

## A Field Experiment on the Calibration of Radars with Raindrop Disdrometers

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15 March 1976 and 2 March 1977

### ABSTRACT

Radar reflectivity factors determined from disdrometer measurements of drop spectra are compared with simultaneous WSR-57 radar measurements in two Oklahoma thunderstorms. The possibility of using a disdrometer for an in-field calibration check of a radar is examined and found to have limited usefulness for convective precipitation sampled at long ranges.

### 1. Introduction

The radar reflectivity factor  $Z$  for Rayleigh scattering in rainfall can be simply determined by the drop size distribution. Direct measurements of the raindrop spectra in precipitation should allow an independent check on measurements of  $Z$  by radar and, thus, provide an accurate method of calibrating the radar in actual field operation conditions. To test the viability of this hypothesis, raindrop spectra have been correlated with simultaneous radar measurements in Oklahoma thunderstorms.

Numerous studies have related rainfall rates derived from drop spectra measurements to reflectivity factors for the purpose of estimating precipitation amounts remotely with radar (Stout and Mueller, 1968). This experiment, however, compares the reflectivity factors determined by the two methods to examine the possibility of using a disdrometer as a calibration instrument for the radar. Only two specific cases (both thunderstorms) are examined but the implications for other situations are suggested.

### 2. The field experiment

In the spring of 1975, a University of Wyoming instrumented weather van was utilized in the National Severe Storms Laboratory (NSSL) Project Storm Intercept in Oklahoma. One of the objectives of the storm chase missions was to obtain raindrop spectra measurements within thunderstorms being quantitatively monitored by the NSSL radar. The drop spectra were measured with a momentum-impact disdrometer of the Swiss design (Joss and Waldvogel, 1967) which was transported in the weather vehicle. This disdrometer had been previously calibrated in a vertical drop tunnel facility at the Illinois State Water

Survey. Quantitative reflectivity measurements of the storms were made with the NSSL WSR-57 radar system (Sirmans and Doviak, 1973) located at Norman, Okla. The radar wavelength is 10 cm, the circular beam width is  $2^\circ$  and the range averaging distance is 1 km.

Two heavy thunderstorms for which good quality disdrometer and radar measurements were obtained serve as the data base for the report. The first storm was a broad, slow moving squall line rainstorm which occurred on 22 May 1975 and caused local flooding. The disdrometer was positioned 5 km east of Anadarko, Okla., as the squall line passed overhead. Therefore, it is referred to in this report as the "Anadarko storm." The second storm was an isolated rain and hailstorm which occurred on 26 May 1975 near Troy, Okla., and is referred to here as the "Troy storm." Time synchronization of the radar and disdrometer measurements, as well as registry of the disdrometer measurement location with the radar gate pattern, was carefully noted.

### 3. Comparison of reflectivity factors from radar and disdrometer measurements

Figs. 1 and 2 display the time sequence of the reflectivity factor values at the disdrometer measurement sites for the Anadarko and Troy storms, respectively. The solid line values were computed from the raindrop size distributions measured by the disdrometer and assuming Rayleigh scattering conditions ( $Z = \sum nD^6$ ). The units of  $Z$  are  $\text{mm}^6 \text{m}^{-3}$ , and  $n$  in units of  $\text{m}^{-3}$  is the concentration of drops of diameter  $D$  in mm. On the figures the values are given in terms of decibels, where  $\text{dBZ} = 10 \log Z$ . A running average of at least 6 s and 150 drops of disdrometer data was used. The dBZ values measured at  $0^\circ$  elevation angle by the radar at the gate which covers the disdrometer location are given

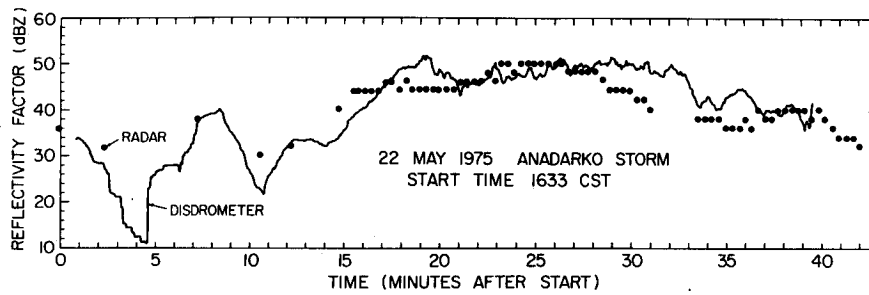


FIG. 1. Time-sequence plot of reflectivity factor calculated from drop spectra measured by the disdrometer (solid line) in the Anadarko storm. The dots represent  $0^\circ$  elevation measurements by the radar over the disdrometer location.

