P 9.1 THE DALLAS-FT. WORTH, TX HAILSTORM: 5 APRIL 2003

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1. INTRODUCTION

On the evening of 5 April 2003, three supercells traversed northern portions of Dallas-Fort Worth, Texas causing nearly one billion dollars in hail damage, making the event the sixth costliest storm in Texas history to date (ICT 2003). The storms produced a swath of damaging hail that extended about 400 mi. (645 km) across the state from near Snyder, Texas to near Texarkana, Texas. A hail damage survey team spent several days examining roofs and other items as well as interviewing eyewitnesses in an effort to map the hail sizes and direction of hailfall. Indirect measurements of hail size were derived from examining roof coverings, vents, wooden fences, and air conditioners. Indirect measurements were then correlated with ice impacts of similar items conducted in the laboratory. We also measured the sizes of hailstones that persons had kept in their freezers and compared them to our findings.

This paper will discuss: 1) the meteorological history of the event, 2) our hail damage survey results, 3) the correlation between hail sizes and various indirect measurements, and 4) the correlation between hail sizes and radar derived estimates.

2. METEOROLOGY OF THE EVENT

Several weather features favorable for severe weather were recognized on the morning of 5 April 2003. A stationary front extended across central Texas with a surface low located north of Hobbs, New Mexico. Cool easterly surface winds were located north of the front whereas moist southeasterly winds were south of the front. A dryline extended southward from the surface low along the Texas and New Mexico border (Figure 1).

A strong upper level storm system dominated the intermountain west. At 500mb on the morning of 5 April 2003, the main trough axis extended through Las Vegas, NV. A broad jet with wind velocities of 50 knots or greater extended through New Mexico (Figure 2). The Storms Prediction Center (SPC) issued a moderate risk for severe weather for later that day across the Red River valley between Texas and Oklahoma.

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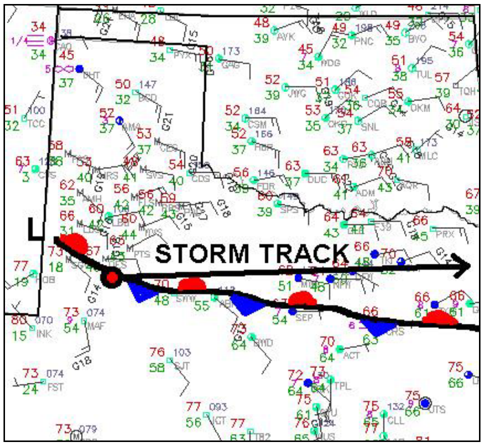

Figure 1. Surface weather features at 1743 UTC on 5 April 2003. The first supercell initially developed near the location of the circle in West Texas and tracked eastward, north of the stationary front, through the Dallas-Fort Worth metroplex.

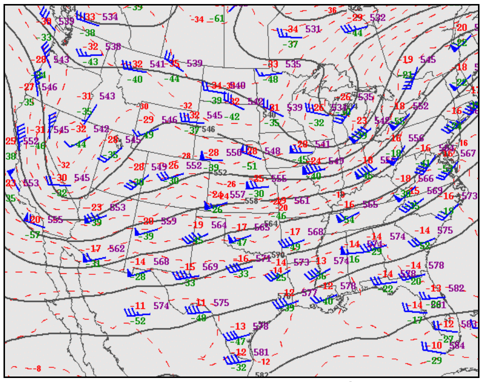

Figure 2. 500 mb map at 1200 UTC on 5 April 2003 with conventional symbols.

Analysis of radar and satellite data indicated that a supercell formed near the intersection of the stationary front and dryline near Big Spring, Texas, around 1730 UTC. The storm became severe and produced a tornado near Aspermont, Texas at 2100 UTC with 3 in. (7.6 cm) diameter hail reported just south of town at 2127 UTC. The supercell crossed the stationary front near Haskell, Texas becoming high precipitation (HP) type around 2230 UTC. Large hail in excess of 4 in. (10 cm) in diameter continued to be reported across rural areas of Throckmorton and Palo Pinto Counties (Figure 3).

