution value.

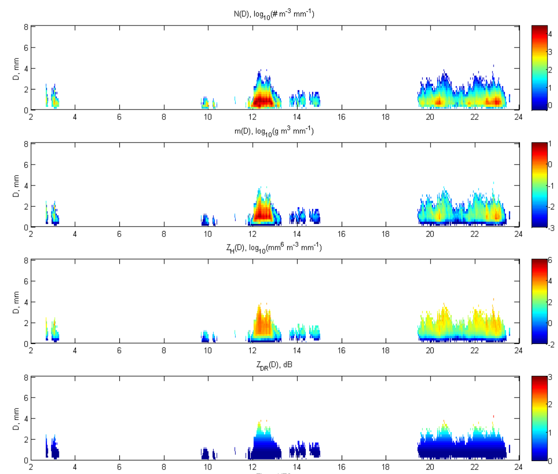

Figure 7: Evolution of DSD, mass, Z_H and Z_{DR} distribution (from top to bottom, respectively) measured with 2DVD.

Evolution in time of vertical profiles over the disdrometer site of radar variables Z_H, Z_{DR} and ρ_{hv} is shown in Fig. 8. Peak of the convection over the 2DVD site has occurred around 1220 UTC (Fig. 8). When convective cell started to decay, bright band signature started to appear in Z_{DR} and ρ_{hv} profiles, but it was not so obvious in Z_H profile. The height of the bright band was about ~ 5.5km. In the process of decaying, dying convective cell has transitioned to short living stratiform structure.

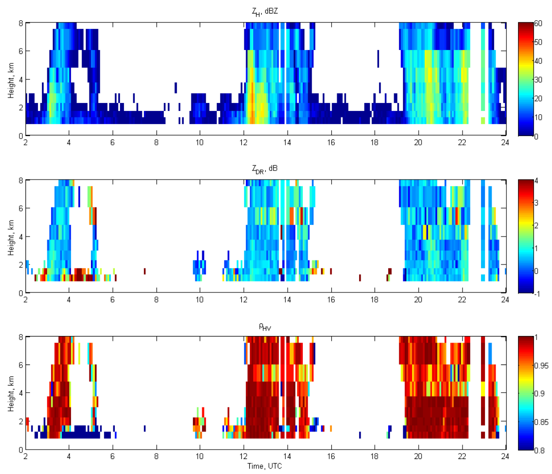

Figure 8: Evolution of vertical profiles of Z_H, Z_{DR} and ρ_{hv} (from top to bottom, respectively) measured with KOUN at 2DVD site.

Comparisons between radar Z_H, Z_{DR}, and DSD retrievals (rainfall rate, R, and median volume diameter, D_0) and 2DVD measurements, are shown in Fig. 9. After radar Z_H and Z_{DR} adjustments for 2.4

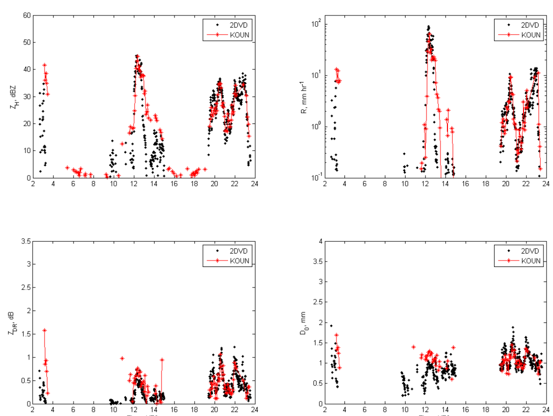

Figure 9: Comparison of Z_H (top left), Z_{DR} (bottom left), rainfall rate (top right), and median volume diameter (bottom right) obtained from radar DSD retrieval (KOUN) and disdrometer, time series for 0.5° KOUN elevation angle

dBZ and -0.21 dB respectively, results are in fair agreement. The radar and 2DVD measured Z_H agree very well for convective cell, but for stratiform part after transition radar measured Z_H seems 4-6 dBZ higher then disdrometer one (also number of radar data points for this period is small). Similarly, Z_{DR} is still slightly higher for convective cell and opposite for transitional stratiform part. For this case, dataset from whole day was used for radar Z_H and Z_{DR} adjustment, instead of the period when convection occurred.

Radar retrieved median volume diameter is slightly overestimated for convective part and slightly underestimated for transitional stratiform part comparing to the 2DVD values (in this period, there was a small number of radar data points). Regarding the rainfall rate, radar estimation is in good agreement for convective part and in not so good agreement for stratiform transitional part.

If we take a look at the later time period, from 1930-2400 UTC, when storm had stratiform character with embedded convection, the agreement between radar and disdrometer is very good. It means that this portion of dataset biased the adjustment of Z_H and Z_{DR} for convective period from 1200- 1400 UTC.

