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THE EFFECT OF SIDE LOBES UPON MEASURED DOPPLER VELOCITIES IN WEAK ECHO REGIONS

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1. INTRODUCTION

The effects of side lobes have long been a major concern to those involved in weather radar detection of severe local storms. Battan (1973) has discussed the problems of side lobe echo distortion that may result from high-reflectivity targets such as intense precipitation cores often associated with severe local storms. Particular attention has been focused on the measurement of storm dimension by Atlas (1964), and more specifically, measured echo height in relation to actual cloud top as examined by Aoygai (1963). Probert-Jones (1963), Donaldson and Tear (1963) and Donaldson (1964). It has been shown that measured echo tops of intense storms may extend several kilometers beyond the actual storm top.

In consideration of the role of Doppler radar in severe storm analysis, side lobe effects become increasingly important since thunderstorm velocity patterns tend to be much more complicated than their reflectivity counterpart. If Doppler reflectivity fields contain distortions due to side lobes, one can infer that those distortions should be reflected in the corresponding velocity field. In light of the recent push towards a National Dopplerization of radars used in daily observation and warning, it is important that the side lobe effects imposed on velocity fields be studied in detail.

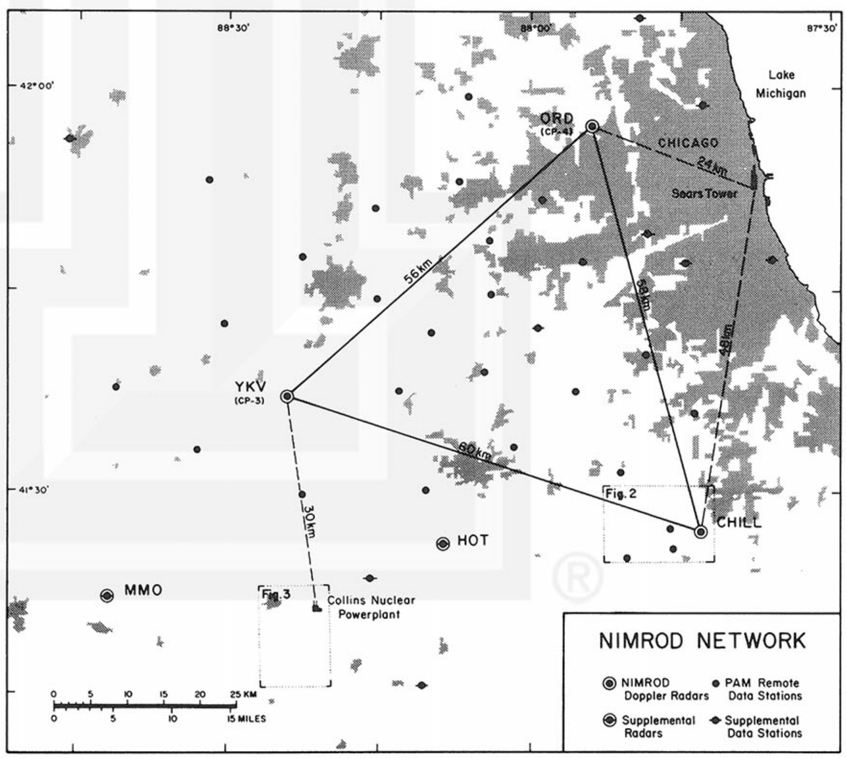


Figure 1. The Project NIMROD network containing a triple-Doppler radar triangle in the Chicago metropolitan area. Figures 2 and 3 are shown in relation to the network. Positions of Sears Tower and Collins Nuclear Powerplant are also shown.

2. RANGE AND AZIMUTH CALIBRATIONS

In an attempt to investigate and gather evidence of downbursts*, Fujita (1979) coordinated a field research program which operated from May 15 through June 30, 1978. Project NIMROD (Northern Illinois Meteorological Research On Downburst) included a triple-Doppler network in the western outlying area of Chicago, Illinois as shown in Figure 1. Two NCAR Doppler radars, CP-3 and CP-4, were positioned near Yorkville, Ill. (YKV) and Chicago's O'Hare International Airport (ORD), respectively. The CHILL (U of C) (ISWS) Doppler radar was positioned at Governors State University near Monee, Ill.

