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Hail Sizing: A Comparison of On-Site Data with Weather Data

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Abstract

When investigating buildings for potential hail damage, determination of the approximate hail size is an important part of the investigation. Weather data resources, including free data made available by the government and fee-based reports from third-party weather analysis services, are often used to help evaluate the reported or estimated hail size in the vicinity of a given site location. In addition, data collected during a site investigation provides valuable, site-specific information regarding hail occurrence(s) at a site.

The authors have investigated buildings, and especially roof coverings, for damages from numerous hail events. Based on this experience and published studies regarding damage profiles from varying hail sizes, observations and measurements obtained during an investigation for hail damage are utilized to determine an estimate of hail size at a given site.

The purpose of this paper is to discuss the methodology used for on-site evaluation of hail size and to compare estimated maximum hail sizes determined from these on-site investigations with the available weather data. Data from multiple storm events affecting populated areas, which generally provides for a more comprehensive and more closely-spaced set of data, will be used. The comparison of on-site evidence with the available weather data will show that this weather data can provide information of varying accuracy with regard to the sizing of hail, and that the data collected during an on-site investigation is essential for the accurate determination of the approximate hail size which has occurred at a given site.

Introduction

The size of a hailstone is the most frequently cited attribute when discussing damage potential from hail impact because the size of a hailstone correlates to the kinetic energy of hailstone impact. In fact, the size of the largest hailstones in a storm event is typically used as shorthand to describe the storm and the expectation of damage to vegetation, building materials, automobiles, etc.

One source of hail size information available to the forensic professional performing the hail damage investigation is weather data. Due to the different types of available weather data, this data may include multiple sources of information, including estimates of hail size at a specific site. Weather data provides valuable information for an investigator, especially in more densely populated areas where there are likely to be more individual hail reports in the vicinity of a given site/building.

Another source of hail sizing data is a site-specific field investigation. A detailed site investigation for hail damage should include an assessment of the various materials and surfaces at the site for information regarding the size and damage profile from the impacting hail. With a sound field investigation methodology and sufficient data collection, an investigator can typically perform a useful analysis to aid in the determination of the approximate hail size at a site.

Hail Sizes and Damage Profiles

Damages associated with hail impact occur due to the transfer of kinetic energy from the hailstone into the impacted material. Factors affecting the potential for hail to damage roofing and other building materials include the density, shape, and size of the hail.

<u>Density</u>

Hail forms during alternating upward movement from air drafts and downward movement from falling, resulting in layers of ice formation (NOAA, 2018). Due to the variability in the amount of entrapped air during formation, hail is commonly composed of alternating layers of higher and lower density ice. Thus, while the density of hail may be similar to that of solid ice, variability of density can occur both within the individual hailstones and between different hailstorms (Greenfeld, 1969, Koontz, 1991). In general, the damage potential of hail increases with increasing density, due to the increased kinetic energy associated with denser hail of a given size.

<u>Shape</u>

Hail shapes can vary from spherical to oval- or elliptical-shaped and can also have warty or jagged surfaces (Koontz, 1991 and Flueler, 2009). The shape of a hailstone may affect the damage potential, although this depends on the specific nature of the individual impact, including the orientation of the hailstone at impact and the characteristics of the impacted material.

Size

Smaller-sized hail is the most common to occur, and the frequency of hail generally decreases with increasing size (Friedman and Shortell, 1967, Noon, 2001, Petty 2013). As hailstones fall to earth, they achieve a velocity approximating the terminal velocity (Laurie, 1960, Greenfeld, 1969, Koontz, 1991). The terminal velocity of a hailstone increases with size, thus the impact energy (and the damage potential) of hailstones increases significantly with increased hail size. As an example, the impact energy of a spherical hailstone 2" in diameter falling at terminal velocity is more than 20x that of a hailstone measuring 1" in diameter.

Because of this relationship between the size of a hailstone and the impact energy, determination of hail size is an important part of an investigation of hail damage to a roof or other building system or component.

Weather Data

A hail investigator has multiple options for sources of hail weather data, including free public data from government entities and reports from third-party weather analysis services, which are available for a fee.

