NOTES AND CORRESPONDENCE

Attenuation of a 5-cm Wavelength Radar Signal in the Lahoma–Orienta Storms

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ABSTRACT

Attenuation problems arise when short wavelength radar is used for severe storm identification and structure analysis. These are illustrated by comparing observations from 5- and 10-cm Doppler radars. Reduced and fragmented storm representations were obtained with the 5-cm wavelength radar. Signal losses exceeding 30 dB so greatly distorted the reflectivity structure of one thunderstorm that the expected association between mesocyclone and reflectivity pattern was not evident. Attenuation of the received signal reduces the signal-to-noise ratio and increases the variance of the spectral moment estimates. However, velocity measurements remain unbiased as long as the received signal remains above the system noise level. Correcting for attenuation appears futile.

1. Introduction

The utility of Doppler radar as a nowcasting and warning tool for the detection of strong winds, tornadoes, low-level wind shears, and downbursts has been documented in a number of studies (Staff, 1979; Wilson et al., 1984; Fujita, 1979). The reflectivity data can be used to estimate possible areas of hail and heavy rains with flash flood potential. Since severe storm identification and warnings are improved through knowledge of radial wind estimates, replacement of the National Weather Service's 10-cm wavelength WSR-57 and the U.S. Air Force Weather Service's 5-cm FPS-77 surveillance radars with 10-cm wavelength Doppler radars is scheduled for the 1990s. However, lower costs and reduced side-lobe contamination cause a continuing interest in 5-cm radar, even though attenuation by intervening precipitation is greater at shorter wavelengths (Skolnik, 1970; Wilson, 1978; Medhurst, 1965). Attenuation problems can become severe when several storms become aligned along the radar beam. Many studies conclude that a longer wavelength radar is necessary to avoid attenuation during heavy rainfall (Allen et al., 1981; Hildebrand et al., 1981; Weible and Sirmans, 1976). Others, e.g., Wilson et al. (1980), suggest 5-cm wavelength radars be used in areas where these conditions are infrequent. However, the combination of radar operator inexperience with infrequent hazardous weather and reduced radar capability could result in disaster (NTSB, 1978).

Severe attenuation of a 5-cm wavelength radar signal is presented in this study. Reflectivity data from the National Center for Atmospheric Research (NCAR) CP-3 Doppler radar (5 cm) are compared with data from the National Severe Storms Laboratory (NSSL) Cimarron radar (10 cm). Both datasets were obtained from the Lahoma–Orienta tornadic storms that occurred in northwestern Oklahoma on 2 May 1979. During the period of interest, the NCAR CP-3 radar was located ~60 km southwest of the storms, while the Cimarron radar was ~80 km to the south of the storms (Fig. 1). Radar characteristics are presented in Table 1.

2. Reflectivity patterns of two storms

The Orienta and Lahoma storms developed in northwestern Oklahoma at ~1300 [all times are Central Standard Time (CST)] and spawned several tornadoes as they moved east-southeastward. These storms were roughly aligned southwest–northeast. By 1718, the separation between the storms had diminished and the Lahoma mesocyclone (in the final stages of tornadic activity) was partly embedded within the precipitation plume of the now dissipating Orienta storm. Baseball size hail (5.1 to 7.6 cm) from the Lahoma storm was reported in Enid, Oklahoma (x, y = 48, 57 km; Fig. 1) at ~1720.

Horizontal cross sections of reflectivity at the 2 km altitude for 1718 are displayed in Fig. 2. Reflectivities were derived with the Cimarron (Fig. 2a) and the NCAR CP-3 (Fig. 2b) radar data. Representative wind vectors are derived from dual-Doppler analysis using the CP-3 and Cimarron radars and indicate the location of mesocyclones. The leading and southern edge of the Lahoma–Orienta storm complex, as delineated by the 20 dBZ contour, is essentially the same for both radars. Notice the broad and continuous area of reflectivity $\geq$ 50 dBZ throughout much of the combined two-storm

