Research to Operations: A Hail Detection Network

Insurance Institute for Business & Home Safety®

Hail Observations

Hail events cause over $1 billion dollars in property damage each year and are some of the most poorly observed weather hazards[1,2]. It is generally accepted that the network of observing stations operated by the National Oceanic and Atmospheric Administration (NOAA) is too coarse to capture the hazards and frequencies associated with severe convective storms. In a recent paper by Kunkel et al. (2013), hail (and all severe convective storm hazards, including tornadoes and thunderstorm winds) was considered in the lowest category of detection knowledge[2]. The majority of the available information on hail and its frequency has come from local storm reports (cataloged into NOAA's monthly report, Storm Data). These reports can be subject to large spatial and reporting biases resulting from population density. The observations do not go beyond providing the maximum diameter found by whoever submitted the report. Research underway by the Insurance Institute for Business & Home Safety (IBHS) and partners has begun to explore ways to improve hail detection in an effort to improve event characterizations, radar detection, forecasting, and mitigation of the hail hazard.

Hail Impact Disdrometers

In 2014, scientists and engineers at the IBHS Research Center began investigating in-situ measurement strategies to detect and sample hail within a thunderstorm. The need was for a deployable or fixed platform capable of sensing hail size and kinetic energy distributions while also withstanding large hail impacts. Available commercial hail disdrometers (sensors that measure particle size distribution) were capable of capturing the needed data, but the high costs and fragile nature of these instruments prohibit the growth of a fixed station or rapidly deployable network. Fortunately, the emergence of low-cost, open-source microcontrollers, sensor packages, and developer environments has opened the door to more cost-effective and rugged solutions. This led to the development of two prototype hail impact disdrometers which were laboratory- and field-tested in 2014. Both designs feature a metallic impact plate (based on that used in a similar system developed and deployed at NASA's Kennedy Space Center[3]), a piezoelectric ceramic disk to measure the vibration caused by the hailstone impact, and a low-cost, open-source microcontroller (Arduino Due) to read and output the data.

The successful pilot testing of the prototypes in 2014 fostered the construction of a fleet of six rapidly deployable impact disdrometer probes. The network was used for the first time during the 2015 annual IBHS hail field program. A sample of the estimated hail size concentrations collected from a thunderstorm during the 2015 field program is shown in Figure 1 on the following page. While these platforms are specifically configured for use as an adaptive research network for fine-scale (at scales less than 10 miles) sampling of hail, their success has fostered the concept of a fixed-platform, permanent hail detection network.

