Evaluating Hail Damage Using Property Insurance Claims Data

TANYA M. BROWN, WILLIAM H. POGORZELSKI, AND IAN M. GIAMMANCO
Insurance Institute for Business & Home Safety, Richburg, South Carolina

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ABSTRACT
A series of thunderstorms on 24 May 2011 produced significant hail in the Dallas–Fort Worth (DFW) metropolex, resulting in an estimated $876.8 million (U.S. dollars) in insured losses to property and automobiles, according to the Texas Department of Insurance. Insurance claims and policy-in-force data were obtained from five insurance companies for more than 67 000 residential properties located in 20 ZIP codes. The methodology for selecting the 20 ZIP codes is described. This study evaluates roofing material type with regard to resiliency to hailstone impacts and relative damage costs associated with roofing systems versus wall systems. A comparison of Weather Surveillance Radar-1988 Doppler (WSR-88D) radar-estimated hail sizes and damage levels seen in the claims data is made. Recommendations for improved data collection and quality of insurance claims data, as well as guidance for future property insurance claims studies, are summarized. Studies such as these allow insurance underwriters and claims adjusters to better evaluate the relative performance and vulnerability of various roofing systems and other building components as a function of hail size. They also highlight the abilities and limitations of utilizing radar horizontal reflectivity-based hail sizes, local storm reports, and Storm Data for claims processing. Large studies of this kind may be able to provide guidance to consumers, designers, and contractors concerning building product selections for improved resiliency to hailstorms, and give a glimpse into how product performance varies with storm exposure. Reducing hail losses would reduce the financial burden on property owners and insurers and reduce the amount of building materials being disposed of after storms.

1. Introduction
Since the 1940s, considerable knowledge about damaging hailstorms has been gleaned from crop-hail insurance data. Hail-related losses were generally thought to be better documented by crop-hail insurance companies than by property insurers, who did not distinguish between hail, wind, tornado, rain, or lightning losses (Changnon 1972, 1977; Changnon et al. 2009). Historically, crop-hail loss data had been used to understand the spatial and temporal aspects of economic losses attributed to hailstorms. Crop-hail loss data were also used as a proxy to estimate total economic loss data. The lack of property-hail loss data was noted by Changnon (1999) as a key problem in conducting economic analyses of hail losses.

Several studies on damaging hailstorms have been conducted on behalf of the property insurance industry (Cook 1995; Devlin 1997; IBHS 2004). Despite few injuries and fatalities, hail is of particular interest to the insurance industry because of large insured losses that average more than $850 million annually and that exceed those of every other country in the world (Changnon et al. 2009). The Dallas–Fort Worth (DFW) area has seen large hail events in 2003, 2011, and again in 2012, with some roofs being replaced three times in nine years (Simmons 2013), creating a large financial burden on property insurers and building owners. The threat of large property losses due to hailstorms is increasing as a result of construction of more new homes and businesses each year, along with modern development trends that place buildings closely together on small lots. Additionally, damaged materials are being replaced well before the end of their expected lifespan, creating additional waste despite attempts at recycling materials (Simmons 2013).

This study utilized insurance claims and policy-in-force data to evaluate roofing material type with regard to
resiliency to hailstone impacts. Relative damage costs associated with roofing systems versus wall systems were also investigated. An understanding of building system vulnerabilities will allow building designers, contractors, and others to make more informed choices or recommendations to property owners, and will allow insurers to appropriately underwrite based on improved estimates of risks. Property insurers often rely on third-party conventional radar reflectivity-based hail products and swaths; thus, comparisons of locations of WSR-88D radar-estimated hail and insured losses were evaluated to examine the reliability of using these data for insurance claims purposes.

