2 Background on Tornadoes and History of the Storm

This chapter presents both a history of the May 3, 1999, tornadoes as they affected Oklahoma and Kansas and insight into the interaction between a tornado and a populated area. The Fujita scale for classifying tornado damage is presented in this chapter. A discussion on tornadoes and tornado damage is also included.

2.1 The Fujita Scale and Tornado Probability

Of the approximately 1,000 tornadoes reported in the United States each year, only a few are rated as “violent” events (F4 or F5 on the Fujita scale). The Fujita scale (Table 2-1), which was created by the late Tetsuya Theodore Fujita, University of Chicago, categorizes tornado severity based on damage observed and not on recorded wind speeds. Wind speeds have been associated with the damage descriptions of the Fujita scale, but the accuracy of these wind speeds is limited. The wind speeds are estimates that are intended to represent the observed damage. They are not calibrated wind speeds, nor do they account for the buildings’ design and construction variabilities.

Although the number of violent tornadoes varies considerably from year to year, the average during the period from 1980 to 1989 was about 10 per year. On average, only one or two of these per year were rated F5 and this number has not increased as the number of reported tornadoes has increased. Historical data indicate that the number of tornado reports have been rising, in general, since tornado data began to be collected in the early 1900s. However, the data suggest that a long-term increase in the frequency of tornadoes is unlikely. Rather, increased reporting of tornadic events has caused the numbers of documented tornadoes to rise.

TABLE 2-1: The Fujita Damage Scale

	F-0: (Light Damage) Chimneys are damaged, tree branches are broken, shallow-rooted trees are toppled.
	F-1: (Moderate Damage) Roof surfaces are peeled off, windows are broken, some tree trunks are snapped, unanchored manufactured homes are overturned, attached garages may be destroyed.
	F-2: (Considerable Damage) Roof structures are damaged, manufactured homes are destroyed, debris becomes airborne (missiles are generated), large trees are snapped or uprooted.
	F-3: (Severe Damage) Roofs and some walls are torn from structures, some small buildings are destroyed, non-reinforced masonry buildings are destroyed, most trees in forest are uprooted.
	F-4: (Devastating Damage) Well-constructed houses are destroyed, some structures are lifted from foundations and blown some distance, cars are blown some distance, large debris becomes airborne.
	F-5: (Incredible Damage) Strong frame houses are lifted from foundations, reinforced concrete structures are damaged, automobile-sized debris becomes airborne, trees are completely debarked.

Even today, tornadoes are unlikely to be rated as violent unless they interact with the built environment, so the actual number of violent tornadoes per year is probably somewhat larger than the reporting statistics suggest. According to calculations performed by the National Severe Storms Laboratory (NSSL) using the most recent data (1980-1994), the regions of the United States with the highest frequency of tornado occurrence, an area of 2,500 square miles, should expect about one tornado (of any intensity) per year (Figure 2-1). In other words, the chance of any particular square mile experiencing a tornado in a given year, within the designated area of "Tornado Alley," is about one in 2,500. The map in Figure 2-1 indicates by color band the probability of tornado occurrence in the continental United States during any given year.