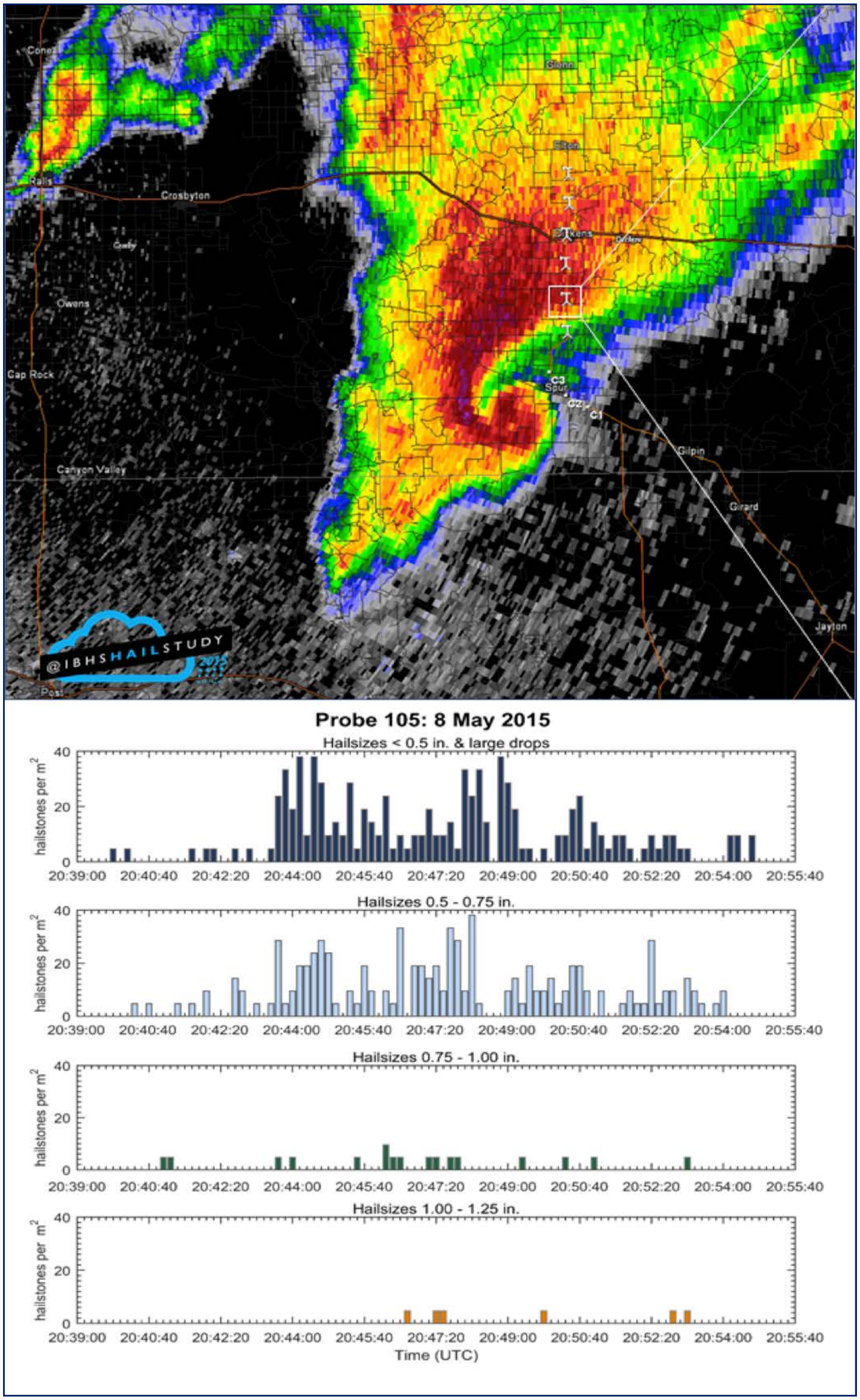

Figure 1. *Radar image (left) and estimated hail size concentrations (right) collected by a deployable hail disdrometer from a supercell thunderstorm on May 8, 2015 near Spur, TX.*

Developing a Hail Detection Network

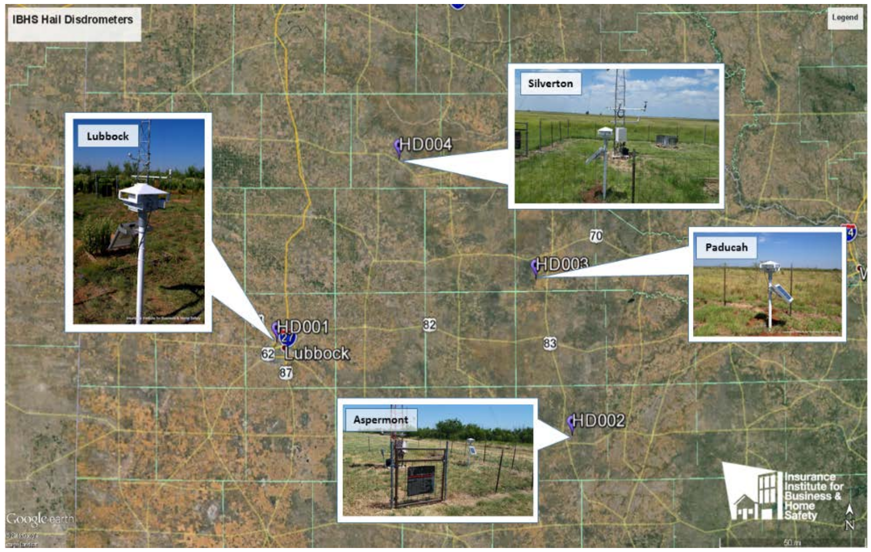

Figure 2. *Map with photographs of the four West Texas Mesonet stations equipped with hail impact disdrometers.*

