Insurance Institute for Business & Home Safety

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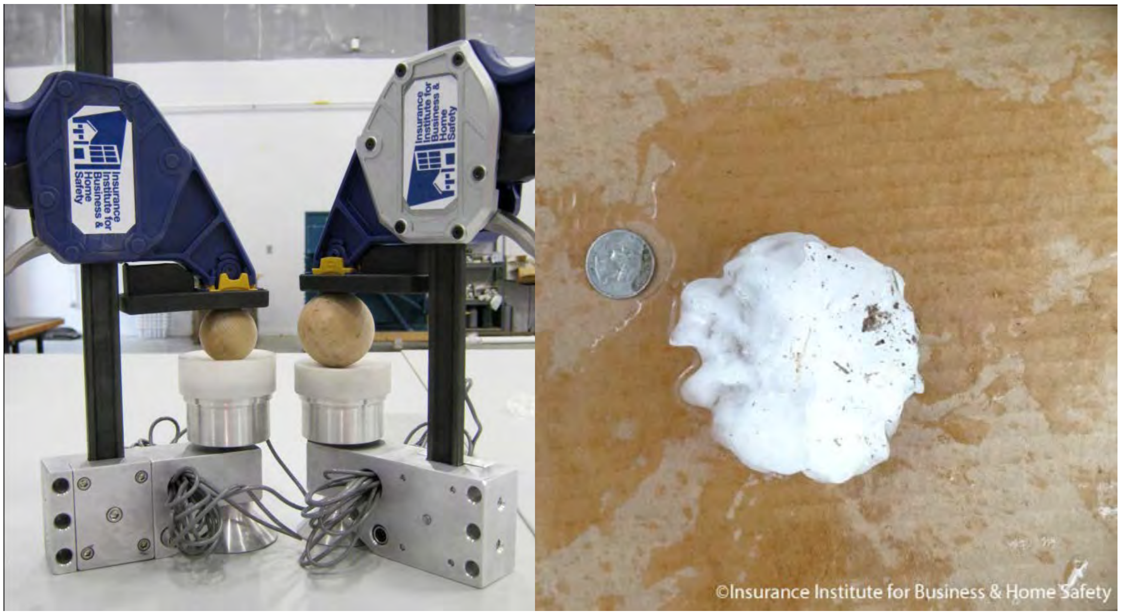

2012 IBHS Hail Field Research Summary

This project provided the first field data about the hardness of hailstones, which is a foundational element of IBHS' research effort to characterize damaging hail.

The Insurance Institute for Business & Home Safety (IBHS) is undertaking a major multi-faceted research effort to study hailstorms with the goal of reducing property losses. As part of this effort, IBHS researchers are evaluating current impact testing standards for roofing products, will be developing improvements to the test standards if warranted, and will be expanding testing to include other kinds of building materials. In addition, the research program seeks to understand modes and severity of damage caused by hail impacts of stones with varying size, density, and hardness; to evaluate how aging and maintenance affect potential damage from hailstorms, and to develop and test repair and replace methodologies.

A foundational element of this research effort is the characterization of damaging hail, which depends on size, density and hardness of hailstones. The field project conducted during the late spring of 2012 described in this summary provides the first field data on the hardness of hailstones, which is measured as the compressive force required to fracture an individual hailstone.

Project Objectives

One of the first objectives of the IBHS research program is to evaluate current impact testing standards by using more realistic artificial hailstones rather than steel or pure ice balls. While the current tests produce valuable measures of the relative resistance of different products to impact related damage, the steel or pure ice balls are not necessarily representative of the damaging hail produced in nature.

IBHS staff recently conducted a field research project to collect scientific information about the properties and characteristics of real hailstones, including size, mass, density, and hardness. Previous studies have cataloged data regarding the size, shape, and density of hailstones. These studies generally refer to hailstones as “soft”, “hard”, or “slushy”, which provides only a qualitative description. Little quantitative information exists regarding the hardness properties of hailstones. IBHS researchers hypothesize that hailstone hardness has a direct bearing on damage caused by hailstones impacts; specifically while harder hailstones may be more likely to shatter brittle materials and crack the substrate of shingles, softer stones may cause less severe damage or cosmetic damage.

