Development of a Rapidly Deployable, Low-Cost, Network of Hail Impact Disdrometers

Ian M. Giammanco*, Conrad J.P. Estes, W. Edwin Cranford
Insurance Institute for Business & Home Safety

INTRODUCTION

Severe hail events are responsible for nearly $1 billion dollars in annual insured property losses in the United States (Changnon *et al.* 2009). With the significant property losses due to hail events, improvements to convective resolving storm-scale models, and the dual-polarimetric upgrade to the WSR-88D network has produced a renewed interest in understanding the characteristics of hail at the ground. The true damage potential of hail is dependent upon the hail size distribution and duration of the event. Hail pads are effective in capturing size distributions but require significant manpower to maintain them and lack any temporal resolution. There remains a need to capture the time history of hail size distributions.

Presented here is the exploration and development of a low cost hail impact disdrometer and its use in a deployable, adaptive network.

CONCEPT & DESIGN

- Could a low-cost platform using open source "maker" components be developed?
- Allow for a large number of probes.
- Adaptive deployable network
- Designed for hail only
- Adapting the design of Lane *et al*. (2006).

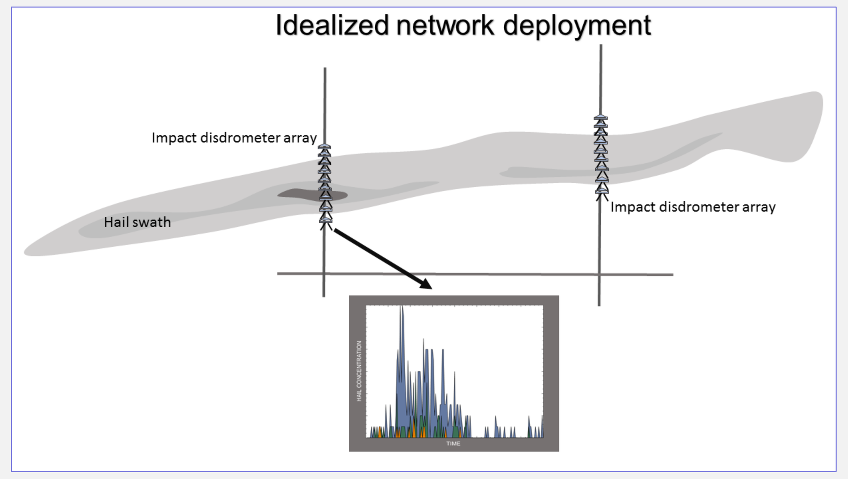

Figure 1: Conceptual view of a deployment of an adaptive network of hail Impact disdrometers, following the in-situ, adaptive observing network concept of Weiss and Schroeder (2008).

IMPACT PLATE DESIGN

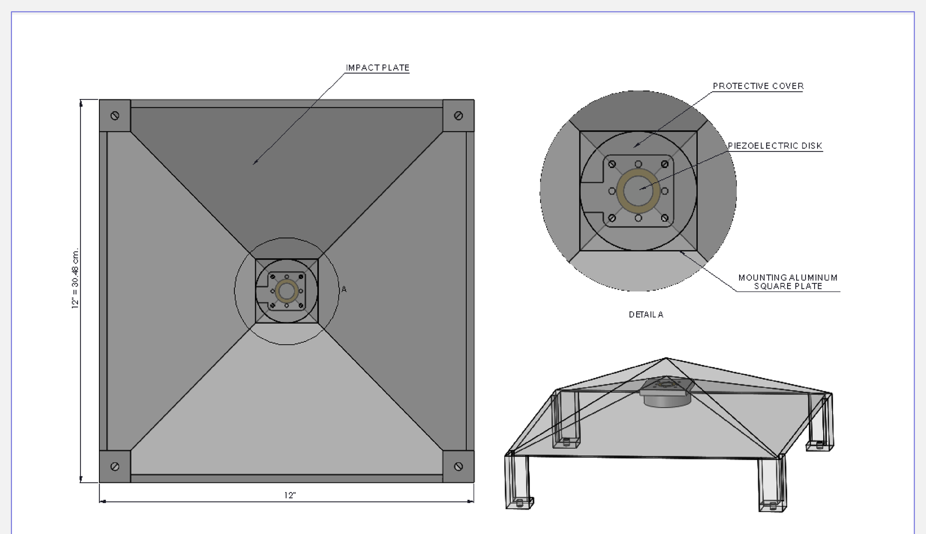

Figure 2. Schematic overview of the 4-side pyramid shaped impact plate and piezoelectric disk mounting configuration. The general design was adapted from Lane et al. (2006).

