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

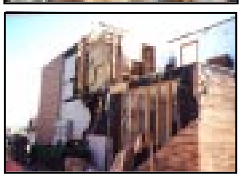
Of the 1,000 or so tornadoes reported each year in the United States, only a few are rated as "violent" events (F4 or F5 on the Fujita scale). The Fujita scale (Table 2-1), which was created by the late Tetsuya Theodore Fujita, University of Chicago, categorizes tornado severity based on damage observed 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 in that they are only estimates that best represent the observed damage and are not calibrated wind speeds.

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. Historical data indicate that the number of tornado reports have been rising, in general, since tornado data began to be collected in the early 1900's. 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.

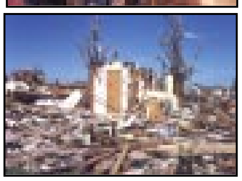
F-0: (Light Damage) Chimneys are damaged, tree branches are broken, shallow-rooted trees are toppled.

F-1: (Moderate Damage) Roof surfaces are peeled off, windows are broken, some tree trunks are snapped, unanchored manufacture homes are overturned, attached garages may be destroyed.

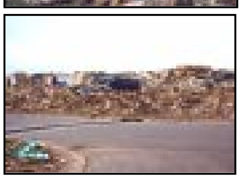
F-2: (Considerable Damage) Roof structures are damaged, manufactured homes are destroyed, debris becomes airborne (missiles are generated), large trees are snapped or uprooted.



F-3: (Severe Damage) Roofs and some walls 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 numbers of violent tornadoes per year are probably somewhat larger than the reporting statistics suggest. According to calculations performed by the National Severe Storms Laboratory (NSSL), the most recent data (1980-1994) indicate that the within 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.