Specific objectives of the field study included:

- quantifying natural hailstone hardness, by evaluating the compressive force required to fracture a hailstone;
- pilot-testing IBHS’ newly developed compressive force measuring device and associated software;
- pilot-testing the experimental plans which allowed IBHS staff and vehicles to stay out of harm’s way while positioning them to make quick intercepts after storms had passed; and,
- examining radar and environmental data to develop relationships between those data fields and the characteristics of fallen hailstones.

IBHS Custom-Designed Instrumentation

When IBHS set out to conduct hail research, the Institute was aware it was breaking new ground and that would demand the development of new technologies. The first challenge was the creation of a rugged instrument to measure the hardness properties of real hailstones. Within two years of opening the IBHS Research Center, the Institute's staff designed and developed instrumentation to gather these data.

The custom-designed instrument features a clamping handle in which a hailstone can be compressed incrementally until the point at which it fractures. A load cell attached to the bottom plate of the device measures the force applied to the hailstone. Figure 1 is a photograph of the two hardness instruments used in the field study, which also involved use of a digital scale, caliper and GPS camera. A unique piece of software was also developed to interface with the instrument and record the data, as well as GPS location.

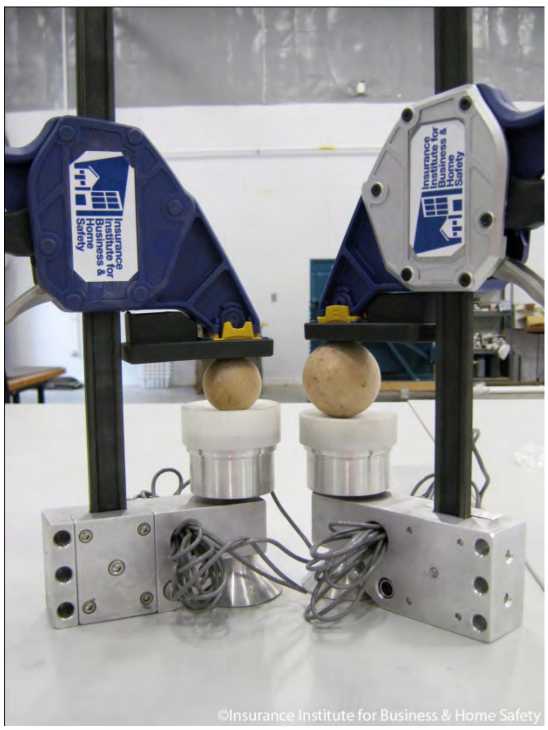

Figure 1. Two IBHS prototype field compressive force measurement devices.

Role of Severe Weather Forecasting for Field Operations

The study was lead by IBHS Research Scientist Dr. Ian Giammanco, a meteorologist who served as field coordinator for the project, and IBHS Research Engineer Dr. Tanya Brown, a meteorologist who served as logistics coordinator. They deployed two research teams to the Great Plains region of the U.S., where severe hailstorms most commonly occur. The teams arrived in Kansas City, Missouri, on May 25, 2012, after long-range computer forecast models indicated that several consecutive days of severe hailstorms were likely in the area. Once in the field, the project coordinators closely monitored weather conditions and evaluated short-term forecasts to determine where hailstorms were likely to develop. Then, they positioned the teams daily to those locations. Once thunderstorms began to develop, Giammanco identified a potential target storm and determined its likelihood of severe hail by evaluating radar data in near real-time. This allowed him to safely position the teams near the target storm to wait until it passed before safely beginning data collection.

Data Collection Methods

Once the storm passed, the teams drove through the radar-estimated hail swath to identify where hail had actually fallen. If hailstones were large enough to measure, ½ in. or larger, the teams selected deployment sites and began data collection. If not, they moved further into the hail swath in search of larger stones. Team members collected a sample of stones which were photographically cataloged, and the dimensions and mass of each were recorded. A schematic of the dimensions measured is provided in Figure 2. Then the hailstones were fractured using the compressive force device. The dimension and mass are vital for normalizing compressive force data, to allow for comparison of results between stones. Figure 3 is an example of a photograph used to catalog hailstone data. The number of stones measured at each deployment site primarily depended upon the amount of time between storms, or upon the desire to continue to operate on the original target storm as it moved further away.