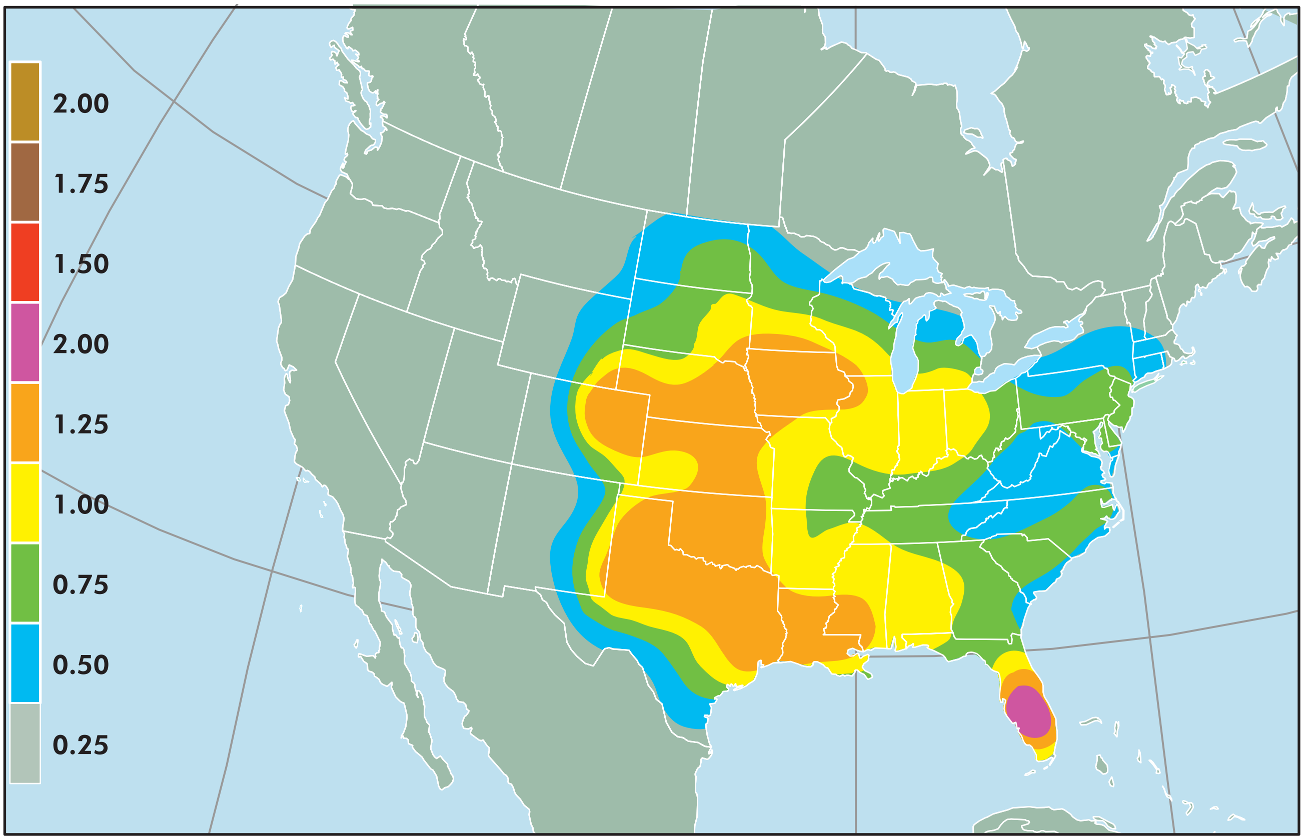

FIGURE 2-1: Annual probability of tornado occurrence in the continental United States. The numbers in the scale on the left side of the map indicate the number of days per year with at least one tornado within the 2,500 square mile area around specific geographic points.

Violent tornadoes correspond to the top 2 percent of all tornadoes; thus an area of 2,500 square miles in the area of peak frequency would be expected to experience a violent tornado only about once every 50 years. Alternatively, a given square mile's chances of being hit in a given year by a violent tornado is about one in 125,000.

Fujita estimated that the total area within a violent tornado's path that actually experiences damage associated with the violent wind speeds (i.e., the area directly impacted or struck by the tornado vortex) is only on the order of 1 percent of the total area affected. That means that a given square mile in

"Tornado Alley" has only about 1 chance in 12,500,000 of being hit by violent tornadic winds. Given that our knowledge of actual tornado occurrences is not complete or perfectly accurate, the true chances of being hit by a violent tornado might vary from these estimates. However, the NSSL believes these estimates to be broadly representative of the probabilities of being affected by a violent F4/F5 tornado.

2.2 Tornadoes and Associated Damage

Tornadoes are extremely complex wind events that cause damage ranging from minimal or minor to absolute devastation. Providing a complete and thorough explanation or definition of tornadoes and tornado damage is not the intent of this section. Rather, the intent is to clearly define some basic concepts associated with tornadoes and tornado damage that will be referred to throughout this report.

In a simplified tornado model, there are three regions of tornadic winds:

1. Near the surface, close to the core (i.e., vortex) of the tornado. In this region, the winds are complicated and include the peak low-near surface wind speeds, but are dominated by the tornado's strong rotation. It is in this region that strong upward motions occur that carry debris upward, as well as around the tornado.