*Downburst is an intense thunderstorm downdraft with strong divergent outflow which results in damaging surface winds.

In order to improve the accuracy in alignment of radar range and azimuth to true geographic coordinates, as is necessary in the comparison of mesoscale wind fields deduced from Doppler data with surface signatures created by various meteorological phenomena such as tornadoes, a calibration method using ground clutter was developed at the University of Chicago. During non-weather periods the NIMROD radars were allowed to slowly scan at a 0° elevation angle to collect reflectivity patterns of the surrounding ground clutter. These patterns could then be aligned with the geographical locations of ground clutter objects as accurately mapped by aerial photogrammetry.

Figure 2 shows the relative reflectivity pattern of a portion of a scan made by the CHILL radar. Note that the high tension towers act as strong reflectivity targets and that even an elevated portion of Interstate 57, in the upper right corner, reflects quite well. It was found that a 0.6° clockwise rotation correction of the CHILL azimuth was necessary to allow the reflectivity pattern to fit the ground clutter.

Figure 2. A relative reflectivity pattern of ground clutter as seen by the CHILL radar at 0° elevation angle. Contour spacing is 10 dBZ. (Refer to figure 1).

Figure 3. A reflectivity pattern of ground clutter in the Collins Nuclear Powerplant area as seen by the YKV (CP-3) radar at 0° elevation angle. Contour spacing is 10 dBZ, starting at 30 dBZ. (Refer to figure 1).

The CP-3 radar showed a similar reflectivity response to high-tension towers up to and beyond 40 km from the radar as depicted in Figure 3. In this case the CP-3 range was found to be correct to within a gate (230 m) and azimuth was correct to 0.1°. However, other scans showed that the corrected CP-3 azimuth was a function of (1) the scan speed and (2) a 0 to 17 millisecond lag time in the assignment of azimuth values to specific scanned volumes.

The CP-4 radar was found to have a 0.5° clockwise correction factor in azimuth when data from a scan across Sears Tower in downtown Chicago was analyzed. Ranges of both CP-4 and CHILL radars were found to be correct to within a gate (230 meters and 150 meters, respectively).

In general, it was determined that the method of radar calibration by ground clutter targets could be executed with an accuracy of 0.1° in azimuth and to the length of a gate in range.

3. CASE STUDY OF A THUNDERSTORM LINE

On Memorial Day, May 29, 1978, a line of thunderstorms formed in the southeast portion of the Project NIMROD Network. The storm line was continuously scanned by all three Doppler radars using three-minute sector scan periods. Simultaneously, 35 mm color pictures were taken of the highly visible thunderstorm line at 1 minute intervals from the CP-3 radar site at Yorkville. The Figure 4 picture shows one cell of the thunderstorm line taken at 1902 CDT, about the time at which the maturing cell had reached its maximum reflectivity and the anvil was most rapidly expanding.

Since the thunderstorm line was orientated almost perpendicular to the CP-3 radar scan, reflectivity and corresponding velocity values were plotted in vertical cross sections on successive pictures to obtain a time sequence on the evolution of the cells within the line. The reflectivity pattern shown in Figure 5 is the result of one CP-3 sector scan made from 19:00:06 to 19:02:15 CDT. The portion of the scan made near the visible cloud top closely corresponds to the picture in Figure 4.

The reflectivity pattern in Figure 5 shows two mature cells with high-reflectivity cores of 55 and 57 dBZ. A developing cell at the rear flank of the line (far right) shows a small core of 40 dBZ. The two mature cells were found to exhibit the effect of side lobes. Reflectivities of 10 to 15 dBZ were found to extend beyond 2° over the visible cloud top, above their respective high-reflectivity cores. Thus, the CP-3 side lobe effects on the order of -50 dB existed as far as, and beyond 10° from the reflectivity core centers. In the area of lower reflectivity between the two mature cells, the contours in Figure 5 more closely follow the visible cloud boundary near the clear area under the anvil.