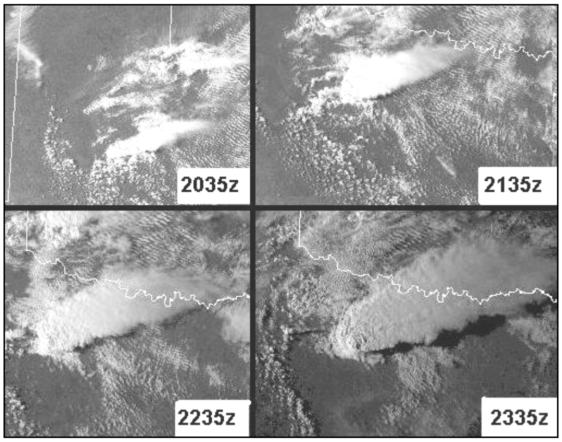

Figure 3. Visible satellite imagery showing the supercell that developed in west Texas and moved eastward towards the Dallas-Ft. Worth area.

By 0000 UTC, a second supercell (Storm B) developed on the west flank of the first storm followed by a third supercell (Storm C) that developed by 0200 UTC on 6 April 2003. All three supercells traveled eastward across northern portions of Dallas-Fort Worth, Texas between 0200 and 0400 UTC producing hailstones up to 3 in. (7.4 cm) in diameter. Radar reflectivity at 0245 UTC shows three supercells with hook echoes traveling eastward across the city (Figure 4). However, only one brief tornado was reported probably since the storms were "elevated" north of the stationary front.

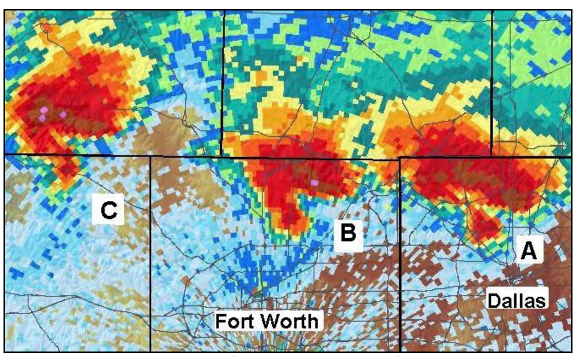

Figure 4. Radar reflectivity view of three supercells A, B, and C with hook echoes traveling eastbound through northern portions of Dallas-Ft. Worth, Texas at 0245 UTC on 6 April 2003.

Storm A merged with Storm B around 0500 UTC and dissipated around 0700 UTC, about 14 hours after Storm A began and seven hours after Storm B began. Storm C dissipated around 0900 UTC, lasting a total of seven hours. In all, there were over 50 reports of large hail associated with these storms (Figure 5).

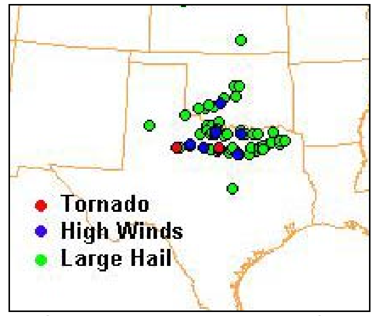

Figure 5. Severe weather reports from the Storm Prediction Center for the evening of 5 April 2003.

3. HAIL DAMAGE SURVEY

A hail damage survey team was dispatched to the metropolitan area after the storm and spent several days examining roofs and other items in an effort to map the hail sizes and direction of hailfall. A hail survey form was filled out for each of the locations visited. The form included the following information: the name and address of the building owner, roof covering type and age, the sizes and directions of hail spatter/scuff marks on metal and wood surfaces, and the sizes and direction of dents on metal and wood surfaces. In addition, some people kept hailstones in their freezers and the hailstones were measured, photographed, and compared to the extent of roof damage (Figure 6). Charlton and Kachman (1987) had conducted a similar hail damage survey in Edmonton, Alberta, Canada.

