P2.4 AN INTER-COMPARISON OF RAINDROP SIZE DISTRIBUTIONS RETRIEVED FROM POLARIMETRIC RADAR PARAMETERS

Michael P. Morris[1,2] *, Philip B. Chilson[1,2], Alexander V. Ryzhkov[2,3], Terry J. Schuur[3], Michihiro Teshiba[1,2], Guifu Zhang[1,2], Qing Cao[1,2], Robert D. Palmer[1,2], Laura M. Kanofsky[1,2]
[1]*School of Meteorology, University of Oklahoma, Norman, OK*
[2]*Atmospheric Radar Research Center, University of Oklahoma, Norman, OK*
[3]*Cooperative Institute for Mesoscale Meteorolgical Studies, Norman, OK*

1. INTRODUCTION

In precipitating systems, the drop-size distribution (DSD) is critical for characterization of the microphysical processes responsible for the development of the precipitation. In addition, the DSD and its moments form the basis of measurable parameters such as radar reflectivity factor and rainfall rate, and as such a great deal of effort has gone into methods for measuring, modeling, and understanding the properties and evolution of DSDs. One of the main methods for exploring the DSD is to analyze the fallspeed spectrum recorded by a vertically pointing Doppler profiling radar, but the relative paucity of profiling radar systems as well as the planned dual-polarization upgrade to the existing WSR-88D network indicates the need to develop methods of extracting the DSD from polarimetric measurands. Central Oklahoma provides an ideal test bed for such research due to the presence of a prototype polarimetric weather radar near the University of Oklahoma campus (hereafter referred to as KOUN), an operational NEXRAD WSR-88D installation at Twin Lakes (KTLX), as well as a 915-MHz wind profiler (OU profiler) and 2-D video disdrometer (2DVD) located at the University of Oklahoma's Kessler Farm Field Laboratory (KFFL - Chilson et al. (2007)), a remote instrumentation site in McClain county. The Oklahoma Mesonet, a network of 117 remote hydrometeorological observing stations spread across the state (Brock et al. 1995), also allows for high spatial and temporal resolution surface observations.

From the KOUN values of radar reflectivity factor at horizontal polarization (Z_h), differential reflectivity (Z_{dr}), and cross-polar correlation coefficient (ρ_{hv}), information about the size distribution of the hydrometeors inside the resolution volume can be deduced assuming a particular analytical form of the DSD (e.g. Cao et al. (2007), Brandes et al. (2004), Zhang et al. (2001)). Similarly, the Doppler spectrum measured by the profiler may be converted into a DSD by applying an assumed fallspeed relationship, but significant errors can result when the profiler spectra are contaminated by ambient vertical velocity. Applying an assumed fallspeed relation to the KOUN DSDs yields a fallspeed spectrum that, unlike the observations from the profiler, is uncontaminated by ambient vertical velocity. By performing a first-moment correction to the profiler spectra the background vertical velocity can be estimated and the DSD can be recalculated from the profiler observations based on this information. The retrieved DSDs are then compared to the 2DVD as a means to assess the error in each. What follows is an overview of the physical framework for each retrieval method, as well as the results of an in-depth case studies where these algorithms have been applied.

2. DSD RETRIEVAL

a. Using Polarimetric Measurands

Numerous analytical forms of the DSD exist in literature (e.g. Marshall and Palmer (1948), Ulbrich (1983), Zhang et al. (2001)). The retrieval method implemented here is based on the constrained gamma distribution with the form:

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

Corresponding author address: Michael Morris, School of Meteorology, Rm 4630, 120 David Boren Dr., Norman, OK 73019; *e-mail: Michael.P.Morris-1@ou.edu.*

where D is the raindrop diameter and λ and μ are parameters related by:

$$\mu = \mu'(\Lambda) + C\Delta Z_{dr} \tag{2}$$

and

$$\mu' = -0.0104\Lambda^2 + 0.7692\Lambda - 1.79 \tag{3}$$

In equation (2), C = 2 and

$$\Delta Z_{dr} = Z_{dr} - Z_{dr}^a \tag{4}$$

$$Z_{dr}^a = 10^{f(Z_h)} \tag{5}$$

$$f(Z_h) = -5.01710 \times 10^{-4} Z_h^2 + 0.07401 Z_h - 2.0122 \tag{6}$$

where Z_h and Z_{dr} are expressed in dB and quantity μ is constrained to fall between 0 and 6 (Cao et al. 2007).