4.3 A squall-line case on 13 May, 2005

This storm was characterized by a leading line of strong convection followed by a small transition zone and then a region of enhanced stratiform rain. Squall-line passed over 2DVD site (29 km south from KOUN) during the time period from 0740-0820 UTC. Storm motion relative to 2DVD and KOUN sites was from west to east.

PPI of Z_H, Z_{DR}, ρ_{hv} and hydrometeor classification for 0730 UTC is shown in Figure 10. The values of Z_H in leading edge of the squall-line are high (up to 55 dBZ), while in stratiform region they went up to 45 dBZ. Values of Z_{DR} are very high for leading edge of the storm with values between 2.2 and 3.5 dB while ρ_{hv} values were close to 1. Some interesting features can be seen from classification PPI. In the verge of leading edge of the squall-line, there is a narrow

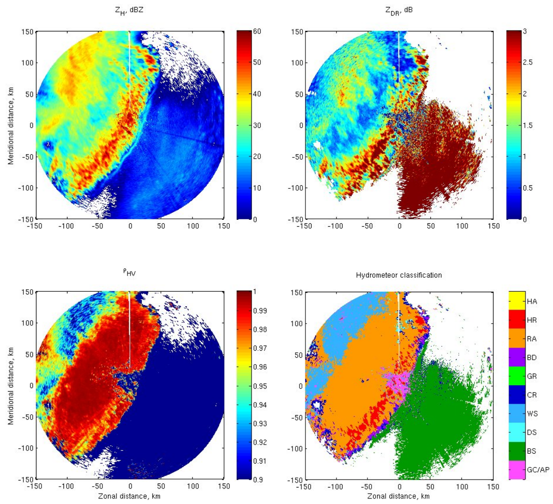

Figure 10: PPI of Z_H, Z_{DR}, ρ_{hv} and hydrometeor classification, as in Fig.2, time: 0730 UTC

region of big drops. Immediately behind, region of heavy rain was present with a couple of tiny regions with hail. Behind the squall-line, region of stratiform rain was present and at the approximate distance of 100-150 km from radar a region of wet snow has appeared. The height of 0.5 degrees of elevation of the radar beam at 100 km distance is roughly at 1 km. It is possible that the region of wet snow is simply residum of unmelted particles from melting layer or due to imperfection of classification algorithm. The melting layer in stratiform part was around 3.3 km at the time when stratiform part passed over 2DVD site. An area of GC/AP is located close to radar, spreading radially aproximatelly 20 km from KOUN, while the large area of BS was seen in front of the squall-line.

Time evolution of DSD, mass, Z_H and Z_{DR} distribution measured from 2DVD is shown in Figure 11. The DSDs were the broadest at the time of the squall-line passage. The highest values of N were found for D within a range of ~0.4-1 mm. As soon as the squall-line passed, N became narrower. Drop size distributions are typically broad in regions of high reflectivity and narrow in trailing portions of the convective zone and stratiform part. Similar conclusion is valid for mass distribution except that

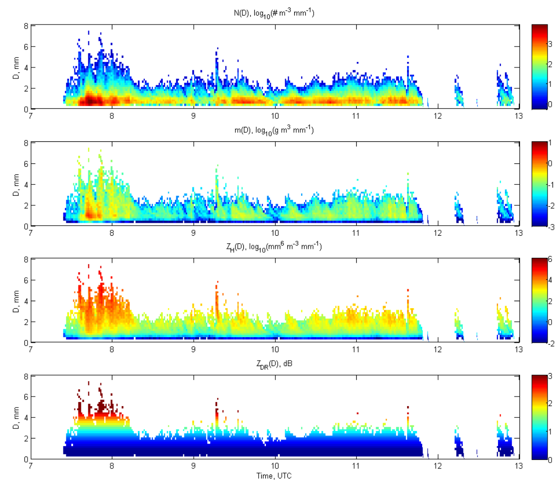

Figure 11: Evolution of DSD, mass, Z_H and Z_{DR} distribution (from top to bottom, respectively) measured with 2DVD.

range for D is little bit higher, from ~ 0.5-0.9 mm. The highest values of Z_H were found for the biggest D's; larger the diameter, larger the Z_H and Z_{DR} distributions values.

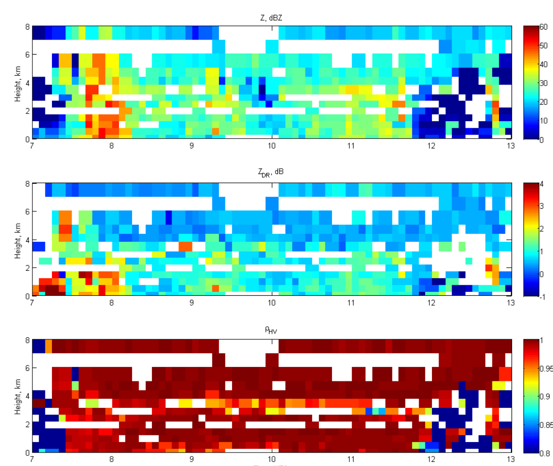

Figure 12: Evolution of vertical profiles of Z_H, Z_{DR} and ρ_{hv} (from top to bottom, respectively) measured with KOUN at 2DVD site.