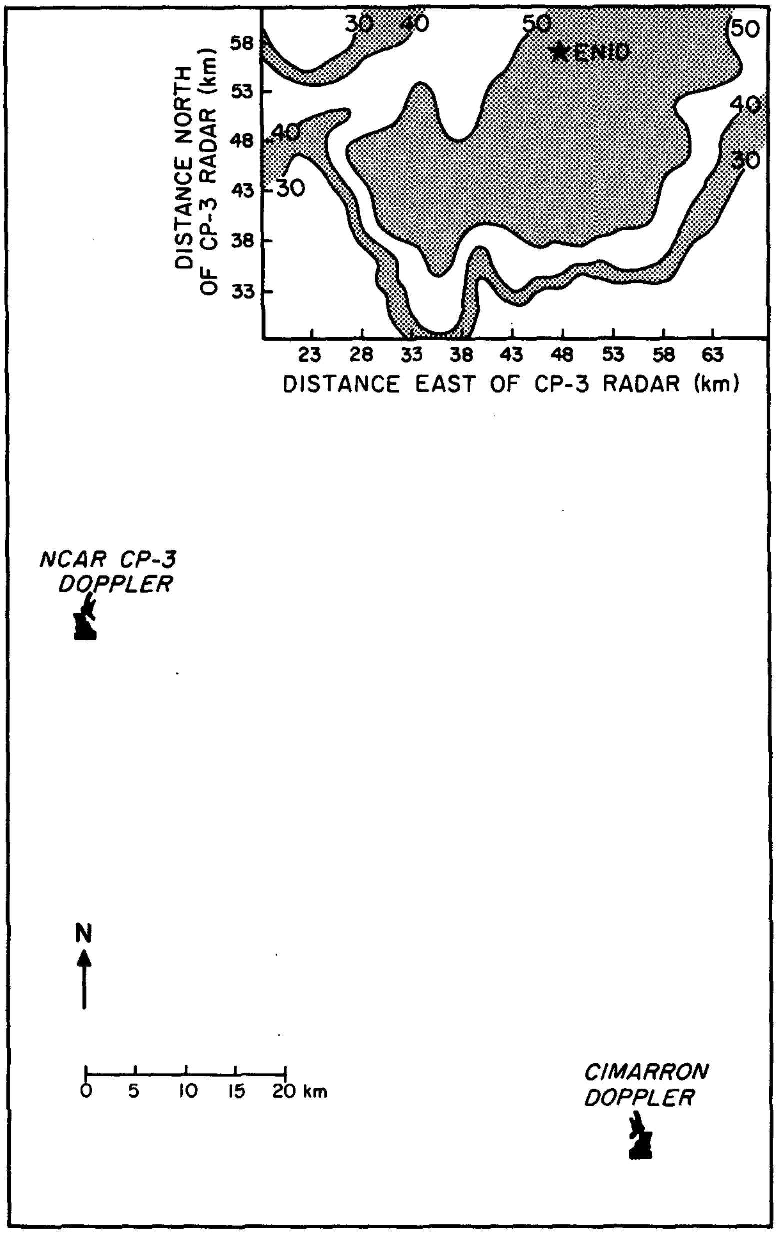

FIG. 1. Locations of the two Doppler radars relative to the 1718 CST analysis grids for 2 May 1979. Cimarron reflectivity at 2 km elevation data are represented, contoured in 10-dB intervals starting at 30 dBZ.

TABLE 1. Doppler radar characteristics.

	NSSL Cimarron	NCAR CP-3
Wavelength	10.94 cm	5.49 cm
Beamwidth	0.85°	1.14°
Transmitted power	750 kW	398 kW
Antenna gain	46.0 dB	40.4 dB
Pulse repetition frequency	1302 Hz	1666 Hz
Pulse length	1 μs	1 μs

complex in Fig. 2a. The region of ≥50 dBZ echo between (27, 46) and (59, 46) is heavy precipitation from the Orienta storm while the reflectivity core extending northeastward from (40, 50) represents the precipitation plume from the Lahoma storm. The Lahoma and Orienta mesocyclones are located at (42, 46) and (38, 35), respectively. The mesocyclones reside on the right rear flanks of each storm.

