

Destruction mechanism of Oklahoma Tornadoes in 1999

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ABSTRACT

On the trace of a devastated zone by a tornado we often catch a strange sight that a heavily damaged house is adjacent to a sound house and a partial half of a roof is lost leaving the last half perfect. Also tales on persons who were flying through the air and softly landed 100 yards away are heard about. These phenomena are hard to be understood without the small but strong vortexes which exist in a large rotational stream in diameter of the funnel cloud.

In the evening of May 3 in 1999, Oklahoma State was attacked by 62 tornadoes killing 42 people. Articles from the newspapers and the video tapes from the television stations were analyzed and arranged in time sequence. A scene of falling thick debris in the KFOR-TV video aided in associating a surface friction model that consists of many child vortexes with axis slanted to the current direction in the parent vortex. This flow system brings destructive power in the right side of the proceeding direction with two actions; one is stretch of the child vortexes and the other the concentrated down draft. If this idea is applied to the disaster by the tornado running 24 miles from Bridge Creek to Midwest City, there can be found a general tendency that the fierce action of small vortexes was more remarkable in the earlier stage and the gusty downdraft was developed in the later stage.

A downburst disaster was identified at Stroud 40 miles apart from the main tornado site.

1. PREFACE

Oklahoma is known as one of the states hit by a great number of tornadoes in the U.S. The group of tornadoes, generated in the evening of May 3, 1999, was a large-scale one covering 21 out of 77 counties in the state, including massive tornadoes. Though the exact number is unknown, NWS (National Weather Service) counted 62 tornadoes, which were generated from a dozen supercells. These tornadoes killed 42 people, completely destroyed 3,016 homes, and damaged totally 12,000 buildings including partly damaged homes, apartment houses and public buildings in the state. They say that this is a disaster that might occur once in half a century even in Oklahoma.

Since the damaged area of this large-scale disaster is too vast to investigate, we tried to describe the phenomena of the winds near the ground judged by the damages on the ground, mostly focusing on the main tornado. With the articles from newspapers, TV news programs, and the web site www.oklahoman.com arranged in time-series, we tried to study the cause and effect of the phenomena on the ground. From June 1 through 4, almost a month after the disaster, we visited the devastated area from Bridge Creek to Midwest City, which covered most of the path the main tornado went through, and then Tanger Outlet mall in Stroud.

2. WEATHER CONDITIONS BEFORE THE OUTBREAK

At least 10 tornado warnings were issued in the north-central part of Oklahoma in the morning of May 3, 1999, and 44 out of 77 counties were under a tornado watch by 4:00 p.m. NWS's regular upper observation evaluated that the risk seemed to be decreased at 11:15 a.m., but the situation became serious afterwards. According to Dennis McCarthy, a NWS forecaster, a dry air mass spread from north to south at the border near Childress, Texas. In the east existed warm moist air up from the Gulf of Mexico riding on south-southeasterly winds, intersecting the dry line. The dry air mass sucked the moist air, creating a trigger for thunderstorms. At midday, NWS released an extra weather balloon. Over 3,000 feet, winds shifted from southeast to due south and increased from 20 mph to 40 mph. At 10,000 feet, winds shifted to southwest and dropped to 35 mph. At 20,000 feet, winds shifted further to the west, increasing to 50 mph. Jet stream over 20,000 feet from southwest helped to create a powerful lifting and circulation of the winds below. As soon as the dry line hit the thunderstorm line, unstable lifting occurred, which produced supercells and powerful thunderclouds with strong updrafts at stunning speed. This is the typical condition for a tornado outbreak. At 3:49 p. m., NWS upgraded the risk evaluation again to high, and at 4:45 p.m. a tor-

planes inside the hangars were turned upside down. Wustrek's home, 100 yards south of the airport, was safe except that the roof of his pool was pulled up. A crop-spraying service building along US81 was broken and a trailer park was damaged. The Wustrek family felt as if a shell attacked them, but they were safe.

A characteristic of the tornadoes around here is that they were generated from a single super-cell and disappeared in so many places and so repeatedly that they were uncountable. This characteristic can be applied to the later cases.