b. Using 915-MHz Profiler Spectra

To facilitate comparison with the DSDs retrieved with the above method, it is also necessary to generate corresponding DSDs from Doppler spectra as measured by the OU profiler. Since the profiler directly measures the Doppler spectrum of fallspeeds inside each resolution volume, the total backscattered power from hydrometeors is

$$P_r = \int S(v)dv \tag{7}$$

which can in turn be expressed in terms of the equivalent radar reflectivity factor Z_e as

$$P_r = C \times Z_e = C \int N(D_e) D_e^6 dD_e \tag{8}$$

where C is a calibration constant related to various hardware parameters and physical constants. In the presence of a precipitating system with hydrometeor backscatter in the Rayleigh regime, the calibration constant is such that the noise-filtered and range-corrected Z_h values agree between the profiler and KOUN. To account for the vertical variation in air density, the correction factor $\frac{\rho}{\rho_0}^{0.4}$ where ρ_0 represents the surface density and ρ represents the air density at a given height, is estimated from a representative sounding and applied to the velocity spectra (Foote and duToit 1969). Equating (7) and (8) and using the fact that only $N(D)$ is unknown, the retrieved DSD is given by:

$$N(D) = \frac{S(v)}{D^6}\frac{dv}{dD} \tag{9}$$

The quantity $\frac{dv}{dD}$ comes from the assumed fallspeed relation (Atlas et al. 1973)

$$v(D) = 3.78D^{0.67}, D < 3\text{mm}$$
$$v(D) = 9.65 - 10.3e^{-0.6D}, D > 3\text{mm} \tag{10}$$

3. VERTICAL VELOCITY ESTIMATION

Since the profiler spectra are obtained from a vertically oriented beam, it is necessary to consider the effects of ambient vertical velocity (i.e. the presence of a storm-scale or mesoscale downdraft or updraft) as its presence can significantly bias the Doppler spectrum and hence, the retrieved DSD. For example, a storm-scale downdraft will increase the fallspeed of all drops inside the resolution volume and result in a bias toward larger drop sizes while a storm-scale updraft will reduce the measured fallspeeds and bias the DSD towards smaller diameters. A first moment correction between the contaminated profiler spectra and uncontaminated fallspeed spectra from KOUN can yield an estimate of the background vertical velocity and allow the profiler-based retrieval method to be accurate in a wider array of meteorological conditions as the contribution to the spectrum from the clear-air motion can be removed, leaving only the signal that arises from hydrometeor backscatter. Figure 1 illustrates graphically how the vertical velocity is calculated from the comparison of the two sets of Doppler spectra.

4. APPLICATION - 18 AUGUST 2007 CASE STUDY

During the afternoon and evening hours of 18 August 2007, an extraordinary event unfolded in western and central Oklahoma as the remnants of Tropical Storm Erin, downgraded to depression status after moving inland 48 hours earlier, reintensified to produce tropical storm-like conditions over much of the state. Two brief tornadoes were reported in western Oklahoma, near Cordell. As the evening progressed,

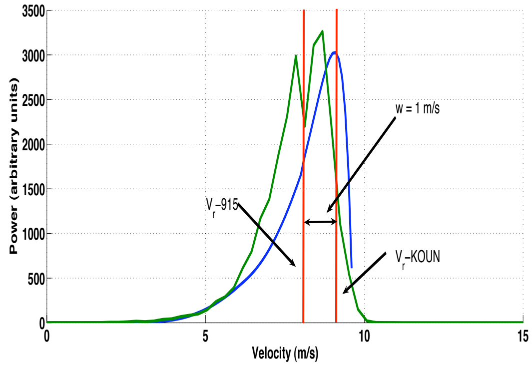

Figure 1: Profiler measured (green) and KOUN estimated (blue) Doppler spectra for 12:37 UTC 11 March 2007. Mean radial velocity for each spectrum shown in red, with discrepancy attributed to vertical motion of about 1 m/s.

the storm continued to wrap up, bringing torrential rainfall across southwestern Oklahoma and slowly spreading eastward and northward across the state. Sustained wind gusts of 40 knots were recorded by the Oklahoma Mesonet site in Watonga, northwest of Oklahoma City.

