6.5 DAMAGE SURVEY AND RADAR ANALYSIS OF THE FORT WORTH AND ARLINGTON, TX TORNADOES ON 28 MARCH 2000

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1. INTRODUCTION

On 28 March 2000, a cluster of severe thunderstorms moved east-southeast through Fort Worth and Arlington, TX spawning two F3 tornadoes as rated on the Fujita scale. One tornado struck downtown Fort Worth causing extensive damage making it one of the most expensive F3 tornadoes on record. The following day, the authors conducted aerial and ground surveys of the tornado damage. Significant construction deficiencies were found in single-family dwellings that led to more severe damage. A consistent failure mode was identified within damaged houses. Homes that faced the wind suffered more severe damage than homes facing away from the wind due in part to failures of the attached garage doors. Also, most homes failed at the wall-to-floor or wall-to-foundation connections. Surviving structures helped provide an upper bound estimate on the tornado wind speeds, between 55 and 65 ms^{-1}. Radar analysis of this event revealed the mesocyclone of the Fort Worth storm first developed at mid levels of the storm then descended slowly. Rapid intensification of the mesocyclone occurred between volume scans making warning of this event difficult. In addition, complex storm interaction from merging cells and small-scale boundaries appeared to have played a role in tornadogenesis.

2. METEOROLOGICAL OVERVIEW

The weather situation on 28 March 2000 was classic for severe weather in north Texas. Surface low pressure was centered near Childress with a warm front extending eastward across the Red River and a dryline extending southward to the Rio Grande River (Fig. 1). Ample surface moisture was in place throughout the warm sector. Analysis of the 1200 UTC (coordinated universal time) sounding at Fort Worth (not shown) revealed a formidable capping inversion that extended up to 675 mb with a convective temperature of 35 ºC (95 ºF). With forecast high temperatures of only 27 ºC (80 ºF), surface heating alone could not break the

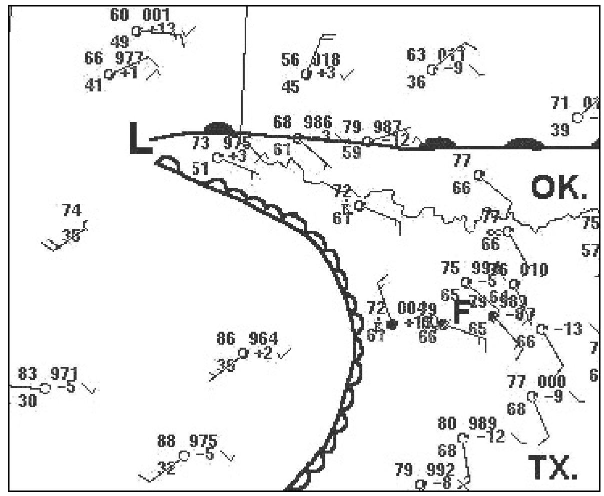

Figure 1. Surface weather map at 0000 UTC on 29 March 2000 for north Texas and Oklahoma. Temperatures and dewpoints are in degrees F. Dryline and warm fronts are indicated. "F" is Fort Worth.

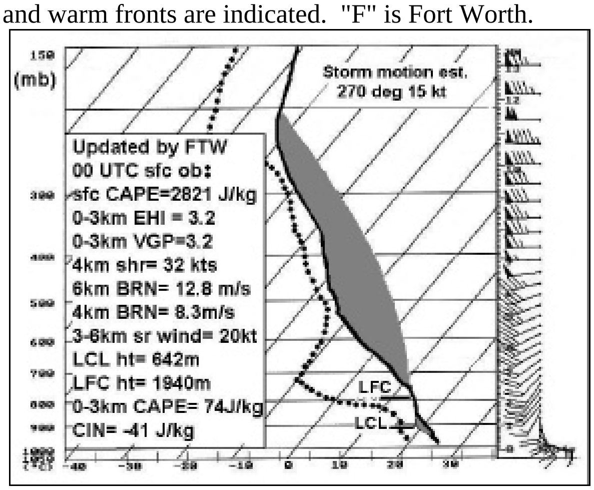

Figure 2. Fort Worth, Texas sounding at 0000 UTC on 29 March 2000 using RUC model data and surface observation. Lifting condensation level (LCL) and level of free convection (LFC) are indicated. CAPE is large shaded area.

cap. Upper air support was needed. The 0000 UTC sounding at Fort Worth was quite unstable (Fig. 2). The sounding showed easterly surface winds, sharp turning of the winds with height, and low LCL (lifting condensation level). Winds at 200 mb reached 50 ms^{-1}.