4. THE MAIN TORNADO

4.1 Grady County

At 6:26 p.m., a tornado was found crossing US92 which runs from Amber to the south (Fig.1). If we suppose this tornado was the one that damaged the airport, it is calculated that it moved six miles in seven minutes, or over 50 mph, which is too fast to be true, so it is inferred that they were not the same tornado but were in the same group because a part of the wing of an airplane and documents blown away from the airport reached South Oklahoma City 30 miles away. At 6:37 p.m. CH4's helicopter saw a tornado moving parallel to I-44, and at 6:43 p.m., CH9's helicopter pilot saw it was going due east of Amber to the northeast. The tornado moved six miles in this 17 minutes, or 20 mph. Ed Tilman in Amber saw three small tornadoes were wrapped by one big tornado in the east. The relationship between them and the main tornado is unknown. A tornado was also reported at 6:40 p.m. in Middleburg, eight miles to the east-southeast, but this is clearly a different one. A tornado was reported also at 6:51 around the place where the main tornado crossed I-44 later. The main tornado is supposed to have been three miles before Bridge Creek at that moment.

After crossing E1280th Road east of Amber, the speed of the tornado increased, became almost 50 mph and attacked the mobile home community in Bridge Creek at around 6:57 p.m. Fig.2, a run-time curve of the main tornado after crossing US92 south of Amber, clearly shows the acceleration. When stretched, a vortex tends to stick to the ground more strongly. The radius of revolution becomes shorter, the atmospheric pressure at the center drops, and the revolving speed increases to gain centrifugal force to balance with the low pressure. An aerial photograph taken the following day shows the bare ground from which grass was torn off. This phenomenon is not yet clarified, but we can imagine that the same thing may happen when we vacuum grass with a powerful vacuum cleaner, which reminds us of Fujita's (1971) suction vortex. All that we could see there on July 2 was the wreckage of a small factory and what seemed to have been trailer houses scattered far away, and it was unbelievable that 235 houses were destroyed and 11 people died. The important point is that the helicopter pilots of CH4 and CH9, consistently following the main tornado, could not catch the scene of the devastation. Though it was quite natural that they could not go close to the dangerous tornado, they must have been south-southeast of the tornado across I-44 at that moment. Therefore it may be inferred that a tornado cannot be seen in case of heavy touch down. What we can see of a funnel cloud is only the part where water vapor becomes drops by the decrease of atmospheric pressure at the center of the tornado.

When the whole tornado becomes like a cloud, you cannot recognize its shape.

Let us consider one of the news reports that relates to physical phenomenon of a strong wind. When the tornado came above him and blew away one mobile home and another just a few yards away from him, Wesley Early could do nothing but grab a crosstie and rush into the ditch. A few seconds later, 30 tons of gravel, having been put down on the premise last year, flew around and scratched his back. Desperately keeping his eyes closed with the debris hitting him, he was lifted in the air, not breathing landed 100 yards away from the original place. He returned in a hurry and helped Mrs. Vandiver, who was dragged from her home and was injured in her legs and head.

Regarding the expression "gravel flew around," the mechanism of this phenomenon is as follows: a small vortex of a few yards in radius, not so long as half a mile, is generated. It is tremendously powerful and produces a strong flow especially just above the ground, and the negative pressure at the core absorbs a human body and lifts it up. When the vortex is gradually scattered and the absorbing power decreases, it slowly releases the body down to the ground. This phenomenon is not extraordinary. One of us has met two cases – Keiko Yoshino and her mother in Mobara, Japan in 1990 and Abdu Joli in Gopalpur, Bangladesh in 1996 – and this is the third case. In three cases, all of them fainted, and we are not sure whether this is because of a sudden drop of atmospheric pressure or terror.

Ridge Crest Baptist Church at Bridge Creek was partly destroyed after 60 children had left, and a brand-new car climbed the altar. Through the window of his house that was safe, Pastor Duckett saw houses were blown up. If this was also caused by a vortex, it leads to the conclusion that a larger vortex than the one that lifts a person exists. It is a well-known fact that a large vortex is divided into many small ones as it disappears. As long as the heating mechanism works that keeps the strong updraft blowing high in the sky, various sizes of vortices can exist at the same time. We cannot tell, however, whether the vortices exist from the beginning or they are generated around objects in the air.