2. Near the surface, away from the tornado's vortex. In this region, the flow is dominated by inflow to the tornado. The inflow can be complicated and is often concentrated into relatively narrow swaths of strong inflow rather than a uniform flow into the tornado's vortex circulation. These winds are typically called inflow winds; this term will be used throughout the report.

3. Above the surface, typically above the tops of most buildings. In this region, the flow tends to become nearly circular.

In an actual tornado, the diameter of the vortex circulation can change with time, so it is impossible to say precisely where one region of the tornado's wind flow ends and another begins. Also, the visible funnel cloud associated with and typically labeled the vortex of a tornado is not always the edge of the strong extreme winds. Rather, the visible funnel cloud boundary is determined by the temperature and moisture content of the tornado's inflowing air. The highest wind speeds in a tornado occur at a radius measured from the tornado vortex that can be larger than the visible funnel cloud's radius. It is important to remember that a tornado's wind speeds cannot be determined just by looking at the tornado.

Figure 2-2 shows the types of damage that can be caused by the tornadic winds of a violent tornado similar to the one that passed through the Oklahoma City Metroplex on May 3, 1999. In general, as shown in the figure, the severity of the damage varies with distance from the vortex and wind speeds within the vortex. Note, however, that the rotation of a tornado can cause winds flowing into the vortex on one side to be greater than those on other sides. As a result, it is not uncommon for the area of damage on one side of the tornado to be more extensive. Figure 2-2 and Table 2-2 reflect this situation.

In a violent tornado, the most severe damage occurs in the area directly affected by the vortex (the area shaded dark red in Figure 2-2). Typically, in this area, all buildings are destroyed and trees are uprooted, debarked, and splintered. In the immediately adjacent area, shaded orange in the figure, buildings may also be destroyed, but others may suffer less severe damage, such as the loss of exterior walls, the roof structure, or both. Even when buildings in this area lose their exterior walls and roofs, interior rooms may survive. In the outer portion of this area, further from the vortex, damage to buildings affects primarily roofs and windows. Roof damage ranges from loss of the entire roof structure to the loss of all or part of the roof sheathing or roof coverings. Typically, most or all of the windows in buildings in this area will be broken by windborne debris. In the area shaded yellow, damage is again primarily to roof coverings and windows. However, roof damage is lighter, and although windborne debris damage still occurs here, not all windows are broken. Damage to buildings in the outer fringe of this area is even lighter. Beyond this area, where the figure shows blue shading, buildings typically suffer no damage.

2.3 Background of the Event

On May 3, 1999, a widespread outbreak of tornadoes occurred in the south central United States, primarily in Kansas and Oklahoma. A strong upper-level storm system moved eastward toward the southern Plains from the Rockies during the day. Winds aloft over Kansas and Oklahoma intensified as the upper-level system approached. Atmospheric conditions indicated that rotating thunderstorms known as “supercells” were quite likely. The flow of moisture northward from the Gulf of Mexico, and daytime heating that pushed ambient surface temperatures up to at least 80 degrees, combined to produce an extremely unstable atmosphere across the southern Plains. In situations like this, forecasters are usually able to predict the tornado threat with reasonable accuracy, as opposed to more isolated tornado events, for which favorable conditions may not be so obvious. See the National Weather Service’s (NWS’s) “Service Assessment” for details of forecasting performance in this event (see Appendix E). The tornado outbreak was anticipated and, once supercells were detected by the WSR-88D radar, the tornado warnings from the NWS were accurate and timely, the first being issued at 4:47 p.m. (all times Central Daylight Time [CDT]). The WSR-88D radar is the advanced Doppler radar system that is now being used nationwide to track and forecast weather.

FIGURE 2-2: Potential impact of a tornado.

Impact of a Tornado

TABLE 2-2: Potential damage table for impact from a tornado.