2. Factors affecting hailstorm risks to properties

There are several factors that may affect the risk of building damage during a hailstorm. As Changnon et al. (2009) noted, many of these factors are specific to the thunderstorm conditions, while others are specific to the object being impacted (e.g., buildings or crops). In some cases, the risks have been studied through field studies or in laboratory testing. Some primary storm and building characteristics that affect the risk include the following:

1) Building materials: Laboratory impact testing of asphalt shingles has indicated the size threshold for damage was as low as 2.54 cm (1 in.) diameter hail, while the threshold for other products such as concrete tiles was 5.08 cm (2 in.) diameter hail. Damage thresholds from field observations were found to be slightly lower than the laboratory tests (Marshall et al. 2002). Data regarding the impact resistance of nonroofing building materials from the field or laboratory are scarce, as there are no impact resistance standard tests for these materials, other than for windborne debris resistance of windows and doors. There are limited impact resistance datasets for materials such as siding (Herzog et al. 2012).

2) Material age: All building materials are subjected to the elements, including high temperatures, freeze/thaw cycles, wind, water, and UV radiation. Roof surface temperatures on asphalt shingles of up to 82°C have been recorded (Dixon et al. 2014). These extremes can cause materials to become more brittle. Observations from a Roofing Industry Committee on Weather Issues (RICOWI; RICOWI 2012) study of the 24 May 2011 DFW event found that older roofing materials had reduced resistance to hailstone impacts (Herzog 2012). Laboratory testing of materials has also revealed reduced impact resistance of some materials with aging (Crenshaw and Koontz 2011).

3) Impact resistance rating of roofing material: Roofing products are either unrated for impact resistance or are rated class 1 to class 4, as determined by the performance of new samples of the product when subjected to one of the standard impact test methods that use steel balls or pure ice spheres to simulate hail impacts (UL 2012; FM Approvals 2005). New class 1 products meet certain performance criteria when impacted by spheres 3.18 cm (1.25 in.) in diameter, while class 4 products meet the same criteria when impacted by 5.08 cm (2.00 in.) spheres. Product ratings do not guarantee against hailstorm damage, but higher-rated products should theoretically experience reduced severity and frequency of hail damage as compared to unrated or lower-rated products.

4) Wind speed and direction: Hailstorms primarily affect the roof system, especially in relatively low-wind speed conditions where hailstones fall vertically. For events with strong winds associated with thunderstorm outflow, the hailstones may be propelled at an angle (Changnon et al. 2009), leading to more wall, window, or door damage. Additionally, certain roof slopes more perpendicular to the predominant wind flow direction, and hence more perpendicular to hail impacts, often have enhanced damage compared to roof slopes facing other directions (Petty et al. 2009). Very high wind speeds may also increase the speed of the hailstones at impact, resulting in a larger kinetic energy at impact, and thus more damage.

5) Sheltering of the building: If a portion of the building is sheltered by an overhanging tree or, in the event of wind-blown hail, is sheltered by a taller building upstream, it may be protected partially from hailstone impacts. Sheltering has been observed in crop damage patterns adjacent to large objects (Towery et al. 1976).

6) Hailstone size and density: The National Weather Service (NWS) defines 2.54 cm (1 in.) diameter hailstones as the threshold criteria for severe hail. Larger, more massive hailstones have a larger kinetic energy at the point of impact, which means that, all else being equal, they apply a larger, more damaging force at impact. A higher-density hailstone will also have a larger impact kinetic energy (all else being equal), as compared to a less dense hailstone of the same diameter.

7) Hailstone hardness: Some hailstones are very hard, while others are soft and slushy. Giammanco and Brown (2014) are conducting research to assess the hardness of natural hailstones. It is hypothesized that harder hailstones will produce greater damage to most building products. Preliminary observations of the compressive strength of both laboratory and natural hailstones suggest that hardness (using compressive
strength as a proxy) and density do not exhibit a one-to-one relationship.