Time plot of vertical profiles over the disdrometer site of radar variables Z_H, Z_{DR} and ρ_{hv} is shown in Fig. 12. The highest values of Z_H and Z_{DR} over the 2DVD site had occurred around 0750 UTC (the time of the squall-line passage). Bright band signature is clearly distinguished in stratiform stage of the storm. It is located at height of ~ 3.3 km. Sudden decrease in ρ_{hv} values along with the delineation of higher and smaler values in Z_{DR} is obvious.

Comparisons between radar Z_H, Z_{DR}, and DSD retrievals (rainfall rate, and median volume diameter, D_0) and 2DVD measurements, are shown in Fig. 13.

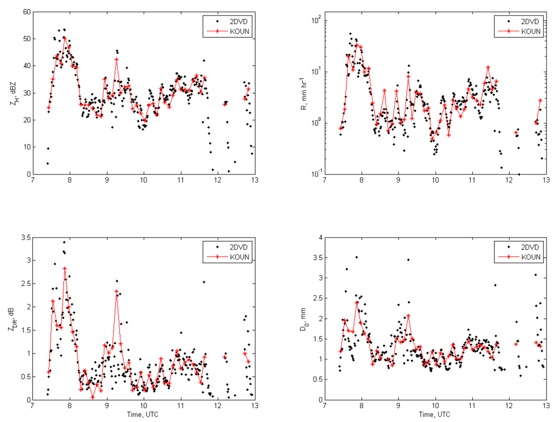

Figure 13: Comparison of Z_H (top left), Z_{DR} (bottom left), rainfall rate (top right), and median volume diameter (bottom right) obtained from radar DSD retrieval (KOUN) and disdrometer, time series for 0.5° KOUN elevation angle

After radar Z_H and Z_{DR} adjustments for 0.21 dBZ and -0.42 dB respectively, results are in good agreement. Radar Z_H and Z_{DR} values are slightly lower (4-5 dBZ and 0.4-0.5 dB, respectively) in comparison with 2DVD measurements at the time of squall-line passage over the 2DVD site. Because of averaging of radar data and differences in resolution of sampling volumes, small number of big drops detected with 2DVD is harder to be seen with radar, especially if the convective updraft/downdraft occurred in small area around the 2DVD site. In stratiform part, measurements tend to agree very well. Again, because whole dataset was used to calculate the adjustment, it is slightly biased towards stratiform part since the number of data points is higher for stratiform period.

Radar retrieved median volume diameter is slightly underestimated overall for convective part (especially for a few time periods in the beginning of the event when 2DVD measured small number of huge drops, which radar couldn't see because of averaging and sampling volumes issues) and for a stratiform part of the storm it seems that the results are in very good agreement. High reflectivity associates with large Z_{DR} and D_0. Drops are large ($D_0 \geq 2.3$mm) at the leading edge of the convection and become small in the mean toward the rear of the convective zone (<1mm). Regarding the rainfall rate, radar estimation is in good agreement for convective part (the same kind of issues as for D_0) and in very good agreement for stratiform part. With some exceptions heaviest rain rates are found in reflectivity cores.

5. SUMMARY AND DISCUSIONS

Observations and data analysis of rain events collected with S-band polarimetric KOUN radar and a 2DVD in Oklahoma were presented in this paper. Several storm types were studied: a convective storm, a convective-stratiform mix, and a squall-line case. Polarimetric radar and disdrometer observations were used to study storm structure and evolution. The morphology of each storm was revealed through PPIs of Z_H, Z_{DR}, ρ_{hv} and hydrometeor classification. Time evolution of DSD, mass and reflectivity distributions were obtained with 2DVD. Vertical structure and time evolution of radar measured Z_H, Z_{DR} and ρ_{hv} at 2DVD site were extracted and shown. Also, raindrop size distributions (DSDs) were retrieved from polarimetric radar measurements and disdrometer was used to validate the DSD retrieval and to deduce the microphysical properties.

The DSD parameters retrieved from radar measurements are in good agreement overall with disdrometer measurements, although there were some discrepancies. In the convective part of the storm, radar measured Z_H seem to be slightly smaller and Z_{DR} slightly higher, comparing with disdrometer. The sources of discrepancies are numerous. The most common one is the difference in sampling volumes. Another one is the averaging over azimuth and range of the radar variables. Also, radar calibration could be the issue. As seen from results, the adjustment made to compensate miss-calibration of the radar gives better agreement between results. At this point it is a little bit speculative, but it seems that convective and stratiform part of the storm should have separate adjustments for compensation of miss-calibration.

Acknowledgement

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