Figure 6. Hailstones to 2 in. (5.1 cm) in diameter and resulting roof damage in Flower Mound, Texas, in southern Denton County.

The sizes of hailstones can be estimated from marks and dents left on various items. Marshall and Herzog (1999) found that dents in wood shingles and shakes were roughly half the diameter of the hailstone whereas spatter marks on the wood surfaces were close to the actual diameter of the hailstone. They also found that hail-caused bruises and punctures in asphalt shingles approached the same diameter as the hailstone with less than solid underlying support.

Common roof items are made from lead, aluminum, or galvanized steel. Lead and aluminum items are soft and malleable and can be dented by relatively small hail. In contrast, larger and harder hail is needed to dent harder galvanized steel.

We checked various items for evidence of hailstone impact. Exposed fins on air conditioners were excellent indicators of hailstone size and direction/angle of hailfall. The aluminum fins were quite malleable and easily dented. The widths of the dents were measured and assumed to be the diameter of the hail. However, care was taken to insure that the dents were caused by the involved storm since the dents are permanent and cumulative, and could indicate prior hailstorms.

Hail-caused impact marks were visible on wood fences. The marks were created when hail impacted and removed some of the weathered grey film on the wood surfaces. Scuff marks were narrow at the point of impact and fanned out downwind appearing similar to that of a bug smear on a vehicle windshield. The bases of the scuff marks were measured and assumed to be the diameter of the hailstones. In addition, the marks also indicated the direction of hailfall (Figure 7).

Likewise, hail-caused "spatter" marks were visible on various steel items. These marks were created when hail impacted and broke apart removing some of the oxidation on the steel surfaces. The bases of these marks were measured as well as their direction. The diameters of the spatter marks were assumed to be the size of the hail.

Various soft metal vents were checked while conducting roof inspections. Aluminum vent caps and lead sleeves were quite malleable and easily dented by hail. In general, the larger the hailstone, the deeper the dent. The widths of the largest individual dents were measured from rim-to-rim. Occasionally, chalk was rubbed over the dent to better determine its perimeter. The diameters of the dents were measured and assumed to be the sizes of the hailstones.

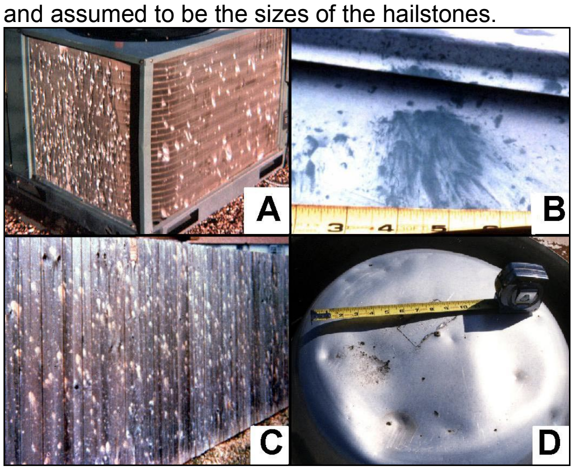

Figure 7. Various indirect indicators of hail size and direction: A) dented fins on an air conditioner, B) spatter mark on metal, C) scuff marks on wooden fences, and D) dents in aluminum vent caps.

Hail survey forms were completed throughout the four county metropolitan area that included Tarrant, Denton, Dallas, and Collin Counties. A total of 634 hail-caused marks and dents were measured at 359 locations on various steel, aluminum and wood items. The largest marks or dents at each location were plotted on a map of Dallas-Fort Worth, Texas (Figure 8). Hailstone sizes could be verified in 19 instances either from spotters or homeowners.

