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COMPARISON OF RAIN DROP SIZE DISTRIBUTION RETRIEVALS FROM POLARIZATION DIVERSITY RADAR AND PROFILING RADAR USING VIDEO DISDROMETER MEASUREMENTS.

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1. INTRODUCTION

Current radar rainfall estimates rely on power-law relationships between rain rate and radar observables. These techniques use best fit relationships based on a range of gamma or exponential rain drop size distributions (DSD's). Accurate DSD retrievals could result in improved rain rate estimates by better capturing the natural variability of DSD's. The DSD retrievals would also be useful in studying the microphysical characteristics and morphology of precipitation events. Recent efforts have resulted in gamma DSD retrieval algorithms using S-band dual-polarization radar (Zhang et al. 2001) and UHF vertical incident profiler observations (Williams 2002). The purpose of this paper is to compare the DSD retrievals from the two radars using video disdrometer data.

During the PRECIP98 field program the NOAA 915 MHz profiling Doppler radar was co-located with a video disdrometer and several surface rain gauges. The National Center for Atmospheric Research (NCAR) S-band dual polarimetric (S-Pol) radar was located approximately 38 km away. This resulted in the lowest altitude S-Pol measurement occurring at approximately 500 meters above the ground. Several precipitation systems with both convective and stratiform characteristics, passed over the profiler/disdrometer site allowing comparison of DSD retrievals.

The gamma drop size distribution is a 3 parameter fit representing the rain drop size spectra as,

$$n(D) = N_0 D^{\mu} \exp(-\Lambda D),$$

where n is the number of drops and D is equivalent volume diameter. The three parameters to be retrieved are N_0, μ and Λ.

The utility of quantitative comparisons of radar data with ground based in-situ measurements is limited by several factors. The radar resolution volume is typically thousands of times larger than the disdrometor or rain gauge. Due to advection, the particles measured on the ground may not have passed through the radar volume directly above the instrument. While it is possible to account for advection using the scanning S-Pol radar, it is not possible with the vertically looking profiler. The precipitation particles may also evolve in the time it takes them to descend from the radar measurement to the ground.

In this study time history plots of the measured reflectivity and retrieved parameters of the gamma DSD from the profiler, S-Pol and the video disdrometer are compared. The rain rates and storm total rainfall are also computed from the DSD retrievals and compared to the disdrometer and rain gauge data. The computed rainfall rain rate values are then compared to conventional power law radar rainfall estimators. By integrating the rain rate estimates and obtaining rainfall totals, some of the problems comparing radar data to the in-situ measurements are mitigated.

Quantitative comparisons of the two radars are accomplished by interpolating the separate data sets to a common time grid using the cubic spline method. Thus standard statistical parameters can be computed.

2. DATA

Coincident S-Pol, profiler and video disdrometer data and gamma drop size distribution (DSD) retrievals for four cases during PRECIP98 have been analyzed. The data from 17 September 1998 are presented below and all data sets will be discussed at the 31st Radar Conference. The 17th was chosen because it is the longest continuous period of observations from approximately 19:00 to 24:00 UTC. Also, the data contain both convective (before ~21:30) and stratiform (after ~21:30) characteristics.

The S-Pol radar was scanning small sectors over the profiler resulting in a 0.5 degree elevation angle scans approximately once per minute. The S-Pol data were averaged in time and space. Observations which occurred within a one minute interval were averaged, as well as a 5 gate (0.75 km) average in range.

The retrieval of the three gamma DSD parameters from S-Pol uses the reflectivity (Z) and differential reflectivity (Z_{DR}) measurements (Zhang et al. 2001). Because it is an ill-posed problem to retrieve three parameters from 2 measurements an additional relation is required to close the system. Zhang et al. (2001) use an

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emperical relation between μ and Λ derived from video disdrometer data.

The profiler is a UHF (915 MHz) vertically incident radar. No smoothing was performed on the profiler data.

The sans air motion (SAM) model is used to retrieve air motion, spectral broadening and the gamma DSD parameters from the Rayleigh scattering portion of the spectra (Williams 2002). The SAM model is used when the vertical air motion from Bragg scatter is not available.