For the 5-cm radar (Fig. 2b), the areal coverage of echo ≥ 50 dBZ is much reduced and fragmented into

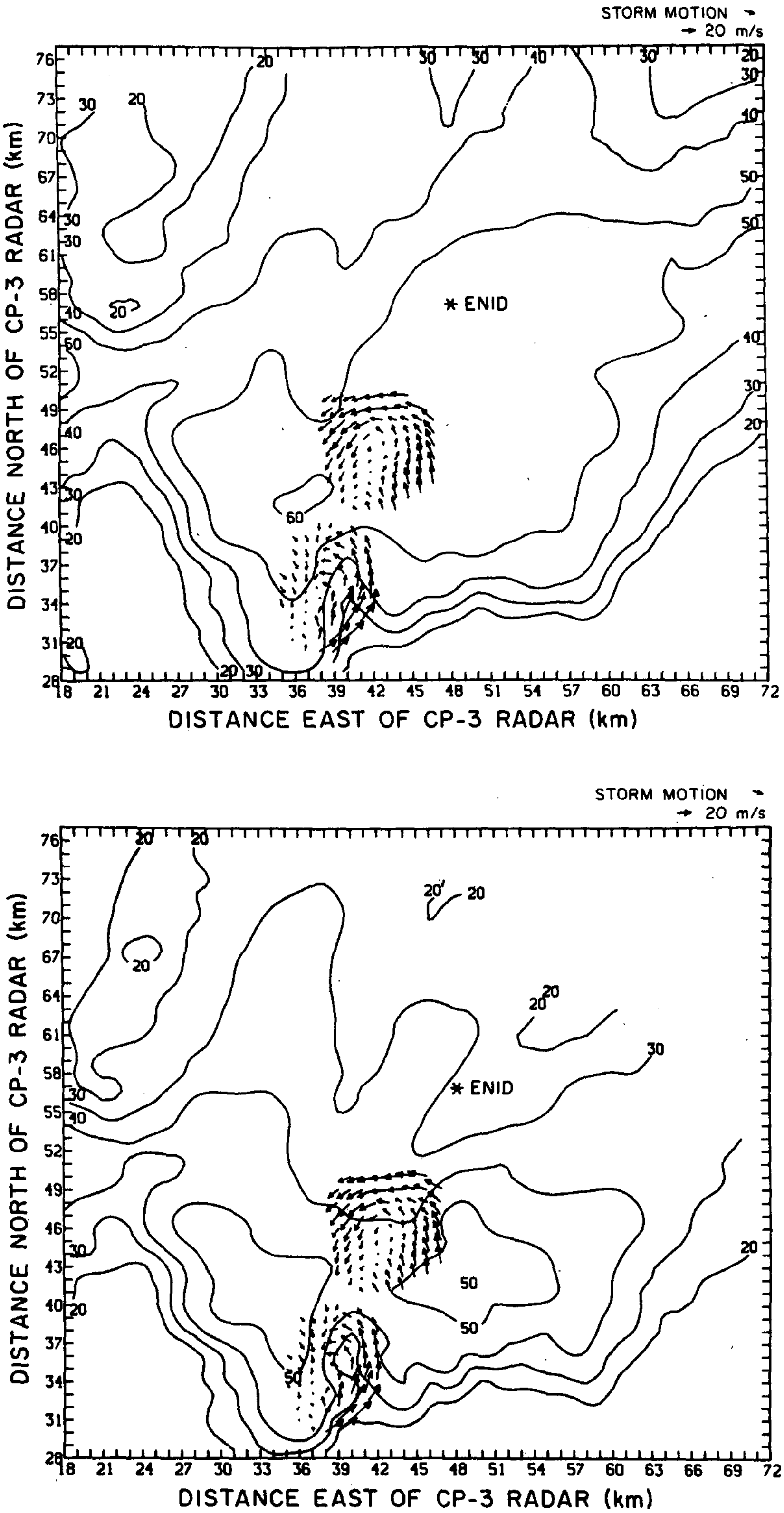

FIG. 2. Reflectivity field for 1718 CST 2 May 1979 from (a) the Cimarron 10-cm radar and (b) the NCAR 5-cm radar data at the 2 km level. The northeast part of the complex is the Lahoma storm and the southwest part is the Orienta storm. The NCAR CP-3 radar is located at the grid origin. Wind vectors indicate locations of the Lahoma (x, y = 42, 46) and Orienta (x, y = 38, 35) mesocyclones.