The zigzagging center of the tornado crossed I-44 at around 7:09 p.m. At just 7:00 p.m., when it almost reached I-44, 40 houses were broken, a farm damaged and scores of livestock injured at northwest Newcastle, which was next to I-44 to the east. We can

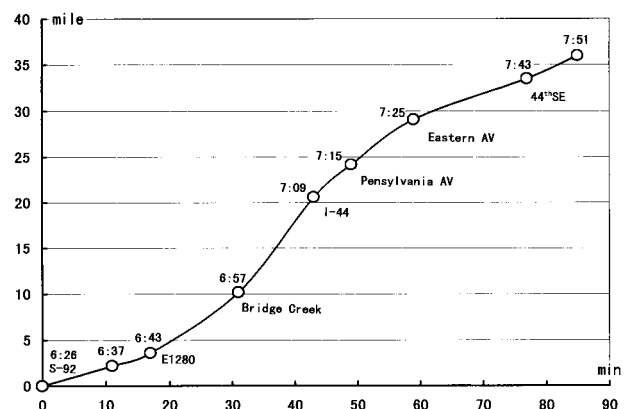


Fig. 2 Run-time diagram of fiercest tornado

not tell whether these damages are caused by the same main tornado or not. At the same time, a woman driving a sports car, who failed to take shelter beneath the overpass because there were too many other cars, was sucked up in the air and miserably killed. Perhaps at another overpass, a mother was also killed, after asking a man from the same town to look after her 11-year-old son.

4.2 Cleveland County

After crossing I-44, the tornado went northeast with its power decreasing, but regained its power again just before reaching Pennsylvania Avenue in South Oklahoma City at 7:15 (Fig.3). It attacked Country Place Estates, south of SW134 Street, and destroyed 60 houses and killed some people. After passing a small forest, tearing off the roof of Eastlake Elementary School and damaging Eastlake residential area to the north, it went almost straight to the east 30 degrees north at 20mph, passing a similar residential area and a prairie, completely destroyed all the houses within the area of 100 yards wide except the prairie out, and reached a golf course in the northeast of City of Moore (Fig.3 and Photo.1).

When the tornado was still around I-35, CH9's helicopter arrived above the Eastlake residential area and took a close-up picture of the destruction (Photo.2). The picture shows almost no projecting things within about 50 yards at the center of 100-yards-wide area. If this is the radius of the vortex core, it is smaller than half a mile vortex in diameter, which will be considered later.

At 5:30 p.m., over 400 people were at Westmoore High School before Western Avenue for a graduation ceremony. The

center of the tornado that brushed the southeast corner greatly damaged the roof and windows of the school building, but injured no people. When it reached Moore, the revolving flow became the strongest in this area, passing SW119 Street before Santa Fe Avenue to the north, and houses on the south side of SW119 were carried away leaving only the concrete slab. It crossed Santa Fe Avenue, and just before Jane Way near Crouch Corner, a family who took refuge in the bathtub was taken away with it. A 14-year-old boy and his parents were carried a few yards away to different directions. The boy and his father were injured and the mother was killed. After completely destroying Kelley Elementary School, the tornado reached the point where I-35 branches off to Shield Blvd (Photo.3). A family was going to take shelter under the overpass, and while the father paid attention to his two children, the mother was carried away and was killed.

After crossing I-35, the tornado attacked Highland District. Photo. 3 shows that a typical revolving flows with unstable wind direction damaged this area; cars were carried one block away. At this time, CH4's car reached the crossing of I-35 and SE89 Street (Fig.3), and videotaped the scene in the south. Photo. 4, taken from the videotape, shows the debris falling thick. Where was the debris sucked up into the air? Judging from the thickness of the debris, it seems that we can exclude distant places such as West Moore and the circumference of the main vortex's core. It seems natural that objects around Kelly Elementary School were torn off by small vortexes, flown into the circulating main vortex, carried from the east to the north, and fell between the water tower and