The use of enhanced observing networks to supplement the conventional observation density provided by NOAA and the National Weather Service has been ongoing for several decades. These range from research-grade networks operated by academic institutions and the private sector (e.g., West Texas Mesonet, Oklahoma Mesonet, Kansas Mesonet, WeatherFlow™, and MesoWest), to "SchoolNets" implemented by local television stations, and personal weather stations compiled into crowd-sourced observations (Weather Underground™). While these have varying levels of capability and quality, the overarching goal is to provide more observations of the atmosphere.

In a 2015 pilot program, IBHS and Texas Tech University began to implement a hail-observing capability on stations within the West Texas Mesonet. This network currently operates over 90 stations across West Texas and Eastern New Mexico and is described in detail at www.mesonet.ttu.edu. Each station collects the standard meteorological variables (wind speed, wind direction, temperature, humidity, barometric pressure, solar radiation, and precipitation) as well as additional agriculture-based variables (e.g., soil temperatures, leaf wetness, etc.). Four stations were selected to receive hail impact disdrometers developed at IBHS. The autonomous instruments were installed in August, 2015 and are currently operating in tandem with the stations shown in Figure 2. The goal of the pilot program is to determine the ruggedness of the design and its ability to collect data over long durations with limited maintenance requirements. Currently, the platforms store data locally and are not transmitting real-time data, though the hardware for real-time data transmission is installed on board each system for future use. Additional development is underway at the IBHS Research Center to enable the remote reception and archival of data.

Expanding Capabilities

The mission of the impact disdrometer program is to foster the growth of partnerships with various groups interested in more detailed information on hail events. The stakeholders identified that would greatly benefit from improved hail observations are:

- Property insurers—improved event characterization, real-time data, claims support.
- Risk modelers—improved observations provide ground truth data for calibration of hail swath frequency and distribution models.
- NOAA/National Weather Service—warning decision-making, verification, forecasting.
- Academic researchers—radar hail detection, numerical forecasting, storm-scale modeling.
- Private weather product vendors—swath product validation and tuning.

An idealized view of what a piece of a larger hail detection network could look like is shown in Figure 3.