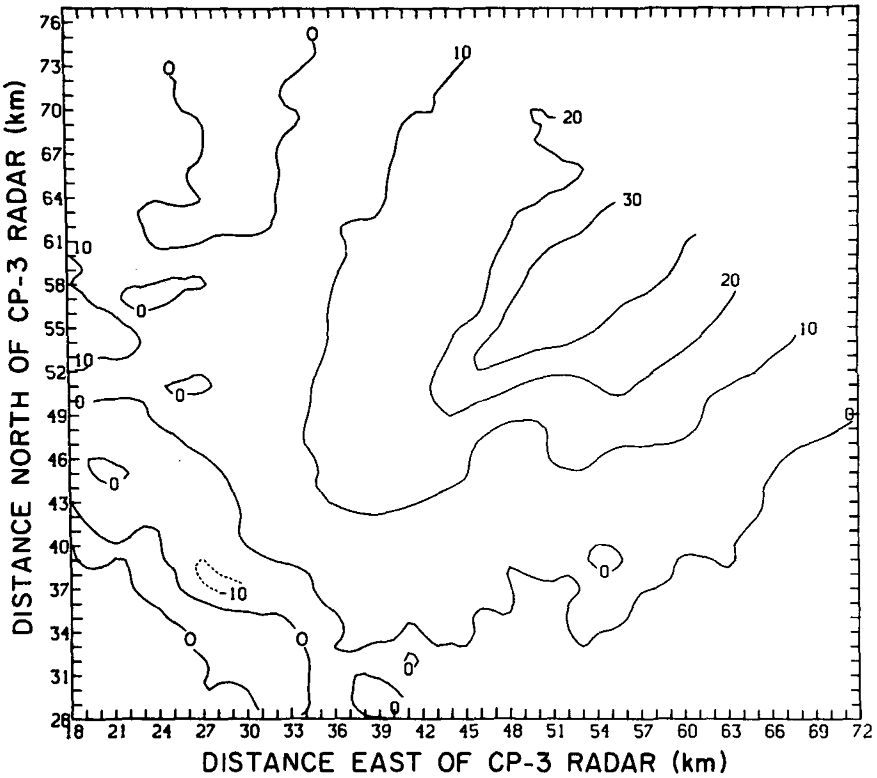

FIG. 3. Difference (dB) ($Z_{10} - Z_5$) between reflectivity fields, showing maximum attenuation for 2 km at 1718 CST.

two small areas. In this presentation, the Orienta storm mesocyclone appears ahead of one reflectivity core, while the Lahoma storm mesocyclone appears to lag behind the easternmost core (which, in fact, is a severed portion of the Orienta storm precipitation plume). Attenuation of the 5-cm radar signal by the Orienta storm causes the heavy precipitation core $\geqslant 50$ dBZ of the Lahoma storm to be missed altogether. Thus, a highly distorted representation of the structure of the storm complex is seen by the 5-cm wavelength radar.

The difference between the radars' reflectivity fields, which were greatest after 1658 when the two storms became radially aligned with respect to the 5-cm radar, is illustrated for 1718 in Fig. 3. Attenuation losses exceed 30 dBZ below 3 km elevation and decrease slowly thereafter with height. This attenuation loss is similar to the loss in 5-cm wavelength radar observations described by Wilson (1978) for a storm that produced large wet hail. Wilson suggested that the decrease in attenuation with height may be due to the presence of dry hail. On 2 May 1979, large hail was reported within the area of maximum attenuation near coordinates (48, 57). The reflectivity is <30 dBZ in this area for the 5-cm radar (Fig. 2b).

