ON THE IMPRECISION OF RADAR SIGNATURE LOCATIONS AND STORM PATH FORECASTS

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Abstract

Weather radar data are often used to determine the location and projected path of severe weather without the understanding of the limitations inherently involved with these data. This paper documents the imprecision of radar-based features by comparing locations of radar-derived circulation centers with over 90 tornadoes surveyed in the Norman Oklahoma National Weather Service County Warning Area. The paper demonstrates that location errors of more than one-half mile are common, with location errors of up to 8 miles also being observed. Meteorological sources of uncertainty are discussed as well as general limitations of weather radar. Both the imprecision of radar to determine where severe weather is currently occurring, and the often non-linear movement and evolution of severe weather, makes the projection of these features difficult in both time and location. The impact of these imprecise projections for users is also discussed.

1. Introduction

Following a number of recent tornado outbreaks, including the May 3, 1999 Oklahoma/Kansas tornado outbreak, meteorologists from the NOAA/National Weather Service Weather Forecast Office (WFO) in Norman, OK and other local NOAA agencies performed numerous ground surveys of tornado damage. Since 1995, detailed ground or aerial surveys were made for over 100 tornadoes within the Norman County Warning Area (CWA). While comparing tornado paths from these damage surveys with the locations of radar signatures, it has been noted that there can be a distance of a few miles between the location of the radar signature and the corresponding tornado damage path. This uncertainty in the radar estimated location has significant implications on the ability to pinpoint where damaging weather is occurring, and the ability to predict the movement and locations of dangerous storms.

For several years, the broadcast media and WFOs have expanded their use of detailed storm path forecasts (also known as pathcasts) to try and provide detailed warning information to those in the path of a tornado or severe thunderstorm. These efforts have resulted in a wide range of levels of detail in forecasts, from highly specific street-by-street forecasts of storm position and arrival times, to more general estimates of location and impact times. Occasionally, these pathcasts are created or interpreted by users who might not be aware of the imprecision inherent with these projections.

2. Data and Methodology

Since 1995, the Norman WFO has conducted or obtained highly detailed ground surveys of over 100 tornadoes within the Norman CWA. Radar circulation locations were taken from the Twin Lakes, OK (KTLX), Vance AFB, OK (KVNX), and Frederick, OK (KFDR) Weather Surveillance Radar 88 Doppler (WSR-88D) radars and were compared to the actual path of 94 of these tornadoes (see Appendix A). The radar circulation center locations were manually identified by finding the strongest gate-to-gate shear using the 0.5 degree elevation angle data. Figure 1 shows an example of the surveyed location of a violent tornado that struck the Oklahoma City metropolitan area on 8 May 2003, and the storm-relative velocity image from the KVNX radar which is approximately 100 miles to the northwest. In this case, the strongest gate-to-gate radar signature was located approximately 3 miles southeast of the damage path. For all of the tornadoes in this study, the latitude and longitude were taken from the cursor readout of the radar Principal User Processor (PUP) or the Advanced Weather Interactive Processing System (AWIPS) workstation. These coordinates were plotted on a street map using the U.S. Census Bureau's Tiger Map web server. The tornado paths were then drawn onto the map using the survey information. An example of surveyed tornado tracks compared to centers of radar circulation for a tornado event on 11 April 2001 is shown as Fig. 2. For this event, the location of the tornado determined by ground and aerial surveys is often displaced from the location of the strongest radar gate-to-gate shear by as much as 2 miles.

3. Results and Sources of Error

The center of circulation identified from the lowest radar elevation angle was compared to the surveyed tornado location of the 94 tornadoes with the one-dimensional difference in distance is shown as Fig. 3. The time of the tornado at any given location is generally unknown, therefore it is not known where the tornado is along the track at the exact time of the radar data. The distances shown on Fig. 3 are one dimensional distances (normal to the damage path) from the circulation center

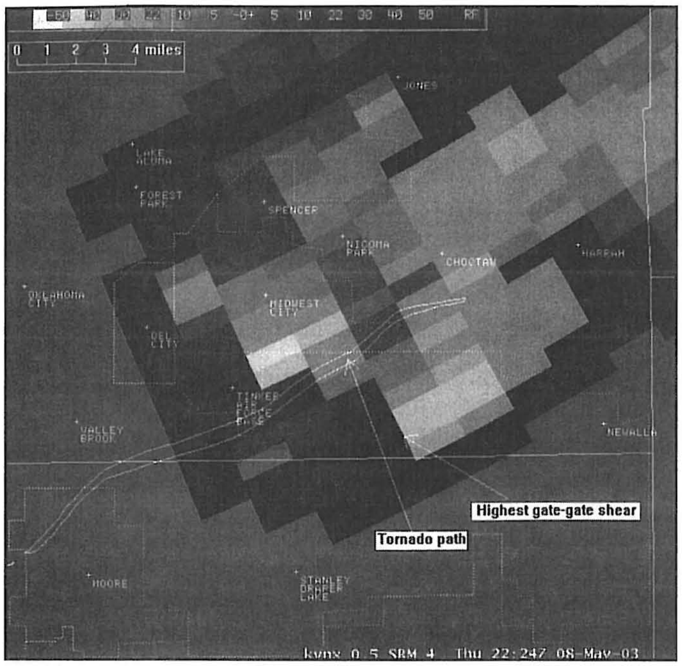

Fig. 1. Storm-relative velocity display from KVNX (Vance AFB) radar at 2224 UTC 8 May 2003, and path of F4 tornado through the Oklahoma City metropolitan area. Location of the highest gate-to-gate shear is shown where the outbound velocity is between 40 and 50 knots next to inbound velocity between 30 and 40 knots. KVNX is 104 miles northwest of the location of the strongest shear signature.