- 4-sided shallow pyramid impact plate, following the design of Lane *et al.* (2006).
- 0.25 in. aluminum plate for fabrication.
- Piezoelectric sensor mounted on a flat plate underneath.

HARDWARE LAYOUT

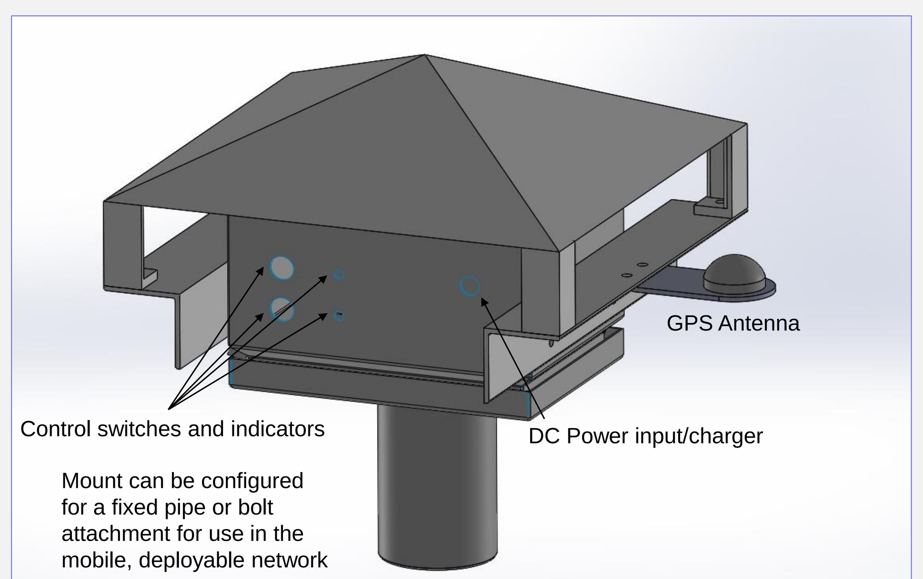

Figure 3. Design overview of the hail impact disdrometer platform.

- Plate is secured to the data acquisition enclosure
- Enclosure houses internal battery and data acquisition components (Figure 3).
- GPS antenna mount.
- Engineering tripod for rapid deployment or fixed pipe fitting.

DATA ACQUISITION SYSTEM & PROBE PLATFORM

DATA ACQUISITION

- DAQ system was assembled with "maker" components (Figures 4 and 5).
- Rechargeable sealed battery.
- Arduino Due achieved 5 kHz timed sampling, with microSD, and GPS modules.

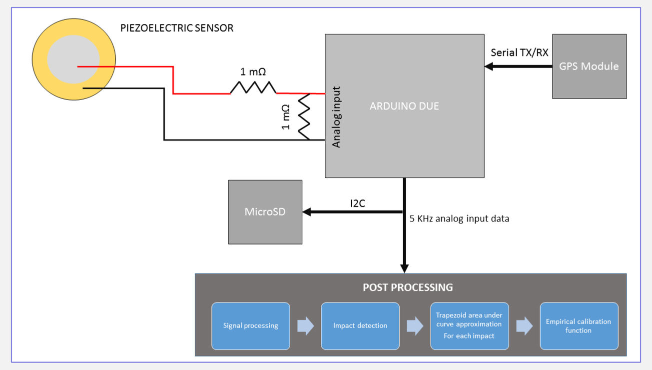

Figure 4: Diagram of the data acquisition system.