The radial velocity data of the NCAR CP-3 radar (not shown) depict both mesocyclones. In general, velocity data should be unaffected by attenuation as long as the received signal remains above the system noise level. Normally, attenuation increases the variance of the spectral moment estimates, but the velocity measurement is not biased (Dale Sirmans, personal communication). Doviak and Zrnić (1984) suggest that radar data may have contaminations through side lobes if the radar beam points toward a location of sufficiently attenuated reflectivity and is a few degrees from strong reflectivity regions. However, the large gradients of reflectivity created by attenuation for this particular case do not appear to produce velocity errors. The signal-to-noise ratio of the data is reduced as range increases. If the Lahoma–Orienta storm complex had been farther away from the CP-3 radar, the Lahoma storm may have disappeared altogether (cf. Allen et al., 1981).

3. Correction of attenuated reflectivity patterns

Attenuation of radar signals is caused by atmospheric gases, cloud, rain, and hail and its magnitude is generally inversely related to wavelength (see Figs. 24-11 and 2-30, Skolnik, 1970). Empirical relationships can be used to account for reduction of backscattered power by attenuation in rain (Hitchfield and Bordan, 1954; Geotis, 1975; Hildebrand, 1978). However, the attenuation factors used are inexact because assumptions must be made concerning the drop-size and temper-

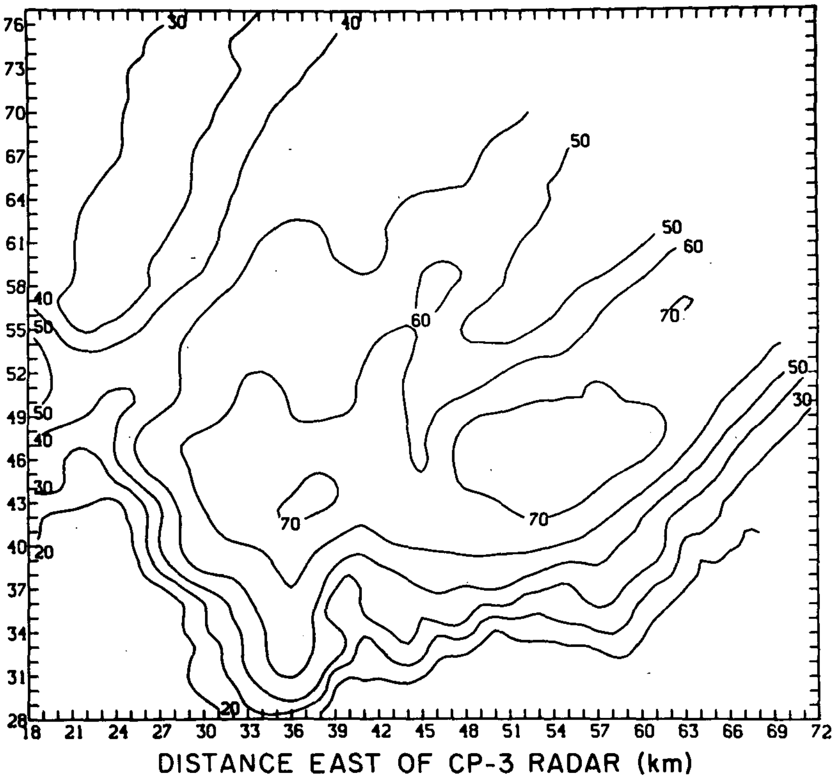

FIG. 4. NCAR CP-3 corrected reflectivity field at 2 km altitude for 1718 CST 2 May 1979 using Marshall–Palmer drop-size distribution.

ature distribution. Further, Hitschfeld and Bordan (1954) suggest that correcting for attenuation is useless unless the calibration error of the radar system is held within extremely narrow limits (absolute calibration error of less than 1 dB); otherwise, large errors in the estimated rainfall rate would probably occur.

Hildebrand (1978) suggested an iterative correction scheme for storms up to 60 dBZ, assuming the radar is correctly calibrated and the appropriate drop-size and temperature distribution are known. With this scheme, the attenuated radar reflectivity factor measurements $Z_a(r)$ at range r are used to estimate $K_a(x)$, the one-way attenuation rate (see Table 1 of Hildebrand, 1978). A corrected reflectivity factor estimate is generated with the relation

$$\log Z'(r) = \log Z_a(r) + 2 \sum_{x=1}^{r-1} K_a(x).$$

New reflectivity factor estimates $Z'(r)$ are used to derive revised attenuation estimates $K'(x)$. Then a new set of reflectivity factor estimates is determined using

$$\log Z''(r) = \log Z_a(r) + 2 \sum_{x=1}^{r-1} K'_a(x).$$

The iterations terminate when $2 \sum_{x=1}^{r_{\max}} K'_a(x)$ changes by less than 1 dB. Hildebrand states that an overestimate of attenuation could result from radar calibration error, temperature overestimation or incorrect drop-size distribution.