to the nearest point of the damage path. A two-dimensional distance (which includes both the distance normal to the damage path and the distance along the damage path) will be greater if the tornado is not at the closest point of the surveyed track at the time of the radar signature.

A least squares fit regression line is plotted on Fig. 3. This figure shows that the error is greater at a longer distance from the radar where the radar beam may be overshooting the low-level circulation. However, even within 30 statute miles of the radar, there were a number of cases where the radar estimated location was one or two miles from the location of tornado damage. Uncertainty of two miles using radar is enough to make specific determination of a tornado location unreliable. At greater distances from the radar, the error has been as much as eight miles as in the case of an F2 tornado in the Oklahoma City metropolitan area. In this extreme case, the mid-level rotation associated with the tornadic circulation had dissipated, while another developing circulation was observed by the Frederick, OK radar (located approximately 110 miles from the storm). Fortunately, in this case, data from a closer radar were available that showed low-level rotation with the tornadic portion of the storm. Table 1 shows the mean one-dimensional distance at various ranges from the radar of the 94 tornadoes studied, and the percentage of signatures that are at least one-half and one mile from the tornado location. When the radar circulation signature is over 20 miles from the radar, the distance between the radar signature and the tornado is one-half mile or greater more than 50% of the time.

The 11 April 2001 case displayed in Fig. 2 shows that although there is an approximate one to two mile error in the tornado location based on the center of radar circulation, the general direction of movement on radar is consistent with the tornado path. However, an example from a tornado outbreak on 9 October 2001 (see Fig. 4) shows that the movement of radar circulation signatures may not always indicate the true direction of tornado movement. Radar indicated that the circulation was moving to the east-northeast, while the tornado moved to the northeast and north-northeast.

One major source of error when comparing mesocyclone locations to the tornado path is the tilt of the vortex. This can often be seen visibly below cloud base as shown in Fig. 5 where the tornado's location at the surface can be significantly displaced from the location of the circulation at cloud base. In this photograph, the location of the tornado's contact with the ground is estimated to be displaced about one-half mile west of the location of the vortex at cloud base. The radar perspective of this tilt has been documented as early as the Union City, OK tornado in 1973 in which the tilt in elevation of the radar's tornado vortex signature (TVS) with height was consistent with the observed tilt of the tornado below cloud base. This tilt continued at elevations well above cloud base (Brown et al. 1978). Figure 6 shows the actual path and radar circulation centers for the tornado that moved through the south Oklahoma City metropolitan area on 8 May 2003. This tornado occurred between 7 and 16 miles from the Twin Lakes (KTLX) radar. Overlaid with the surveyed damage path are the manually identified circulation centers at the 0.5°, 4.3°, 10.0° and 14.0° elevation angles from the KTLX radar. The centers of circulation at the 0.5° elevation angle (altitude between 300 and 1,000 feet AGL) are within about one-quarter mile of the center of the tornado

Table 1. Error distance between tornado location and radar-indicated circulation center as a function of distance from radar.

Distance From Radar	Number of Radar Data Points	Mean Error	% of Radar Signatures with error of 0.5 miles or greater	% of Radar Signature with error of 1.0miles or greater
0-20 miles	52	0.2 miles	13%	6%
20-50 miles	128	0.6 miles	51%	22%
50-80 miles	120	0.8 miles	63%	33%
80-110 miles	105	1.1 miles	79%	49%
110-140 miles	141	1.5 miles	79%	67%
Total	546	0.9 miles	63%	39%

damage path. But as the elevation angle is increased to 14.0° (altitude between 11,500 and 20,000 feet AGL), the radar-detected circulation was up to 3 miles away from the damage path, even at close range. Most commonly, the tornado damage path was located to the south of the center of radar circulation (as shown in Figs. 2 and 6) which suggests that storm tilt can lead to discrepancies between radar circulation centers and tornado paths in situations of increasing southerly winds with elevation that are usually present during severe weather events in the Southern Plains. However, there were still a significant number of events where the tornado damage occurred to the north of the radar circulation. In some cases, there was variability even with the same tornado event. We found no systematic bias. For a given radar elevation angle, the height of the radar beam above the surface increases and the uncertainty based on the tilt of the storm increases at greater distances from the radar. Although precise beam height is not known because the refraction of the radar beam varies with the thermodynamic properties of the atmosphere, estimates can be made using a standard atmosphere as shown in Fig. 7 (NOAA 2004).