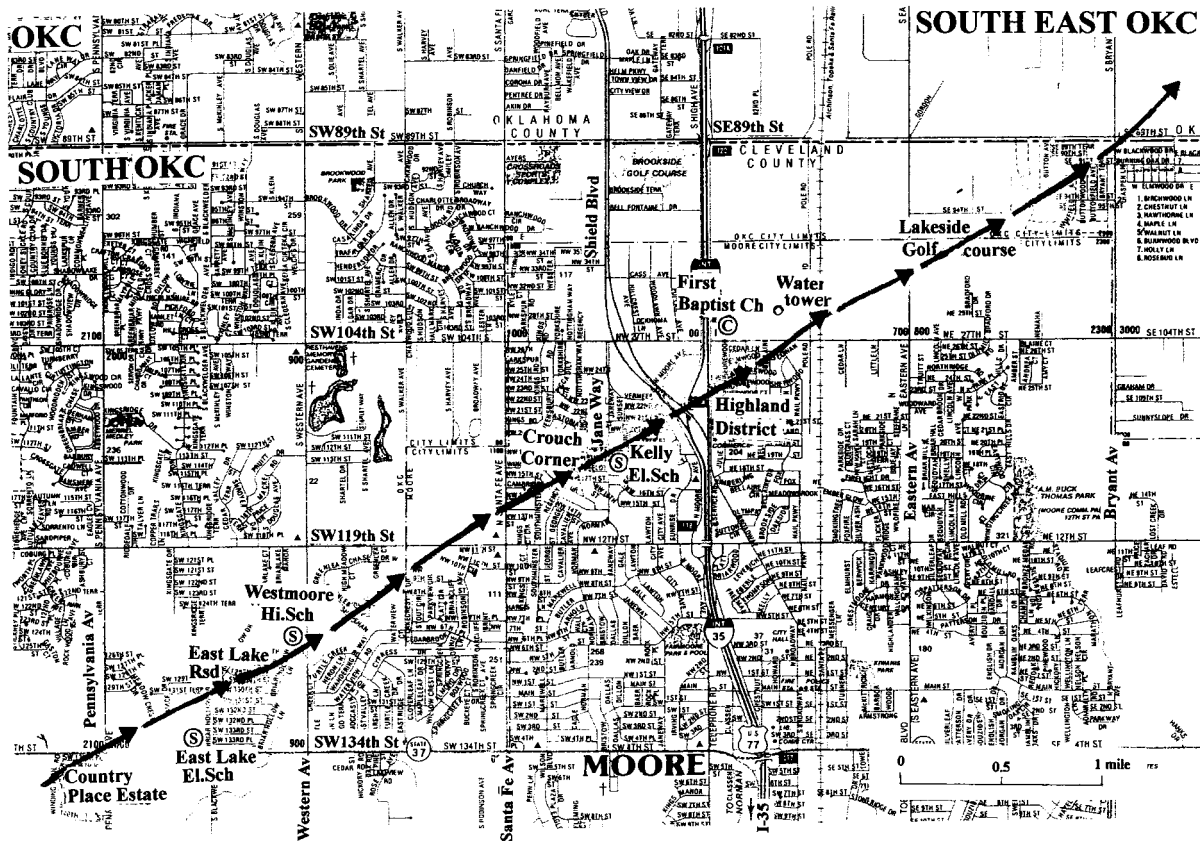


Fig. 3 Tornado path through Cleveland County



Photo. 1 Tornado trail from Pennsylvania Avenue to Midwest City via South Oklahoma, Moore, Southeast Oklahoma and Del Cities (from Dairy Oklahoman May 8 1999)



Photo. 2 Disaster of Eastlake Residential Area, seen also in Photo. 1, (from broadcast by KWTU)



Photo. 3 Disaster in Moore, tornado coming from top to left side bottom (Photo by Roger Bondy, from The Norman Transcript May 6 1999)



Photo. 4 Falling thick debris between Moore water tower and SE89th (from video by KFOR-TV)

SE89th Street, which is far away from the course of the main vortex.