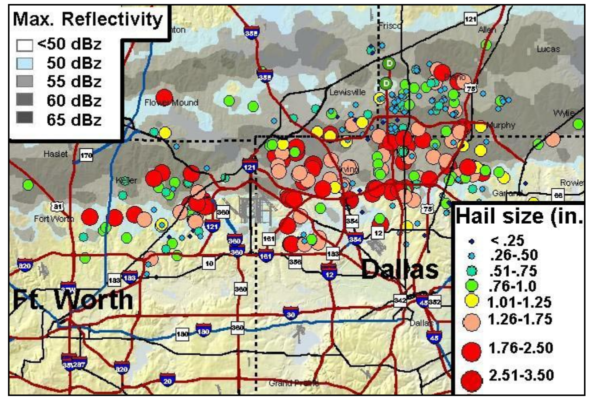

Figure 8. Plot of direct and indirect measurements of 359 hail size locations in northern portions of Dallas-Ft. Worth, Texas from Storms A, B, and C. Hail sizes are in inches. Maximum radar reflectivity also is shown.

We discovered that hailswaths of Storms A and B overlapped each other extending through northern Tarrant and Dallas Counties. The hailswath of Storm C extended through southern Denton and Collin Counties. There was a clear delineation between hailswaths of Storms A-B and C in northern Tarrant County, however, the hailswaths merged just north of the Dallas-Ft. Worth Airport and continued as one large hailswath through southern Collin and northern Dallas Counties.

The largest marks or dents on steel, wood, or aluminum items were compared to the largest hailstones at 19 locations (Figure 9). We found that

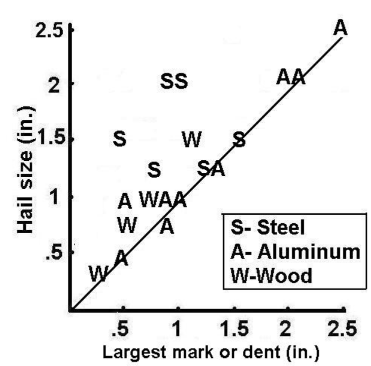

Figure 9. Comparison between the largest hailstones with the largest marks or dents on steel (S), aluminum (A), and wood (W) items at 19 locations.

the largest marks and dents on steel, aluminum, and wood items equaled the largest hailstone sizes about half the time. The remaining marks and dents on the items were smaller than the largest hailstones. Variabilities between the largest hail and largest mark or dent sizes were attributed to a number of factors including angle of hailstone impact, hardness of hail and item impacted, and whether or not the largest hailstones actually struck the items.

Hail damage to asphalt and wood roof coverings was widespread especially in the areas where hailstones exceeded 1.5 in. (3.8 cm). Such roof damage correlated well to ice ball impact tests conducted by Marshall et al. (2002).

The IBHS (Institute for Business and Home Safety 2004) conducted an insurance study after the event. They reviewed almost 77,000 insurance claims in 115 zip codes and found that almost 95 percent of the roofs were asphalt shingles with a 24 percent claims rate. Wood shingle or shake roofs comprised only 1.4 percent of the claims, however, wood roofs had a 43 percent claims rate.

The IBHS utilized data from our ground survey along with other data sources to determine the lowest hail size reported in a zip code. They then compared the lowest hail size reported to the total number and type of roof claims in that zip code (Figure 10).

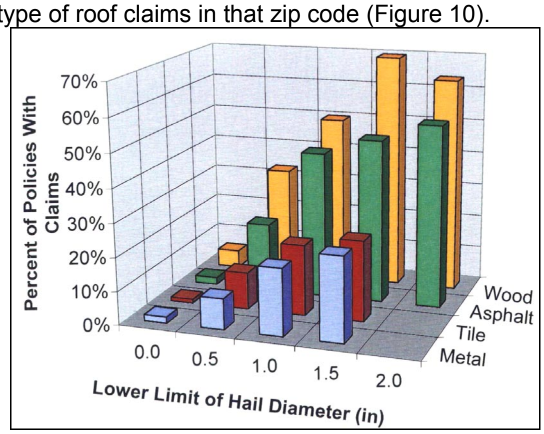

Figure 10. Percent of insurance policies with roof claims by roof type and lower limit of hail size reported for the 5 April 2003 hail event. Courtesy of Institute for Business and Home Safety

As expected, the number of insurance claims increased for all roof types in areas where larger hailstones were reported. About half of the insurance policies with wood and asphalt roofs had claims when the minimum reported hail size was 1 in. (2.5 cm) in diameter. Note the percent claims reported on tile and metal roofs lagged asphalt and wood roof claims, perhaps due to increased hail resistance of such products.