The width of the radar beam can also influence the location of a radar-identified circulation, and as with beam height, increases with downrange distances. On average, the WSR-88D has a beam width of 0.93°, but because of the radar antenna rotation and the pulse repetition frequency, the effective beam width broadens to 1.29° (Wood and Brown 1997). Therefore, at a distance of 50 miles from the radar, the effective diameter of the radar beam is 1.13 miles, and at 240 miles from the radar, it is 5.4 miles. Since the velocity signature of a circulation would be detected between two adjacent radar azimuths, depending on where the circulation happens to fall relative to the radar beams, this will lead to uncertainty on the location of the circulation of up to one-half of the beam diameter based solely on this sampling. Although the specific values listed here represent the WSR-88D radar, the issue of beam width would apply to any radar. The width of a radar beam depends on the radar wavelength and the diameter of the radar dish (Doviak and Zrnic 1984). The radar beam will be larger for smaller radar dish diameters or longer wavelengths. Similarly, the uncertainty in location along a radar radial is one-half of the length of a radar bin. Upon initial deployment of the WSR-88D, the storm relative velocity was determined using a bin length of 1 kilometer along the radial. Therefore, the distance from the radar would have an uncertainty of up to 0.5 kilometer (0.31 mile). Storm-relative velocity data are now available in some circumstances with bins of 0.25 kilometers, reducing this uncertainty to 0.08 miles.

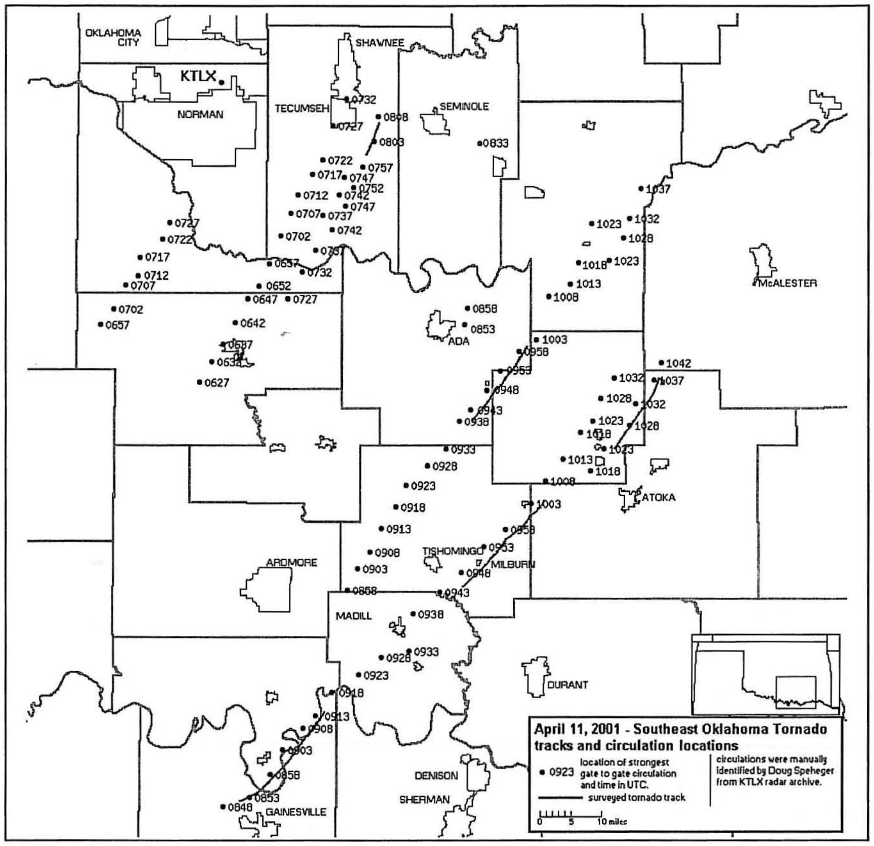

Fig. 2. Low-level circulation centers from KTLX radar (dots) with times (in UTC) and tornado paths (lines) from 11 April 2001 in southeast Oklahoma. KTLX is shown in southeast Oklahoma City.

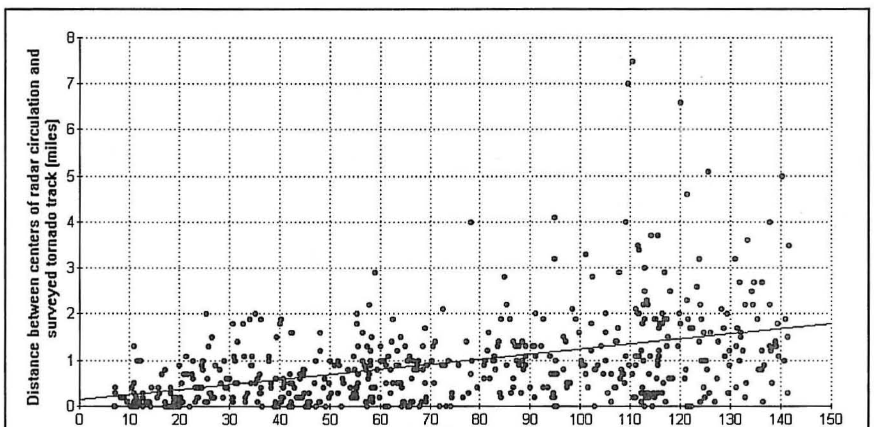

Fig. 3. One dimensional errors between low level (0.5° elevation) radar circulation centers and surveyed locations of corresponding tornado damage paths. Graph includes 546 radar observations from KTLX, KFDR and KVNX radars and 94 tornado damage paths between 1995 and 2003 in the Norman CWA.

