P14R.3 A COMPARATIVE STUDY OF DROP SIZE DISTRIBUTION RETRIEVAL USING TWO VIDEO DISDROMETERS AND A UHF WIND PROFILING RADAR

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1 INTRODUCTION

Knowledge of the drop size distribution (DSD) is critically important for the accurate retrieval of all rainfall parameters from weather radar data. Vertically pointed wind profiling radars can be used to directly measure the DSD by means of the Doppler velocity spectrum, which is then converted to a DSD with appropriate fallspeed relations.

During periods of precipitation, the measured velocity spectrum includes contributions from both the hydrometeors and ambient air motion in the sampled volume. The amplitude of each contribution depends on the wavelength of the radar used for the measurement (Doviak and Zrnić, 1993). The portion of the spectrum due to the hydrometeors is shifted by the ambient air motion and broadened by turbulence. In order to accurately retrieve the DSD from these velocity spectra, it is necessary to know how much of the observed motion is due to the hydrometeors and how much is due to the ambient air.

Under appropriate conditions, the Bragg scattering component (from variations in the refractive index) and the Rayleigh contribution (from hydrometeors) can be separately resolved within the same velocity spectrum. The Bragg component is then used to correct for the ambient air motion and the resulting velocity spectra from the profiler can be used to generate height profiles of the DSD. If the Bragg component cannot be resolved, models such as the Sans Air Motion (SAM) model (Williams, 2002) may be applied to estimate the DSD and ambient air motion.

Since regions of stratiform rain do not usually contain significant vertical air motions, this study focuses on DSD retrieval during periods of stratiform rain and assumes that the velocity spectra measured by the profiler are primarily due to hydrometeor fallspeed. This assumption is a target for improvement in the study; future work will include quantification and removal of ambient air motion where appropriate.

This is a preliminary study in preparation for future work involving the polarimetric capabilities of the NSSL KOUN radar. Some work in this area involving a 2DVD, a profiler, and a polarimetric radar has already been done by Ellis et al. (2003).

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2 RETRIEVAL PROCEDURE

Since disdrometers measure the DSD directly, this section focuses on DSD retrieval from a wind profiler.

The velocity spectrum of rain in the absence of ambient air motion and turbulence is given by (Atlas et al., 1973):

$$S_{precip}(v) = N(D)D^6\frac{dD}{dv} \qquad (1)$$

where D is the drop diameter, $N(D)$ is the number of drops of diameter D, and $\frac{dD}{dv}$ is the relationship between drop diameter and terminal fallspeed. The terminal velocity of a raindrop can be related to the drop diameter by (Atlas et al., 1973):

$$v(D) = 3.78D^{0.67}, D < 3\text{mm} \qquad (2)$$

$$v(D) = 9.65 - 10.3e^{-0.6D}, D > 3\text{mm} \qquad (3)$$

where D is the drop diameter in millimeters and v is the terminal velocity in m s^{-1}. With these relations, one can directly retrieve the DSD from the velocity spectra measured by the profiler.

In order to compare retrieved DSDs, this study focuses on time averaging and integral parameters such as reflectivity factor Z and rainrate R. The reflectivity factor Z is given by:

$$Z = \int_0^\infty N(D)D^6 dD \qquad (4)$$

where D is the drop diameter and $N(D)$ is the number density of hydrometeors per unit diameter in m^{-3} mm^{-1}. The rainrate R is given by:

$$R = \frac{\pi}{6}\int_{D_{min}}^{D_{max}} N(D)D^3(v(D) - w)dD \qquad (5)$$

where D_{min} and D_{max} are the minimum and maximum diameters respectively, $N(D)$ is the number density of hydrometeors per unit diameter in m^{-3} mm^{-1}, $v(D)$ is the terminal velocity of the drop, and w is the vertical velocity of the ambient air.