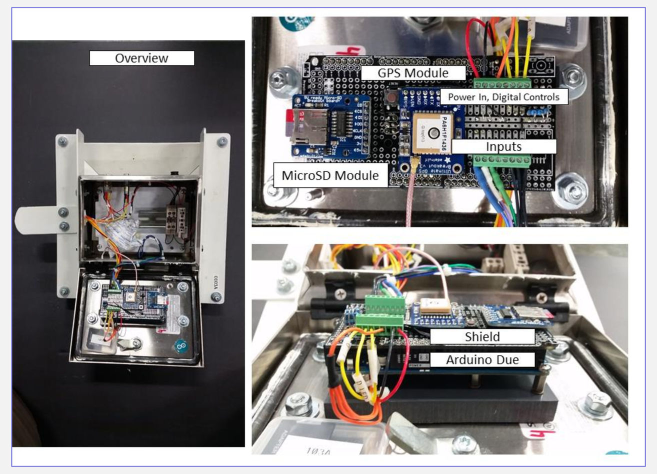

Figure 5: Data acquisition system and components.

DEPLOYMENT PLATFORM

- Impact plate and DAQ enclosure assembly attached to a small, adjustable engineering tripod (Figure 6).
- Rapid deployment (30-60 seconds).
- Six probes developed in 2015.

Figure 6: Photograph showing a probe deployed during the 2015 field campaign.

CALIBRATION

- Impact signal is integrated in time using a trapezoid approximation to give an area under the signal curve (Figure 7), similar to Joss and Waldvogel (1967).
- Probes were impacted by laboratory ice spheres (Figure 8).
- Power-law fitted to area under the signal curve and kinetic energy relationship (Figure 9).

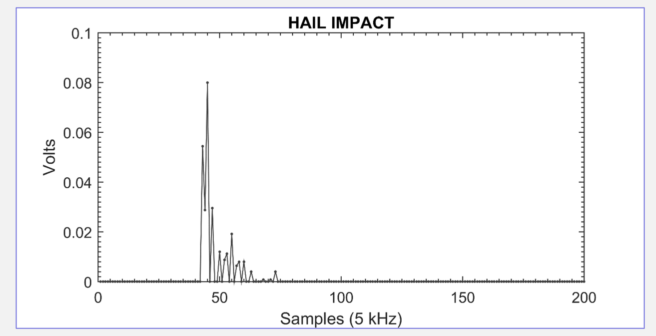

Figure 7: Example of a measured hail impact time history. The Arduino Due does not have the ability to capture voltages < 0 without an additional analog to digital module.

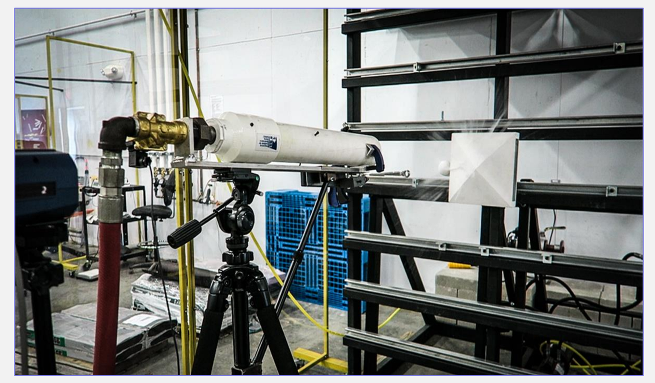

Figure 8: Photograph of the laboratory calibration of a disdrometer probe. Impact angle of ~ 20° was used. Impacts were randomly distributed across the surface area of the plate.

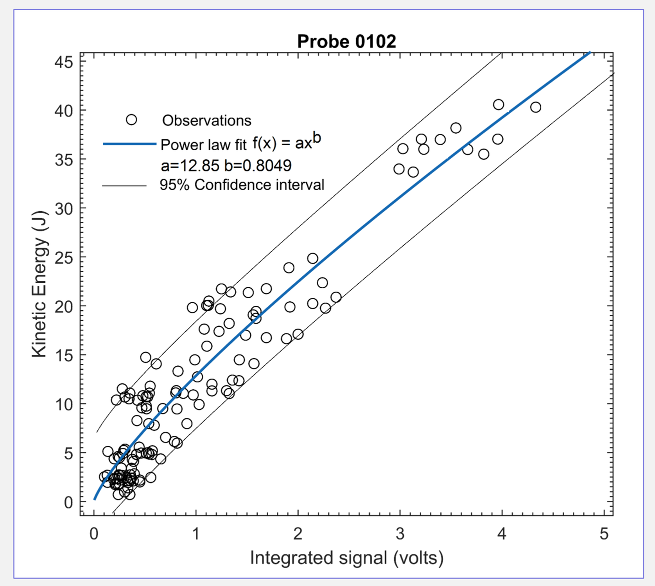

Figure 9: Calibration curve (blue) and 95% confidence interval (black) for disdrometer probe 102.