Managing Risk	Damage Color Code	Description of Damage
The Threat to Property and Personal Safety Can Be Minimized Through Compliance With Up-To-Date Model Building Codes and Engineering Standards		Some damage can be seen to poorly maintained roofs. Unsecured light-weight objects, such as trash cans, are displaced.
		Minor damage to roofs and broken windows occur. Larger and heavier objects become displaced. Minor damage to trees and landscaping can be observed.
Property and Personal Protection Can Be Improved Through Wind Hazard Mitigation Techniques Not Normally Required by Current Building Codes		Roofs are damaged, including the loss of shingles and some sheathing. Manufactured homes, on nonpermanent foundations can be shifted off their foundations. Trees and landscaping either snap or are blown over. Medium-sized debris becomes airborne, damaging other structures.
		Roofs and some walls, especially unreinforced masonry, are torn from structures. Small ancillary buildings are often destroyed. Manufactured homes on nonpermanent foundations can be overturned. Some trees are uprooted.
Personal Protection Can Only Be Achieved Through Use of a Specially Designed Extreme Wind Refuge Area, Shelter, or Safe Room		Well constructed homes, as well as manufactured homes, are destroyed, and some structures are lifted off their foundations. Automobile-sized debris is displaced and often tumbles. Trees are often uprooted and blown over.
		Strong frame houses and engineered buildings are lifted from their foundations or are significantly damaged or destroyed. Automobile-sized debris is moved significant distances. Trees are uprooted and splintered.

The number of tornadoes that occurred in this outbreak was just over 70, according to the "Service Assessment". Within this outbreak, there were four violent (F4 or F5) tornadoes according to surveys performed by the NWS. Figure 2-3 shows the outbreaks in Oklahoma; Figure 2-6 shows the outbreaks in Kansas.

The tornado that caused the greatest damage and that had the greatest effect on residential areas was the reported F5 tornado that struck the south side of the Oklahoma City Metroplex. Its source was a supercell thunderstorm that had spawned several tornadoes earlier (Figure 2-4). This tornado had a track 38 miles long and lasted more than an hour, from 6:23 p.m. to 7:50 p.m. The track began between the towns of Chickasha and Amber, Oklahoma, southwest of Oklahoma City.