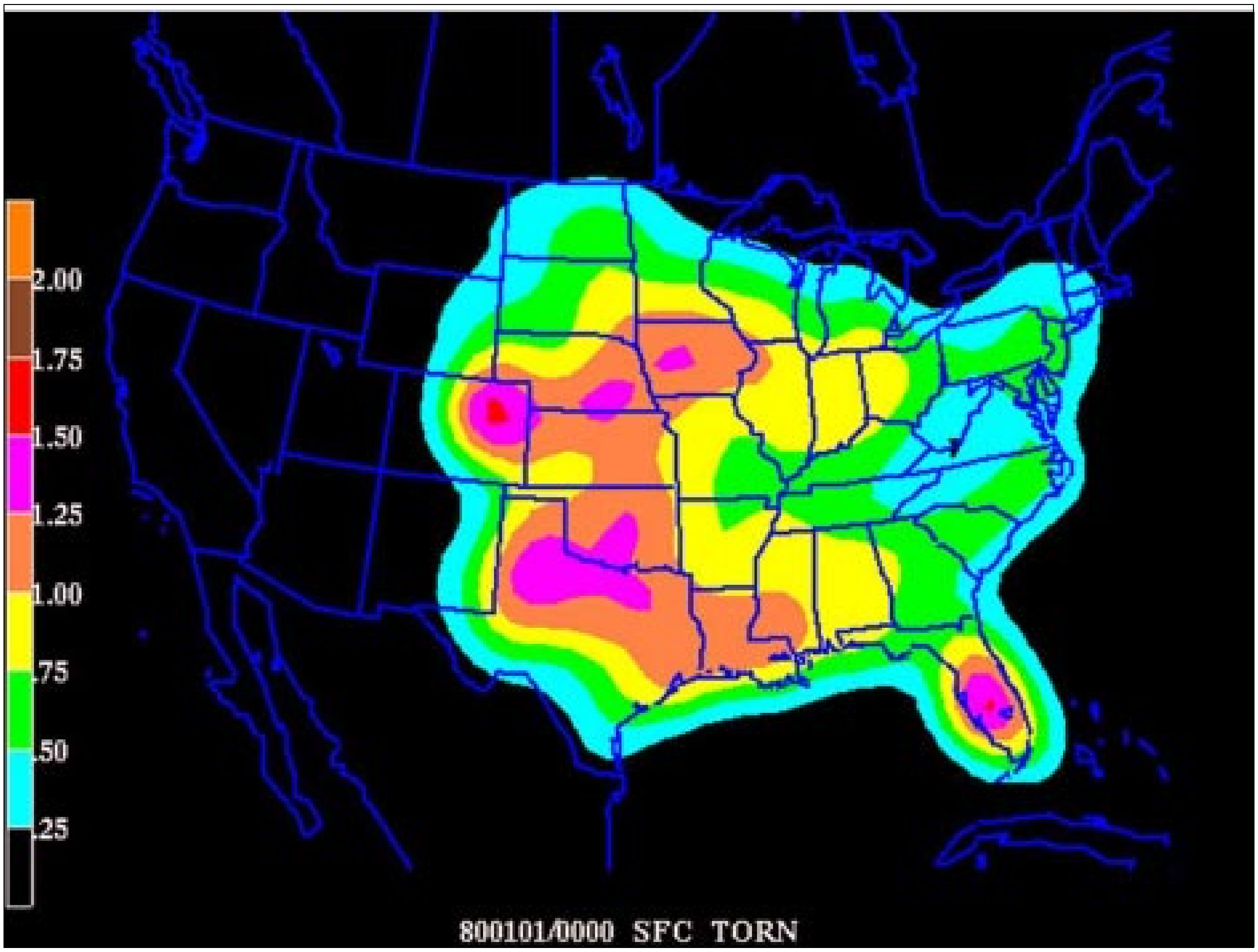


FIGURE 2-1: Annual probability of tornado occurrence in the continental United States.

If violent tornadoes correspond to the top 2 percent of all tornadoes, 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 are 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 the winds of the vortex of a violent tornado. 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 the estimates given here. However, the NSSL believes these numbers 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 wind:

1. Near the surface, close to the core or vortex of the tornado. In this region, the winds are complicated and include the peak low-level 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 core or 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 core circulation.

3. Above the surface, typically above the tops of most structures, the flow tends to become very nearly circular.

In an actual tornado, the diameter of the core or vortex circulation can change with time, so it is impossible to say precisely where one region of the tornado's 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 core 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 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. 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 reflects this situation.

In a violent tornado, the most severe damage occurs in the area directly affected by the vortex (the area shaded dark red [dark gray] 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 [medium gray] 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 roof, 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 [light gray], damage is again primarily to roofs 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.