A commonly used source of free data is the database archives of storm events maintained by the National Oceanic and Atmospheric Administration (NOAA) through their National Centers for Environmental Information (NCEI) and Storm Prediction Center (SPC). The hail data from NCEI and SPC include hail size, the approximate location (latitude/longitude), and may include a narrative description of the storm event. The investigator can then determine the approximate distance between a specific site of interest and a report of hail. As noted above, this information can be especially valuable in more densely-populated areas due to the likelihood of more closely-spaced hail reports. Due to the nature of the data collection for "weather spotter" reports of hail, the potential for inaccuracies in the exact sizing and location of hail reports should be considered.

For some select hail events, additional free, public weather data may be available. As an example, the National Weather Service (NWS) prepared approximate hail swaths (i.e., a contour map indicating approximate hail sizes over a geographic area) for the April 12, 2016, and April 25, 2016, hail events affecting the San Antonio, Texas area (NWS, 2018).

Hail data from third-party forensic weather services is also frequently utilized during hail investigations. Such reports typically provide an estimate of maximum hail size at a given site and may be graphical (i.e., a map with contour lines showing the estimated maximum hail) or may be in tabular form. These services generally use radar data from a storm event in combination with data from human observations and apply proprietary algorithms and/or modeling to analyze the storm. From this analysis, an estimate of the hail size likely to have occurred is determined, and the area where such hail likely fell is also determined (Mitchell, et. al., 2008).

Weather reports for a specific site based on such analyses by third parties can provide information helpful to an investigation. However, these reports are not intended to be substitutes for a detailed site investigation, rather they are intended to act as a tool to compliment site evaluations (Mitchell, et. al., 2008).

Field Investigations and Methodology

When investigating hail sizing at a specific site, a field investigation is required to gather data from the site. The investigator should gather data pertaining to evidence of hail impacts and data pertaining to damage (or the lack of damage, as the case may be) to various materials at the site. If performed properly, a field investigation can provide a significant amount of hail sizing data.

Burnish Marks

Burnish marks (commonly referred to as "splash" or "spatter" marks) can be valuable for analyzing the sizing, characteristics, and fall orientation of hail. A burnish mark results when an object, such as a hailstone, removes the exterior layer, algae, dirt, oxidation, or film on the surface of a material. This leaves a localized clean area amongst the weathered or dirty surface (**Figure 1**). Such burnish marks associated with hail events commonly result in a freckled or mottled appearance on the impacted surface. With the passage of time, burnish marks become less distinct as the burnished surface naturally weathers. The time frame over which burnish marks remain distinct or visible depends on the specific material/weathering conditions of the burnished surface.

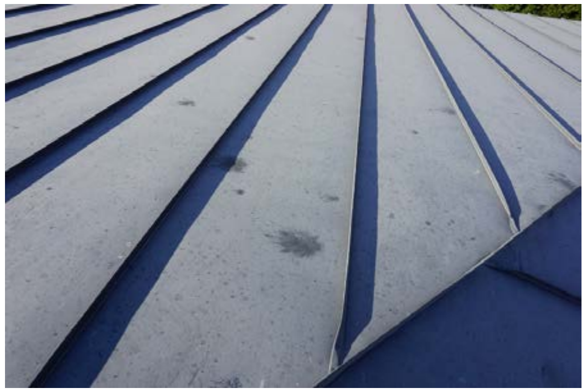

Figure 1. Burnish marks on metal roof panels with coincident indentations.

The width of burnish marks can be used in the determination of hail size (Crenshaw and Koontz 2002 and Petty, 2013). This determination is based on both the available research and investigative experience reviewing burnish marks and comparing them to damage profiles. The shape of the burnish marks must be considered and the measurements must be performed in a consistent and repeatable fashion (i.e., measurement should be performed at the same relative area of various burnish marks).

The pattern of burnish marks on vertical surfaces can indicate the directionality of the hail. If the burnish marks appear on the south and west vertical surfaces, but not on the north and east vertical surfaces, the hail can be determined to have traveled generally southwest-to-northeast. On horizontal surfaces, the shape of burnish markings can indicate the directionality of hailstone impacts, as hail impacting with a distinct directionality will frequently have shapes similar to a comet, with the tail pointing in the direction of travel at impact (**Figure 2**).