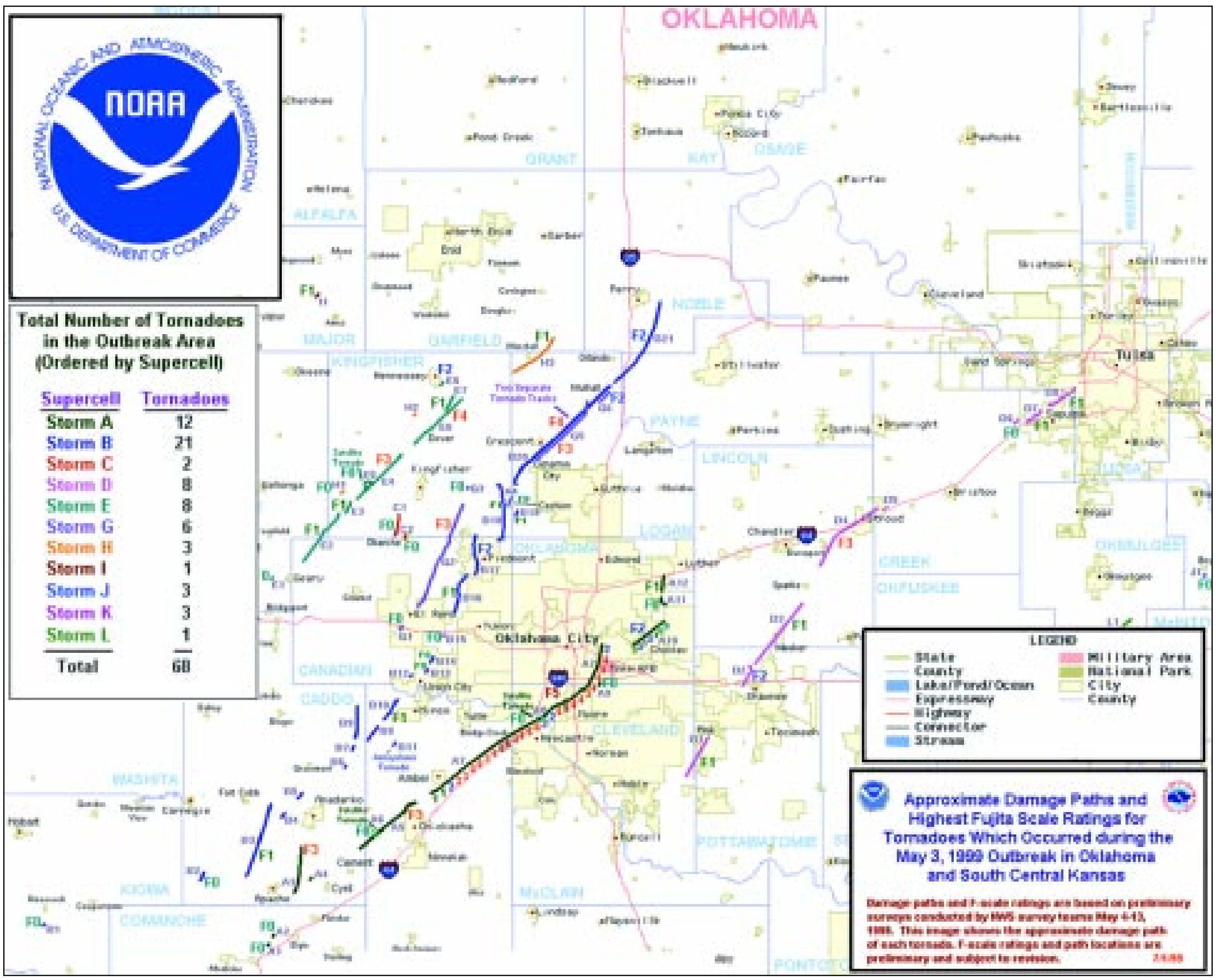

FIGURE 2-3: Outbreak map of tornadoes in Oklahoma that struck on May 3, 1999. Courtesy of the National Weather Service.

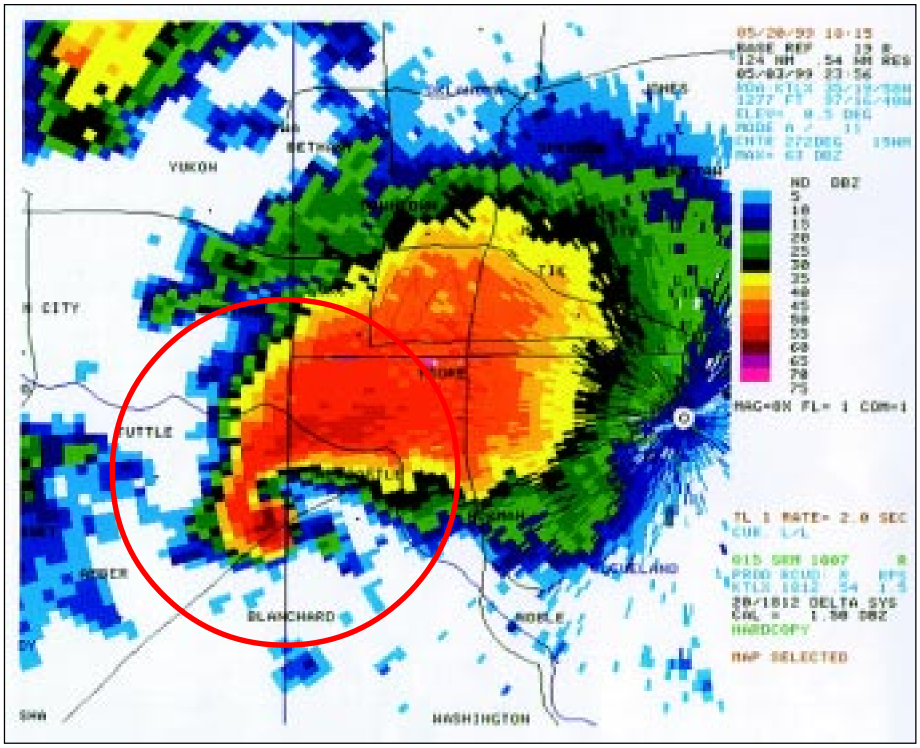

FIGURE 2-4: Radar reflectively map at 6:56 p.m., showing hook echo (circled). A hook echo is a structure associated with supercell storms. In many instances, the radar echo shows this type of structure when tornadoes are present. Courtesy of the National Severe Storms Laboratory.