by the dots on the graphs. The radar values were taken from NSSL digital processed listings of the dBZ value at each gate. Since these printouts listed the dBZ value only to the nearest even whole number, error bars of  $\pm 1$  dBZ should accompany each point. Inspection of the radar data revealed that adjacent gates in both cases usually differed by only 2 dBZ or less. Therefore, the unadjusted dBZ value at the disdrometer site gate was used without employing sophisticated smoothing techniques which average values from adjacent gates and scans. During the Troy storm several tilt scan sequences were conducted; hence, few  $0^\circ$  elevation measurements are available. In an attempt to fill in the time gaps, the dBZ values from the  $2^\circ$  scans (about 4 km AGL over Troy) are included in Fig. 2. Adjustments for time lags required for the drops aloft to reach the ground have not been made. The radar was operated in the  $360^\circ$  azimuth scan mode to provide severe storm surveillance over the entire Oklahoma region. Therefore, measurements at the same location could not be taken more than once every 20 s.

An inherent problem in the comparison of the two sets of instantaneous data is the vastly different size of the sample volumes. The radar averages precipitation in each pulse over a tremendously larger volume than does the disdrometer. At the range of Anadarko (70 km) and Troy (121 km) the radar sampling volume is on the order of  $10^9$  m<sup>3</sup>. The volume sampled by the 50 cm<sup>2</sup> disdrometer target which depends on the

duration of sampling and the fall speeds of the drops is many orders of magnitude smaller.

The radar dBZ measurements are plotted against the disdrometer calculations in Fig. 3. Fairly good agreement is shown for the Anadarko storm but not enough data are available to make a reliable comparison in the Troy case. An important feature to be noted in Fig. 3 is that consistent biases do not appear. If either instrument had been grossly out of calibration, we would expect to see a consistent offset between the two sets of values. For the Anadarko storm one standard deviation of the data from perfect agreement is about 3.5 dBZ. For the Troy storm the spread is larger but still unbiased.

Fig. 2 shows that in the Troy storm the radar recorded significantly higher dBZ values than the disdrometer from about 1615 to 1629 CST. Hail was falling at the site during this period; hailstones as large as grape size were observed by the crew. The hailstones were never numerous enough to cover the ground. During the 14 min period, the disdrometer did not record any hits in its oversize channel ( $D > \sim 5.5$  mm). It appears that the large hailstones were too sparse to be adequately sampled by the disdrometer target, but were, of course, detected by the radar. This would help explain the radar-disdrometer discrepancy during the period.

In a rudimentary  $Z = \sum nD^6$  calculation it can be shown that the average discrepancy of roughly 52

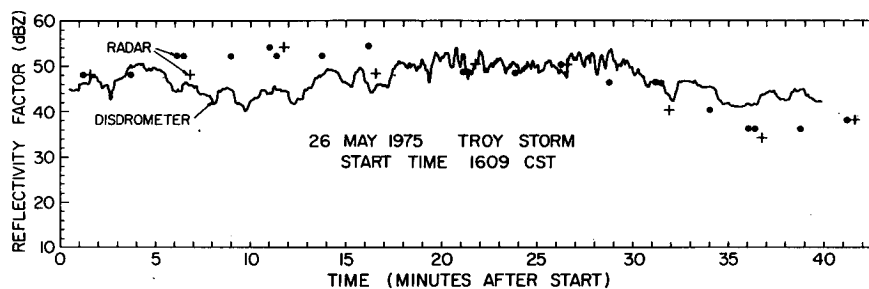


FIG. 2. As in Fig. 1 except for the Troy storm; in addition the + points represent  $2^\circ$  elevation radar measurements.