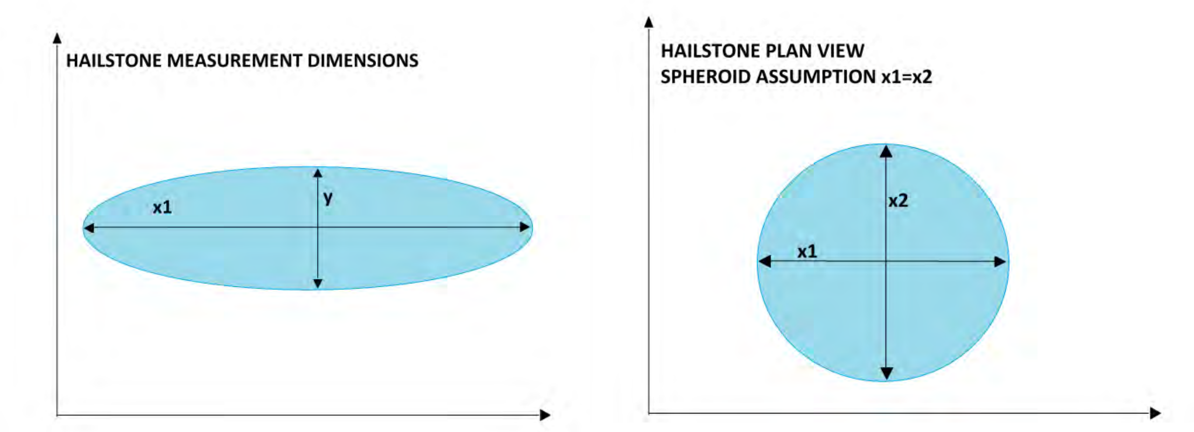

Figure 2. Diagram of the measured dimensions of hailstones. Each stone was assumed to be a spheroid in shape with dimensions x_1 and x_2 equal. Only dimensions x_1 and y were measured in the field.

Figure 3. A measured hailstone collected on May 29, 2012 in Kingfisher, Oklahoma.

During the two-week project, teams traveled to Colorado, Kansas, Nebraska, Oklahoma, Texas and Wyoming and successfully collected 12 significant datasets on hailstones from nine separate storms on seven days. Many hailstones measured more than 1.5 in., including a single stone larger than 3 in. Table1 below provides summary statistics from the 2012 field deployment. The compressive force required to fracture each hailstone was normalized by the estimated cross-sectional area ($\pi x_1 y$) of the stone perpendicular to the compressive force, calculated from the dimension measurements. This normalization technique gives the resulting compressive force of fracture in pounds/inch^2 (psi). As shown in Figure 4, this normalization technique results in a range of values of 9 psi to more than 620 psi. Additionally, Figure 5 presents the compressive force of fracture with no normalization, as compared to the mass of the stone. It is important to note, there are many ways in which the compressive force data could be normalized. Continued field data collection and further analysis, along with more sophisticated measuring tools are needed to determine the best approach for normalization. The analysis methodology also must be evaluated for laboratory-created hailstones. Additionally, it should be emphasized that the sample sizes collected during the field project are miniscule when compared to the total number of hailstones that fall in a given storm. This emphasizes the need for a large-scale field project over many years to continue cataloging hailstone data to establish a more robust database.

Table 1: Summary Data.

Deployment ID	Date	Location	Dual-Pol Coverage	No. stones measured	Largest stone dimension (inch)	Mean stone dimension (inch)	Smallest stone dimension (inch)	Maximum compressive force (psi)	Mean compressive force (psi)	Minimum compressive force (psi)
1A1	05/27/2012	Ravenna, NE	No	5	0.76	0.53	0.33	193	127	103
2A1	05/28/2012	Lindsay, OK	No	32	1.87	1.09	0.45	321	130	27
3A1	05/29/2012	Kingfisher, OK	KVNX	20	3.05	0.91	0.16	540	181	19
3B1	05/29/2012	Greenfield, OK	KVNX	17	1.20	0.76	0.24	628	190	39
4A1	06/01/2012	Channing, TX	KAMA	45	1.23	0.71	0.28	610	124	23
5A1	06/02/2012	Eads, CO	No	17	1.31	0.64	0.21	110	57	27
6A1	06/06/2012	Remmington Ranch, WY	No	16	1.21	0.80	0.48	69	29	16
6A2	06/06/2012	Remmington Ranch, WY	No	20	1.27	1.01	0.65	79	34	9
7A1	06/07/2012	Cheyenne, WY	No	8	1.48	1.23	0.73	93	55	29
7B1	06/07/2012	Cheyenne, WY	No	14	1.44	0.96	0.56	402	84	18
7B2	06/07/2012	Cheyenne, WY	No	35	2.13	1.28	0.72	109	72	38
7B3	06/07/2012	Cheyenne, WY	No	10	1.75	1.33	0.92	114	77	27