From its touchdown point, the tornado moved northeastward, nearly parallel to I-44, toward Oklahoma City, hitting the town of Bridge Creek, Oklahoma, at 6:55 p.m. and crossing I-44 at about 7:05 p.m. near the South Canadian River. From there, it moved through several small subdivisions before slamming into the city of Moore, Oklahoma, and crossing I-35 near an overpass for Shields Boulevard. Continuing through a less densely populated area, the tornado crossed I-240 at about 7:35 p.m., began a wide left turn to travel along a north-northeast path that took it into Del City, Oklahoma, skirted Tinker Air Force Base, and then moved into Midwest City, Oklahoma, where it finally dissipated.

Analyses by the NWS in Norman, Oklahoma, indicated that this single tornado destroyed over 2,750 homes and apartments, damaged approximately 8,000 homes, and was responsible for 41 fatalities and approximately 800 injuries. Early damage estimates were on the order of at least $750 million. There has not been a tornadic event even approaching this magnitude since the F4 tornado that devastated Wichita Falls, Texas, on April 10, 1979. Magnitude relates to the severity of the storm, impacted area, and loss of life.

Figure 2-5 presents four WSR-88D images of the reported F5 tornado as it tracked from Moore to Midwest City. Figures 2-5a and 2-5b are actual radar cross-sections of the tornado taken at the location identified by the white line in Figure 2-5c. Figure 2-5a represents reflectively, while Figure 2-5b represents storm-relative radial velocity (wind velocities, however, are not specifi-