Figure 2. Burnish marks on a metal surface with a distinct directionality.

Indentations

Indentations in metal surfaces also provide useful information for the determination of hail size. For typical steel panels and flashing, a common rule of thumb is that the diameter of an impacting hailstone is on the order of twice the diameter (a multiplier of 2) of the resulting indentation (Noon, 2001). However, as studies have shown, in many instances this provides a conservatively large estimate of hail size and the multiplier is frequently less than 2 (Crenshaw and Koontz, 2002, Petty, 2013). Based on the available research and the authors' experience, more malleable metals, such as copper or aluminum, will have a lower ratio of hailstone-to-indentation diameter.

The measurement of indentations in metal, as performed in the field, is an important part of the investigation (**Figure 3**). Typical indentations have an outer width of indentation and a smaller inner indentation width. This inner indentation width is measured between the well-defined slopes within the indentation. The available research suggests that this inner indentation width provides a better correlation to the hail size and this width has therefore been used to define the indentation diameters used for the impacting hailstone ratio described above (Crenshaw and Koontz, 2002, Petty, 2013).

Figure 3. Indentation at metal roof panel.

The investigator should consider the material in which indentations occur and should evaluate a sufficiently large representative area of metal surface when searching for indentations to be used to aid in hail sizing. Additionally, the physical characteristics of the hail can affect the appearance and measurements of indentations in a given surface.

Damage Profiles

In addition to indentations and burnish markings, the evaluation of the damage profiles of building materials at the site provides information regarding the size of hail which occurred at and around a given site. A thorough investigation includes evaluation of materials at the site that are relatively susceptible to damage from hail impact and materials which are relatively resilient to impact damage. Multiple publications discuss the impact damage threshold of building materials (Greenfeld, 1969, Koontz, 1991, Petty, et. al., 2009, and Flueler, 2009). Once an investigator develops experience evaluating hail impact damage to various building materials, this experience can also be useful in determination of hail size based on the damages observed at a site.

Discussion and Analysis

The authors have performed hail damage evaluations for several hundred buildings, with the majority of such evaluations having occurred in Texas. For many of these evaluations, there was sufficient evidence at the site to develop an estimate of hail size (referred to herein as a "field estimate").

Weather data, including free data and/or fee-based data from third party meteorological services, was collected for the sites included in the data set analyzed for this study. The hail sizes indicated in weather data from various sources was compared to the field estimates to evaluate the relationship.

NOAA Database Weather Reports

The authors compared 143 field estimates of hail size to reports of hail reported within 5 miles of the respective sites/buildings, using the data from the NOAA databases (NCEI/SPC). The NOAA data was further broken down into distance ranges with respect to the closest hail report to each site/building as follows: within 1 mile (51 reports), greater than 1 mile to 3 miles (81 reports), and greater than 3 miles to 5 miles (11 reports).

The authors determined the variance between the field estimates and the size of the closest reported hail from the NOAA databases. This variance was charted in 0.25" increments, as shown in **Figure 4**.

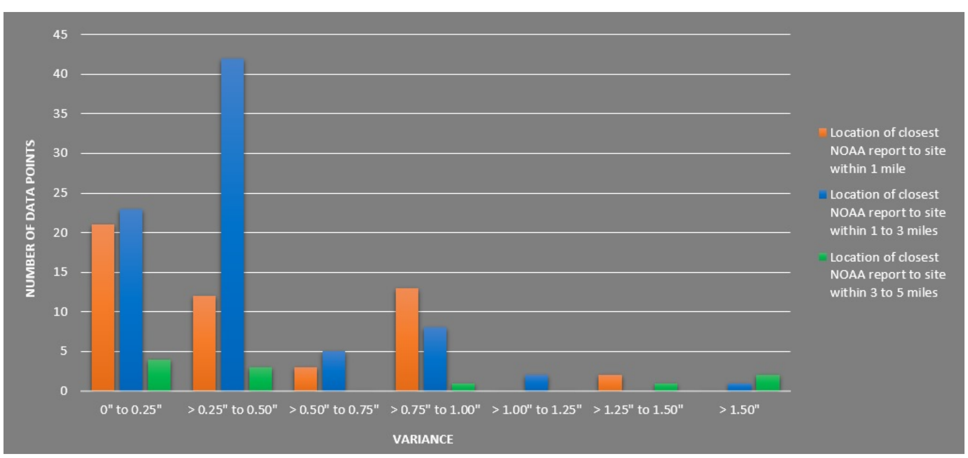

Figure 4. Hail size variance between closest NOAA weather reports and field estimates.