3. Insurance data to assess hail losses

In 1948, the crop-hail insurance industry established an industry-wide association to systematically archive all hail and wind loss data (Roth 1949; Changnon and Changnon 1997; Changnon 1972, 1999), leading to more complete datasets. Insured loss data are integrated with hail activity measured with networks of hailpads and hail observations (Changnon 1970, 1971). These data have been recorded at the county level for the entire United States since 1948 (Changnon and Changnon 1997). Although the Crop-Hail Insurance Actuarial Association (CHIAA) includes approximately 90% of all crop-hail insurance coverage in the United States (Changnon and Changnon 1997), an earlier study (Changnon 1972) showed that most of the crop value in the United States (80%) is typically not insured, whereas lower uninsured rates would be expected for buildings. In the 1940s, the mean of hail-related annual crop losses in the United States was estimated to be $100 million (Lemons 1942). In the 1970s, crop losses were about 10 times greater than property losses (Friedman 1976). However, that is no longer true. Today, average annual property losses attributed to hail damage exceed crop-hail losses by approximately $270 million (Changnon et al. 2009).

The lack of property-hail loss data was noted by Changnon (1999) as a key problem in conducting economic analyses of hail losses. However, Changnon et al. (2009) noted that property insurance data were more reliable than the National Weather Service’s Storm Data, which often severely underestimated the true losses. Thus, studies on hail-property losses and improved data quality and quantity are needed.

4. DFW hail events on 24 May 2011

On 24 May 2011, a series of thunderstorms that produced significant hail moved through the DFW metroplex causing an estimated $876.8 million in insured property and automobile damage, according to the Texas Department of Insurance. This is more than the national average annual losses of approximately $850 million (Changnon et al. 2009). The timing of this event (approximately 0000–0300 UTC) occurred such that a large number of vehicles would likely have been on the roadways as people traveled home from their workplaces. A similar event occurring earlier or later in the day might have resulted in fewer automobile losses, and thus fewer overall losses. While a very costly event, it still did not exceed losses from a 1995 storm that caused property losses of $1.1 billion in the DFW area (Hill 1996; IBHS 1998).

Several broken lines of thunderstorms with embedded supercell structures passed over DFW. There were many reports of severe hail across the country, including many around the DFW metroplex (NCDC 2011). The post-event National Weather Service Storm Data contained 47 hail event reports with 10 exceeding 5.08 cm (2.00 in.) in Dallas, Tarrant, Collin, and Denton Counties as shown in Fig. 1 (NCDC 2011). There were also four giant hail events in excess of 10.16 cm (4 in.) in diameter, as defined by Knight and Knight (2001). The data are overlaid on radar observations, which are described later.

Radar-derived quantities have been used for hail detection to guide poststorm assessments and claims activities for many years. These tools rely on an underlying assumption that a relationship between horizontal reflectivity ($Z_h$) and hail size exists and is statistically significant. The original WSR-88D hail detection algorithm was developed to indicate whether or not a storm sampled by operational radar was producing hail (Petrocchi 1982). In 1998, the National Severe Storms Laboratory (NSSL) developed an enhanced hail detection radar algorithm, providing additional beneficial information such as the probability of hail, probability of severe hail, and maximum expected size of hail (MESH), herein referred to as “single radar MESH,” based on a radar volume-integrated technique (Witt et al. 1998). This product is run within the Storm Cell Identification and Track algorithm (SCIT; Johnson et al. 1998). Data for the event examined here were obtained from the National Climatic Data Center through the WSR-88D archived level III data. The single radar product was improved by Lakshmanan et al. (2006) by blending the reflectivity from the nearest three WSR-88D radars on a latitude, longitude, and height 3D grid using 1 km × 1 km horizontal grid spacing. From this, the Witt et al. (1998) algorithm is applied to the vertical column at each horizontal grid point to calculate a MESH value. Data were then assimilated every two minutes to produce a composite areal MESH swath (K. Ortega 2015, personal communication). This product herein will be referred to as “composite MESH.”