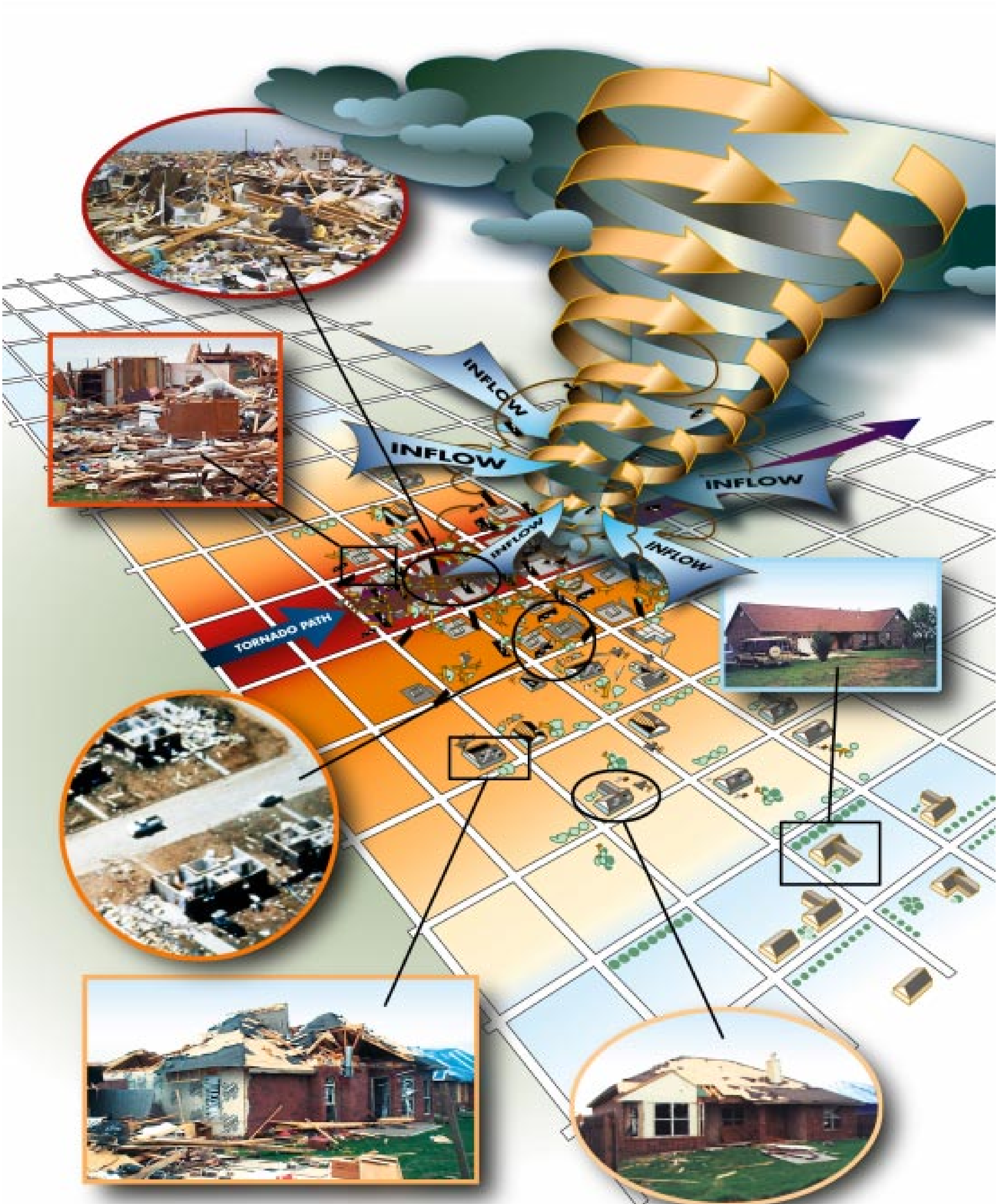


Figure 2-2: Impact of a

Impact of a Violent 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.

violent tornado.

2.3 BACKGROUND OF THE EVENT

On May 3, 1999, a widespread outbreak of tornadoes occurred in the south central United States, primarily in Oklahoma and Kansas. A strong upper-level storm system moved eastward towards 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 Oceanic and Atmospheric Administration's (NOAA’s) “Service Assessment” for details of forecasting performance in this event. 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 preliminary count of tornadoes that occurred in this outbreak is 67, but this number may change during the analysis of all the data, which will take many months. Within this outbreak, there were four violent (F4 or F5) tornadoes according to preliminary surveys performed by the NWS. Figure 2-4 shows the outbreaks in Oklahoma; Figure 2-7 shows the outbreaks in Kansas.