Instances where the closest NOAA report was more than 3 miles away from the site/building were limited (only 11 out of 143 locations) and, as seen in **Figure 4**, exhibited a higher occurrence of large variances when compared to the data reported within 3 miles. Therefore, the data reported within 3 miles of the respective sites/buildings generally had less variance than the reports from farther away.

The NOAA data from within 3 miles of the respective sites/buildings was further evaluated and the variances between this data and the field estimates were charted in 0.5" increments (0" to 0.5", >0.5" to 1", >1" to 1.5", and >1.5") to show the percentages of NOAA reports that fell within each variance range (**Figure 5**).

This evaluation revealed that, for NOAA hail size reports within 3 miles of the sites/buildings, 74% had variance of 0.5" or less compared to the field estimates, and that 96% had variance of 1" or less.

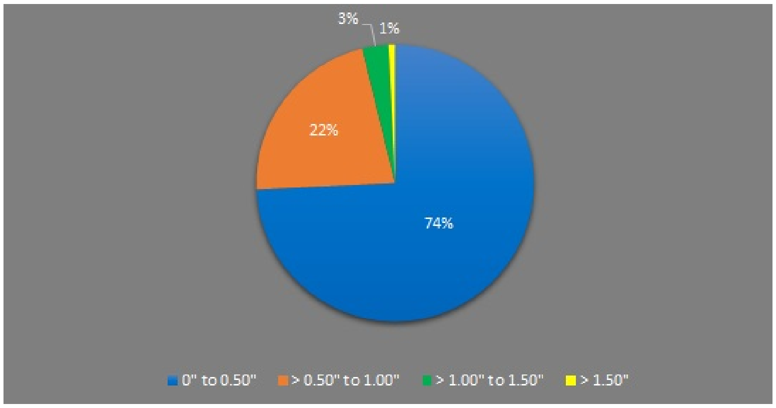

Figure 5. Hail size variance for NOAA reports within 3 miles, as percentages.

<u>Fee-Based Weather data</u>

The authors also compared field estimates with reports of hail available from meteorological services offering estimates of hailstone sizes at a given site for a fee. Two such sources of data were reviewed: Source 1 included data for 219 distinct sites/buildings and Source 2 included data for 235 sites/buildings.

The variance between the field estimates and the hail size estimates from these fee-based weather data sources was determined. Similar to the NOAA data, the variance was charted in 0.25" increments. The results of the data comparisons are shown in **Figure 6** and **Figure 7**.

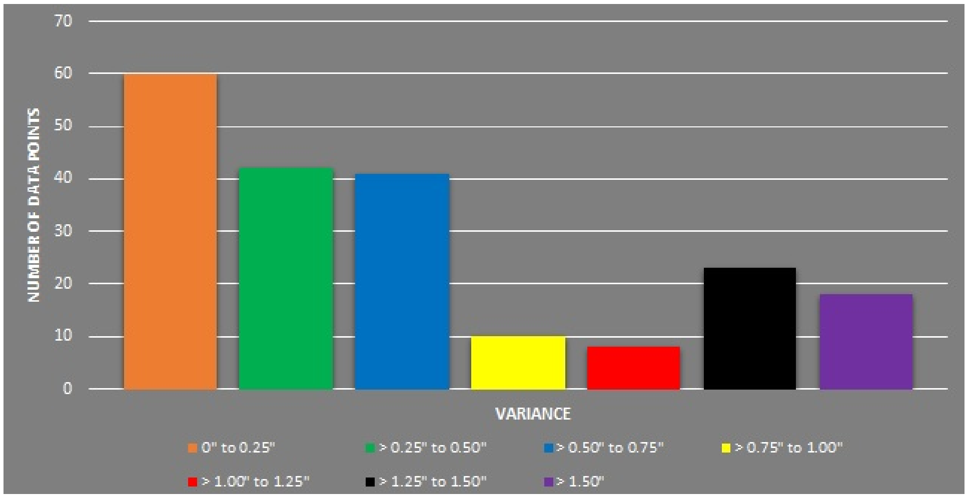

Figure 6. Hail size variance between Source 1 estimates and field estimates.