To evaluate the consistency between locations of insurance claims and radar-derived hail swaths, level III MESH values from 0000 to 0300 UTC 25 May 2011 from KFWS were assimilated to produce an estimated hail swath (Fig. 1a). An inverse distance weighting interpolation function was applied to the point MESH values to produce the estimated swath of hail with maximum size estimates. It is noted that some of the observed gradients, smoothing, and other discontinuities in Fig. 1a represent artifacts of the interpolation scheme coupled with the relative coarse temporal sampling of the WSR-88D.
The composite MESH swath is shown in Fig. 1b and obtained using the “OnDemand” system run at the National Severe Storms Laboratory, which represents the experimental multiradar, multisystem product. It is noted that this product could differ from that used operationally now by the National Centers for Environmental Prediction (NCEP) or what could be extracted from the Warning Decision Support System (WDSS II). The blending of reflectivity information contained in the composite MESH swath may yield somewhat smaller maximum estimated hail sizes than the single radar swath relying solely on the Witt et al. (1998) algorithm.
The swath of largest values for both the single radar and composite MESH products is oriented from west-northwest to east-southeast, and covers large portions of Dallas and Tarrant Counties. The areas of largest hail depicted by both products in southern and eastern Dallas County show similar estimates of sizes of hail. The KFWS WSR-88D is within 90 km of all points within Dallas and Tarrant Counties, and within 125 km of all points in the project domain. Additionally, the height of the 0.5° radar beam is less than 1 km over the claims analysis domain. The relative proximity of the area of interest to the KFWS radar could introduce some error in the MESH hail size estimates as the full volume of individual hail-producing cells may not be sampled as the Witt et al. (1998) algorithm relies on detecting reflectivity aloft. The multiradar technique used by Lakshmanan et al. (2006) to produce the composite MESH swath relies on nearby radars to fill the measurement gap. The largest MESH values shown in Figs. 1a and 1b are not spatially well correlated with the largest hail sizes given in Storm Data, where the larger reports occurred near Irving and Keller. This could be due to lack of observations where the largest MESH values were depicted, or could be due to errors in the derived MESH product caused by proximity to the radar and the relatively coarse temporal resolution of the WSR-88D. Limitations in the ability of the single radar MESH product to effectively capture maximum hail sizes have been shown by Ortega et al. (2009) and Wilson et al. (2009). The single radar MESH estimates were evaluated and are compared spatially with claims data in section 6c.

The NWS recently upgraded all WSR-88D radars to feature dual-polarization capability, which will improve their ability to detect the presence of hail. This upgrade began in March 2011 and was completed in 2013, but at the time of this event the KFWS radar had not yet been upgraded (National Weather Service Radar Operations Center 2013). Data signatures and algorithms for hail detection using the three additional variables provided by the upgraded polarimetric radars are being explored (Ryzhkov et al. 2013a,b; Picca and Ryzhkov 2012; Snyder et al. 2013; Kumjian and Ryzhkov 2008; Kumjian 2013; Kumjian et al. 2014).

5. Claims data summary

The design of this study required careful selection of claims data fields and areas for investigation to study the effects of many variables that potentially contribute to hail damage to buildings. Observations of areas of differing damage levels, ages, and material types from the RICOWI damage survey (RICOWI 2012; Herzog 2012), radar information, NWS Storm Data, and information from participating insurance companies regarding the density of claims and presence of varying construction materials and building ages were used to select areas to investigate. The communities included in this study were selected primarily to provide variety in roofing materials, ages of houses, and radar-estimated or publicly reported hail sizes. The selected ZIP codes are shown in Fig. 2 and summarized in Table 1, which tabulates some of the key reasons for selection. A third-party claims estimating and claims management company, Xactware, collected the insurance carriers’ policy data and matched them with their claims data. Data were gathered for all policies-in-force and all claims for residential properties in the selected ZIP codes from each participating insurer. Once collected, data were concatenated into a single, uniform format.

A homeowners’ insurance policy comprises several pieces, each of which has its own cost, terms, and conditions and varies by insurance company. Coverage A addresses damage to the house itself, and does not include components such as contents of the house, attached structures (garages, fences), and other types of losses. Coverage A contains a dollar limit, which is the most a policyholder could receive if his or her house were totally destroyed by an insured peril. For this study, claims data fields for the main house were selected for analysis. Basic insurance policy information such as location, square footage, and primary roof covering type were included. Additionally, damage estimates for certain building components were included and grouped into the following categories for analysis purposes: roof, wall, door, window, other.