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The dominant feature aloft was a closed low centered over the Great Lakes. A ridge was in place over the central and southern plains and there was a trough over the intermountain west. Upper air maps showed a short-wave trough over the Texas panhandle at 0000 UTC. An arc of supercells stretched along the leading edge of this short wave all the south to Houston. It is believed this short wave played a crucial role in providing the necessary lift to overcome the capping inversion. In addition, the axis of the subtropical jet extended from El Paso to Houston. Strong southwesterly winds aloft helped ventilate the storms.

By mid-afternoon, storms began to develop along the dryline to the west of the Dallas-Fort Worth area and a tornado watch was issued for the area. Storms north and south of the city were isolated. However, a cluster of storms developed to the west of Fort Worth. At 2238 UTC (4:38 p.m.), the first severe thunderstorm warning was issued for Parker County, the county just west of Fort Worth.

3. RADAR ANALYSIS

The Fort Worth radar was located at Spinks airfield located 19 km south of downtown. Close proximity of the radar to the storm afforded high resolution in elevation scans. At 2330 UTC, a cluster of storms moved eastward from Parker County into Tarrant County (where Fort Worth is located). The leading cell exhibited a sharp reflectivity gradient on its south side and broad counterclockwise circulation at 18 k-ft AGL (above ground level). In the next volume scan, just five minutes later, a BWER (bounded weak echo region) developed at the same elevation. In addition, broad circulation of the mesocyclone had descended to 4.7 k-ft. At 2350 UTC, a hook echo was noted at 11 k-ft. Maximum reflectivities at 18 k-ft were positioned on top of the weak echo region. The mesocyclone circulation remained aloft and broad. At 0000 UTC, a hook echo was apparent at all levels, although the circulation in the mesocyclone remained broad. A wall cloud was visible at this time and baseball-size hail was falling in north Fort Worth along Interstate Highway 820. East surface winds also were blowing in front of the wall cloud. Based on the low-level convergence signature on this storm, a tornado warning was issued for Tarrant County. A TVS (tornado vortex signature) was not detected in the radar data at this time.

By 0005 UTC a small storm, identified herein as storm B, had moved rapidly northeastward out of Johnson County toward the Fort Worth storm. A small arc in the reflectivity extended from the north side of storm B and intersected the hook echo on the Fort Worth storm at the next volume scan. This resulted in the rapid extension of the hook echo at low-levels on the Fort Worth storm. The arc tilted back toward the Fort Worth storm in the lowest three elevation scans. The authors believe this arc was a boundary that either emanated from forward flank downdraft the Fort Worth or Storm B. Regardless, this boundary appeared to play a role in the intensification of the mesocyclone circulation (Figs. 3 and 4). The boundary was not identifiable on the radial velocity scans.

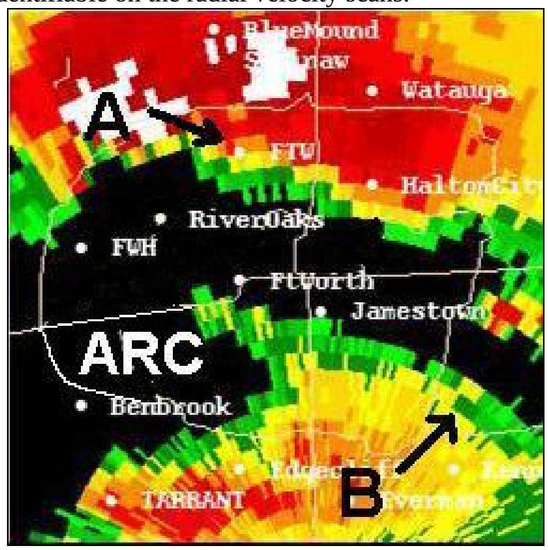

Figure 3. Radar reflectivity at 0005 UTC on 29 March 2000 showing Fort Worth storm (A) and smaller storm (B). Direction of each storm is indicated by arrows. Reflectivity "arc" indicates boundary. The center of the radar image is 8.6 k-ft AGL and is directly over downtown Fort Worth. Thin lines are interstates.