There is also an inherent limitation to the mechanical accuracy of the radar determining the azimuth. A monthly maintenance check is performed on the WSR-88D radars where the radar is pointed at the known azimuth and elevation of the sun to minimize this source of uncer-

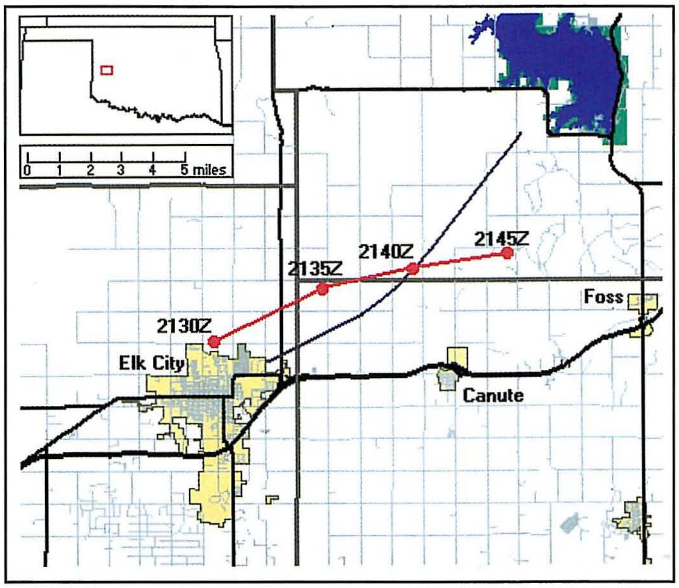

Fig. 4. Low-level (0.5° elevation) circulation centers from KTLX radar (dots and connecting lines) and surveyed path of tornado near Elk City and Foss Lake (line) from 9 October 2001. KTLX radar is 120 miles east of Elk City.

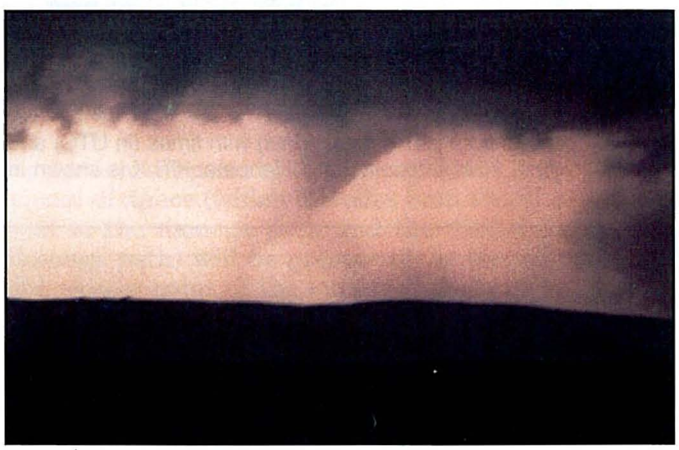

Fig. 5. Photograph (toward north) of tornado near Kingsdown, KS on 7 May 2002. Photo © 2002 Doug Speheger.

tainty. This test places the radar within a +/- 0.33° tolerance. A 0.33° uncertainty in the azimuth would yield an uncertainty of 0.29 miles at a range of 50 miles, and 1.39 miles at a range of 240 miles. The actual uncertainty in azimuth is usually less than these values with radars that are properly maintained.

Non-meteorological factors contribute to the complexity of communicating the location of a threat with precision. For example, cities and towns are often defined as a single point on a radar display (such as the location of city hall, or the geographic center of the town), even though the city may cover many square miles. The interpretation of a phrase such as "6 miles southwest of Oklahoma City" is difficult when the city limits of Oklahoma City encompass 607 square miles (U.S. Census Bureau 2000) in four different counties. The latitude/longitude coordinates initially used in the AWIPS system, and probably also used in other computer systems, were taken from the U.S. Census Bureau's Gazetteer files. The Census Bureau defines these coordinates as "The lat/long for each place was calculated with reference to the legal boundaries of the entity as of the 1990 census and 2000 census respectively, not to the center of a collection of buildings (like the central business district)." It further states that "The resulting point is the approximate geographic center of the polygon making up the legal entity" (U.S. Census Bureau 2002). Figure 8 shows the result for the city of Norman, OK. The city of Norman encompasses an area of 177 square miles (U.S. Census Bureau 2000) with most of the population in the western section of the city. The U.S. Census Bureau coordinates for Norman are more than 5 miles east of the downtown area and almost 12 miles east of the western city limits. As a result, the location of a tornado in downtown Norman would be described ambiguously as "5 miles west of Norman" using these coordinates. The 3 May 1999 Bridge Creek/Oklahoma City/Moore tornado caused F5 damage and a number of deaths within the city limits of Oklahoma City. However, its location was 9 miles from downtown Oklahoma City and the point of reference used for the city in the Census Bureau's Gazetteer files. Without manual intervention, Oklahoma City would not have been listed as being in the path of the tornado.