The dataset for this study included 67 100 residential policies from five insurance companies from the 24 May 2011 DFW hailstorm. A total 6697 of the policies in the dataset had claims; of those, 6490 (97%) had roofing-related claims. The locations of all exposures in the study with and without claims are provided in Fig. 2. The ages of the buildings ranged from older than 150 years to less than a year old. As shown in Fig. 3, asphalt composite shingles made up nearly 80% of the dataset. Additional roofing materials included tile, metal, wood, and slate. A small number of roofs with other materials were reported, but these were removed from the dataset prior to analysis due to their small sample size, leaving 66 883 policies.

6. Analysis

The frequency and severity of residential property claims were investigated by roof cover type to determine vulnerabilities associated with various materials. Additionally, frequency and severity of damage to windows, walls, doors, and other nonroofing components were investigated and compared to roofing component damage.

The term “claim frequency” of a category $x$ (i.e., asphalt shingle roofs) can be described by
where \( c_x \) is the number of claims in category \( x \), and \( p_x \) is the number of policies in category \( x \). The term “claim severity” can be described by

\[
CS_x = \frac{\sum l_x}{c_x},
\]

where \( l_x \) is the claims losses in dollars in category \( x \). The term “normalized average claim severity” is

\[
NCS_x = \frac{\sum \frac{l_{xn}}{CovA_{xn}}}{c_x},
\]

where \( l_{xn} \) is the claims losses in dollars from structure \( n \) in category \( x \), and \( CovA_{xn} \) is the Coverage A limit for structure \( n \) in category \( x \). The normalized average value provides a way to evaluate damage severity as a ratio of the value of the home, which allows for relative comparisons of less expensive homes to more expensive homes. It should be noted that the Coverage A limit is affected by the size of the home, location of the home, and the internal and external materials and finishes of the home, among other things.

**a. Roof damage**

For purposes of damage estimates, the roof system included the roof covering material along with other roofing components such as flashing, vents, underlayment, and sheathing, among others. There were 207 homes that had a claim that was not associated with the roofing system, and these are excluded from the analysis of roofing damage in this section, but are included in the component damage analyses in section 6b.

The results indicated the claim frequencies from this event were highest for metal and wood roofs as shown in Fig. 4. However, sample sizes of those materials were small as compared to sample sizes of asphalt shingle
roofs. Metal and wood roofs also had the highest normalized claim severities, as shown in Fig. 5. Another way to examine the severity of roofing losses associated with this event is the average roofing loss per exposure, which is illustrated in Fig. 6. This represents a way to evaluate the expected insurance payout for a property with particular roofing characteristics. For example, this graph illustrates that for each insured property with a tile roof, an insurance carrier could expect to pay out an average of $1027 in roofing-related losses following an event similar to this hailstorm in a similar location. Carriers could expect to pay out the highest amounts for metal and wood roofs, which reflects their damageability and higher material costs combined.

b. Component damage

In addition to roof damage, hailstorms frequently cause damage to other building systems and components. However, the results showed roofing-related claims occurred more frequently than those for other building systems, as illustrated in Fig. 7. Additionally, claim severities for roofing materials far exceeded those

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**Table 1. Selected ZIP codes and key parameters for selection to provide variation in the dataset.**