For a significant portion of this event, KOUN was operated in a concentrated-RHI mode over the OU profiler to examine the microphysics of this storm between 2230 and 0100 UTC, while the profiler collected data continuously until 0715 UTC, at which point the power supply to the profiler control computer failed. Unfortunately, a malfunction to the 2DVD prevented it from sampling surface DSDs after 2215 UTC. As a result, the only DSD data available are those retrieved from the KOUN polarimetric variables and the profiler Doppler spectra, but based on the results from a similar squall line case presented by Teshiba et al. (2007), it appears the retrieval techniques are consistently robust at higher altitudes.

Precipitation during this event was intermittent in nature and relatively light during the time in which the combined observations were made. Several instances of rain evaporating before it reaches the surface are apparent from Figure 3 as fallstreaks of slightly enhanced reflectivity, and the strong fallspeed gradient corresponding to the melting layer is easily seen on Figure 2 at approximately 4 kilometers AGL.

Mesoscale downdraft (22:30 UTC / Figure 4) During the early phase of the event, it appears that the melting of snowflakes is the dominant process responsible for rain formation. Low fallspeeds above the melting layer, as well as low Z_h and Z_{dr} confirm the presence of snowflakes, while the depressed ρ_{hv} indicates mixed phase precipitation. Z_{dr} values close to 1 indicate that precipitation is dominated by small drops, which is also consistent with the DSD retrievals. A weak mesoscale downdraft is evident in the vertical velocity structure, again coincident with a slight lowering of the melting layer and associated ρ_{hv} depression. Based on these two cases, we surmise that the vertical structure of ρ_{hv} may be connected in some way to the vertical velocity field.

Precipitation echoes contaminated by clear air (23:44 UTC / Figure 5) Due to the banded and intermittent nature of the precipitation during the event, there were many periods where the rainfall echo was comparable to the echo from clear air, or even nonexistent. One such region can be clearly seen in Figure 3 between 18:30 and 18:45 CST (2330 - 2345 UTC). In this case, it is difficult to determine the relative contribution of the two scattering media and the retrieval methods are not as robust. However, it is possible to sometimes estimate the clear air peak based on a two-peaked Gaussian fit to the 915-MHz Doppler spectrum in cases where the two contributions are of about the same magnitude. From the velocity spectra, it is apparent that there is substantial turbulence at mid-levels, but the vertical velocity removal appears to yield very consistent results below the melting layer. Again, it appears that the precipitation forms as a result of melting snow, though the bright band is not very apparent in the reflectivity profile. A small mid-level updraft is also indicated, likely resulting in rapid aggregation of small drops by larger ones through size sorting, leading to slightly enhanced Z_{dr}.

5. CONCLUSIONS

An investigation into the microphysical processes inside of two Oklahoma squall lines was presented