Although a detailed structure of the tornadic vortex standing still on the ground was investigated by Rotunno (1984), we placed focus on the ground surface friction of a counterclockwise rotating cylindrical air mass in which the full system of the vortexes was built. When the cylinder imitated by the parent vortex horizontally moves keeping its shape, the rotational axis deviates toward right side of the line the cylinder goes on, because the frictional stress becomes stronger at the right side and weaker at the left. Therefore, the flow is faster at the narrow right side of the axis, and slower at the wide left side. Let us consider a small vortex at the bottom of the side surface of cylinder, with its top slanted along the direction of cylinder rotation (Fig. 4). If the velocity increments induced by the child vortex with the same rotational component as the cylinder is u' in the rotational direction and w' in the upward direction, $u' > 0$, $w' < 0$ outside and $u' < 0$, $w' > 0$ inside the cylinder, and the Reynolds stress $\rho \overline{u'w'} < 0$ (ρ : air density) acts as the friction.

If a lot of such child vortexes are around the parent vortex, the child vortex density becomes thicker in the right side of the proceeding direction where the friction is stronger, and thinner in the left side. Also, the child vortexes usually adhere behind the protuberances on the ground and sustain the frictional force of the rotational motion of the parent vortex. When these vortexes cling around the parent vortex and stretched by the parent vortex flow, the angular momentum of the child vortexes is conserved, speeding up the rotation and lowering the pressure at the child vortex's center. The flow falls from the rear to the right side to compensate the momentum consumed by friction, and the flow rises from the right to the front side. A child vortex often sucks up, conveys everything and releases it when the friction decays. This idea can be applied to the cases in Bridge Creek and Eastlake residential area (Photo.2), and describes the damage in Del City and Midwest City, which is mentioned later.

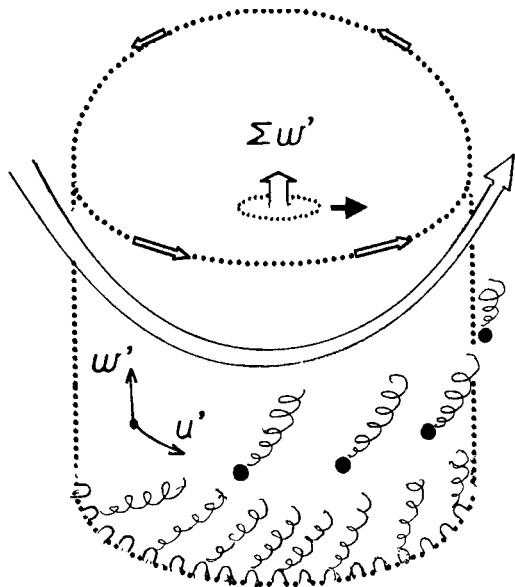


Fig. 4 Systematic flow pattern in right side of tornado-rotational stream

The tornado went straight over the prairie, missing First Baptist Church, which was used as a relief center later, and the water tower at its northeast corner by 300 yards to the left. Then it destructed facilities in Lakeside Golf Course, and reached Southeast Oklahoma City from Moore.

4.3 Oklahoma County

Entering Southeast Oklahoma City, the tornado gradually turned to the left, damaged a group of apartments, and crossed the county border at SE89th and Sunnylane Rd. Then the tornado reached the residential area in the northern part of Southeast Oklahoma City, slanted the southeast edge of Del City across SE44th Street and brushed the northwest edge of Tinker Air Force Base along Sooner Road, reaching Midwest City. Then the tornado went almost due north, entered the center of the city across I-40, went through the residential area in the north, and the damage ended before Reno Avenue just before 8:00 p.m. (Fig. 5).