<table>
<thead>
<tr>
<th>ZIP code</th>
<th>City</th>
<th>County</th>
<th>Radar-estimated severity</th>
<th>Field observation severity</th>
<th>Claims %</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>75006</td>
<td>Carrollton</td>
<td>Dallas</td>
<td>Low</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75007</td>
<td>Carrollton</td>
<td>Denton</td>
<td>Low to moderate</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75019</td>
<td>Coppell</td>
<td>Dallas</td>
<td>Low to moderate</td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75038</td>
<td>Irving</td>
<td>Dallas</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Mixed</td>
</tr>
<tr>
<td>75062</td>
<td>Irving</td>
<td>Dallas</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Mixed</td>
</tr>
<tr>
<td>75063</td>
<td>Irving</td>
<td>Dallas</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Mixed</td>
</tr>
<tr>
<td>75068</td>
<td>Little Elm</td>
<td>Denton</td>
<td>Low</td>
<td>High</td>
<td></td>
<td>New</td>
</tr>
<tr>
<td>75078</td>
<td>Prosper</td>
<td>Collin</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>High</td>
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<td>Dallas</td>
<td>Moderate</td>
<td>Moderate</td>
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<td>Dallas</td>
<td>Low</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>Dallas</td>
<td>Dallas</td>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75253</td>
<td>Dallas</td>
<td>Dallas</td>
<td>Sharp transition from low to high</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>76051</td>
<td>Grapevine</td>
<td>Tarrant</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>76092</td>
<td>Southlake</td>
<td>Tarrant</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>76132</td>
<td>Fort Worth</td>
<td>Tarrant</td>
<td>Low to moderate</td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>76133</td>
<td>Fort Worth</td>
<td>Tarrant</td>
<td>Low to moderate</td>
<td>High</td>
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<td></td>
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<td>Tarrant</td>
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<td>Low</td>
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<td>New</td>
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<td>Tarrant</td>
<td>Low</td>
<td>Low</td>
<td></td>
<td>New</td>
</tr>
</tbody>
</table>

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**Fig. 3.** Distribution of roof cover materials for all policies contained in the dataset.
of other building systems for this particular event. When there was a claim, the costs of roofing-related losses were more than 10 times higher than for any other component group as shown in Fig. 8.

A study in St. Louis in the 1960s found roof losses made up 75% of the total losses, while losses to siding and glass were 3% and 5% respectively (Collins and Howe 1964). Average loss per exposure data given in Fig. 9 show that 92% of total losses were for roof damage, 0.9% for wall damage, and 1.3% for window damage in this study.

c. Claims versus horizontal reflectivity-based hail sizes

The spatial distributions of normalized average claim severities are shown in Fig. 10 for a grid size of 0.1 km × 0.1 km, along with open contours of single radar MESH data from KFWS (same MESH data as shown in Fig. 1a). This illustrates the average claim severity calculated based on the total number of exposures within a given map grid cell. The single grid cell with the highest normalized average claim severity was just over 5%. The swath of highest damage rates is oriented west-northwest-to-east-southeast, from north-central Tarrant County into northwestern, central, and eastern Dallas County. The damage and single radar MESH data revealed similar swath orientations, although the areas of largest radar-derived hail sizes are shifted south along I-20 in southern Dallas County, which was not included in this study. The inset figure shows a zoomed-in area of highest damage. The inset shows several localized areas of relatively higher damage that do not correspond with higher values of the single radar MESH product.

A mathematical spatial comparison between normalized average claim severity and single radar MESH data over the grid cells was completed. Both datasets were reclassified into an arbitrary dimensionless integer from −4 to +4 as outlined in Tables 2 and 3. Negative
Integers represent lower damage values and smaller single radar MESH data, while positive integers represent higher damage and larger single radar MESH values. The reclassified radar spatial values were subtracted from the reclassified claim severity spatial values. The resulting data of the subtraction is provided in Fig. 11 for grid cells of size 0.1 km × 0.1 km. The reclassification schemes were designed so negative results from the subtraction would indicate localized areas of relatively lower damage severity and higher radar-estimated hail sizes as shown in blue for values ranging from −8 to −2. Similarly, positive results ranging from +2 to +8 would indicate localized areas of relatively higher damage severity coupled with lower radar-estimated hail sizes as shown in red. Results ranging from −1 to +1 are shown in green to indicate reasonable agreement between the two datasets. These areas had relatively good agreement between the radar estimates of hail size and damage regardless of whether the hail size was large or small. This range of values is smaller than the other two to reflect the level of uncertainty that exists in assigning a good agreement rating.