3 INSTRUMENTATION

This study was conducted in Central Oklahoma at the National Severe Storms Laboratory (NSSL) site in Norman. Two separate two-dimensional video disdrometers (2DVD) of similar design (manufactured by Joanneum Research in Austria) and a UHF Doppler profiler (manufactured by Radian Inc., currently Vaisala Inc.) were located at NSSL during late April and early May of 2005 for calibration purposes. One disdrometer is owned and operated by NSSL and the other is maintained by the National Center for Atmospheric Research (NCAR). The profiler is owned by Vaisala and is currently on loan to the Oklahoma Climatological Survey and the University of Oklahoma School of Meteorology.

3.1 2DVD

The 2DVD directly measures DSDs by creating a virtual measuring area with two orthogonal light sheets, each monitored by a line-scan camera. Drops that pass through the virtual measuring area create shadows that are detected by the cameras. This information is then processed to determine properties such as diameter, oblateness, and number of drops that fell through the measuring area. The 2DVD collects data continuously and reports rainfall properties for consecutive one minute periods. For a complete description of 2DVD operation, see Kruger and Krajewski (2002).

3.2 Wind profiler

The UHF Doppler wind profiler used in this study operates at 915 MHz. For the experiment, the following parameters apply. The pulse width is 700 ns corresponding to a range resolution of 105 m. The number of coherent intergrations is 80 and the interpulse period is 60 μs, corresponding to a Nyquist velocity of 17.2 m s^{-1}. The profiler was maintained in a vertically pointed mode during each of the rain events. In this mode, the profiler completes a scan of the vertical volume above the radar approximately every 16 seconds, covering 60 range gates between 97 m and 6.3 km above ground.

4 RESULTS

4.1 21 April 2005

On 21 April 2005, thunderstorms initiated by a dryline in western Texas moved into Oklahoma overnight, and a stratiform region associated with the decaying storms passed over the NSSL site by morning. Both disdrometers and the collocated vertically pointed profiler were collecting data during this event.

Figure 1 shows time-height plots of signal to noise ratio, Doppler velocity, and spectral width recorded by the profiler. Positive velocities indicate motion towards the radar (down). The period of rain from 05:30 through 06:45 UTC is visible in all 3 panels of this plot as a narrow area with increased signal to noise ratio and spectral width and nonzero Doppler velocities with consistent vertical extent. The diffuse feature below 2 km extending onwards from 15:00 UTC is the convective boundary layer.

The profiler dwell time is approximately 16 s while the 2DVD collects data continuously but reports statistics for each whole minute. Additionally, the time it takes for drops to fall to the surface ranges from seconds to minutes depending on the size of the drops and their initial height. Averaging data for both instruments over an appropriate interval before attempting any comparisons compensates for these effects. Figure 2 reflects calculations for Z after averaging data over 5 minute intervals. The time axis is shown in terms of the first minute of the 5 minute period; "5:31", for example, covers the 5 minute time period consisting of 5:31 through 5:36. Since the profiler is uncalibrated, time histories of Z for the two sampling volumes shown in this figure have been uniformly adjusted to facilitate comparisons of major features between data from the profiler and the disdrometer. The first gate from the profiler (97 m