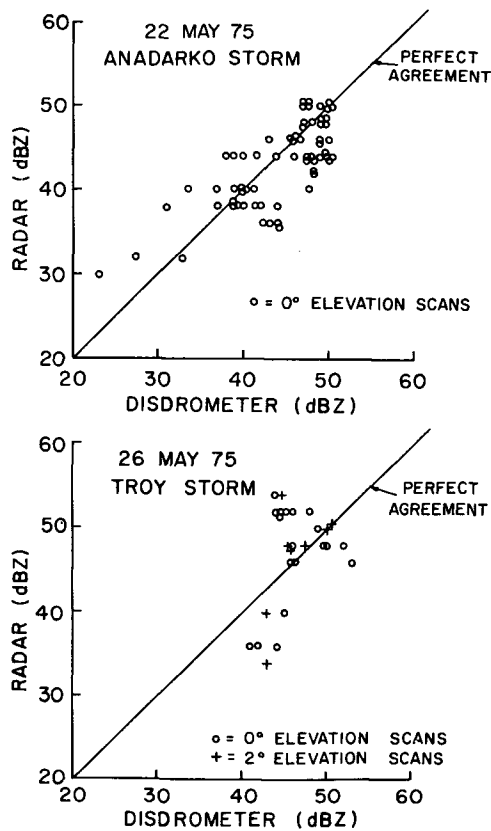


FIG. 3. Comparisons of reflectivity factors measured by radar and calculated from the disdrometer measurements.

dBZ (radar) to 44 dBZ (disdrometer) during the 14 min period could be entirely accounted for by about  $10^{-2}$  stones per cubic meter of size  $D = 15$  mm (approximately the grape sizes observed). In this case, it could be expected that the disdrometer would be struck by one such stone every 11 min. This is not much different from the zero hits actually recorded. It seems reasonable, then, that the radar volume aloft may have contained one grape size hailstone in every 100 m<sup>3</sup>, and that these escaped detection by the disdrometer at the ground. Other factors which produce smaller hydrometers at the ground than aloft such as drop break-up and sub-cloud evaporation might also have contributed to the discrepancy.

Disdrometer dBZ values exceeded the radar values near the end of the sampling period of both storms. There are no obvious explanations for the apparently lighter precipitation aloft in these cases. Drop coalescence and attenuation of the radar signal could have contributed slightly to the discrepancies.

**4. Calibration of radars with a disdrometer**

The possibility of calibrating radars with a disdrometer does not look very encouraging from the results of this experiment. Accepting the premise in this case that both the WSR-57 radar and the dis-

drometer were properly calibrated, the rather wide dispersion of points from the line of perfect agreement in Fig. 3 then is due to "natural variations." These consist partly of random variations of drop spectra within sub-volumes of the radar beam. It would be difficult to detect small offsets due to a poorly calibrated radar within the context of such wide natural dispersions of data. Thus, the usefulness of calibrating radars with a disdrometer *in such configurations* is limited. Only a rather crude check of the radar calibration seems reasonable. If a radar set is grossly out of proper calibration ( $> \pm 4$  dB), a disdrometer-radar comparison should reveal a decided consistent offset of values. Conventional calibration techniques which use standard test equipment or backscattering from metal spheres can yield more precise ( $\pm 1$  dB) results.

It should be noted, however, that the circumstances of these measurements were not very favorable for expecting good agreement between radar and disdrometer. The large radar volumes which resulted from sampling the storms at long ranges, the elevated beam and the presence of hail in the Troy storm complicated the comparisons. One can visualize more favorable situations for which better correlation of the two sets of data is expected; hence, more accurate calibration of radars may be possible. Measurements in more uniform precipitation such as stratus rain would be suitable for this purpose. Restricting the radar antenna scan to a small sector over the disdrometer location would yield many more radar data points, allowing statistical comparisons. Measurements taken in precipitation close to the radar are also preferable. Breuer and Kreuels (1976) have found good radar-disdrometer agreement for spectra measurements taken 11 km away from a narrow beam radar.

The disdrometer should provide more precise calibrations if it is located adjacent to a zenith-pointing radar during precipitation overhead. The reflectivity can be measured at very short ranges above the disdrometer and the radar sample volume ( $\sim 10^5$  m<sup>3</sup>) would be several orders of magnitude smaller than those in this study. Joss *et al.* (1974) performed such an experiment. They used long-term average  $Z$  values calculated from disdrometers to adjust radar measurements 580 m aloft and found good correlation of the two sets of data. A disadvantage of the vertically pointing configuration for operational use is the relatively infrequent passage of storms directly over the radar.

*Acknowledgments.* The author is grateful for the assistance of personnel at the National Severe Storms Laboratory. This research was funded by the U. S. Department of Commerce, NOAA, under Contract 03-5-022-6, in cooperation with the Nuclear Regulatory Commission.

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