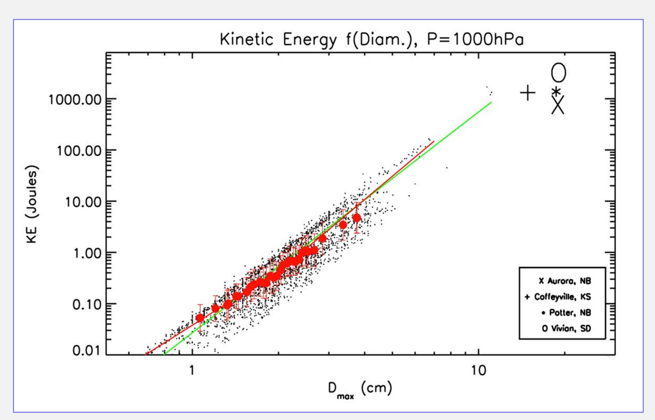

Figure 10: Calculated kinetic energy shown as a function of maximum hailstone diameter from Heymsfield et al. 2014. The median power-law fit is shown in red. The Laurie (1960) curve is also provided (solid- green).

CASE STUDY: 8 MAY 2015

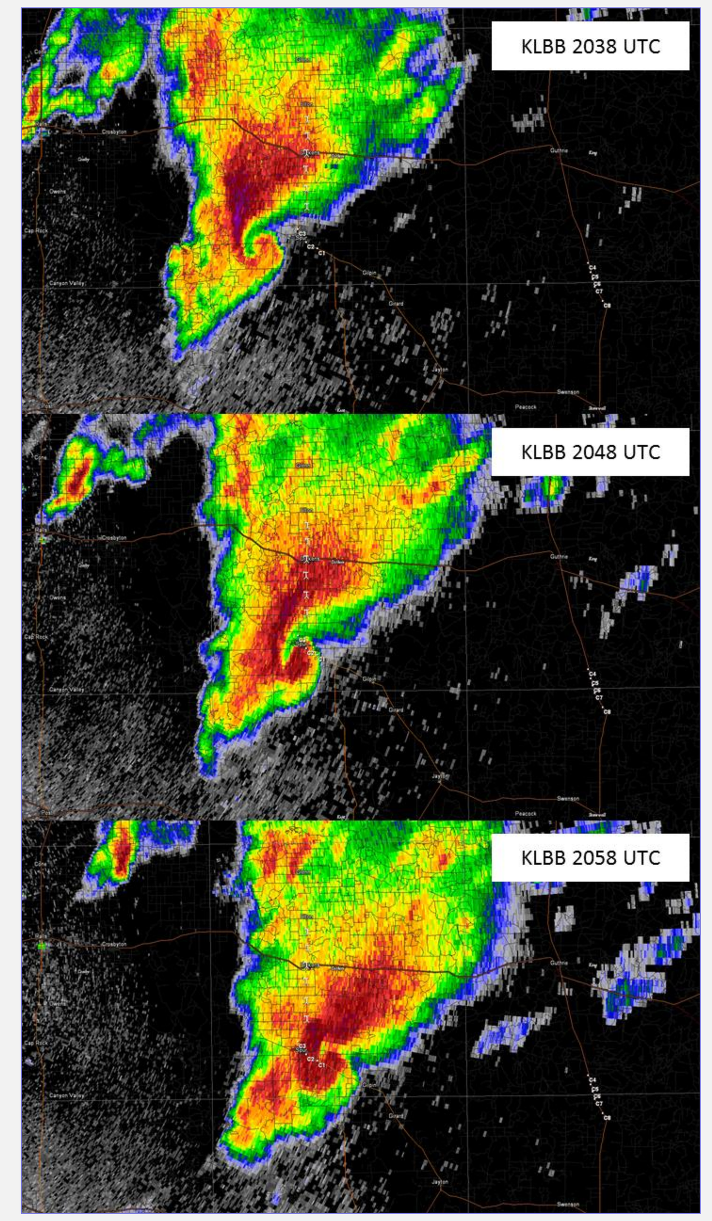

Figure 12. KLBB 0.5° reflectivity at (top) 2038, (middle) 2048, and (bottom) 2058 UTC on 8 May 2015. Probe locations are shown as the small instrument symbols. Additional measurement locations are also provided.