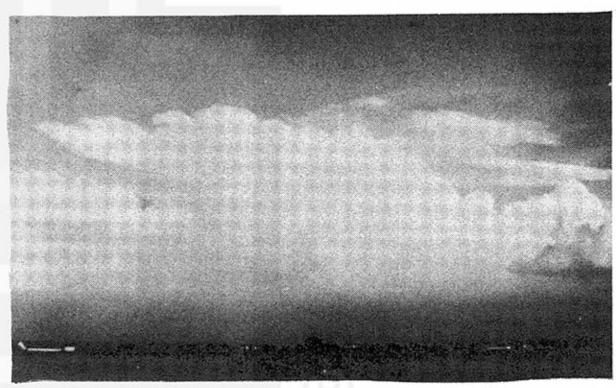


Figure 4. The thunderstorm line of 29 May, 1978 taken at 1902 CDT from the YKV (CP-3) radar site.

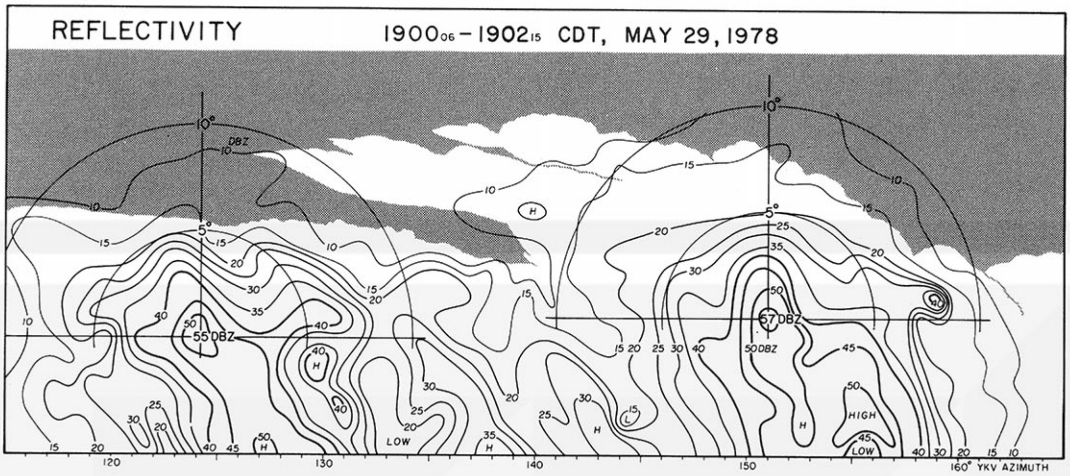


Figure 5. A vertical cross-section of CP-3 reflectivities superimposed on the 29 May, 1978 thunderstorm line.

Upon analysis of the velocities corresponding to the reflectivity pattern in Figure 5, it was discovered that velocity values had also extended beyond the cloud top. The left cell exhibited velocities up to 6 m/sec at 2° over the cloud top and 7° from the reflectivity core center which had a 0 m/sec velocity. The right cell showed velocities as high as 9 m/sec at 1° over the cloud top and about 9° over the core center, which had velocities of about 5 m/sec. In all cases the motion was away from the radar.

These results indicate that velocity patterns, in a manner similar to reflectivity patterns, may be altered by side lobes. This means that the Doppler velocities measured in weak echo regions could be seriously affected by those of the high-reflectivity core. Although the exact relationship between the core velocities and those altered by the side lobes has not been established, it would appear to be within the present capabilities of radar science and it is suggested herein as a topic of future research.

4. SIDE LOBE EFFECTS FROM GROUND TARGETS

As pointed out by Battan (1973), radars will some times detect power reflections in the side lobes from nearby buildings. Taking this into consideration, a large highly reflective structure, if considered as a point target, could be used to construct a reflectivity pattern that would represent the side lobe effects that

Figure 6.