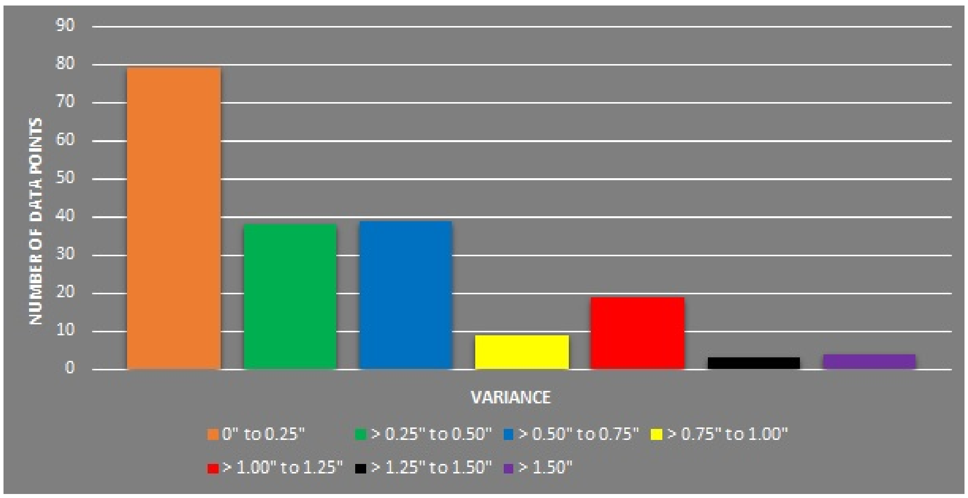

Figure 7. Hail size variance between Source 2 estimates and field estimates.

The variance data was further evaluated and charted in 0.5" increments (0" to 0.5", >0.5" to 1", >1" to 1.5", and >1.5") to show percentages of estimates that fell within each variance range. For Source 1, this evaluation revealed that 51% of site estimates had variance of 0.5" or less compared to the field estimates and that 76% had variance of 1" or less (**Figure 8**). For Source 2, this evaluation revealed that 61% of Source 1 estimates had variance of 0.5" or less compared to the field estimates and that 86% had variance of 1" or less (**Figure 9**).

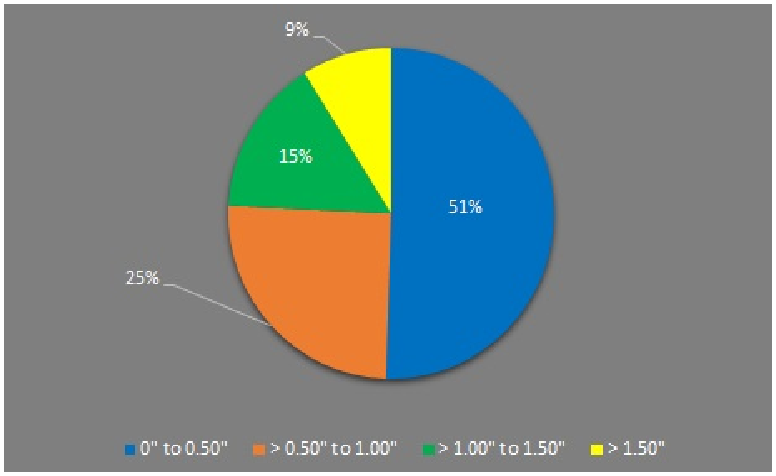

Figure 8. Hail size variance from Source 1 as percentages.