3. COMPARISON RESULTS

Figure 1 shows time history plots of reflectivity for S-Pol (solid line), the profiler (dashed line), and the video disdrometer (dotted line) for the 17 September 1998 data. There is an approximately one minute time lag between the two radar curves and the disdrometer curve to roughly take into account the particle fall time. The profiler and S-Pol have very similar reflectivity trends. The S-Pol reflectivity values are generally higher. The computed mean difference was 1.01 dB with a root mean square difference of 5.8 dB. There are larger reflectivity differences between the two radars and the video disdrometer between 19 and 21 UTC. This is not surprising given the convective nature of the precipitation during that period.

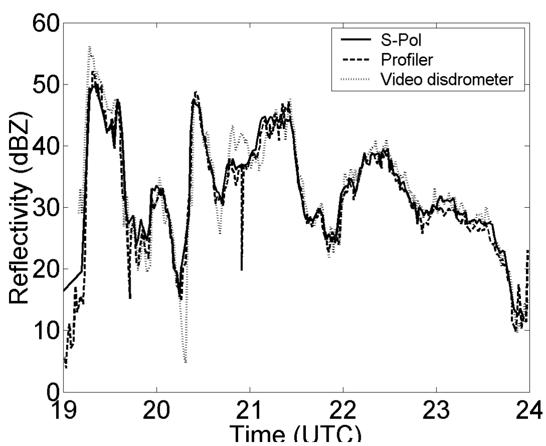

Figure 1. Time history plots of reflectivity (dBZ) measured by S-Pol (solid), the profiler (dashed) and the video disdrometer (dotted).

The time history of the gamma DSD shape parameter μ is shown in Figure 2. Both radars capture the trends seen by the video disdrometer. The profiler estimated μ is consistently higher than that of the other two estimates. On average the profiler is 3.20 higher than S-Pol with an rms difference of 13.38.

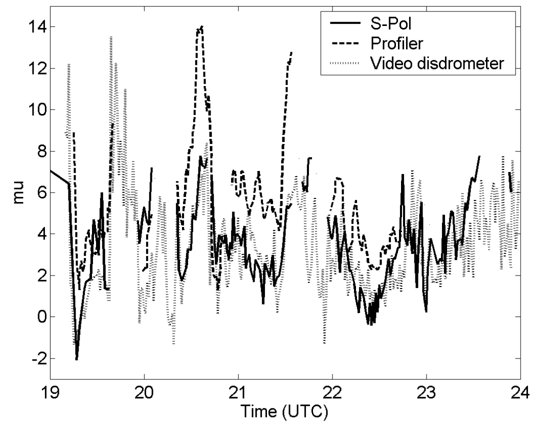

Figure 2. Time history plots of μ estimated by S-Pol (solid), the profiler (dashed) and the video disdrometer (dotted).

Figure 3 is similar to Figure 2 for the parameter Λ. Again the major trends are similar for all three instruments. The profiler estimates of Λ are generally higher than S-Pol and the video disdrometer. The average difference in Λ between the profiler and S-Pol is 2.34 mm^{-1} and the rms difference is 13.92.

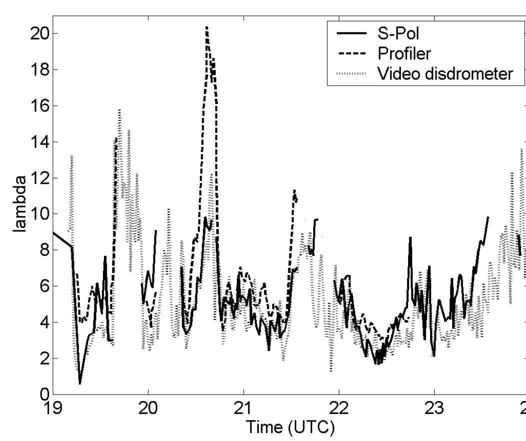

Figure 3. As in Figure 2 for Λ (mm^{-1}).