4. Implications for "Pathcasting"

These results have obvious implications on the accuracy of storm track forecasting. Not only is there already some uncertainty in the initial location and movement of the storm based on radar signatures, the pathcast often makes a linear extrapolation of storm motion, which is often non-linear. This can lead to significant errors in the projected path.

A major source of error in pathcasts is the assumption that a certain linear motion will continue through the duration of a projection. While this will occasionally work reasonably well, there will often be deviant motion within a storm that will violate this assumption, especially with longer projections. There may also be a difference in the motion of the tornado and the parent thunderstorm. The NWS Warning Decision Training Branch cites two examples in their Tornado Warning Guidance (2002) observed by researchers during the Verification of the Origin of Rotation in Tornadoes Experiment (VORTEX) project:

> Storm motion and tornado motion (direction and speed) may be significantly different. For example, on two VORTEX days (6/2/95 and 6/8/95), there were several instances where the parent thunderstorm was moving toward the northeast while the tornado was moving north. In addition, for another case, the tornado's forward movement was measured at 60 mph only to become nearly stationary before it dissipated. Be careful about issuing tornado warning locations based on the storm cell centroid motions; use the motion of the radar vortex signature, whenever available, and allow adequate room to allow for uncertain (and nonlinear) tornado motion.

Figure 9 shows an example from 3 May 1999. A supercell thunderstorm that had already produced five tornadoes began producing a sixth tornado about nine miles southeast of the town of Anadarko, OK. For three radar volume scans, the circulation's path was to the northeast at 27 mph. If a pathcast had been issued on the storm at this point using this linear motion, it might have read:

* The storm will be...
2 miles southeast of Verden at 6:00 p.m.
8 miles northwest of Chickasha
at 6:15 p.m.
5 miles northwest of Amber at 6:30 p.m.
3 miles west of Tuttle at 6:45 p.m.

As Fig. 9 shows, the storm turned to the right and continued to produce tornadoes during this time, including the beginning of the F5 Bridge Creek/Oklahoma City/Moore Tornado (A9) as documented by Speheger et al. (2002). Not only was the center of radar circulation one mile away from where the tornado was initially producing damage west of Chickasha, this pathcast would have yielded errors of approximately 2 miles, 4.5 miles, 7 miles, and 8 miles at each forecast time. In addition, tornadoes associated with this thunderstorm hit the northwest edge of the city of Chickasha, the Chickasha airport, and the southeast edge of the town of Amber despite the fact that the pathcast would have indicated that the tornado would stay well to the west and north of these towns. As mesocyclones or tornadoes occlude and redevelop, additional non-linearity is observed – both in the perceived motion of radar circulations and in the tornadoes themselves. Other inaccuracies can result from radar mapping errors, and errors in radar derived speed and motion information.

Most systems used to generate storm path forecasts require the user to manually select the storm features to be tracked. This introduces the possibility that the wrong part of the storm might be selected for tracking, thus introducing additional time and location errors in the pathcast. There are many potential areas that can be identified and tracked in a severe thunderstorm (S.F. Piltz, personal communication, October 1998) including the mesocyclone, hook echo, gust front, leading edge of the precipitation, high reflectivity cores, high reflectivity gradient, and algorithm-based feature locations. For example, there is an anecdotal account of a tornadic supercell being tracked by a meteorologist through a major metropolitan area. The storm exhibited a pronounced hook echo and velocity signature at low levels on radar. Spotter reports corroborated the tornado's location. However, despite this information, the meteorologist incorrectly chose the high reflectivity core of the supercell as the basis of a tornado path projection, which in this case, was seven to eight miles north of the tornado location. This forecast resulted in misinformation and confusion concerning who was in the tornado's path.