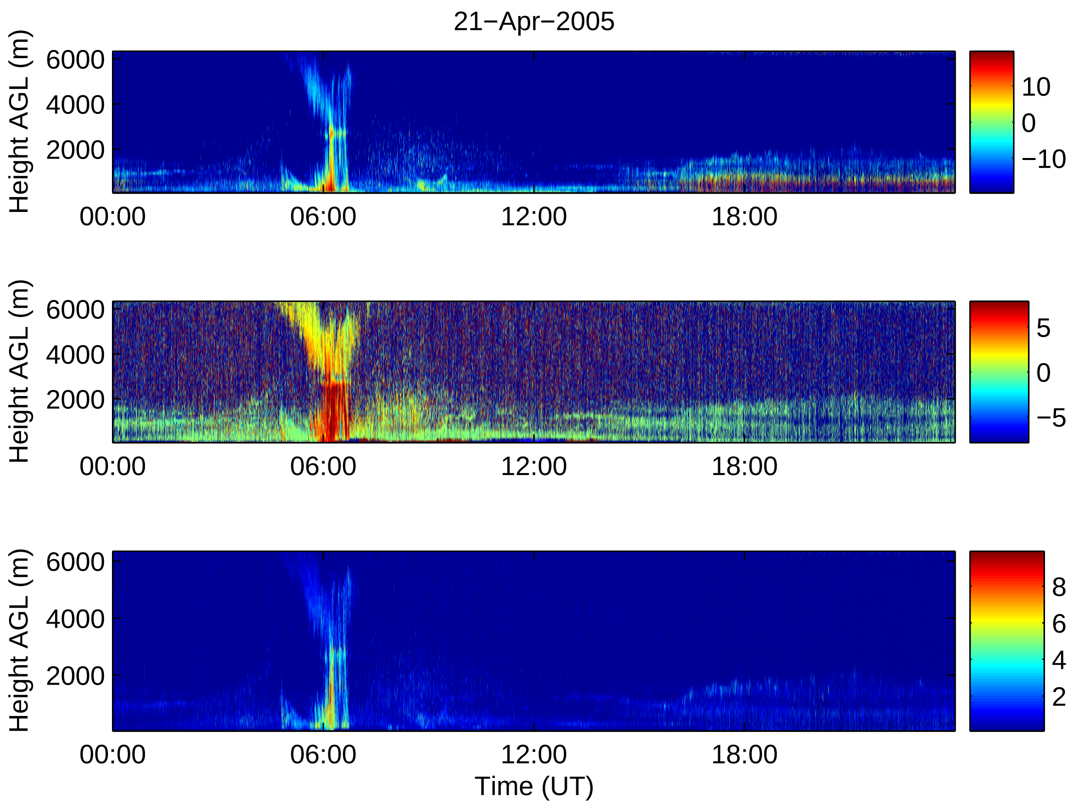

Figure 1: Profiler data plot of signal to noise ratio (top), Doppler velocity in m s^{-1} (middle), and spectral width in m s^{-1} (bottom) for 21 April 2005.

above ground) was found to be consistently different from higher gates and is not shown. At this time, ground clutter is believed to be the source of the difference between the lowest and higher range gates. The agreement between the profiler and both disdrometers is good from 5:51 UTC onwards. Disagreement prior to 5:51 is primarily between instruments as both disdrometers, while in similar agreement with each other, differ markedly from the profiler gates in absolute values of Z while showing a similar trend of increasing Z. One possibility for the disagreement below 20 dB is that enough noise may still be present in the profiler data to affect the calculation of Z during periods of small rainrates even after applying noise removal following the method described by Hildebrand and Sekhon (1974).

4.2 2 May 2005

On 2 May 2005, a broad area of stratiform precipitation formed over the Texas panhandle and moved across Oklahoma before dissipating farther east. The NSSL disdrometer and the collocated profiler were collecting data at the NSSL site during this event. The closest operational WSR-88D is Twin Lakes (KTLX), located approximately 20 km to the north-northeast of NSSL. Figure 3 shows a representative reflectivity image from KTLX during the extended period of stratiform precipitation.

A time-height plot of profiler data for 2 May 2005 is shown in Figure 4. The extended period of rain from 08:00 through 18:00 UTC is clearly visible on all three plots. Variations in precipitation intensity over time near the surface can be seen in the Doppler velocity plot.

Figure 5 reflects calculations for Z after averaging data over 5 minute intervals. As in Figure 2, the two profiler sampling volumes have been uniformly adjusted. The agreement is very good over most of the precipitation event. The degree of agreement indicates that these two profiler range gates and the disdrometer are observing similar quantities, suggesting that it is reasonable to compare DSDs retrieved from the lower profiler gates to DSDs measured by