In areas where there was not much damage, the single radar MESH swaths and damage data were generally in reasonable agreement. When compared with radar-derived hail estimates, damages were higher than expected in areas of northwestern Dallas County, especially east of the DFW airport; however, ground observations of damage from the RICOWI survey indicated large hailstones fell in these areas. This discrepancy may be a result of size sorting of hydrometeors such that larger hailstones may have fallen outside the reflectivity core region of a given thunderstorm (Kumjian and Ryzhkov 2012; Dawson et al. 2014; Kumjian et al. 2014). Observed damage was lower than what would be expected based on the single radar MESH swaths in north-central Tarrant County, and in central and southeastern Dallas County. For these

![Fig. 6](image-url)  
**Fig. 6.** Average expected roofing-related losses per insured exposure by roof cover type.

![Fig. 7](image-url)  
**Fig. 7.** Frequencies of claims with losses by major building component groups.
instances it is noted that the Witt et al. (1998) hail detection algorithm was designed to overestimate the hail size approximately 75% of the time. This was used to provide some degree of lead time for operational warning decision making (K. Ortega 2015, personal communication). As dual-polarization radar algorithms and signatures are developed and employed, it is expected the agreement would further increase. Detailed ground surveys could aid in investigating the size sorting of large hailstones with relation to a storm-relative position, and contribute valuable information regarding the specific characteristics (e.g., hard, slushy, dense) of hailstones in a given event that would lead to more or less damage. It should be noted that the aging and upkeep conditions of properties at each location are unknown, and locally higher damage rates in some instances could be indicative of properties with lesser hail resistance due to older materials and lack of upkeep, and not necessarily larger hail. The same could be true for locally lower damage rates, where properties with more hail resistance due to newer materials or better upkeep might be indicated as opposed to smaller hail.

7. Conclusions, data limitations, and recommendations

The 24 May 2011 DFW hail event caused more than $876.8 million in insured property and automobile damages, of which more than $545.2 million were attributed to damages to residential properties, according to the Texas Department of Insurance. Rather than focusing on the event’s total insured losses as Changnon historically did, the focus for this study was on the damages caused to residential building systems. Local areas of damage were compared to single and composite MESH swaths of radar-estimated maximum hail size.

From this dataset, it was apparent the majority of damages were associated with the roofing system, with...
more than 90% of claims dollars being spent on roofing damage. Exterior wall surfaces in the DFW area are commonly brick veneer, which is fairly hail-resistant. Hail coupled with very high wind speeds in regions where less hail-resilient wall materials are used may cause higher relative rates of damage to walls, but the predominant loss driver is still expected to be damage to roofing materials. A comparison of the relative performance of roofing materials revealed the highest claim frequencies occurred on metal and wood roofs. When normalized by Coverage A values, the average claim severity was less than 10% for each roofing product included in the study (Fig. 5).

This study also illustrated the difficulty in correlating radar-estimated maximum hail sizes to building damage. The highest claim severities were not always collocated with the largest radar-derived hail estimates. Blair et al. (2011), Ortega et al. (2009), and Wilson et al. (2009) have previously shown discrepancies between radar-derived hail sizes and Storm Data hail sizes, and these discrepancies are further supported by building damage data as illustrated in this study. Some of the most severe damage observed during the RICOWI field surveys, and reflected in the spatial claim severity data, were in ZIP codes 75063, 75038, and 75062 in western Dallas County, east of the DFW airport, where radar estimates of hail sizes were relatively small, but there were a few Storm Data reports of 5.08 cm or larger. These areas were also highlighted in Fig. 11 in red, indicating relatively high damages in areas with relatively smaller hail radar-derived sizes. Some of the discrepancies between hail sizes and claim severity may be a function of the building materials and condition of those materials at the time of the hailstorm combined with storm-scale processes.