- Classic supercell at time of deployment.
- Array of 6 probes deployed.

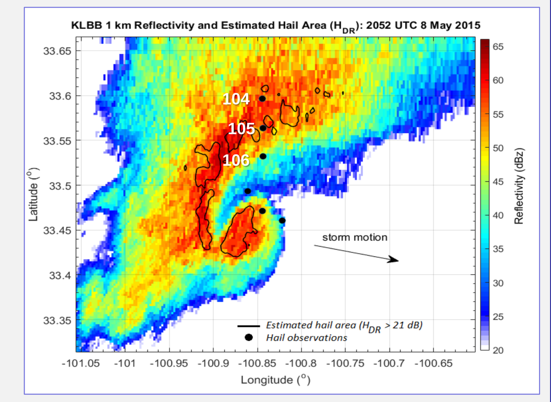

Figure 13. KLBB 1 km reflectivity CAPPI at 2052 UTC. The 21 dB hail differential reflectivity contour (solid black) are shown. Probes 104-106 detected hail. Additional hail measurements were made further south of the disdrometer array.

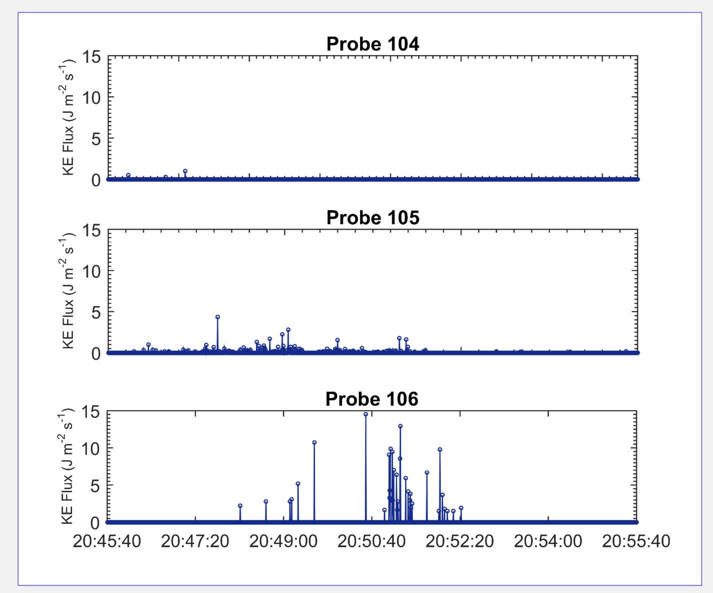

Figure 14. Kinetic energy flux estimated by probes (top) 104, (middle) 105, and (bottom) 106 on 8 May 2015.

- **Probe 104:** Few small impacts, low concentration.
- **Probe 105:** High concentration of small hail/large drops. Maximum diameter estimated 2-3 cm bin. Estimated peak kinetic energy flux approached 5 J m^{-2} s^{-1} at 20:47 UTC.
- **Probe 106:** Low concentration of larger impacts. Closer to mesocyclone/updraft. Maximum estimated diameter 3.4 cm and peak estimated kinetic energy flux nearly 15 J m^{-2} s^{-1} at 20:50 UTC.