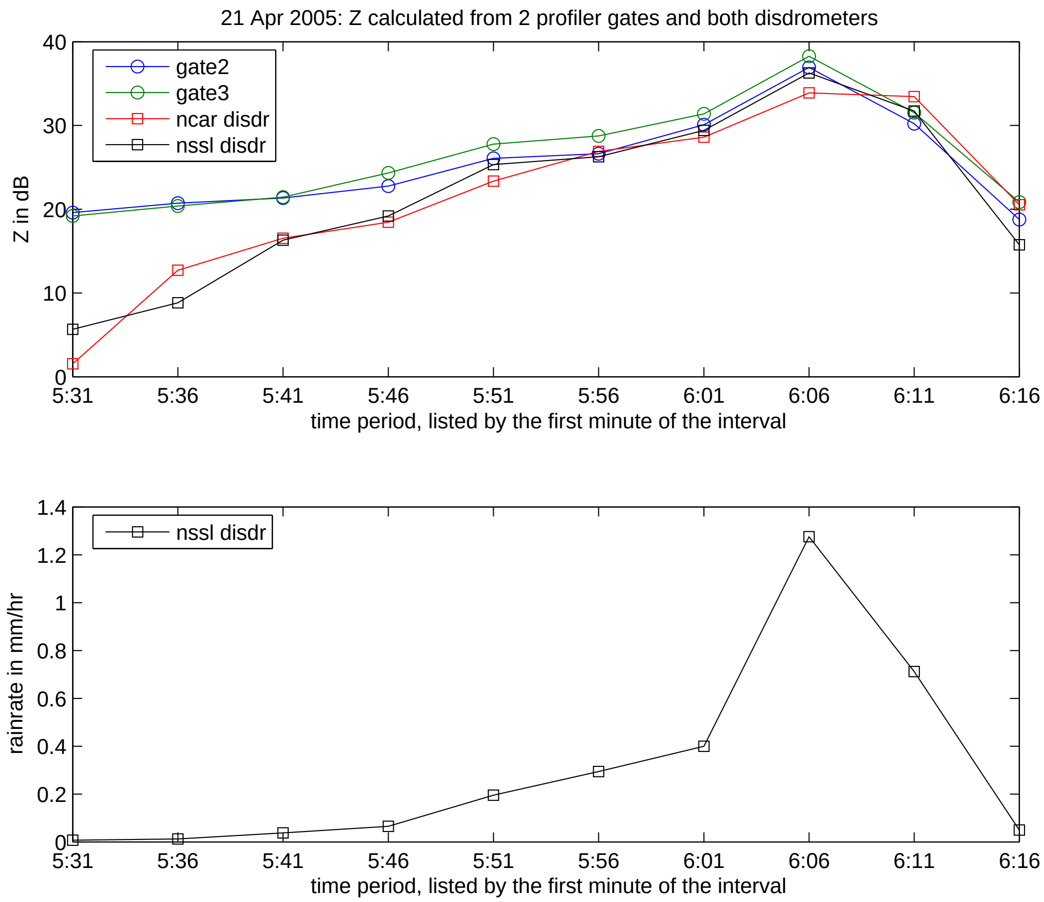

Figure 2: Reflectivity factor Z calculated from 2 profiler gates and both 2DVDs. The two gates shown are range gate 2 (202 m) and range gate 3 (307 m). The bottom plot shows the rainrate in mm hr^{-1} reported by the NSSL disdrometer.

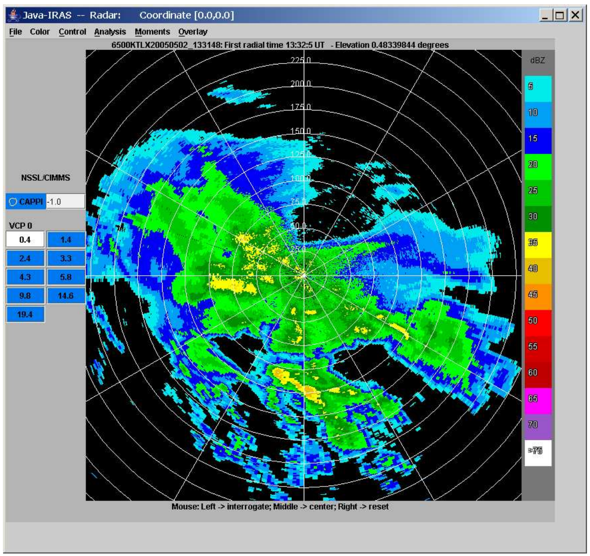

Figure 3: Extended stratiform precipitation on 2 May 2005. The radar image is centered on KTLX with range rings every 25km. NSSL is located approximately 20km west-southwest of KTLX. The data was imaged with the Interactive Radar Analysis System (IRAS), written by David Priegnitz at NSSL and available from the National Climatic Data Center at http://www.ncdc.noaa.gov

the disdrometer over this time interval.