Because the physical interpretation is straightforward, the median diameter (D_0) is shown in Figure 4 rather than the gamma DSD parameter N_0. The D_0 values were computed from the retrieved gamma DSD's. The profiler retrieved D_0 values are on average 0.16 mm

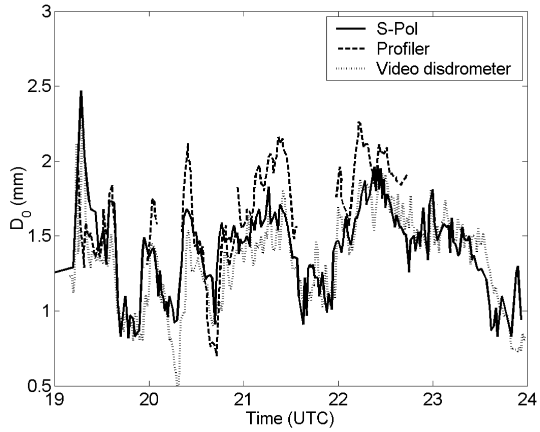

Figure 4. As in Figure 2 for D_0 (mm).

larger than S-Pol and the rms difference is 0.28 mm. It is not surprising that the S-Pol D_0 estimates more closely match the disdrometer than the profiler, since the measured differential reflectivity (Z_{DR}) is analogous to the reflectivity weighted axis ratio. In contrast the profiler technique has to separate the particle fall speed (related to D_0) from the vertical air motion, adding uncertainty. If the vertical velocity can be obtained from the Bragg scatter this uncertainty is not an issue. Of particular importance in Figure 4 are the anomalously low D_0 values retrieved from the profiler near 19:20 UTC. As explained below, this leads to large errors in the profiler rain rate estimate.

The rain rates retrieved from the estimated DSD's are plotted in Figure 5. Most of the peaks in estimated rain rate are well correlated among the instruments. However, the profiler has a large and unrealistic overestimate near 19:20 UTC. At

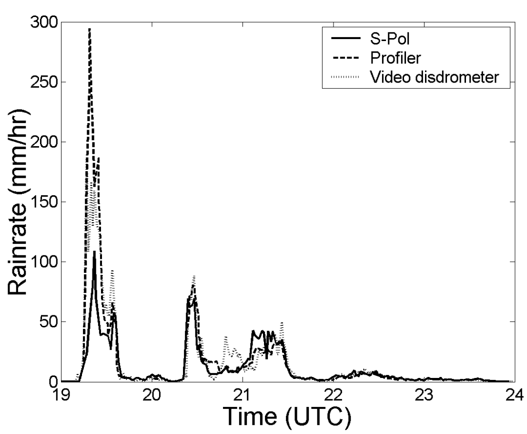

Figure 5. Rain rates computed from the retrieved gamma DSD's from S-Pol (solid), the profiler (dashed) and the video disdrometer (dotted).

the leading edge of convection it is common to have a nearly mono-disperse population of large drops. These drops have a large terminal fall speed which is measured by the profiler. Within the large drop region, the SAM model converged to a solution with underestimated drop sizes and overestimated downdrafts. The profiler retrieved vertical velocity (w, m s^{-1}) is plotted along with the S-Pol measured values of Z_{DR} (dB) in Figure 6. Notice that the period of rain rate over estimation by the profiler corresponds to a large retrieved

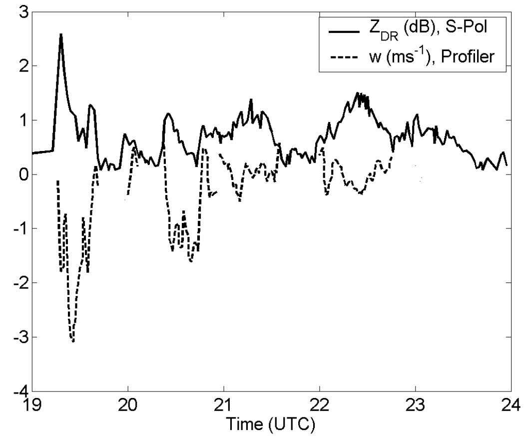

Figure 6. Profiler retrieved w (m s^{-1}, dashed) and S-Pol measured Z_{DR} (db, solid)

downdraft. At the same time, large Z_{DR} values from S-Pol are indicating large drops which have large fall velocities. This is confirmed by the D_0 measured from the disdrometer (Figure 5). The under-estimate of drop size results in an over estimate of the total number of drops and a corresponding over estimate in rain rate. This can be seen in the plot of the gamma DSDs from the retrieved parameters at 19:19 (UTC) in Figure 7.