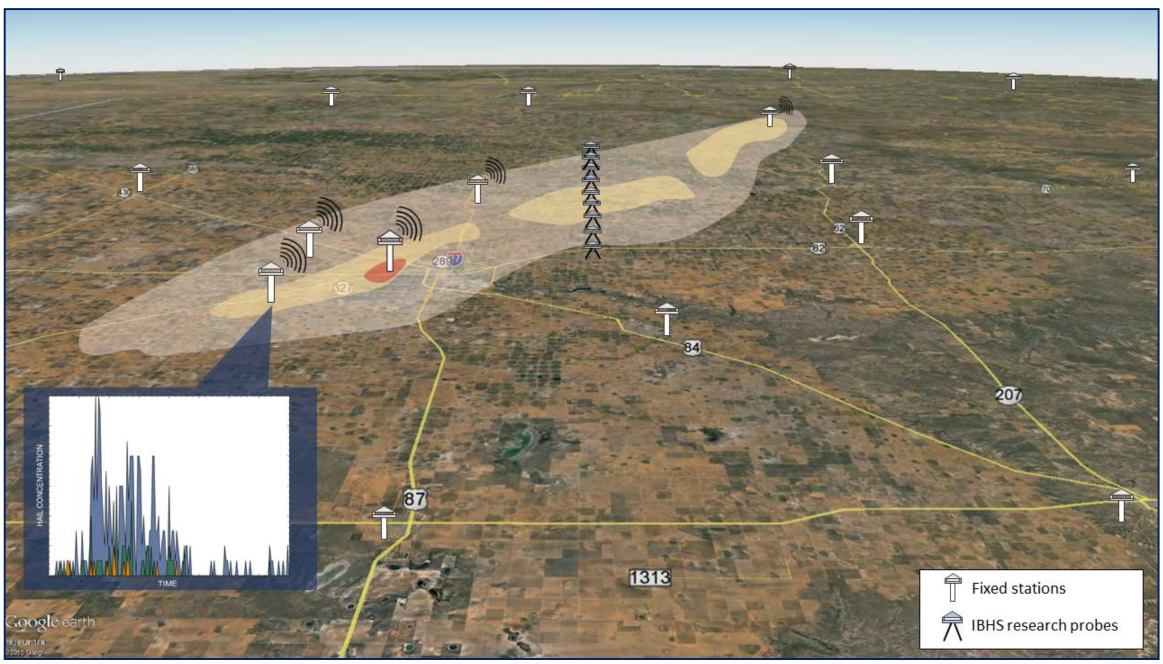

Figure 3*. Conceptual view of a real-time hail detection network and hail swath, augmented by a research deployment of the IBHS mobile disdrometer fleet (line of sensors near the center of the map).*

The initial pilot testing phase of the first four fixed disdrometers is scheduled to last through the summer of 2016. Autonomous disdrometers will also be deployed at the IBHS Research Center and IBHS' remote aging farm installations in Madison, WI and Amelia, OH. The priority over the next six to twelve months is to develop real-time data transmission and data archival capability, and to identify ways to streamline the production of the instruments. Production-ready fabrication and assembly drawings will be produced, and a custom electronic circuit board will be developed to more easily integrate components. This is the first major step toward improving production efficiency and is crucial for the program to expand. A secondary objective is to modify the existing design to communicate easily with commercial data loggers and controllers. This capability will allow external partners to integrate the instrument into their particular system and merge the hail information with their existing data streams. With the successful completion of these milestones, IBHS can begin to explore collaborative opportunities. We will continue to document our progress in the event future development warrants patent and intellectual property opportunities. The current system builds upon past scientific and engineering work in published literature, and utilizes open-source electronic components and open-source developer environments.

Existing meteorological observing networks are the first target audience for collaboration as they offer complementary comprehensive meteorological data to aid ongoing research at IBHS. These networks and the organizations that operate them (e.g., Texas Tech University and the University of Oklahoma) also have extensive experience with maintaining observing systems. It may also be possible to leverage existing data transmission infrastructure already in use by these networks to supply real-time data. Once the true functionality and ruggedness of the platforms has been evaluated, opportunities for expansion to other sites can begin. An estimated timeline illustrating development milestones and program goals is provided in Figure 4 on the following page. The current instrumentation and deployment site specifications are also provided in Appendix A. Future plans also include the development of a database available to IBHS member companies (and potentially other collaborative institutions) to allow query access to historical datasets collected by the network and by the annual field research program.

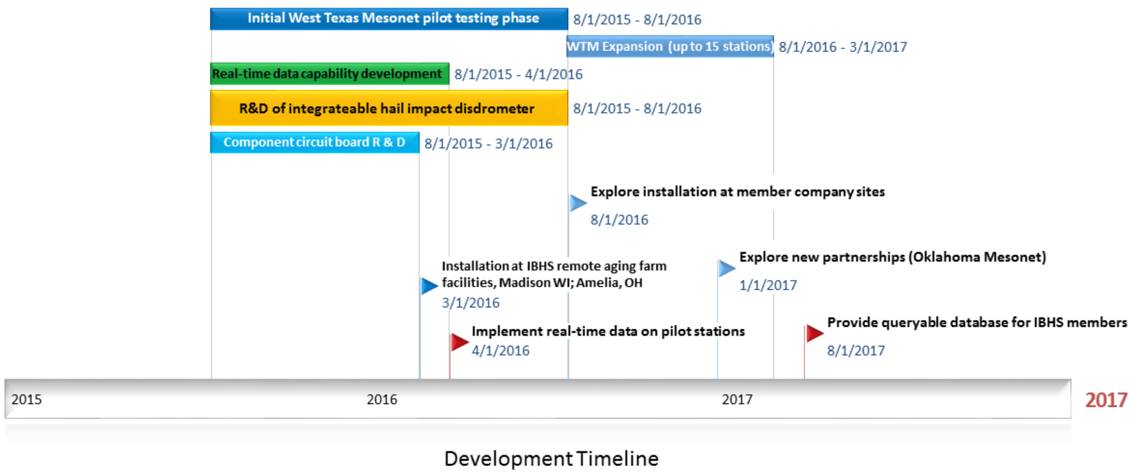

Figure 4. *Anticipated development timeline including research and development goals, capability milestones, and expansion timeframes.*