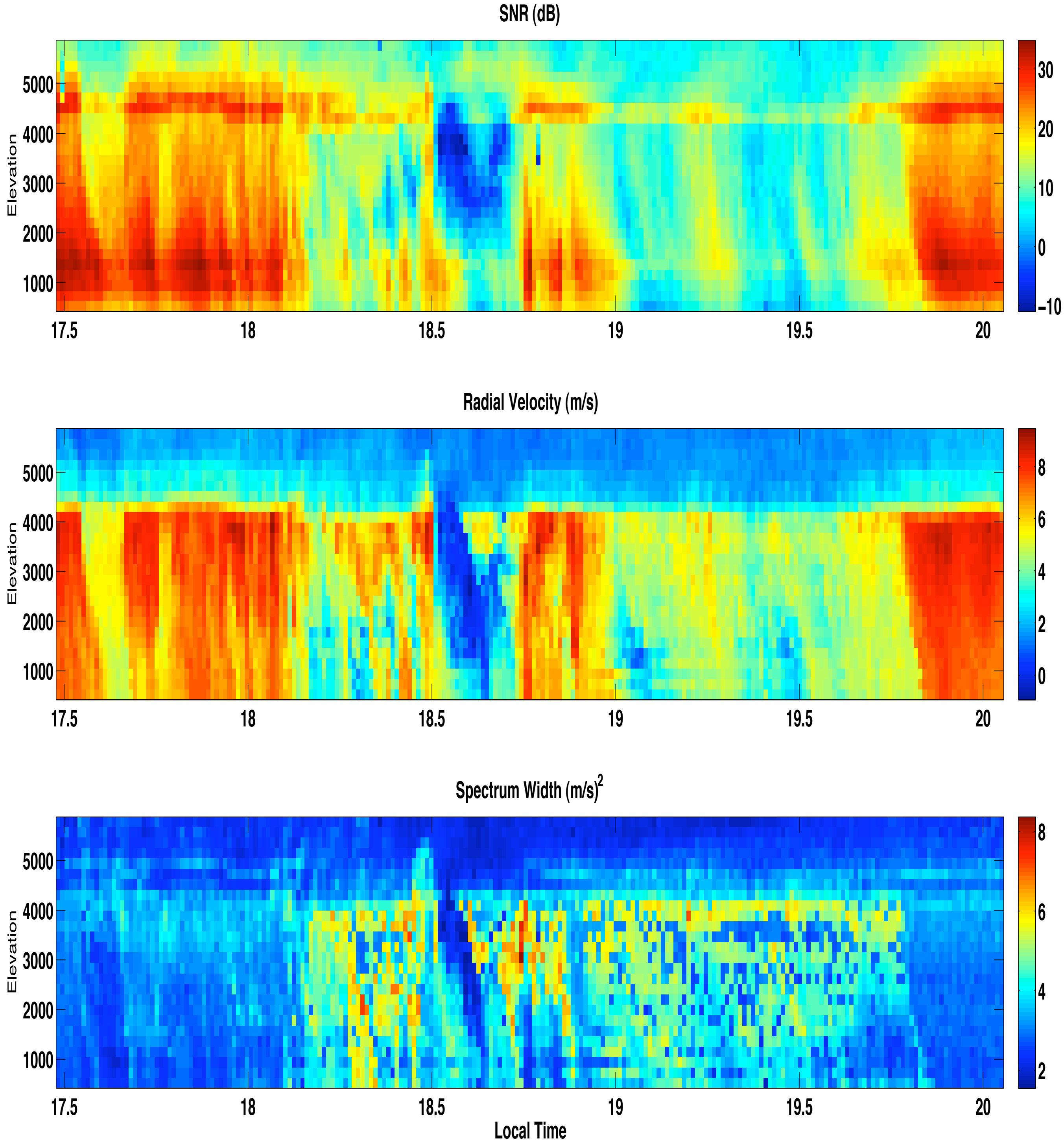

Figure 2: Time-height cross sections of SNR, radial velocity, and spectrum width measured by OU profiler on 18 August 2007. Elevation is in meters above sea level. Time is local (CST)