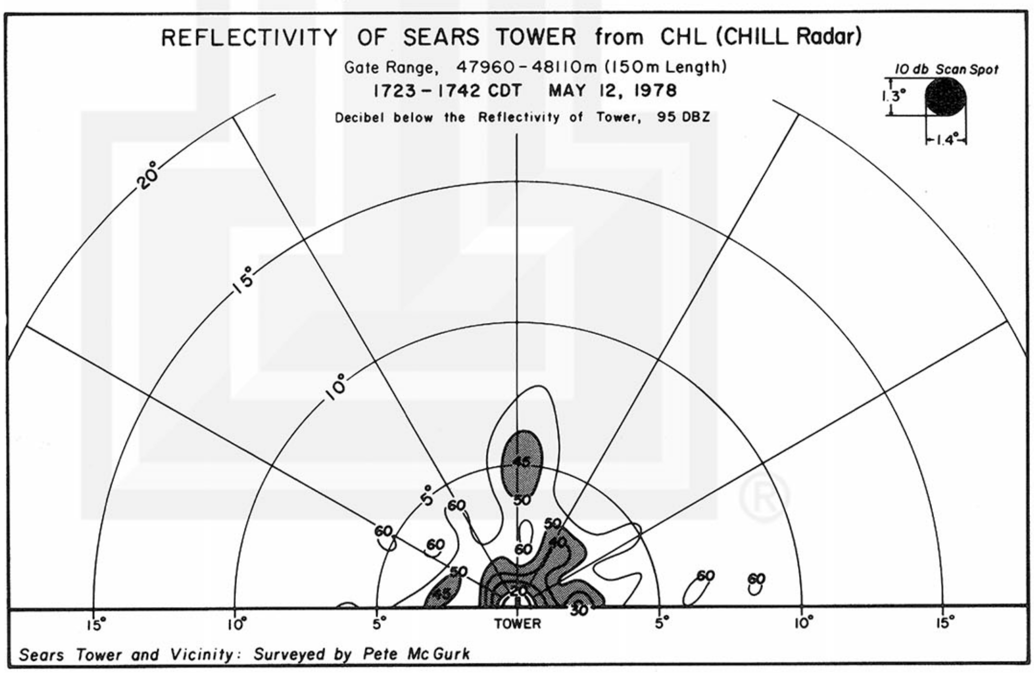


Figure 7.