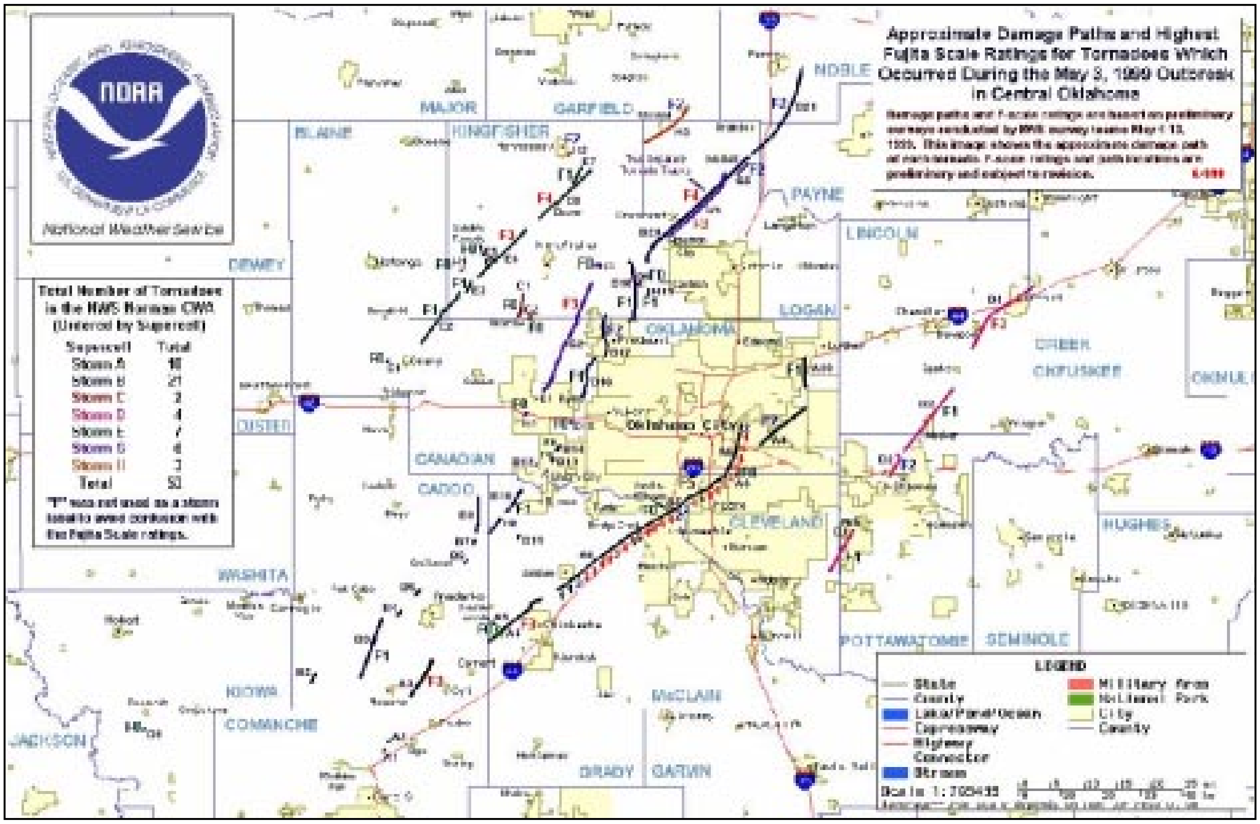


FIGURE 2-4: Preliminary outbreak map of tornadoes in Oklahoma that struck on May 3, 1999. Courtesy of the National Weather Service.

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 (Fig. 2-5). This tornado had a track 38 miles long and lasted more than an hour, from 6:23 to 7:50 p.m. The track began between the towns of Chickasha and Amber, Oklahoma, southwest of Oklahoma City.

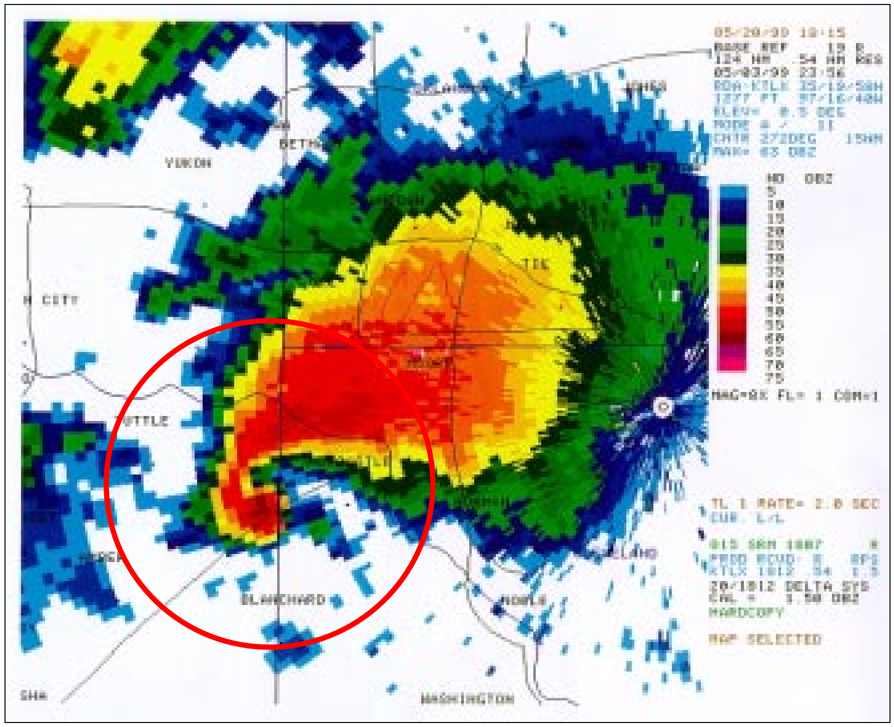


FIGURE 2-5: Radar reflectivity map at 6:56 p.m., showing hook echo (circled). A hook echo is a structure associated with supercell storms. In many instances, the radar echo shows this type of structure when tornadoes are present. Courtesy of the National Severe Storms Laboratory.

From its touchdown point, the tornado moved northeastward, nearly parallel to I-44, towards Oklahoma City, hitting the rural 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.

Preliminary analyses by the NWS in Norman, Oklahoma, indicated that this single tornado damaged or destroyed more than 8,000 homes, and was responsible for 41 fatalities and approximately 800 injuries. Early damage estimates are 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.

Figure 2-6 presents four WSR-88D images of the reported F5 tornado as it tracked from Moore to Midwest City. Figures 2-6a and 2-6b are actual radar cross-sections of the tornado taken at the location identified by the white line in Figure 2-6c. Figure 2-6a represents reflectivity, while Figure 2-5b represents storm-relative radial velocity. 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 eye are delineated by different color patterns that relate to debris in the vortex and the wind speeds within the vortex itself.