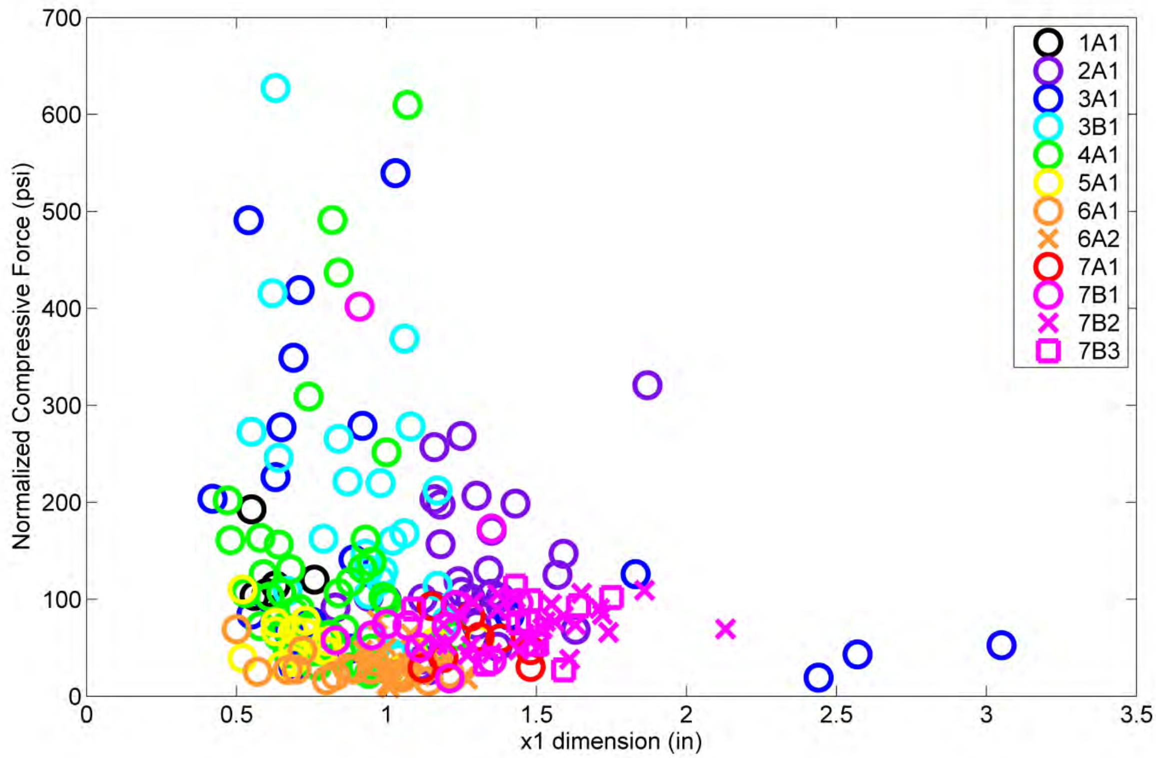

Figure 4. Normalized compressive force as a function of the measured x_1 dimension. Each color circle represents data points from a single storm, while additional symbols of the same color indicate more than one deployment on a single storm.