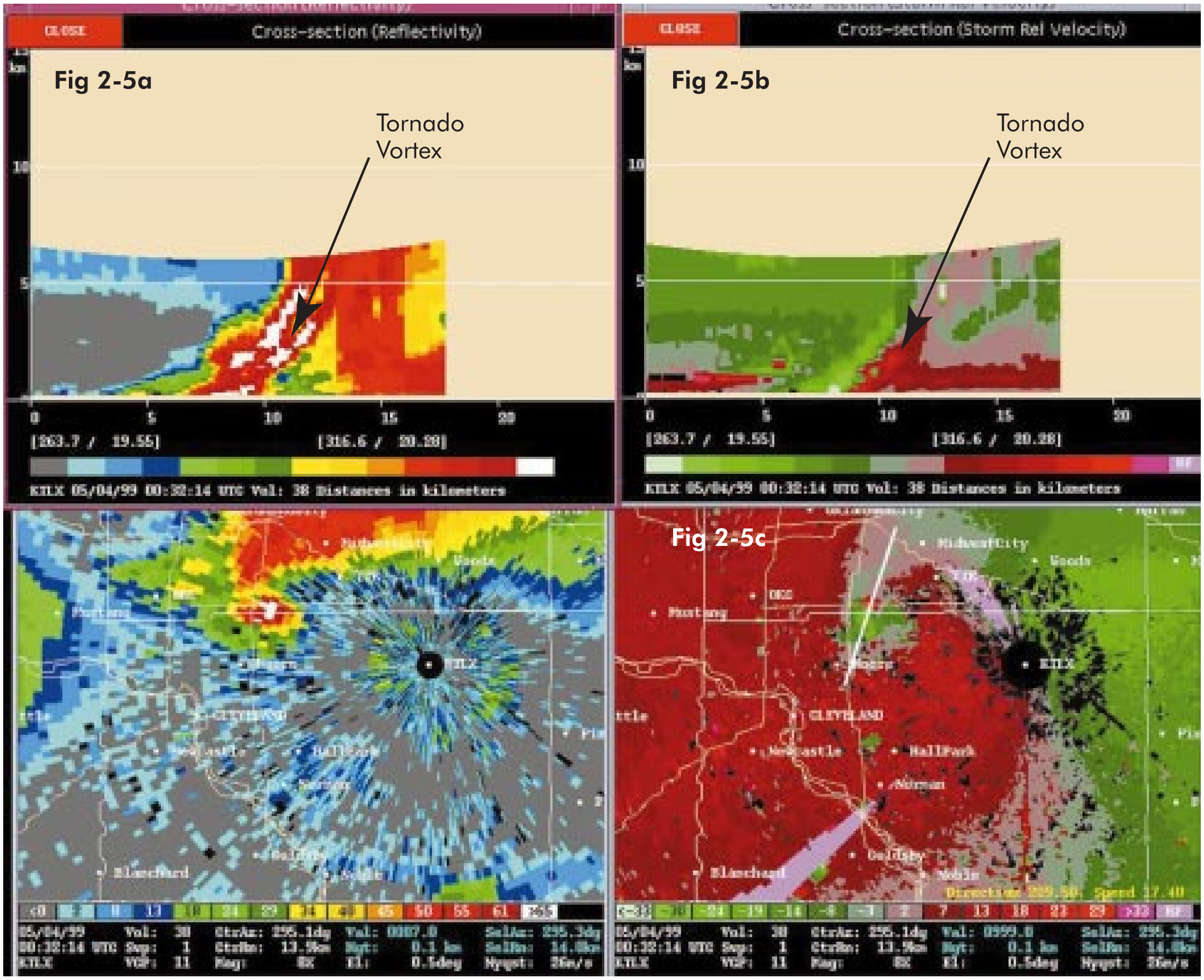

FIGURE 2-5: WSR-88D radar cross-section through the reported F5 tornado located approximately halfway between Moore and Midwest City, showing the debris and an apparent "eye."

cally indicated). These images were recorded at 7:32 p.m. on May 3, 1999. Horizontal and vertical scales are in kilometers. The vortex walls and the core of the tornado itself are delineated by different color patterns that relate to debris in the vortex and the wind speeds of the tornado.

Another violent tornado (rated F4) struck the small town of Mulhall, Oklahoma, which is located about 50 miles north of Oklahoma City. This tornado was produced by a different supercell storm to the north of the Oklahoma City Metroplex supercell. This second supercell produced approximately 19 tornadoes. The F4 tornado that struck Mulhall originated in open country, northwest of the town of Cashion, Oklahoma, at about 9:25 p.m. It spent the majority of its life in relatively unpopulated open country, hitting Mulhall around 10:15 p.m., late in its life cycle. Most of the homes and businesses in the Mulhall downtown area, including a school, a post office, and many historic buildings, were damaged or destroyed. There were no fatalities recorded in Mulhall. However, the tornado was responsible for one fatality in Logan County and one fatality in Payne County.

Dover, Oklahoma, was hit by a violent F4 tornado around 9:20 p.m. from another supercell that produced a “family” of tornadoes. This tornado was responsible for one fatality. This track was not investigated by the BPAT.

The fourth violent tornado (a reported F4) struck the Town of Haysville, Kansas, and the southern portion of the City of Wichita, Kansas (Figure 2-6) and was responsible for 6 fatalities. This tornado began around 8:13 p.m. in open country, west of the town of Riverdale, Kansas, in the unincorporated areas of Sedgwick County. Moving north-northeastward, close to the Union Pacific railroad tracks, the tornado hit Haysville at roughly 8:39 p.m., and continued into southern Wichita, crossing I-235, at about 8:44 p.m. It then veered to the east-northeast for a few miles, before turning north-northeastward again and dissipating in eastern Wichita at about 9:00 p.m. The track of this tornado was 24 miles long and extended east-northeastward through southern Wichita. The track was similar to that of the deadly tornado of April 26, 1991, that hit the Golden Spur Manufactured Home Park in Andover, Kansas. The 1991 tornado produced 17 fatalities, more than 100 serious injuries, and $140 million in damage, according to preliminary estimates by the NWS in Wichita, Kansas.