As far as we look at the distribution map of damaged areas made by the computer team of Oklahoma City (The Sunday Oklahoman May 9 1999), there seems to be nothing strange about the damage. Since this shows only the final condition of the tornado, let us check in detail. First, in Del City, the tornado killed several people, and Oakbrook Drive, just north of SE44th Street, was the center of the damage. CH4's helicopter reported the destruction next day (Photo.5). Seeing carefully, we notice a slight difference from Eastlake (Photo.2). The tornado completely destroyed homes 100 yards wide in both areas, but in Del City there remained many projecting things and little debris could be seen on

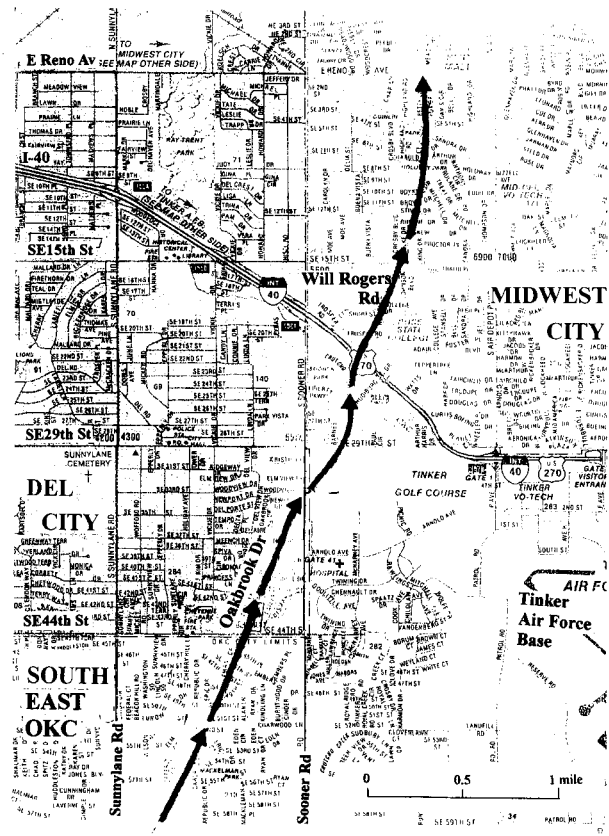


Fig. 5 Tornado path through Oklahoma county



Photo.5 Disaster of Oakbrook Dr., tornado coming from top to bottom , compared with Photo.2 (from video KFOR-TV, not Midwest City but Del City)



Photo.6 Disaster of Arkadelphia in Arkansas, strong wind blowing from WSW (from Shifting Herald March 6 1997)

the roads. Therefore it is thought that small vortexes hardly caused the destruction and winds that blew almost straight were the main factor of the destruction. What matters here is whether a parent vortex causes downward wind without a hard child vortex. The uplifting flow at the parent vortex center in Fig.4 is also the driving power of the tornado rotating system on the ground. If the up-drift is slow, it is inferred that the parent vortex itself became too weak

to give energy to the child vortexes.

The tornado crossed Sooner Road, broke a part of the lodging in Tinker Air Force Base, went through the field and wood of about 800 yards in the southwest corner of Midwest City and attacked a small town along I-40 that runs northwest to southeast. Mike Penderson, a Cracker Barrel employee, helped about 30 people into the restaurant's back kitchen and then went to the front to

look at the tornado. Facing southward, he saw a massive debris wall coming to the restaurant. He went in and told the people to get down. 15 seconds later he felt his ears “pop”. Then silence came and as he looked around the only thing that had survived was the kitchen. Though a rental truck was blown into the dining room, no one was injured. This is a little different from the Moore case, in which they heard in the shelter first the sound of the hitting debris and then a sound as if a train were passing; after those sounds they noticed that nothing remained around them. The fall of a cold air mass might cause the destruction of the restaurant.

The tornado slightly attacked the market on 15th Street and came to Will Rogers Rd. There it blew up the bathtub in which York and his two sons were and threw them out. This is similar to the Moore case. The debris of the destructed north residential area simply moved northward. This directional clearness is very similar to the disaster in Arkadelphia, Arkansas, on March 3, 1997 (Photo.6). Each case coincides with Fujita’s (1993) theory that the cause is the strong downward wind which appears in the right side of the line that a tornado goes on.

5. OTHER STRONG WINDS

5.1 The Tornadoes in Choctaw

As the Fig.6 shows, at 8:10 p.m. immediately after the main tornado disappeared, a new tornado was found at the center of Choctaw, which was nine miles east-northeast of the place where

the main tornado vanished. It went through to the northeast by three miles and disappeared at 8:15 p.m. The new tornado destroyed some 20 homes and stores, ripped off the roof of the library and soaked the books. It is easily inferred from the distance that it was generated from the same supercell as that of the main tornado.