4.3 Discussion

This is a preliminary study in preparation for future work to study DSD development with height. Future work will focus on fitting DSD models to disdrometer data and to DSDs retrieved from profiler data to compare the retrieved model parameters between instruments. It is expected that the profiler and NSSL 2DVD will be moved to the Kessler Farm Field Laboratory (KFFL) located 30 km south of NSSL. Observations and retrieved DSDs from KOUN, the UHF profiler, and 2DVD will be compared to examine DSD development with height as well as agreement between instruments. It is possible that a VHF profiler may become available for additional measurements. The enhanced detection of Bragg scattering provided by a VHF profiler would be particularly beneficial for further quantification of the ambient air motion during periods of precipitation (Fukao et al., 1985).

5 FUTURE WORK

Future work will involve the polarimetric capabilities of the NSSL KOUN radar following work done by Schuur et al. (2001) in comparing DSDs retrieved from video disdrometers with polarimetric radar data. Rainfall measurements and DSDs retrieved from the KOUN radar will be compared to observations from a UHF wind profiler and a 2DVD that will be located approximately 30 km from the weather radar site. Possible future supporting data include an emerging rain gauge network and the existing Oklahoma Mesonet station.

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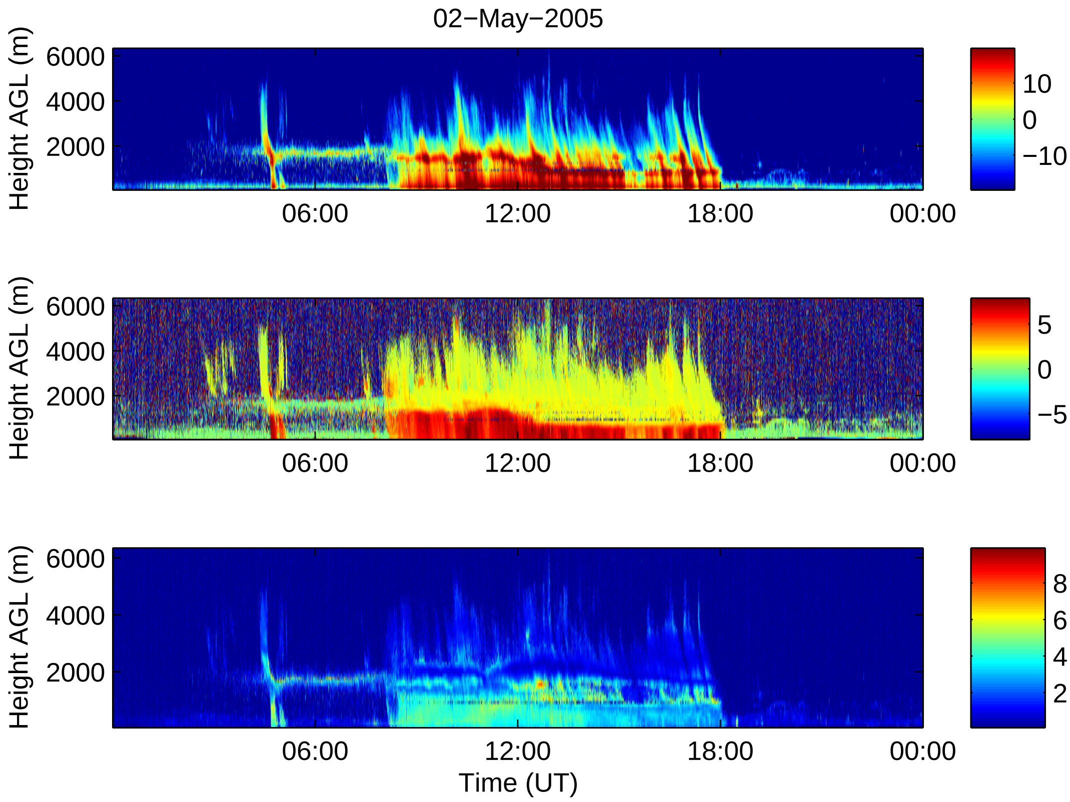