Although Hildebrand cautions against applying this method for storms with reflectivity maxima > 60 dBZ, the iterative correction scheme was tested using em-

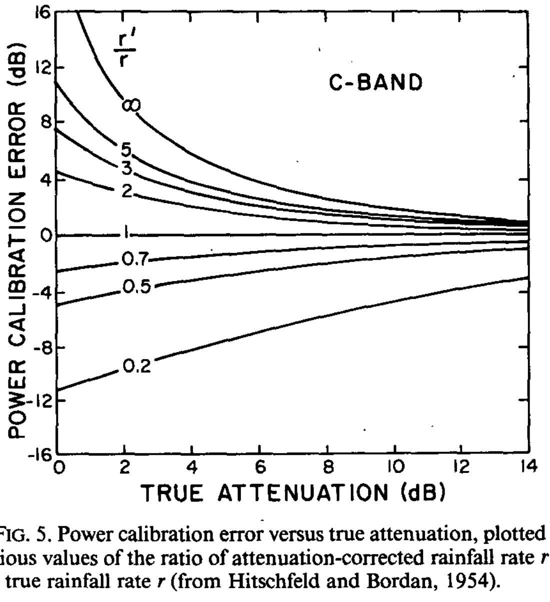

FIG. 5. Power calibration error versus true attenuation, plotted for various values of the ratio of attenuation-corrected rainfall rate r' to the true rainfall rate r (from Hitschfeld and Bordan, 1954).

pirical relations between one-way attenuation and rainfall rates using Marshall and Palmer (1948) and Sekhon and Srivastava (1971) drop-size distributions for various temperatures. For temperatures between −10° and 20°C and both drop-size distributions, one iteration produced a large overcorrection of the attenuation and hence overestimates of the reflectivity (maximum values > 70 dBZ). Further iterations only increased the overcorrection. Figure 4 illustrates test results using a Marshall and Palmer drop-size distribution and a temperature of 10°C. A reflectivity maximum that exceeded 70 dBZ was produced within the core of each storm. Correction attempts using the Sekhon and Srivastava drop-size distribution yielded reflectivity maxima that were at least 20 dBZ greater than that produced using the Marshall and Palmer distribution. With both drop-size distributions, the large overestimation of the radar-received power produces unrealistic rainfall estimates. Also, the corrected 5-cm pattern never comes close to resembling that of the 10-cm data and a normal or gradual end to the storm side opposite the radar is never obtained because a large residual correction remains when the received power falls to the noise level.

Figure 5 (from Hitschfeld and Bordan, 1954) shows the impracticality of correcting for attenuation. For example, when the actual attenuation is <6 dB, rainfall estimates within a factor of 2, are obtained provided the calibration error is <1 dB. However, as the actual attenuation becomes large, reasonable rainfall estimates are obtained only if the power calibration error is essentially negligible. It is believed that most radars are calibrated to within 1 dB accuracy. Hence, experience with 2 May data supports the conclusion of Hitschfeld and Bordan (1954) that correcting for attenuation is futile.

4. Summary and discussion

Attenuation can greatly reduce the 5-cm wavelength radar echoes of a severe storm. Hail detection and rainfall estimation would also suffer. The velocity data of 5-cm Doppler radars would be lost in regions where the attenuation reduces the received signal below the system noise level.

Correction of the 5-cm data proved useless due to the magnitude of the attenuation. Partial correction of the attenuated reflectivity may be possible if the calibration error is restricted to extremely narrow limits (absolute calibration error of less than 1 dB) and the attenuation is not severe or serious. However, such precise radar calibration is probably not within the present state of the art. Correction errors are likely if incorrect drop-size distributions and temperatures are assumed in calculating the attenuation factor.

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