5.2 The Tornado in Dover

At 9:20 p.m. a tornado attacked the town of Dover in King Fisher County, 40 miles north-northeast from Oklahoma City, which damaged one-third of the town from southwest to west and northwest, leaving 17 homes completely destroyed. A woman was crushed to death under the walls fallen from two sides in her bedroom of a single-storied brick house.

5.3 The Tornado in Crescent and Mulhall

This tornado was first found at 9:29 p.m., four miles southwest from Cimarron City in southwest Logan County. At around 9:50 p.m., it attacked a village a little away from the center of Crescent and destroyed 25 homes. It caused some incidents that equal those of Bridge Creek: Patrick Fuller’s mobile home completely disappeared; Paul Keispart was sucked out of his house into the air and landed 100 yards away, which is the fourth example of soft landing. Then, going to the northeast, the tornado attacked the little town of Mulhall, in the northeast of Logan County, shortly after 10:00 p.m. It destroyed 80 out of 115 buildings, the school,

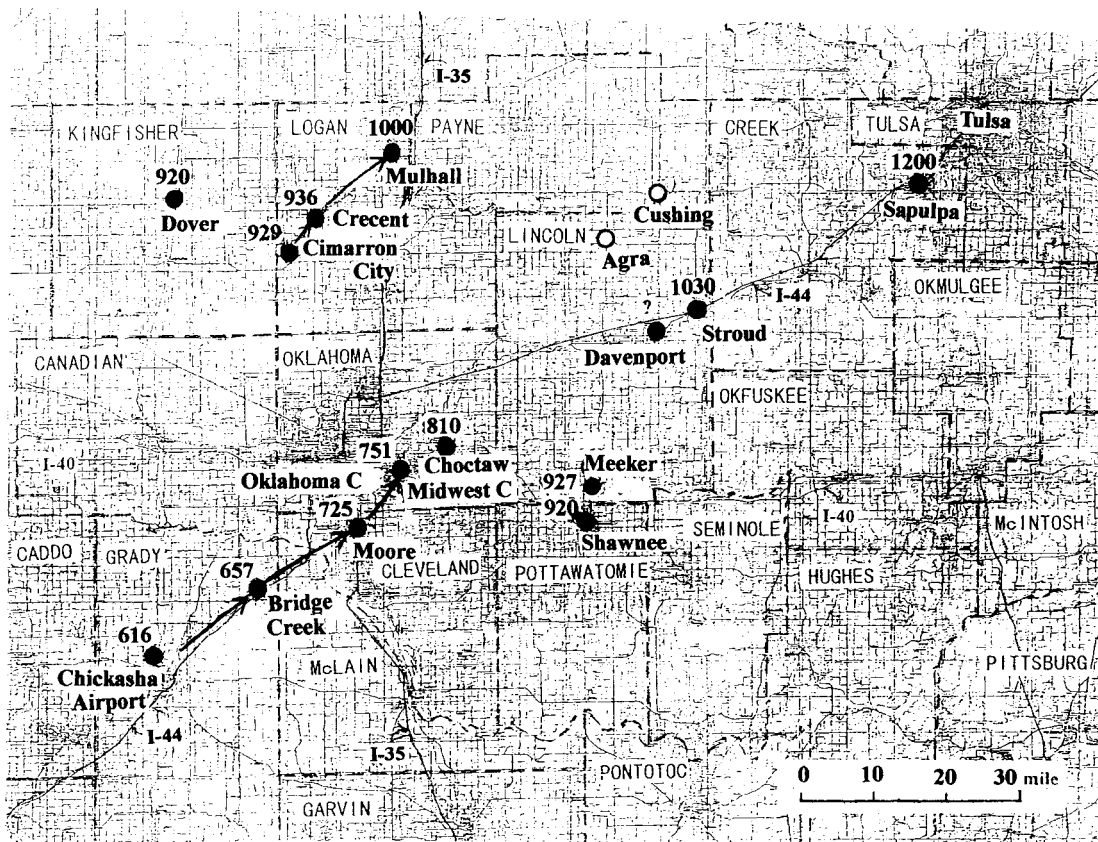


Fig. 6 Disaster sites by strong winds in Oklahoma State



Photo. 7 Disaster of Tanger Outlet Mall in Stroud (from broadcast by KWTV)