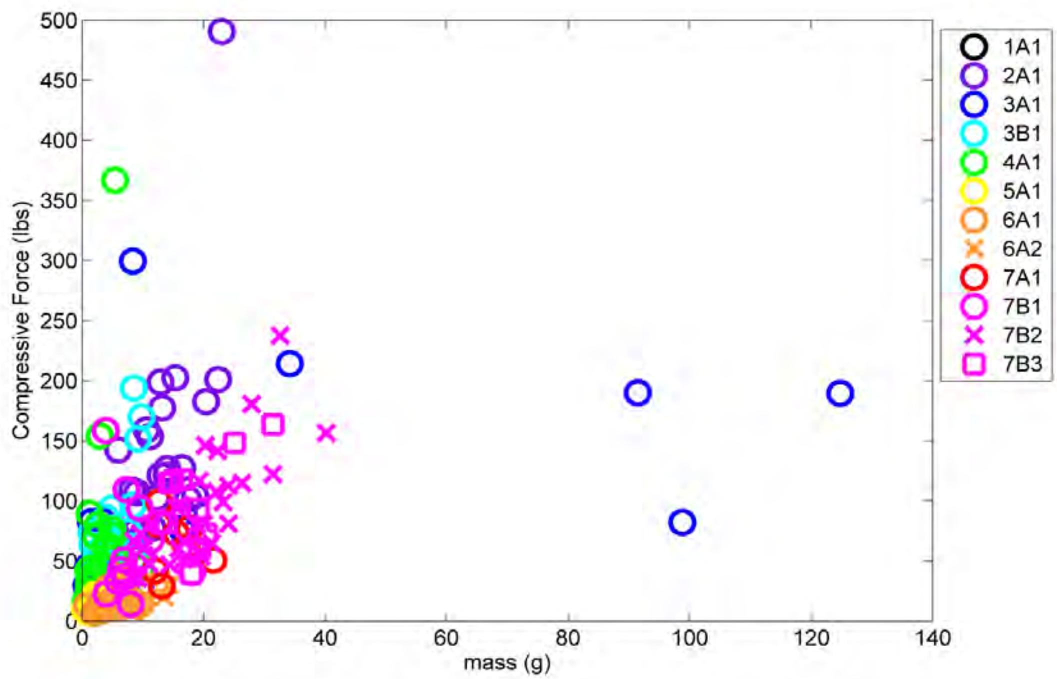

Figure 5. Measured compressive force as a function of the measured mass. Each color circle represents data points from a single storm, while additional symbols of the same color indicate more than one deployment on a single storm.

Research Partnership

In addition to collecting field data, IBHS partnered with member company WeatherPredict Consulting Inc., an affiliate of RenaissanceRe, to collect environmental characteristics data. This firm focuses on modeling atmospheric hazards and vulnerability. They supported the IBHS project by archiving radar, weather balloon sounding profiles, and computer model initialization data for each storm surveyed during the field deployments. IBHS will use these data in the coming months to determine if certain environmental conditions result in different hailstone characteristics. Identifying such conditions is expected to provide information that may prove important in risk modeling applications. Preliminary observations, shown in Figures 4 and 5, indicate hailstones within a particular storm seem to have similar hardness characteristics (i.e. the data points of each color are relatively close together), while there is larger variability in the hardness values from storm-to-storm (i.e. more spread between the different color datasets). Analysis of the archived weather data will begin to establish why.

These findings are preliminary and further analysis is required, which reinforces the need for larger sample sizes from each storm, as well as a larger number of storms, requiring a larger, multi-team, multi-year project.

Application of Field Findings in Laboratory Testing

The successful field study provided valuable data and insights for shaping ongoing work at the IBHS Research Center. IBHS is presently manufacturing artificial hailstones for use in impact testing inside the large test chamber, as well as in the small impact testing lab. Researchers have completed various experiments to alter the density of artificial hailstones to match with real-world results. In addition, the hardness of the laboratory produced hailstones has been measured using an instrument that is similar to the field instrument in Figure 1. However, until the field data on hardness was collected, there was no basis for comparison, to determine if the laboratory-produced hailstones were realistic in terms of hardness. Using the field data, IBHS is now beginning to evaluate the hardness of the artificial hailstones and to formulate manufacturing techniques that produce artificial hailstones that are representative of both the density and hardness of natural hailstones. This will enable IBHS engineers to appropriately analyze the impact of hail on buildings and specimens tested at the Research Center.

A comparison of the field and laboratory data on the compressive force required to fracture hailstones is provided in Figure 6. Each of the different types of laboratory hailstones (e.g. distilled water, tap water, seltzer water ratios, crushed ice) is highlighted in a different color. It is important to note that planned future calibration may result in small changes to the data presented here. It is also important to note that in working to understand the hardness of laboratory hailstones, the manufacturing process has been altered, such that the density is not as controllable as it previously was. In moving forward, it will be important to strike a balance between the need to vary the density and the hardness properties of the laboratory hailstones.