Interestingly, the IBHS study found that homes with impact-resistant roofs only had a 14 percent claims rate of which only 9 percent resulted in insurance payments. Such impact-resistant roofs are comprised mostly of an SBS (styrene butadiene styrene) modified asphalt that gives the shingles rubber-like properties. Other impact-resistant roofs include stone-coated metal panels and polymer-based shingles. These roofs must pass the UL 2218 (1996) impact test in order to qualify as "hail-resistant." Texas homeowners can receive discounts on their annual premiums if they install such roofs.

4. DETERMINING HAIL SIZE FROM INDIRECT MEASUREMENTS

Morrison (2002) conducted a series of ice ball impacts on various metal items in order to correlate dent sizes with hail sizes. Five common items were selected for ice impact testing. These items were: 1) lead soil stack flashing, 2) galvanized steel turbine vent, 3) aluminum flue cover, 4) aluminum box vent, and 5) aluminum air conditioner fins.

A mechanical device, was utilized to launch ice balls at the above metal items (Figure 11). The items were struck with solid ice balls of 1/2 in. (1.2 cm) to 2-1/4 in. (5.7 cm) using standard velocities similar to Greenfeld (1969). Impacts were done perpendicular to the metal surfaces as well as at 45 degrees. After striking the metal items, deformations in the metal were examined visually and the widths and depths of the dents were recorded.

In summary, Morrison found that the dents in lead soil stack flashing, galvanized steel turbine vent blades, and aluminum air conditioner fins were slightly smaller than the diameter of the ice ball, about 10 to 20 percent smaller. Thus, the assumption that hail size was equivalent to dent size in our damage survey was reasonable for these items. However, not all vents had such good correlations between dent sizes and hail sizes. Morrison found that dents in the aluminum box vents were about half the diameter of the ice ball. In contrast, dents were twice as large as the ice balls in the malleable aluminum flue vent caps. These vent caps tended to buckle when impacted. Experiments are currently under way to determine if impacting these objects with softer ice balls, which break apart more easily upon impact, would lead to better correlations.

Figure 11. Ice ball launcher (IBL-7) utilized to impact various metal items. A chronograph was positioned between the launcher and item to be impacted in order to obtain the velocities of the ice balls.

Crenshaw and Koontz (2002) also conducted ice impact tests on various metal items and found similar results. They concluded that indentations in aluminum fins on air conditioners were close to the diameters of the impacting ice spheres. They also concluded that splash or spatter marks on heavy gauge surfaces of the units provided an indication of hailstone size and direction. Roos (1978) derived hail sizes from hail pads clad with aluminum sheet.

5. DOPPLER RADAR HAIL ESTIMATES

A combination of the WSR-88D Hail Detection Algorithm (HDA) (Witt et al. 1998) and the radar observed storm reflectivity was employed to construct an estimate of the hailswaths for the 5 April 2003 hail event. The HDA has proven to be a reliable tool used routinely by the National Weather Service to estimate the probability of severe hail (≥ 0.75” diameter) and the maximum expected hail size. These estimates are principally derived from a vertical integration of temperature-weighted radar reflectivity. A reasonable estimate of the area impacted by severe hail can be constructed by first identifying those storms that are deemed severe according to the HDA and then mapping the associated radar observed storm.

Comparison between radar derived estimates of hail and our field measurements indicated qualitatively good correlation in the overall width of the hailswaths (Figures 12 and 13). Even the trough of smaller hail between the hailswaths Storms A-B and C appears in the two data sets. Although there appears to be some overlap between the troughs, the trough in the radar-derived estimate is shifted to the north about 3 mi. (5 km) into Denton County. Both data sets do show the merger of all hailswaths over southern Collin and northern Dallas Counties.