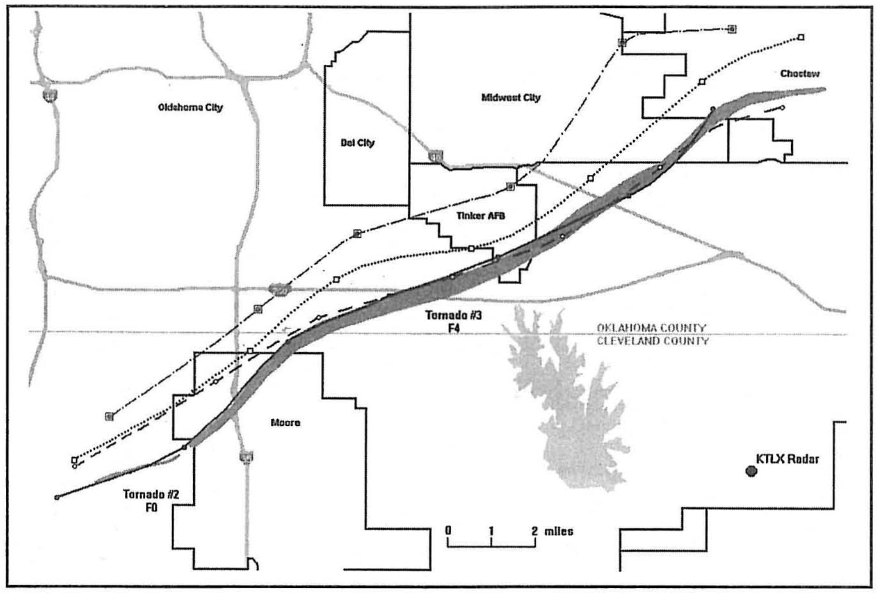

Fig. 6. Path of the 8 May 2003 Moore/South Oklahoma City metro tornado (gray), and circulation centers from KTLX radar at 0.5° (solid line), 4.3° (dashed line), 10.0° (dotted line), and 14.0° (dashed-dotted line) elevation angles.

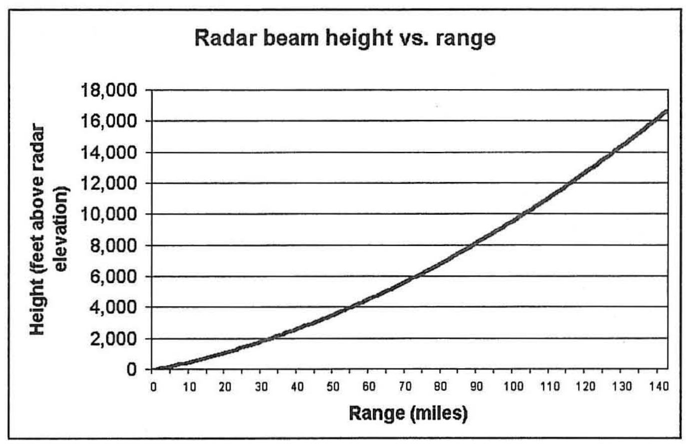

Fig. 7. Height of a radar beam at 0.5° elevation angle above the radar elevation as a function of range, assuming a standard atmosphere. Equation used is from NOAA (2004).

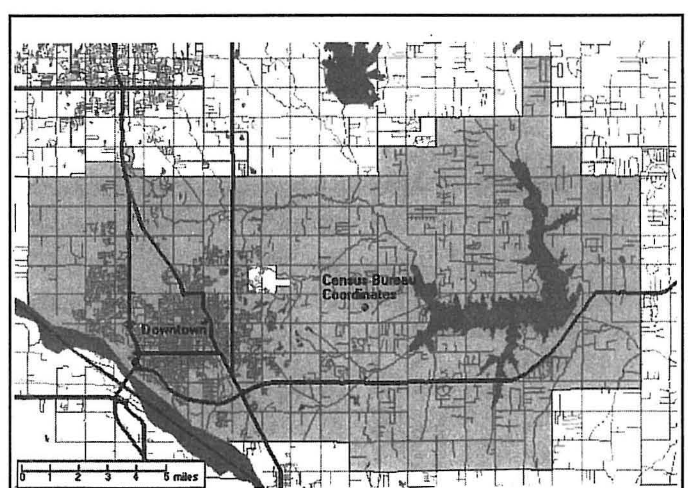

Fig. 8. Norman city limits (dark), location of downtown Norman and the U.S. Census Bureau coordinates for Norman.

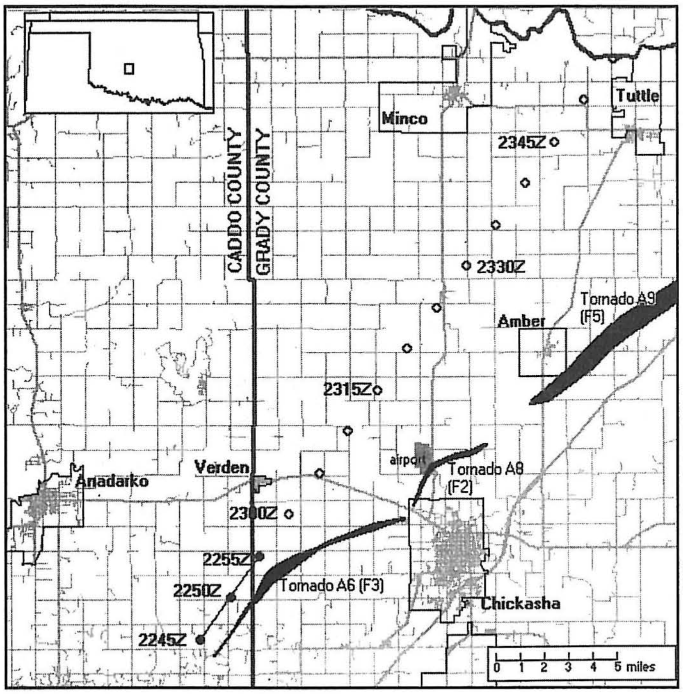

Fig. 9. Low-level (0.5° elevation) circulation centers from KTLX radar (solid dots and connecting lines), projected locations at 5 minute intervals (open dots) based on extrapolation of linear motion between 2245 UTC and 2255 UTC on 3 May 1999, and surveyed tornado paths. KTLX radar is 27 miles east of Tuttle.