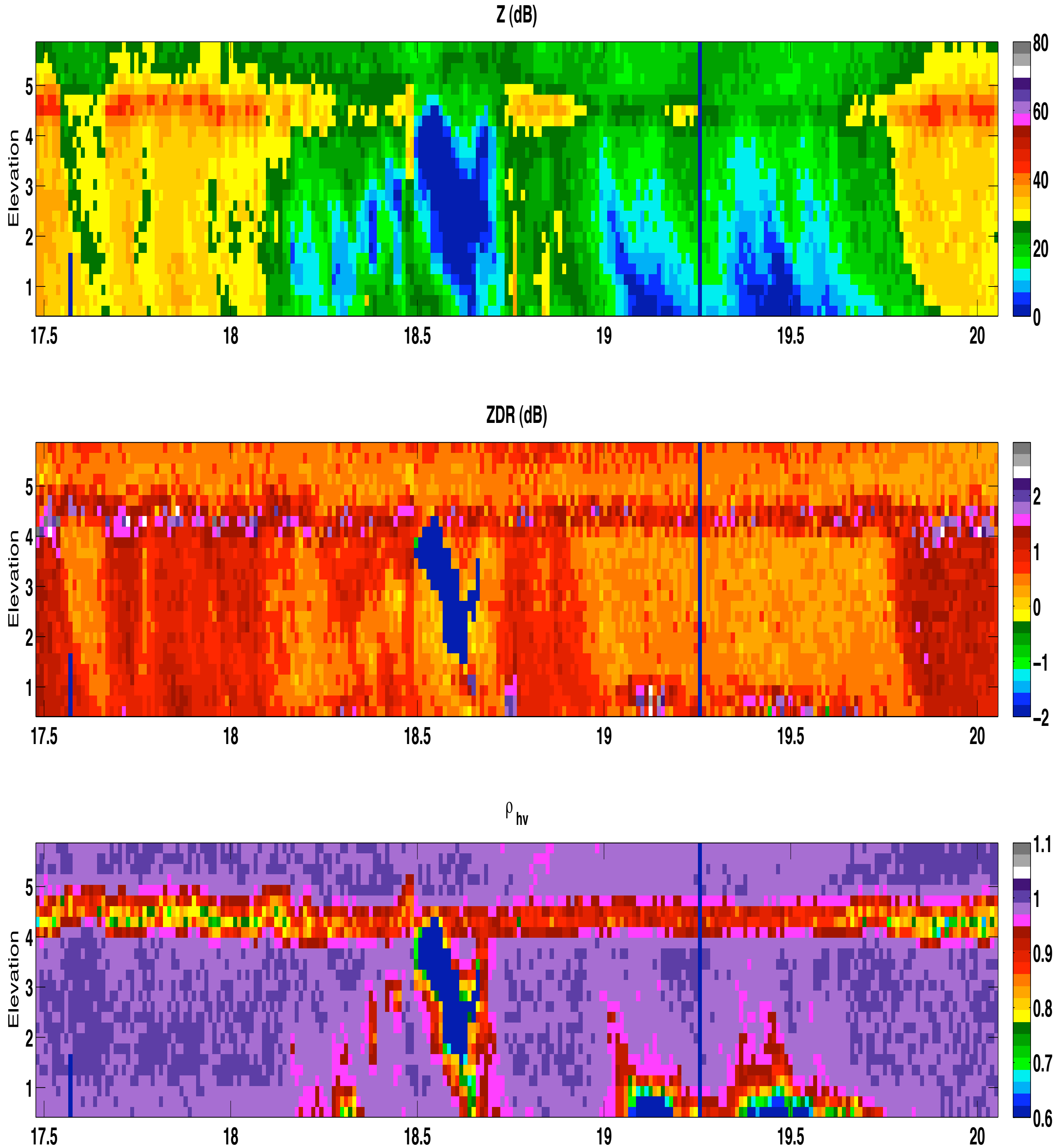

Figure 3: Time-height cross sections of Z_h (dB), Z_{dr} (dB), and ρ_{hv} measured by KOUN above the OU profiler on 18 August 2007. Elevation is in kilometers above sea level. Time is local (CST)