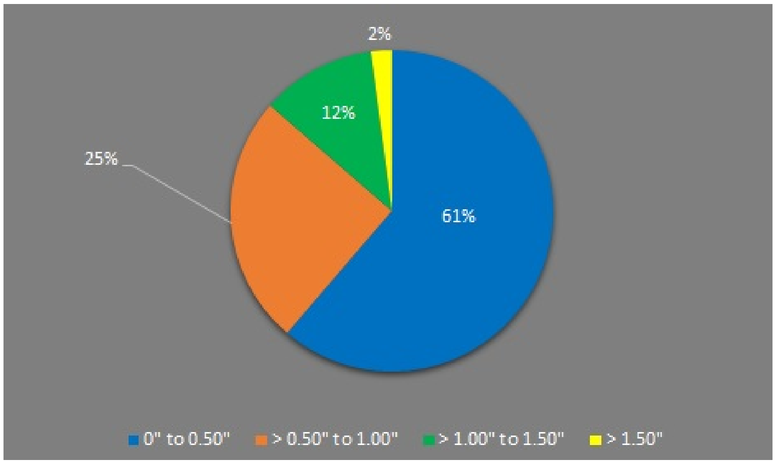

Figure 9. Hail size variance from Source 2 as percentages.

NWS Hail Swath

The authors also compared 229 field estimates of hail size to approximate hail swaths for the April 12, 2016, and April 25, 2016, hail events affecting the San Antonio, Texas area, which were prepared by the NWS. The variance between the field estimates and the hail size estimates from these hail swaths was determined and was charted in 0.25" increments (**Figure 10**).

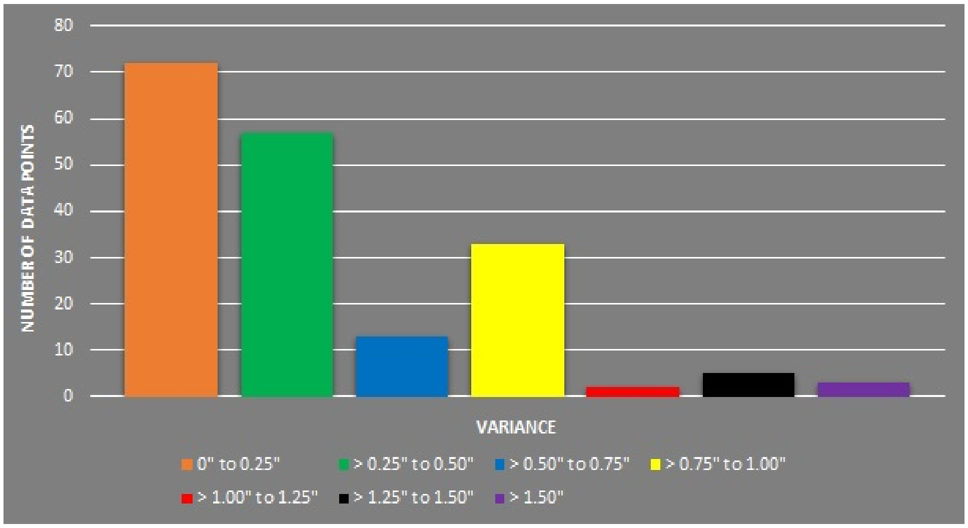

Figure 10. Hail size variance between NWS swath estimates and field estimates.

The above variance data was further evaluated and charted in 0.5" increments (0" to 0.5", >0.5" to 1", >1" to 1.5", and >1.5") to show percentages of locations that fell within each variance range. This evaluation revealed that 70% of swath estimates had variance of 0.5" or less compared to the field estimates and that 95% had variance of 1" or less (**Figure 11**).

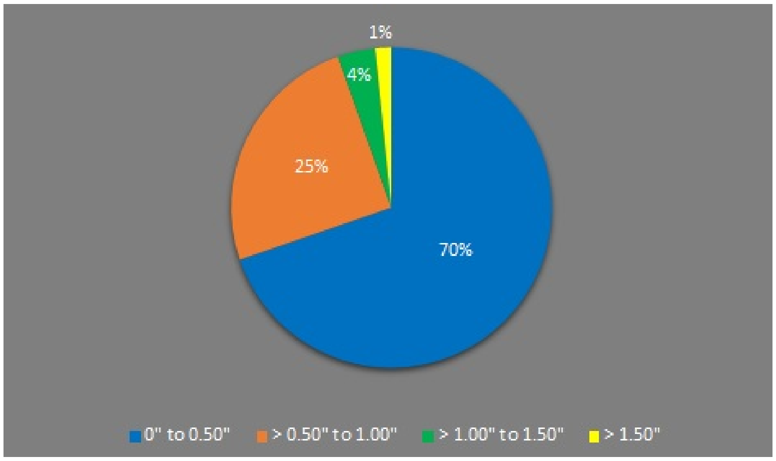

Figure 11. Hail size variance from NWS swath estimates as percentages.