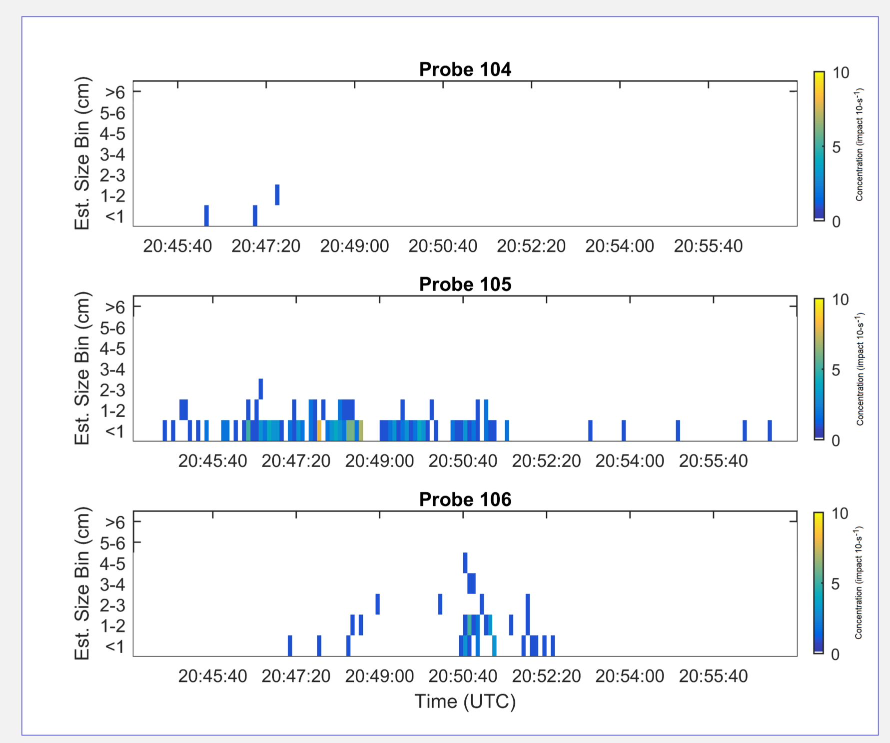

Figure 14. Hail impact concentrations for 10-second bins for (top) probe 104, (middle) probe 105, and (bottom) probe 106. Estimated hail diameters are grouped using 1 cm bin sizes. The probes not shown (101,102,103) did not resolve any impacts.

2015 FIELD DEPLOYMENT SUMMARY

2015 EVENTS

Table 1. Summary of disdrometer deployments during the 2015 field campaign. Included is the largest size bin with a recorded impact.

Location	Date	Number of probes	ID	All probes largest detected (bin, cm)
7 NW Vernon, TX	6 May 2015	5	1A	2-3 cm
10 SW Woodson, TX	7 May 2015	6	2A	1-2 cm
9 NW Childress, TX	8 May 2015	3	3B	3-4 cm
Spur, TX	8 May 2015	6	3C	4-5 cm
Bucklin, KS	9 May 2015	5	4A	2-3 cm

- Five successful targeted thunderstorms in 2015
- Typically 1.5 – 2 km spacing between probes.
- Not all probes in the array detected hail. In two cases hail was detected but not found by field teams.