Research to Operations

The significant amount of interest in improving our ability to detect and quantify damaging hail events warrants investigating ways to transition work, which began as research, toward an operational framework. It also offers an opportunity to provide a unique service to IBHS' member companies. The overall scope can be modeled after the National Center for Atmospheric Research's (NCAR) GPS dropwindsonde program. These instruments are used widely in applications in which a vertical profile of the atmosphere is required (e.g., Hurricane Hunter Aircraft) and developed, assembled, and maintained at the NCAR laboratory. Through partnerships with vendors, components are mass produced externally and then assembled; then each completed instrument is calibrated. The units and associated software are then sold to research groups who require the system for measurement use (GPS dropwindsondes are purchased by NOAA, U.S. Air Force, NASA, Japan's Meteorological Agency and various academic institutions). NCAR is responsible for maintaining the data acquisition system and quality control software. The program is managed by a Senior Scientist with support from two full-time laboratory technicians. While NCAR is a much larger institution than IBHS, its funding structure is similar. The program, while not identical, appears plausible and could be developed and housed at IBHS. The potential revenue stream could be used to supplement IBHS research programs and/or provide support for the staff necessary to sustain the program.

Appendix A: Instrument Characteristics, Site Specifications, and Estimated Costs

IBHS Hail Impact Disdrometer (Rev 1.)

Sampling: Kinetic energy, size concentration estimates at 10 second intervals

Measurement Height: 1.5 m above ground level

Impact Kinetic Energy: Minimum detectable kinetic energy: 0.15 Joules

Estimated Hail Size Resolution: 9 size groups:

- < 0.5 in. and large drops
- 0.5–0.75 in.
- 0.75–1.00 in.
- 1.00–1.25 in.
- 1.25–1.50 in.
- 1.50–1.75 in.
- 1.75–2.00 in.
- 2.00–2.50 in.
- > 2.50 in

Figure 1A. *Photograph of a fixed hail impact disdrometer deployed at a West Texas Mesonet station.*

Size estimates are based on median kinetic energy to diameter relationships from Heymsfield et al. (2014)[4]. Size estimates are subject to large errors during extreme winds.

Instrument Output: RS232 Serial, MicroSD local storage (ASCII text)

Power Requirements: 12 VDC input

Mounting: Attaches to 1.75–2.25 in. pipe diameters

Deployment Site Requirements

- 100 sq ft (~10- x 10-ft) open area with unobscured view of the sky; no vertical obstructions (minimize hailstones rebounding off other objects); and away from any high voltage electrical hazards or RF interference sources
- Available internet access (Wi-Fi or LAN)
- Mounting pipe with 1.75–2.25 in. diameter, at 1 m above ground/surface
- 110 VAC power supply preferable (solar panel can also be used for more remote locations)

Estimated Unit Costs

Hardware and materials cost per unit: **$550.00**
External fabrication estimated cost (labor per unit): **$300.00**
Total: **$850.00***

**Additional overhead cost for instrument installation by IBHS staff. Costs may vary regionally.*

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[1] MunichRe (2014), 2013 Natural Catastrophe Review, MunichRe NatCat Services, Philadelphia, PA., www.munichre.com/en/reinsurance/business/non-life/natcatservice/annual-statistics/index.html.

[2] Kunkel, K. and others, 2013: Monitoring and understanding trends in extreme storms. Bull. Amer. Meteor. Soc., **94** (4) 499–514.

[3] Lane, J.E., R.C. Youngquist, W.D. Haskell, R.B. Cox, 2006: A hail size distribution impact transducer, J. Acoust. Soc. Am., **119**, 47–53.

[4] Heymsfield, A.J., I.M. Giammanco, R.L Wright, 2014: Terminal velocities and kinetic energies of natural hailstones, Geo. Phys. Res. Lett., **41,** 8666–8672.