Photo. 8 Microburst disaster near Little Rock Airport in Arkansas, March 1997

three churches and a silo—everything on its way. This tornado is also considered to have come from the south of Caddo County, not so far from where the main tornado came. One went to the northeast a little to the east and the other a little to the north. It was second only to the main tornado in power. Quite coincidentally, another tornado took almost the same course an hour later.

5.4 The Downburst in Stroud

The characteristic of the articles of the damage in Stroud, 44 miles east-northeast of Midwest City is that there is no description of how the people escaped. The closest tornado was reportedly generated at 9:27 p.m. at four miles southwest of Meeker, which is another 23 miles southwest of Stroud. So the people might feel secure. But the sudden strong wind shortly after 10:30 p.m. that shut off the electricity surprised them. Fortunately no one was injured as the strong wind missed the center of the city. Though a

hospital, a storehouse and some homes were destroyed, the most damaged was Tanger Outlet Mall. This shopping mall occupies 200,000ft² at the north of the west exit of I-44, which runs east to west along the north side of the town. In that vast lot the one-storied market that is one mile long is placed like the letter U (Photo.7), its open side facing I-44 and the center space being the parking area. The downburst brushed by the road from the southwest and blew out the west wing to the parking lot and the other part of building outward, their exterior and interior together. A glimpse of the destruction was enough to convince us that it resulted from a different type of downdraft from that of Midwest City, which was gradually ending. We have ever seen the same type as this in the suburb near Little Rock Airport in 1997 (Photo. 8). But we do not have a definite explanation of where the falling cool air perhaps with momentum of a jet stream comes from. The nearest tornadoes were in Shawnee or Meeker, but we cannot exclude the

possibility of the downburst coming from the main tornado. There are two evidences: first of all, 10 miles north-northwest from Stroud is Cushing, and photographs and other things blown up from Moore and South Oklahoma were scattered from Cushing southward to Agra (Fig.6); secondly, a tornado was generated at midnight in Sapulpa, 35 miles away on I-44 from Stroud toward Tulsa. Moore, Stroud and Sapulpa are almost in a straight line and we have seen in some past large tornadoes the cycle of ascending and descending currents—such as ascending in Moore, descending in Davenport-Stroud and ascending again in Sapulpa.

6. CONCLUDING REMARKS

It was fortunate that the dead were only 42, considering the power of the tornadoes. It is still difficult to predict exactly where and when a tornado breaks out. But the NEXRAD system enables us to observe the movement of a thundercloud in real time and to broadcast the result at once. Without this system more people might have died. Live broadcasting on TV from helicopters, though it is rather dangerous because we cannot know when a tornado breaks out near the helicopter, can attract the attention of people. In considering security against tornadoes, examination after disaster is important. NOAA's research on the courses of the tornadoes has Fujita scales calculated by NWS. The Fujita scale is inferred from the degree of the destruction and converted into wind speed for objectivity. This wind speed, however, is different from the one used in a wind tunnel because small but strong vortices involved in the large vortex of a tornado speeds up the current. When we actually see destruction sites, it is often impossible even to decide the course of the flow. Clearly small vortices help the destruction. When some stronger flows extend them, their speed becomes unstable. We must understand the system of the destruction caused by them.

Another interesting fact of the tornadoes is that though the updraft which caused super-cells was observed only on the border

of Texas, the courses of the tornadoes were divided into the north-west ones and the southeast ones from the center of Oklahoma City, where skyscrapers are. It is impossible to know the relationship between the courses and the surface roughness of the ground or the heat radiation. But the measurement of the surface roughness itself is not so difficult. While tracing the course of the helicopter by GPS, the laser shot vertically downward tells us the distance. Considering the condition of landing for a vortex that has the vertical axis, it is natural to think the effect of the surface roughness is not small.

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