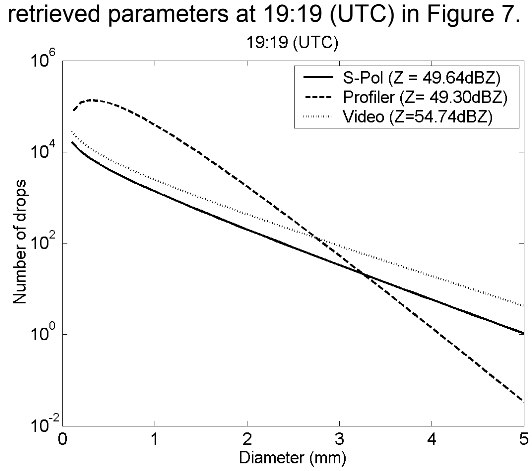

Figure 7. The gamma drop size distributions from the 3 retrievals at 19:19 (UTC).

The plot corresponds to the time of maximum profiler estimated rain rate. Notice that the number of small drops computed for the profiler is 1 to 2 orders of magnitude higher than for the disdrometer. Similar examples of this were observed for two other cases during PRECIP98.

The accumulated rain was computed from 20:00 to 24:00 UTC using the three DSD estimates from S-Pol, the profiler, and the disdrometer as well as power law relations for Z and Z-Z_{DR}. Note that the accumulation time excludes the convective period from 19:00 to 20:00 UTC. The Z-R relationship used is the same as is used in the Weather Surveillance Radar-88 Doppler (WSR-88D) and the Z/Z_{DR}-R relationship is derived by Bringi and Chandresekar (2001). They are given by,

$$R = 0.017Z^{0.714}$$

$$R = 0.0067Z^{0.93}Z_{DR}^{-3.43}$$

where R is rain rate in mm h^{-1}, Z has units mm^6 m^{-3} and Z_{DR} has units of dB. The power law estimates were only computed for S-Pol measurements. Two tipping bucket rain gauges were also co-located at the profiler site and the accumulations from the gauges were computed. The results are presented in Table 1. The rain accumulation estimates from DSD retrievals for S-Pol, the profiler and the disdrometer are within approximately 15% of each other as well as the gauges. The profiler estimate is lower than the S-Pol and disdrometer totals by about 5 mm. The WSR-88D Z-R relationship underestimates the rain compared to the gauges and disdrometer by about 25%, while the Z/Z_{DR}-R relationship matches much better. This is not surprising because the additional information from the Z_{DR} measurement accounts for the drop size.

Table 1

Method	Rain accumulation (mm)
Gauge 1	38.9
Gauge 2	36.5
Video disdrometer	36.4
S-Pol DSD	36.0
Profiler DSD	31.3
R-Z	27.5
R-Z/Z_{DR}	37.5

4. SUMMARY AND CONCLUSIONS

The gamma drop size distribution retrievals from a S-Band dual-polarimetric scanning radar, a UHF vertical incident profiling radar and a video disdrometer were compared. The resulting rain rate and accumulation values were compared to rain gauge data. Each radar captured well the trends in the DSD parameters and rainfall values with the notable exception of the profiler in the presence of large drops with large terminal fall speeds. In this case the profiler DSD retrieval results in a dramatic overestimate of rain rate.

It is encouraging to find that both radars give reasonable rain rate and DSD estimates (in the absence of large drops). The scanning polarimetric radar has the advantage of large spatial coverage and the profiler has the advantage of very high vertical resolution. Therefore DSD retrievals from both sensors should prove valuable to the study of cloud and rain microphysics.

5. ACKNOWLEGEMENTS

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