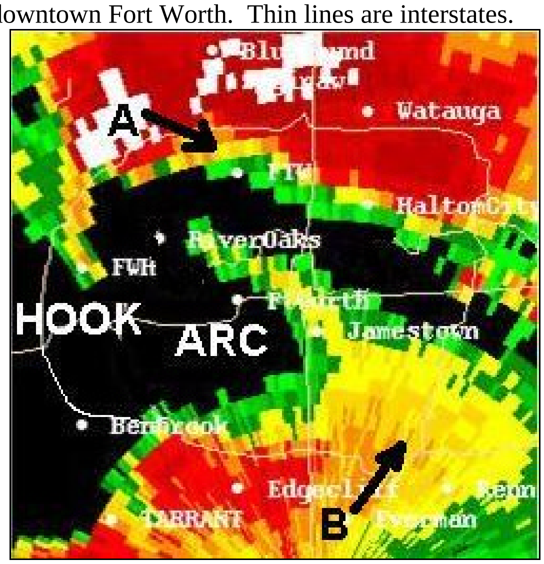

Figure 4. Same as figure 3 only at 3.8 k-ft at 0010 UTC, five minutes before the tornado.

At 0015 UTC, the first continuous dust whirls were observed on the ground beneath the wall cloud along Rt. 183 in northwest Fort Worth. Over the next five minutes, circulation at the ground intensified.

Occasional power flashes, tree, and roofing debris were observed within the circulation. A condensation funnel did not appear until five minutes after the dust whirls began. At 0020 UTC, the tornado began to move toward the downtown area where tall buildings contaminated the radar data by showing a spot of high reflectivity in the lowest elevation. A TVS (tornado vortex signature) was indicated at all levels at this time. At 0025 UTC, the tornado struck downtown Fort Worth. The first author was just north of downtown and encountered strong northeast winds at this time. A few minutes later, storm B merged with the Fort Worth storm, heavy rain ensued, and the tornado dissipated.

As the Fort Worth storm proceeded southeastward, another cell moved northeastward out of Johnson County and merged with its forward flank echo. By 0105 UTC, a large hook echo had formed on the back end of the Fort Worth storm along with a TVS. This was the beginning of the Arlington tornado.

4. DAMAGE SURVEY

The morning after the tornadoes, the National Weather Service in Fort Worth assembled a damage survey team that included the authors. Ground and aerial surveys were conducted of both tornadoes.

4.1 *Fort Worth, TX tornado*

The Fort Worth tornado damage path was 8 km long and up to 200 m wide. Damage was first observed on Rt. 183 in the River Oaks area with the removal of some metal roof panels on a vacant fast food building and shifting of rooftop air conditioner cabinets. The tornado then crossed Rt. 183 and entered an older residential neighborhood. Sporadic F0 damage was found to trees and outbuildings along Sam Calloway Road; the damage path was only a few hundred feet wide. A few masonry chimneys were toppled. The first indication of F1 damage involved partial removal of a roof near Roberts Cut Off Road. Some large, rotted trees were uprooted along Blackstone Road between Roberts Cut Off and Churchill Road.

The tornado continued southeast passing directly over Castleberry High School. The field house sustained considerable roof damage when an overhead door failed allowing wind to enter the building. Open web steel roof joists were not anchored to the tops of the masonry walls and thus, the roof was easily uplifted. Flying debris impacted the west side of the high school; the debris included roofing material, gravel, and some of the rooftop air conditioners. Fortunately, the tornado was relatively weak during this time and school was not in session. The tornado crossed the Trinity River and traveled up an embankment into another residential area comprised of high dollar homes. F1 damage was found in the area involving the partial removal of some roofs. Many large trees were toppled or lost big limbs. The tornado continued southeast along Monticello and Potomac Roads, still only a few hundred feet wide. When the tornado reached West Sixth Street, it made a sudden turn to the east and crossed busy University Road entering the Linwood residential area. Homes along Merrimac and Mercedes Roads were small, wood-framed structures on pier and beam foundations which easily broke apart in the 100 mph winds. Failure of these homes occurred where the wall plates were nailed through the floors. Overall, about 100 homes sustained F1 or greater damage.

The tornado continued east traveling over the Montgomery Wards distribution center. Numerous trucks overturned in the parking lot and one fell on and killed a worker. The distribution center sustained roof damage. The tornado then entered a light industrial area toppling several metal buildings before crossing the Trinity River again into downtown Fort Worth. A brick wall collapsed killing a second person. The first high rise struck was the nine-story, steel-framed, Cash America building. All windows on the southwest and northwest faces of the building were blown inward and the brittle travertine stone facade crumbled. Some people were still working in the building and dove for cover. Miraculously, no one was injured or killed by flying debris in the building. The building interior was heavily damaged but the steel-frame remained intact. Partition walls and the suspended ceilings had fallen.