Besides the meteorological uncertainty related to the projection of a tornado location, there is also the issue of a person's misperception of pathcast precision. A victim of the Moore tornado of 8 May 2003 mentioned in a post-storm interview, "Leroy told me they were saying on TV it would hit at 5:27, so I better get in. But it hit before then" (Patton 2003).

Researchers with the Oklahoma Department of Health also interviewed tornado survivors following the 8-9 May 2003 Oklahoma City metro tornadoes regarding the tornado warning system. A number of respondents indicated they were confused by the tornado locations and arrival times presented by the broadcast media. One respondent said the warning on television had indicated the tornado would strike in about 20 minutes, but in reality, the tornado hit after only "a couple of minutes." Others responded that they felt some of the television pathcast times were inaccurate, and that they were confused by different arrival times being projected by different television stations (R.D. Comstock, personal communication, 2003).

After a tornado outbreak in Arkansas on 1 March 1997, USA Today (1999) carried an Associated Press article describing a young woman who at 2:30 p.m. heard the warning of a tornado predicted to hit the town of Arkadelphia, AR around 2:50 p.m. She and a friend drove to her house in Arkadelphia to rescue her sister from the approaching storm.

> Comforted by the advance notice, they braved heavy winds and rain and reached home at 2:47 p.m., a minute *after* [italics added] the storm entered the town of Arkadelphia. Thinking they had several minutes more, [the three women] returned to the car - right on the tail of a twister concealed by the surrounding rain.

The National Weather Service warning issued at 2:14 p.m. mentioned that the tornado would reach Arkadelphia at 2:50 p.m. The tornado continued in a generally linear motion allowing the projection to verify within 5 minutes. However, this young woman perceived the forecast to have greater precision than is possible, and placed herself in danger.

Warnings and other statements might still include information on the projected movement, arrival times at certain locations, etc, while accounting for the uncertainties and imprecision inherent in the process. A warning might use a range of times for arrival to a certain area, such as the statement "this storm will impact western parts of Oklahoma City between 5:15 p.m. and 5:30 p.m." The meteorologist may also want to account for the fact that different threats exist at different locations within the same storm. This could be done with statements such as: "the leading edge of the storm, producing strong winds, heavy rain and hail, will move into the city around 4:30 p.m. The highest potential for a tornado will occur after 4:45 p.m." or "The threat of a tornado will be highest along and just south of Interstate 44. However, large damaging hail will also be likely, especially just north of the interstate."

5. Summary

There are a number of meteorological, mechanical, and mapping uncertainties inherent in radar data, and it is important for the radar and broadcast meteorologist to understand these limitations in order to give accurate information without conveying a false sense of precision. Although some of these limitations, such as radar beam width, can be addressed with the design of individual radar systems, other sources of uncertainty will still apply to all radars. For example, the uncertainty based on the tilt of the tornado vortex will apply to any radar system. As shown in this paper, there are limitations to current technology, and the public may perceive precision that is not available. The radar circulation signature may be some distance from where a tornado is occurring, and there is a much greater uncertainty at greater distances from the radar. Users can not use isolated cases where radar detected a tornado location well, especially those near the radar, to demonstrate that the radar will always have this precision. When this uncertainty in a current position of a tornado is combined with the linear extrapolation of a potentially significantly non-linear event, the resulting uncertainty in projected locations and times in a pathcast can be large. The implications associated with potentially significant time and location differences in severe storm pathcasts suggests that meteorologists and others involved in disseminating severe weather forecast information must use caution when dealing with storm path forecasts. Warnings giving specific locations at times in the future (such as the theoretical example in Section 4) are especially problematic since they combine the uncertainties of both where the tornado is currently occurring and the linear extrapolation of its motion, but also give "exact" locations of the projection. Pathcasts listing approximate arrival times to or near specific locations should be used cautiously and with an understanding of the uncertainty inherent in such a projection. Frequent updates to storm information and projections are important to update the changes in the storm character or projection of movement.

Although this paper discussed tornado damage specifically, most of the limitations mentioned will also apply to detection of other phenomenon including hail, rain, and wind. Additional limitations may also exist with these features such as displacement of rain from its apparent position on radar by low-level winds.

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Appendix A: Surveyed tornadoes used in study