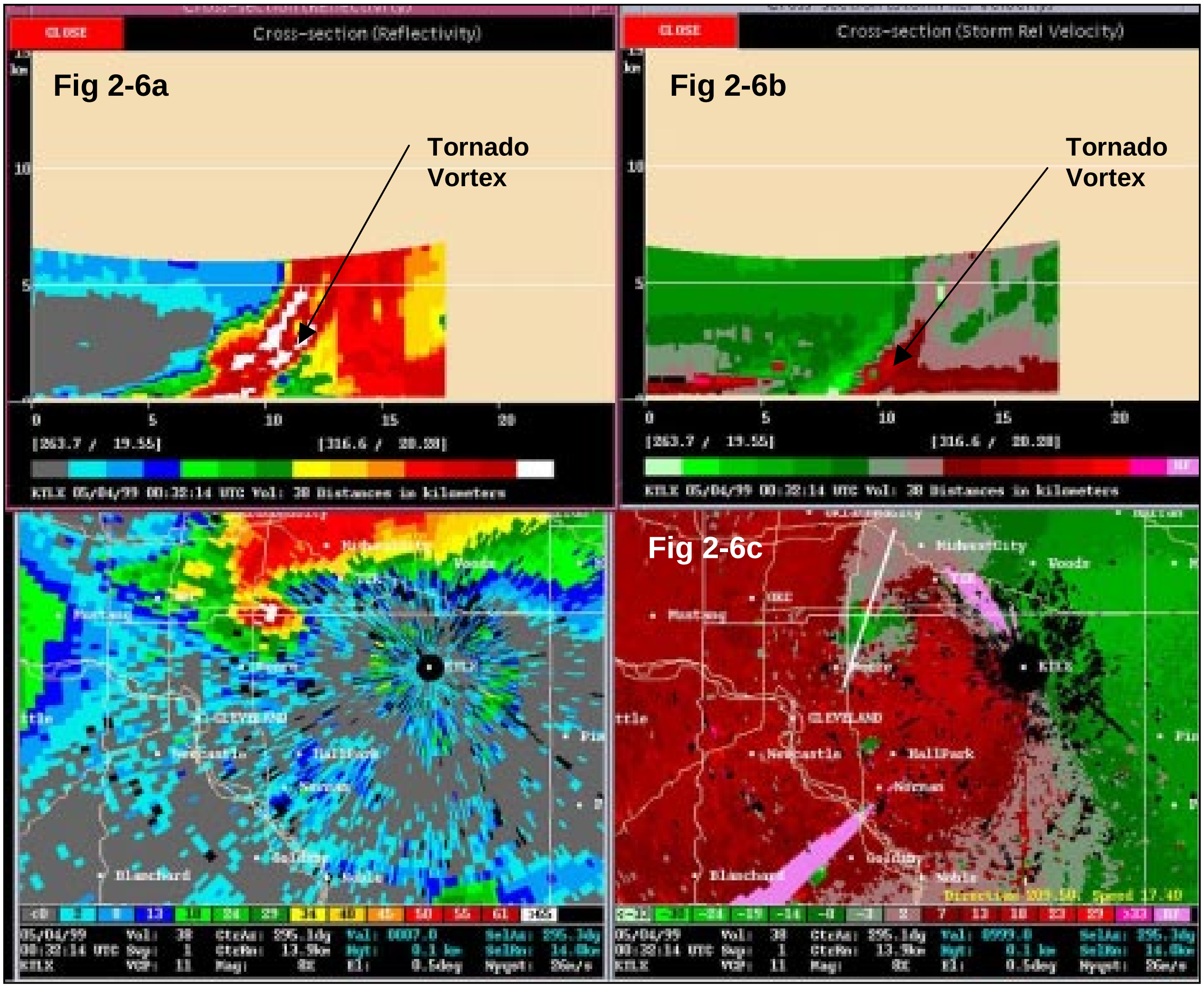


Figure 2-6: WSR-88D radar cross-section through the reported F5 tornado located approximately halfway between Moore and Midwest City, showing the debris and an apparent "eye."

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 public 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 two fatalities; one fatality in both Logan and Payne Counties.

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. The 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 (Fig. 2-7) and was responsible for 5 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, which hit the Golden Spur Manufactured Home Park in Andover, Kansas. The 1991 tornado produced 5 fatalities, more than 100 serious injuries, and $140 million in damage, according to preliminary estimates by the NWS in Wichita, Kansas.