Figure 4: Same as Figure 1 for 2 May 2005.

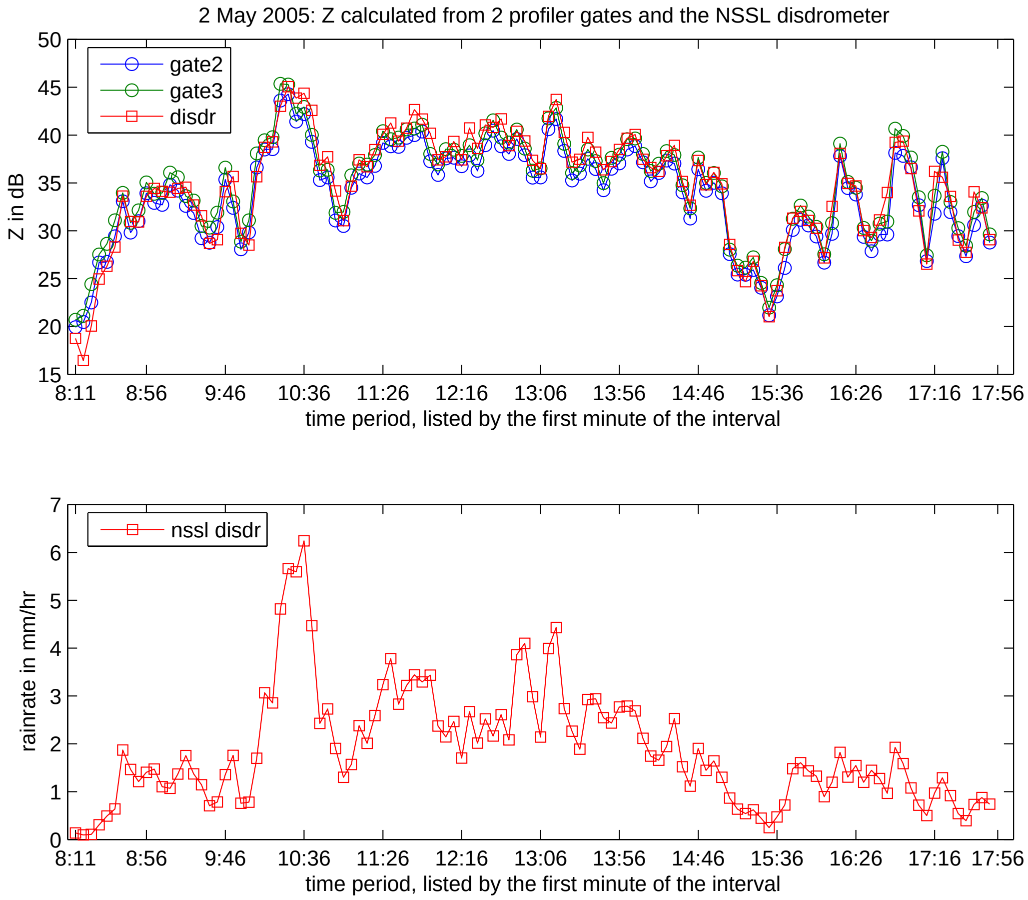

Figure 5: Reflectivity factor Z calculated from 2 profiler gates and the NSSL 2DVD. The two gates shown are gate 2 (202 m) and gate 3 (307 m). The bottom plot shows the rainrate in mm hr^{-1} reported by the NSSL disdrometer.