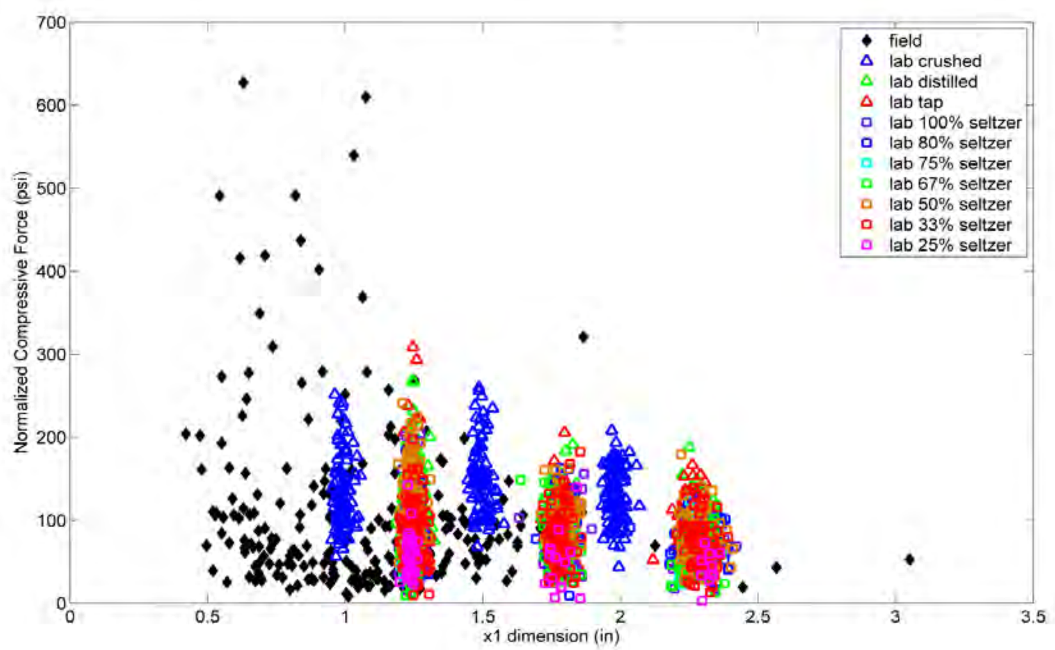

Figure 6: Comparison of field and laboratory compressive force values as a function of the measured x_1 dimension.

In comparison to the field data, the measured compressive force of fracture for the smaller sized laboratory hailstones falls within the range of the field stone data, although there is a much larger range in the field stones. At larger sizes, the opposite is true, where there is larger variability in the laboratory hailstones compared to the field stones. Given the small field sample size for the biggest hailstones, it is difficult to say with confidence that the larger laboratory stones are comparable to the real hailstones in terms of hardness, but this emphasizes the need for further measurements of the larger real hailstones.

It is also apparent that there is a large variability in the range of compressive forces required to fracture each type of laboratory hailstone. Some of the variability may be random in nature, but some may be due to inherent flaws in the laboratory stones which exist because of the conditions in which they are manufactured and extracted. Molds for laboratory stones are filled at room temperature and pressure, frozen in temperature controlled freezers, and stones are extracted at room temperature. These conditions differ from the atmospheric conditions in typical thunderstorms.

These comparisons are encouraging, illustrating that although there is variability in the laboratory data, the artificial hailstones are reasonably representative of the natural hailstones, especially for the smaller size stones, and further work will be needed to distinguish a relationship for the larger stones. Given the large range of compressive force values obtained from fracturing the laboratory hailstones, it seems that there are two possible paths that researchers can take. One option is to invest a significant amount of time and effort investigating ways to control the hardness values and reduce the variability of laboratory stones. An alternative method would be to conduct impact testing that is statistical in nature, such that multiple impacts of artificial hailstones are used to ensure a representative distribution of hailstone hardness. Because of the destructive nature of the compressive force testing in which the hailstones are crushed, it is impossible to know the exact value of compressive force for any hailstone which is used for impact testing, so in this case, researchers would need to rely on a statistical distribution of values.

Summary

In the upcoming months, IBHS will be digging more into the field data to determine relationships between hardness and the other hailstone characteristics. In addition, researchers will begin evaluating environmental characteristics data to try to determine relationships between weather conditions and the types of hailstones produced. In addition, they will be formulating ideas for altering the laboratory production of hailstones to simulate the properties quantified by this pilot study, and will be brainstorming methods for statistical impact testing.

The Institute will continue to adapt instrumentation, software, and experimental plans to improve them for a larger-scale field study in the future. This is an important step moving forward from any pilot study. Researchers also will explore new instrumentation possibilities to document the hail size distribution, duration of severe hailfall events, and impact angles for each deployment as well as a ruggedized video collection device to stage within the hail swath.