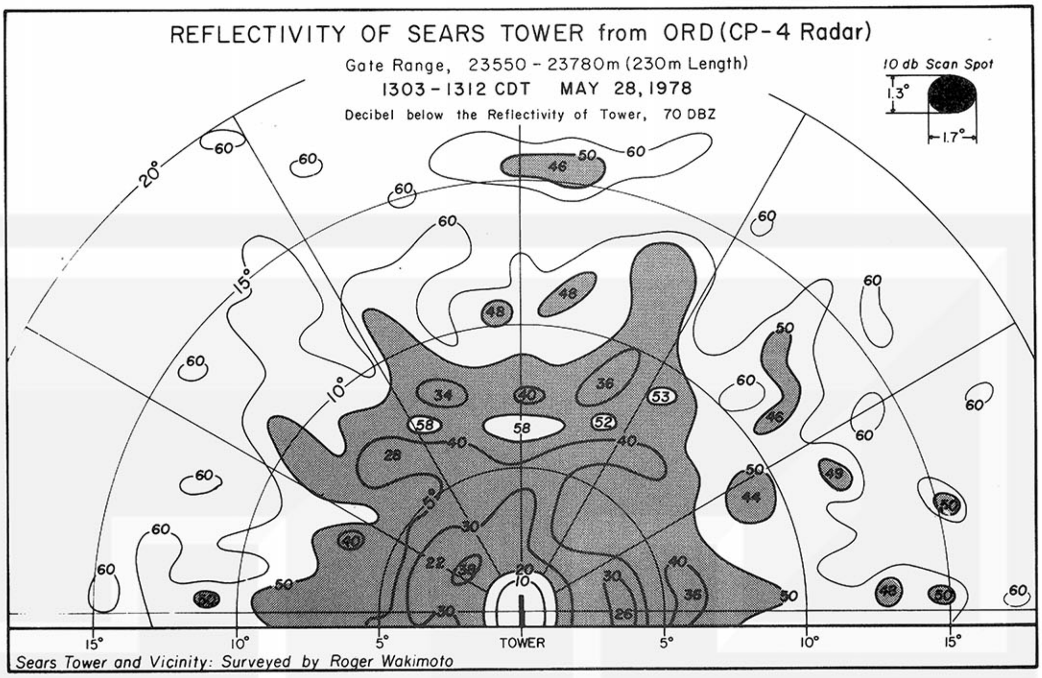
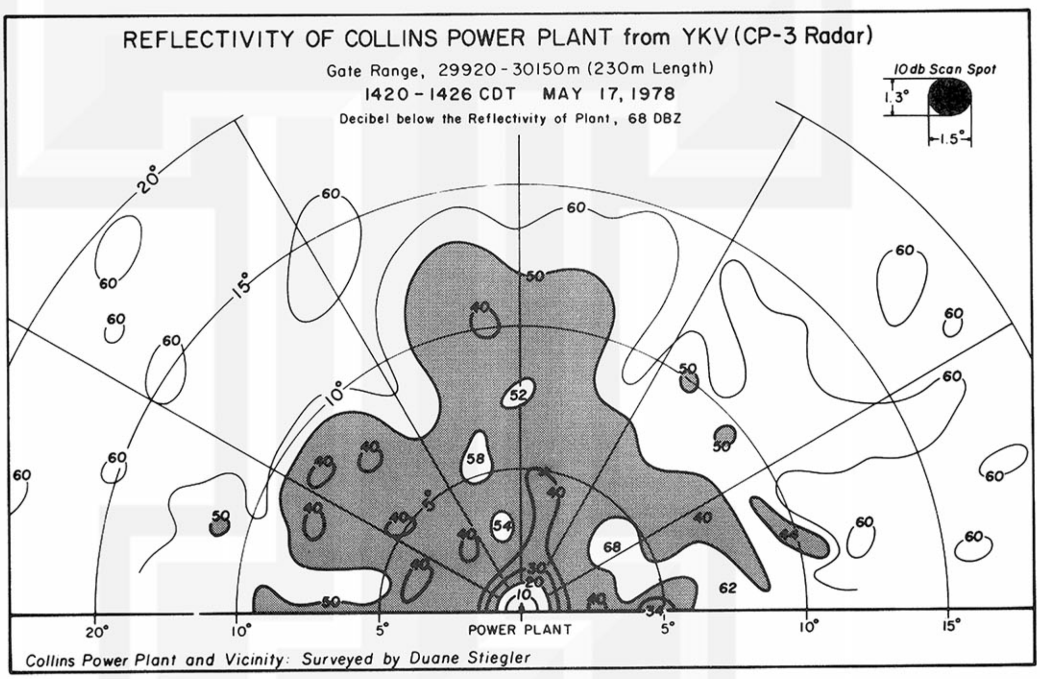


Figure 8.



are unique to a particular radar. Sears Tower in downtown Chicago was chosen as a target and scanned during non-weather periods by the CHILL and ORD (CP-4) radars which were located 48 km and 24 km, respectively, from the Tower (see Figure 1). And, Commonwealth Edison's Collins Nuclear Power Plant at Morris, Illinois was scanned by the YKV (CP-3) radar from a distance of 30 km.

Figures 6, 7 and 8 show the results of the scans made by the CHILL, ORD and YKV radars, respectively. The scan spot on each figure represents the size of the pulse volume perpendicular to the beam axis at the distance of the ground target.

The CHILL radar shows a -50 dB side lobe effect which extended up to 7° in elevation. Similar effects were produced by the CP-3 and CP-4 radars to an elevation of 15°. The greater extent of the CP-3 and CP-4 patterns as opposed to the CHILL pattern, is most likely due to their smaller range from the radar (Battan (1973)). The overall patterns appear somewhat symmetric, however the extent of variation within the pattern should be noted. One could conclude that side lobe effects are much more complicated than previously believed and that correction schemes would be extremely difficult if not impossible.

5. SUMMARY

In consideration of the future expansion of Doppler radar use in meteorology, it becomes increasingly important that limitations such as those which result from side lobe effects be fully understood. Using an accurately calibrated Doppler radar, it was discovered that side lobe effects can extend several degrees above the cloud top of thunderstorms with high-reflectivity cores. Further examination showed that velocities were also found to extend beyond the cloud top, indicating that the high-reflectivity cores can alter velocities in weak echo regions. The use of ground structures as point targets produced reflectivity fields that were closely representative of side lobe patterns associated with a specific radar. It becomes apparent that future research in this area is necessary, so that proper Doppler data interpretation can be realized.

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