#	Date	F-scale	Tornado
1.	7 May 1995	F3	Eastman/Ardmore
2.	25 May 1997	F1	Middleberg
3.	25 May 1997	F2	Purcell
4.	24 May 1998	F3	Lamont
5.	8 June 1998	F1	Maud
6.	8 June 1998	F2	Wewoka
7.	8 June 1998	F2	Yeager
8.	13 June 1998	F1	Oklahoma City (Lake Hefner)
9.	13 June 1998	F2	Oklahoma City/ Nichols Hills
10.	13 June 1998	F1	Oklahoma City (Walker Ave.)
11.	13 June 1998	F2	Oklahoma City (Frontier City)
12.	4 October 1998	F2	Dacoma
13.	4 October 1998	F2	Watonga
14.	4 October 1998	F1	Dover
15.	4 October 1998	F2	Blanchard/Newcastle
16.	4 October 1998	F0	Canadian Valley
17.	4 October 1998	F2	Moore
18.	4 October 1998	F1	northwest Shawnee
19.	4 October 1998	F1	southeast Shawnee
20.	4 October 1998	F2	Meeker
21.	4 October 1998	F2	Prague #1
22.	4 October 1998	F1	Prague #2
23.	4 October 1998	F3	CenterView
24.	9 November 1998	F1	Purcell
25.	29 November 1998	F0	Cushing
26.	3 May 1999	F3	Apache (A3)
27.	3 May 1999	F3	Laverty (A6)
28.	3 May 1999	F2	Chickasha airport (A8)
29.	3 May 1999	F5	Bridge Creek/Oklahoma City/Moore/Del City (A9)
30.	3 May 1999	F0	Oklahoma City (Sooner Road) (A11)
31.	3 May 1999	F2	Choctaw (A12)
32.	3 May 1999	F0	Jones #1 (A13)
33.	3 May 1999	F1	Jones #2 (A14)
34.	3 May 1999	F1	Washita (B3)
35.	3 May 1999	F1	Minco (B10)
36.	3 May 1999	F1	Yukon/ Piedmont (B16)
37.	3 May 1999	F2	Piedmont (B17)
38.	3 May 1999	F1	Piedmont/Cashion (B18)
39.	3 May 1999	F4	Abell/ Mulhall (B20)
40.	3 May 1999	F0	Okarche (C1)
41.	3 May 1999	F1	Pink (D1)
42.	3 May 1999	F2	Shawnee (Clarks Heights) (D2)
43.	3 May 1999	F1	Shawnee/Meeker (D3)
44.	3 May 1999	F3	Davenport/Stroud (D4)
45.	3 May 1999	F1	Geary/Altona (E2)
46.	3 May 1999	F3	Altona/ Kingfisher (E3)
47.	3 May 1999	F4	Dover (E6)
48.	3 May 1999	F1	Hennessey (E7)
49.	3 May 1999	F0	El Reno (G1)
50.	3 May 1999	F3	El Reno/ Kingfisher (G2)
51.	3 May 1999	F0	Cashion (G3)
52.	3 May 1999	F3	Mulhall #2 (G5)
53.	3 May 1999	F2	Mulhall #3 (G6)
54.	3 May 1999	F2	Hennessey (H3)
55.	3 May 1999	F2	Marshall (H4)
56.	2 December 1999	F1	Seward
57.	2 December 1999	F2	Cimarron National/Guthrie
58.	2 December 1999	F1	Perry
59.	26 March 2000	F1	Daisy
60.	26 May 2000	F2	Dacoma
61.	26 May 2000	F1	Lambert/Carmen
62.	26 May 2000	F1	Fairview
63.	22 October 2000	F1	Valley Brook
64.	11 April 2001	F1	Gainesville/Thackerville
65.	11 April 2001	F1	Harjo/Maud
66.	11 April 2001	F2	Milburn/Fillmore
67.	11 April 2001	F2	Jesse
68.	11 April 2001	F2	Cairo/ Wardville
69.	20 May 2001	F2	Dustin
70.	9 October 2001	F0	New Liberty (A3)
71.	9 October 2001	F3	Elk City (B1)
72.	9 October 2001	F3	Cordell (C1)
73.	9 October 2001	F1	Corn (C2)
74.	9 October 2001	F3	Mountain View (D2)
75.	9 October 2001	F1	Alfalfa (D3)
76.	9 October 2001	F1	Gracemont (E3)
77.	9 October 2001	F0	Binger #1 (E4)
78.	9 October 2001	F1	Binger #2 (E5)
79.	17 April 2002	F3	Cestos
80.	17/18 April 2002	F2	Carmen/Lambert
81.	17 March 2003	F1	Komalty #1
82.	17 March 2003	F1	Komalty #2
83.	15 April 2003	F1	Choctaw
84.	15 April 2003	F1	Wellston
85.	8 May 2003	F0	Southwest Oklahoma City
86.	8 May 2003	F4	South Oklahoma City metro
87.	8 May 2003	F0	Red Rock
88.	9 May 2003	F0	Cogar
89.	9 May 2003	F1	Union City
90.	9 May 2003	F1	Bethany/Warr Acres
91.	9 May 2003	F1	Northwest Oklahoma City (Northwest Expwy)
92.	9 May 2003	F3	Northeast Oklahoma City/Jones
93.	9 May 2003	F1	Luther/Wellston
94.	9 May 2003	F1	Davenport/Stroud

Surveyors Include:

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National Severe Storms Laboratory: Harold Brooks, Don Burgess, Carl Hane, Christine Hannon, Janelle Janish, Kevin Manross, Kevin Scharfenberg, Terry Shuur, Travis Smith, Greg Stumpf, Matt Wadanish

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Warning Decision Training Branch: John Ferree, Jim LaDue, Mike Magsig, Liz Quoetone, Andy Wood

National Weather Service - FAA Academy: John Jarboe, Robert Prentice

Storm Prediction Center: Mark Darrow, Roger Edwards, Jack Hales

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Other: R. J. Evans, David Ewoldt, Mark Hill, Mike Honigsberg, Tim Marshall