![FIG. 10. Spatial distribution of normalized average claim severity compared with contours of MESH data from KFWS WSR-88D.](image)

**Table 2. Reclassification scheme for normalized average claim severity values for use in spatial comparison with radar data.**

<table>
<thead>
<tr>
<th>Original normalized damage severity</th>
<th>Reclassified damage severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00% – 0.15%</td>
<td>-4</td>
</tr>
<tr>
<td>0.16% – 0.30%</td>
<td>-3</td>
</tr>
<tr>
<td>0.31% – 0.50%</td>
<td>-2</td>
</tr>
<tr>
<td>0.51% – 1.00%</td>
<td>-1</td>
</tr>
<tr>
<td>1.01% – 1.50%</td>
<td>1</td>
</tr>
<tr>
<td>1.51% – 2.00%</td>
<td>2</td>
</tr>
<tr>
<td>2.01% – 3.00%</td>
<td>3</td>
</tr>
<tr>
<td>3.01% – 4.00% +</td>
<td>4</td>
</tr>
</tbody>
</table>
as size sorting of hydrometeors. It is important to recognize the value of these tools to provide a general spatial representation of an event; however, there are inherent difficulties in using these data for individual building insurance claims processing or as predictor of claims severity or frequency. Accurate data on the type, age, and condition of building materials are needed, coupled with laboratory or field data concerning their impact resistance, to be able to better relate size of hail with building damageability.

While this study provides valuable information, there were some limitations associated with the claims dataset. The lack of data on roof ages prohibited an examination into how roofing material performances degrade due to environmental exposure. Additionally, sample sizes associated with nonasphalt roofing materials were small, as asphalt roofs are the most commonly used material throughout the country (ARMA 2011; Dixon et al. 2014). Future projects may benefit from including commercial properties to allow for examination of other nonasphalt roofing products, or from focusing on areas known to have high concentrations of nonasphalt products on residential roofs. Reviews of aerial imagery could be used to identify these areas. Additionally, documentation of the presence of impact-resistant roofs is necessary for hail studies to provide field test data as to the effectiveness of these products. To gain a better

<table>
<thead>
<tr>
<th>Original MESH value</th>
<th>Reclassified hail size</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00–1.27 cm (0.00–0.50 in.)</td>
<td>–4</td>
</tr>
<tr>
<td>1.28–2.54 cm (0.51–1.00 in.)</td>
<td>–3</td>
</tr>
<tr>
<td>2.55–3.81 cm (1.01–1.50 in.)</td>
<td>–2</td>
</tr>
<tr>
<td>3.82–5.08 cm (1.51–2.00 in.)</td>
<td>–1</td>
</tr>
<tr>
<td>5.09–6.35 cm (2.01–2.50 in.)</td>
<td>–1</td>
</tr>
<tr>
<td>6.36–7.62 cm (2.51–3.00 in.)</td>
<td>2</td>
</tr>
<tr>
<td>7.63–8.89 cm (3.01–3.50 in.)</td>
<td>3</td>
</tr>
<tr>
<td>8.90–10.16 cm + (3.51–4.00 in.+)</td>
<td>4</td>
</tr>
</tbody>
</table>

Fig. 11. Dimensionless spatial correlation between damage severities and single radar MESH data.
understanding of relative building system losses, it may be necessary to focus future studies on other regions where wall materials differ. To use these kinds of claims analyses for future damage studies associated with a variety of hazard events, additional and better quality data are needed. Increasing the sample size by either including a larger spatial area or incorporating data from additional insurance companies would be beneficial.

Recently, the field campaigns of Blair et al. (2011) and Brown et al. (2012) have made measurements of hailstones either in situ or shortly after they have fallen (Giammanco and Brown 2014). Should data from these programs be collected in a high-population area, the combination of hail observations at the ground coupled with an improved insurance claims analysis, dual-polarization radar information, and damage survey data would greatly enhance the ability to understand why some properties are more severely damaged by hail than others. Changnon (1999) recommended more complete datasets to conduct these kinds of studies, and demonstrated the value of comprehensive and systematic data collection by the crop insurance industry.

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