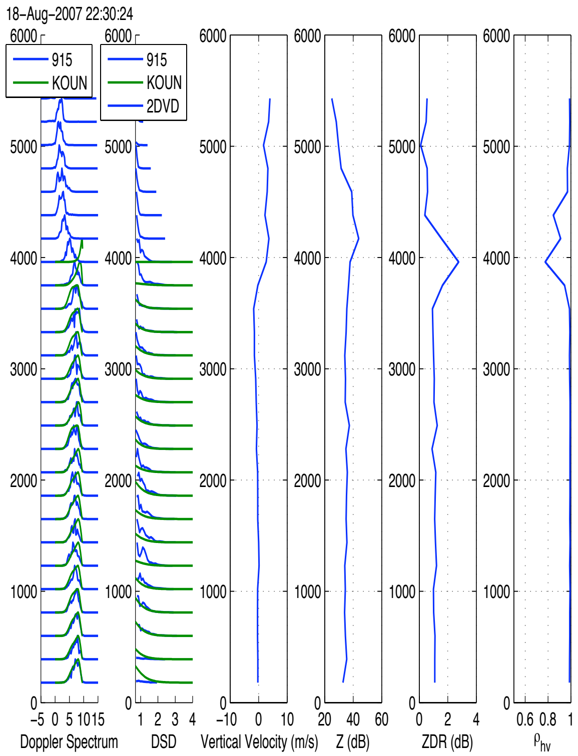

Figure 4: Vertical profiles of (left to right) Doppler spectra, DSDs, vertical velocity, Z_h, Z_{dr}, and ρ_{hv} at 2230 UTC 18 August 2007. The spectra of retrieved (KOUN) velocities and measured (profiler) velocities are shown in green and blue, respectively. DSDs retrieved from KOUN, and the profiler are given in green and blue respectively. KOUN retrievals are displayed only below the melting layer. Elevations are relative to MSL.

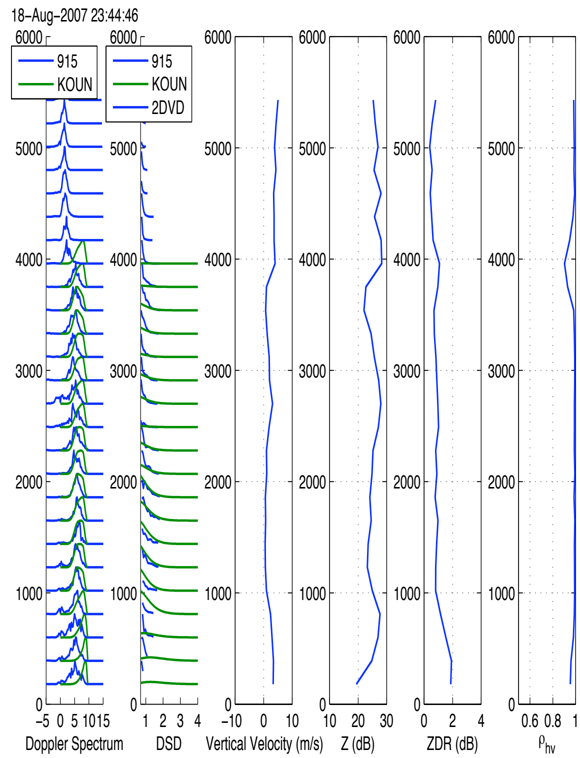

Figure 5: As in Figure 4 but for 23:44 UTC 18 August 2007

using a combined analysis of wind profiler and polarimetric radar data, while also providing a unique opportunity to validate the DSD retrieval techniques from both instruments and estimate the vertical velocity. When oriented vertically, Doppler spectra of wind profilers can be used to directly measure the terminal velocities of hydrometeors above the instrument, while the polarimetric radar variables are related to the mean size, shape, and orientation of the precipitation inside the resolution volume. The ground-based video disdrometer provides in-situ ground truth to the remotely estimated DSDs and may also act as a means of calibrating the two radars.

The vertical profiles of DSDs retrieved from KOUN and the wind profiler also offer a variety of applications in addition to what we present. For example, local short-term NWP would greatly value accurate microphysical information available over a large domain and at relatively high temporal and spatial resolution. An effort is already being made to apply the methods presented here to more conventional PPI datasets, as the operational use of polarimetric radar would preclude the collection of high-resolution RHI data over a small portion of the domain. Were forecasters able to visualize the microphysical data presented here in real-time or quasi-real-time, it could be of great value to life and property.

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