The NWS hail swath only included contours for hail of 1" or greater; therefore, the authors also compared 44 instances where individual sites/buildings were located outside of the hail swath limits (i.e., hail was estimated by NWS to be less than 1") and compared this to field-estimated hail sizes. Considering these 44 sites/buildings, the authors field-estimated hail sizes were less than 1" at 33 of the buildings/sites (75%).

<u>Variance of Hail Size Estimates from Weather Data Sources</u>

In addition to comparison of the weather data to field estimates, the authors compared weather data from the sources discussed previously herein, including NOAA databases (NCEI/SPC), fee-based weather Source 1 and Source 2, and the NWS hail swaths. The comparison was performed by evaluating sites/buildings where two or more sources of data were available. The difference between the upper and lower bounds of the estimated/reported hail sizes were calculated and charted in 0.5" increments (0" to 0.5", >0.5" to 1", >1" to 1.5", and >1.5") to show percentages that fell within each variance range. This evaluation revealed that only 44% of the weather data agreed on the hailstone size to within 0.5" or less, and that 18% had variance exceeding 1" in diameter (**Figure 12**).

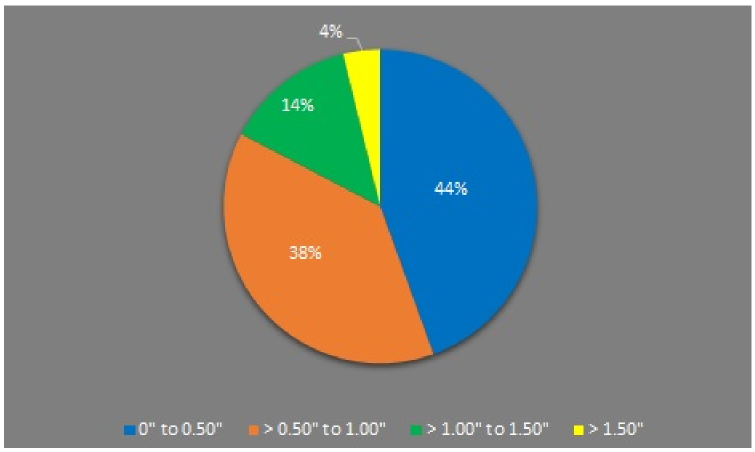

Figure 12. Hail size variance between weather data sources as percentages.

Conclusions

Determination of the approximate hail size is an important part of an investigation for hail damage. Weather data resources, including free data made available by the government and fee-based reports from third-party weather analysis services, can provide insight into the dates of likely occurrence of hail and the approximate size range that may be expected at a given building/site. However, comparison of this data with estimated hail sizes based on field observations and comparisons between the data sources revealed that the accuracy of available weather data varies.

Considering the data set evaluated, NOAA database weather reports of hail size within 3 miles (closest report) were generally within 0.5" of the field estimates at 74% of the sites/buildings evaluated, while hail swaths available from NWS were generally within 0.5" of the field estimates at 70% of the sites/buildings evaluated. Considering fee-based reports from meteorological services offering estimates of hailstone sizes, these estimates were within 0.5" of the field estimates for only 51% to 61% of the sites/buildings evaluated for the sources considered. Therefore, the data showed that spotter-based reports from NOAA databases within approximately 3 miles of the site/building provided the best correlation with field estimates of hail size.

Comparison of the weather data where two or more sources were available for a given site/building revealed additional evidence of the variability of the weather data, with only 44% of the weather data agreeing on the hailstone size to within 0.5" or less, and 18% having variance exceeding 1" in diameter.

Considering the variance between the available weather data and the field estimates and variability between weather data sources regarding hail size, an on-site investigation is essential for the accurate determination of the approximate hail size which has occurred at a given site.

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