However, there was significant difference between the two data sets in the area covered by the larger hailstones. In particular, radar derived estimates of hail sizes greater than 2 in. (5.1 cm) in diameter covered a much larger area than actually found in our ground survey. Therefore, it would be inaccurate to pick a point on the map (in both figures 12 and 13) and assume hail had to be that size.

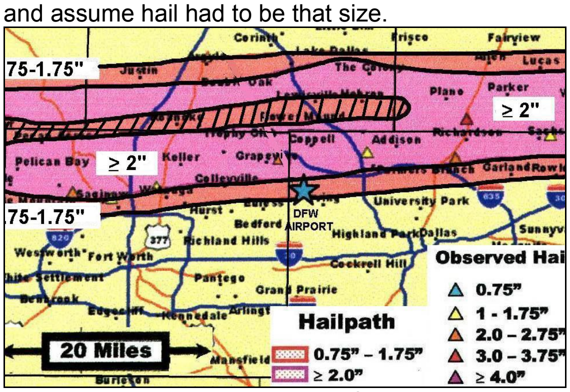

Figure 12. Hail size derived from the analysis of Doppler radar for the 5 April 2003 storm extending through northern portions of Dallas-Ft. Worth, Texas. Hatched area indicates smaller hail size between Storms A-B and C. Diagram courtesy of Weather Decision Technologies.

6. SUMMARY

This paper summarizes an incredible hail event in north Texas that occurred on 5 April 2003. A supercell had developed in west Texas early in the day along a stationary front and tracked eastward becoming a prolific hail producer. Two other supercells developed on its western flank and together, all three supercells tracked across the Dallas-Ft. Worth, Texas area dropping hail up to baseball-size resulting in nearly one billion dollars in damage. Overall, the storms traveled about 400 mi. (645 km) across the state from near Snyder, Texas to near Texarkana, Texas.

Hail damage survey teams spent several days after the storms examining roofs and other items in an effort to map the hail sizes and direction of hailfall across the metropolitan area. Indirect measurements of hail size were derived from examining roof coverings, vents, wooden fences, and air conditioners and compared to hailstones that people had kept in their freezers.

Indirect hail size measurements also were compared to the results of ice impact tests on various common metal items. Generally, we found good agreement between the dents in certain metal vents and the actual hailstone sizes. Likewise, there was good correlation between the sizes of spatter marks on metal items and the diameter of the hailstones.

Comparison of radar derived estimates of hail occurrence and our field measurements showed good correlation in certain qualitative characteristics of the hailswaths (i.e. widths and lengths of hailswaths), however the radar algorithm overestimated the aerial coverage of larger hailstones. This study has shown that caution must be exercised in using radar derived hail data to obtain hail sizes. It would be inaccurate to pick a point on a hail map and assume hail had to be that size. Hopefully, more ground surveys of this type can be conducted in the future to better correlate radar derived hail data to hail size.

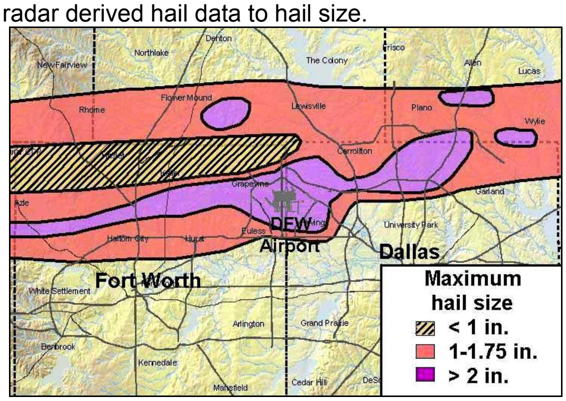

Figure 13. Smoothed hail size data derived from 359 direct and indirect measurements from our ground survey of the same area as shown in Figure 12. Hatched area indicates smaller hail sizes between Storms A-B and C.

7. ACKNOWLEDGEMENTS

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