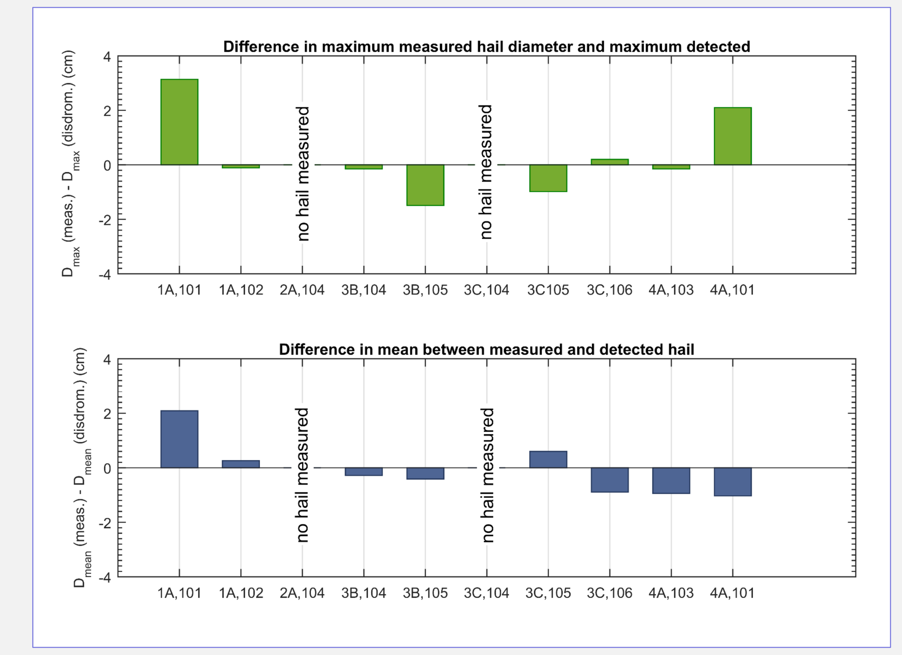

Figure 12. Difference between the measured maximum (top) and mean (bottom) hailstone diameter and disdrometer estimated maximum and mean diameter for probe locations where hail was detected. Deployment locations are labeled by IOP and probe number.

Figure 13. Probe deployment during the 2015 field campaign.

PERFORMANCE SUMMARY

- Large differences in events with small concentrations (1A & 4A).
- Comparison to conventional hailpads planned for 2016.
- System does not allow precision hail size estimates. Sufficient for kinetic energy estimates, hail detection, and basic categorization.
- Cost-effective, total hardware & fabrication cost ~$750.
- Could be improved with faster sampling.
- Issues with large rain drops/hail sizes < 1 cm.

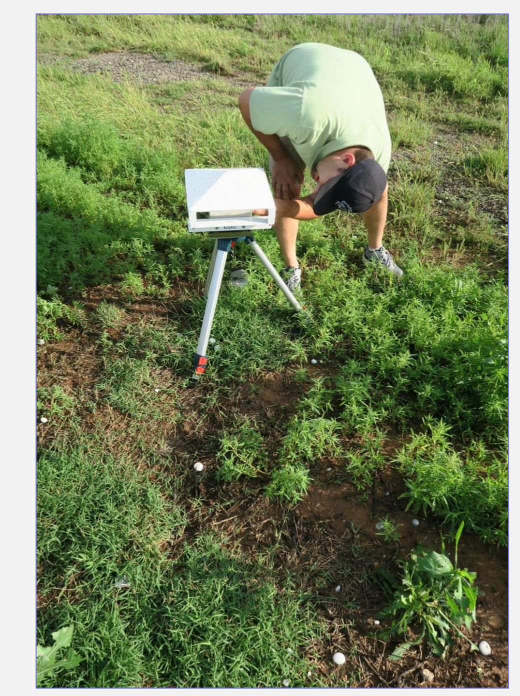

Figure 14. Probe deployed near Vernon, TX on 6 May 2015. Note the presence of hail on the ground.

REFERENCES

Changnon, S.A. (2009), Increasing major hail losses in the U.S., *Climatic Change*, **96**, 161–166, doi:10.1007/s10584-009-9597-z.

Hanson, C. L., F. B. Person, and G. L. Johnson (2004), Dual-gauge system for measuring precipitation: Historical development and use, *J. Hydrol. Eng*., **9**, 350–359.

Joss, J. and A. Waldvogel, (1967), Ein spektrograph fur Niederschlagstropfen mit automatisch er Aus-wertung. *Pure Appl. Geophys*., **68**, 240-246.

Lane, J.E., R.C. Youngquist, W.D. Haskell, R.B. Cox, (2006), A Hail size impact transducer, *J. Acoust. Soc.* Am., **119**, 47-53.

Weiss, C. C., and J. L. Schroeder, (2008), StickNet: A new portable rapidly deployable surface observations system, *Bull. Amer. Meteor. Soc*., **89**, 1502-1503.

ACKNOWLEDGEMENTS

This program is supported by the Insurance Institute for Business & Home Safety and its member companies.
Thanks are extended to the IBHS staff for the safe collection of the data presented in this study and Dr. Tanya Brown-Giammanco for logistical planning during the 2015 field program. The authors would like to thank Zanaya Craig for assistance in calibrating probes. We would also like to acknowledge Dr. Matt Kumjian, Max Vido, and Matt Flournoy from Penn State University who participated in the 2015 IBHS field campaign.

*Corresponding author: Ian M. Giammanco
igiammanco@ibhs.org