Then, the tornado went right over the dome at the Calvary Baptist Church where portions of brick masonry around the dome collapsed. Brick masonry also was peeled from the five-story prayer tower on the southeast side of the church. Two parishioners were up in the prayer tower at the time of the tornado and somehow escaped injury despite tons of flying glass and stone debris. The tornado next struck the ten-story, glass-faced Mallick tower and lost most of its glass exterior. Although the tornado circulation weakened after striking the Mallick Tower, flying debris continued to break windows in nearby low-rise office and condominium buildings.

The circulation continued eastward striking the 35 story, glass faced Bank One Tower (Fig. 5). Most of the 3,000 windows shattered leaving the building open like a large doll house. Glass damage also was observed at the nearby Tandy Center and UPR Building due to flying debris. A third fatality occurred in north Fort Worth during the storm when a teenager was struck in the head by a baseball-size hailstone while trying to move his newly purchased car into the garage to avoid the hailstorm. The last U.S. hail fatality was recorded on July 30, 1979 in Fort Collins, CO.

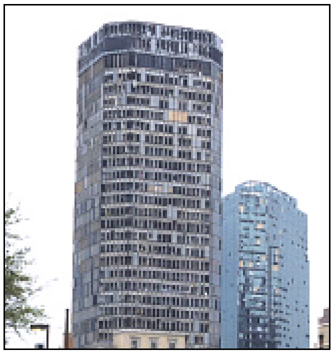

Figure 5. West façade of the Bank One Tower (left) and the UPR building (right) showing extensive loss of window glass.

4.2 *Arlington, TX Tornado*

The Arlington tornado damage path was 8 km long and up to 200 m wide. The first damage occurred in a residential area along Embercrest Drive about one mile south of I-20, just east of Collins Blvd. Homes were one-story, wooden-framed structures built on concrete slab foundations and had attached two-car garages. Damage up to F-3 occurred when the garage doors failed leading to uplift of the roofs or pushing out of exterior walls. Homes with attached garages facing the wind sustained far greater damage than homes with attached garages facing away from the wind (Fig. 6).

The tornado crossed Matlock Road and entered another subdivision comprised of larger one- and two-story homes. The damage path then started to curve to the northeast with the worst damage being on Chasemore Lane. Brick masonry walls fell from many homes since they had not been attached to the framing with corrugated metal ties. In many instances, the ties were attached to the framing but were never bent into the mortar joints (Fig. 7). Overall, about 200 homes sustained F1 or greater damage.

Figure 6. Garage failures (circled) on homes that faced the wind.

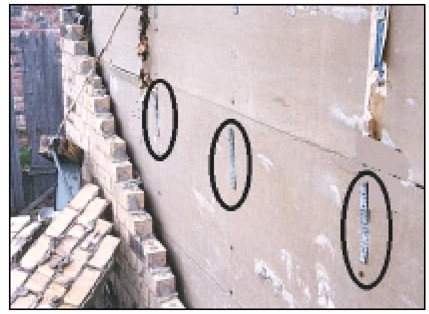

Figure 7. Brick ties (circled) were not bent into mortar joint, so the brick wall was not attached to the house.

SUMMARY

A tornado struck downtown Fort Worth on 28 March 2000 causing extensive damage to homes and high rise buildings. This case study illustrates once again that downtown regions are just as likely to be struck by tornadoes as less populated areas. Even more critical was the pervasive use of glass in the downtown Fort Worth that increased the risk of injury or death. In addition, such buildings sustained considerably greater damage when opened by the wind. Impact resistant glass should be installed on buildings prone to flying debris.

Our damage survey revealed homes had serious construction defects that led to more extensive damage. Homes that faced into the wind suffered greater damage than homes facing away from the wind due in part to failures of the garage doors. Also, homes failed first at the wall-to-floor or wall-to-foundation connections. As long as builders are left to police themselves, such building deficiencies are going to be routine. Surviving structures helped provide an upper bound on tornado wind speeds at between 55 and 65 ms^{-1}.

Radar analysis of this event revealed the mesocyclone of the Fort Worth storm first developed at mid levels and then descended slowly. Rapid intensification of the mesocyclone occurred between volume scans making warning of this event difficult. In addition, complex storm interactions from merging cells and small-scale boundaries apparently played a role in tornadogenesis.

6. ACKNOWLEDGEMENTS.

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