Among the less violent tornadoes of May 3, were five, including a moderate F3 tornado, that struck near the town of Stroud, Oklahoma, around 10:40 p.m. There were no fatalities, but a regional outlet mall along I-44 in Stroud was destroyed, and the roof covering on a hospital in the town was blown off.

A moderate tornado entered 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. There were no fatalities, but the Carbondale Assembly of God Church, on the north side of I-44, suffered significant structural damage.

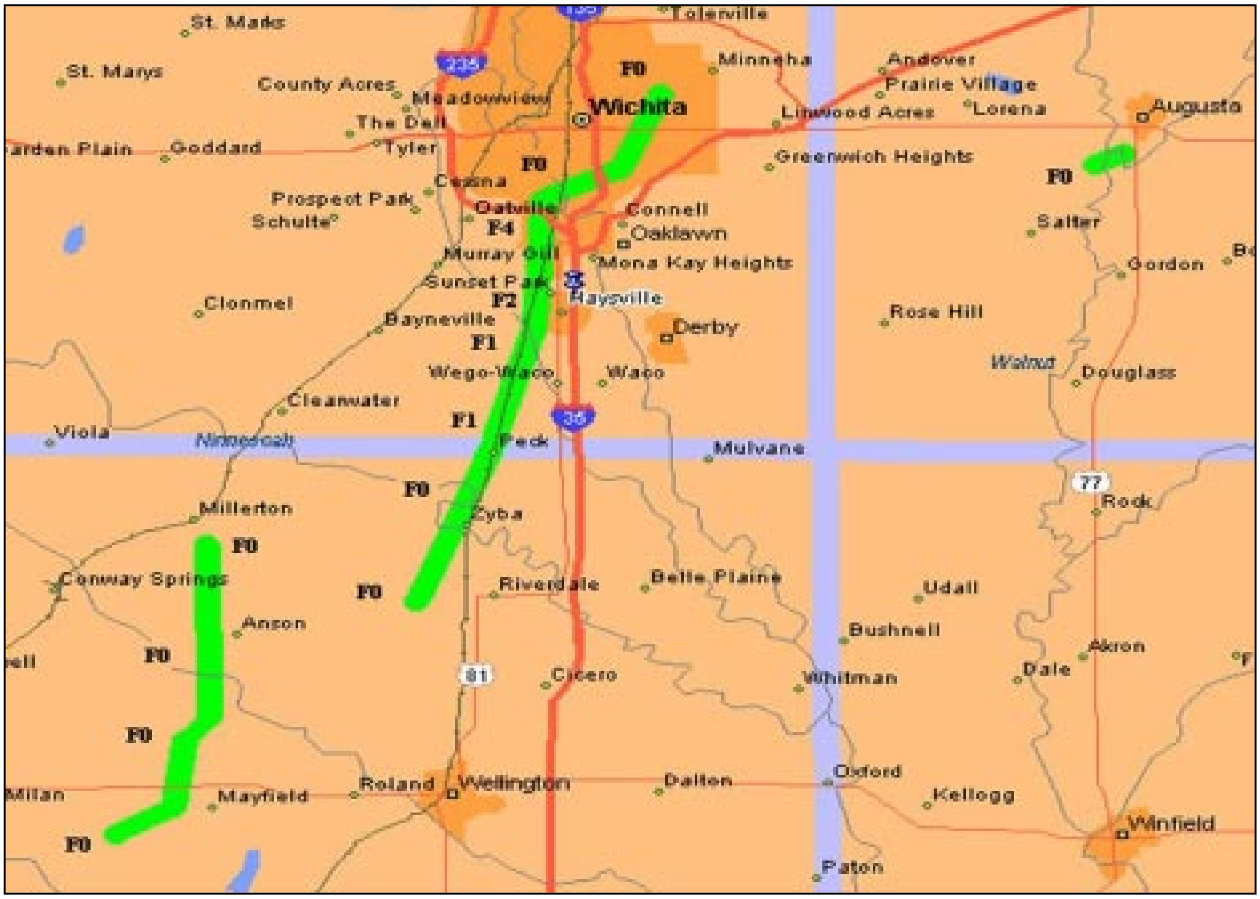


FIGURE 2-7: Map of tornadoes in Kansas that struck on May 3, 1999. Courtesy of the National Oceanic and Atmospheric Administration.