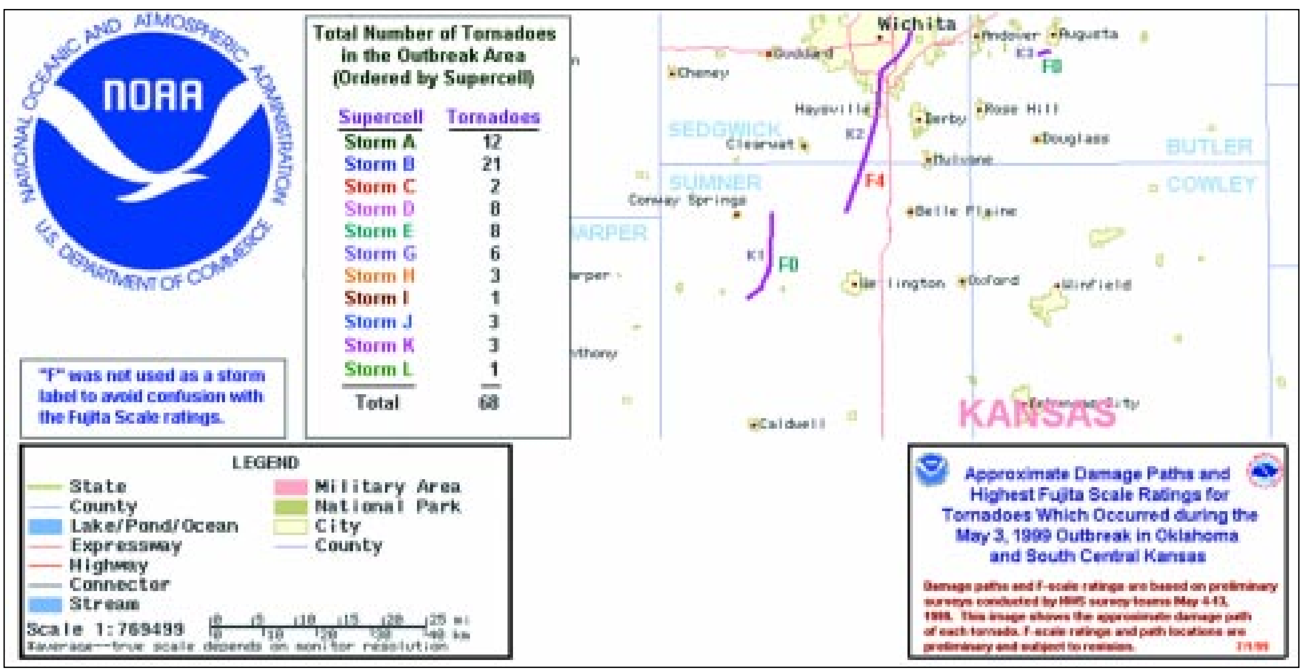

FIGURE 2-6: Preliminary outbreak map of tornadoes in Kansas that struck on May 3, 1999. Courtesy of the National Oceanic and Atmospheric Administration.

There were numerous less violent tornadoes on May 3, 1999. One of these was a strong F3 tornado that struck near the town of Stroud, Oklahoma, around 10:40 p.m. Damage associated with this tornado included a regional outlet mall along I-44 in Stroud that was destroyed, a manufacturing building that was heavily damaged, and the roof covering on a hospital in the town that was blown off. No fatalities were associated with this tornado.

Another less violent tornado was the weak tornado that struck Tulsa, Oklahoma, in the southwest neighborhood of Sapulpa, where it destroyed or heavily damaged several manufactured homes and site built structures. The tornado moved northeast to the Mountain Manor neighborhood, where it damaged roofs and uprooted trees. The roof at Remington School was extensively damaged, and several industrial and commercial structures on the south side of I-44 experienced roof and siding damage, including the Carbondale Assembly of God Church, on the north side of I-44, which suffered significant structural damage. No fatalities were reported.

The NOAA and NWS provided timely and accurate information that saved many lives and avoided numerous injuries by providing time for individuals to seek shelter. In the Oklahoma and Kansas tornadoes studied in the "Service Assessment", tornado warnings ranged from 13 to 65 minutes. Using back-up WSR-88D radar, the Wichita, Kansas office of NWS was able to continue operating after their primary radar malfunctioned. Many lives were saved during the May 3rd tornado outbreak due to the efforts of the Norman and Wichita NWS offices.