A Workshop on North American Hail and Hailstorms

What Next?

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The First North American Workshop on Hail and Hailstorms

What: A diverse group of global researchers, operational meteorologists, insurance and reinsurance analysts, private sector weather product developers, forensic engineers, and roofing manufacturers met to discuss the current understanding of hail and the future of hailstorm research.

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Where: Boulder, Colorado

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Hailstorms have caused over \$10 billion in damage for each of the last 11 years, according to insurance industry estimates. From 1960 through the early 1980s considerable research was conducted on hail and hailstorms. The work investigated the possibility of mitigating hailstorms through weather modification. The research outputs provided foundational knowledge on hailstone properties, microphysics, and severe storm dynamics. Until a recent resurgence, little attention was paid to hail within the research communities, relative to more threatening perils (e.g., tornadoes, hurricanes), despite the mounting costs of hail damage across the globe. Fatalities and injuries to humans from hail are quite rare, but it is a peril to livestock, and damages now are comparable to other severe weather hazards. Annual severe convective storm losses now typically fall between \$15 and \$17 billion according to multiple estimates from the analytics and brokerage firm AON, global reinsurer MunichRe, and catastrophe modeling firm Risk Management Solutions (RMS). Of those losses, the catastrophe modeling industry estimates that, in any given year, 60%–80% of the damage is from hail. The level of damage is now comparable to the annual mean losses from landfalling tropical cyclones in the United States (Klotzbach et al. 2018). Despite the high financial toll of hailstorms, research output on this peril has remained relatively constant. Figure 1 provides a time history of AMS journal publications that have “hail” or “hailstorm/s” in the title or as a keyword relative to other topics (i.e., hurricanes/tropical cyclones, tornadoes, and climate change). Even with an increasing number of available journals for publication, articles focused on hailstones have shown no upward trend while as a whole hail research publications have shown only a small increase.

With the rising cost of hailstorms across the country, the authors believed the time was right to convene a workshop to bring together the communities that have a vested interest in spurring new research on hail and hailstorms. The workshop took place in summer 2018 at NCAR in Boulder, Colorado, and it brought together a diverse group of global interests in hail and hail research (Fig. 2).

Background

To explore the motivation for the workshop, we can look back at the history of hail research in the United States and elsewhere and some of the existing scientific gaps that remain. The

Fig. 1. Keyword and journal title search using hail/hailstones, tornado/tornadoes, and hurricane/hurricanes for American Meteorological Society scientific journals by decade. The linear trend is also provided.

Fig. 2. Breakdown of the number of attendees by sector for the 2018 North American Workshop on Hail and Hailstorms.

acronyms used in the discussion below are listed in Table 1. During the 30-yr period beginning in the mid 1950s, several major field campaigns were conducted to learn more about how hail develops in thunderstorms, the dynamics driving these storms, and the potential for hailstorm mitigation. The National Hail Research Experiment (NHRE), conducted in 1972–76, focused on these aspects, using Doppler radar, surface observations including the collection and examination of hailstones, and measurements with the South Dakota School of Mines and Technology (SDSMT) T-28 hail penetration aircraft (Foote and Knight 1979). The Alberta Hail Studies Project (1974–85) conducted five field programs dedicated to determining whether cloud seeding could mitigate hailstorm damage (Barge and Isaac 1973). Both the NHRE and the Alberta projects were motivated by the desire to determine whether reports of an experimental hail-suppression program in the Soviet Union would provide significant protection against hail damage in North America, and whether the Soviet experiments were well conceived. The Cooperative Convective Precipitation Experiment (CCOPE) in 1980, based out of Miles City, Montana, used a combination of Doppler radar and the T-28 aircraft to better quantify hail formation and the production of precipitation in intense thunderstorms. The T-28 continued flying hail missions for 33 years, with its last flight in 2003. Since the 1980s, field programs have focused on severe storm dynamics and thermodynamics (VORTEX, STEPS, VORTEX-2, PECAN, TORUS, etc.). These have helped continue themes from earlier work on hail and improve numerical weather prediction models, but they rarely had any hail-centric component to their objectives. The Severe Hazards and Analysis Verification Experiment (SHAVE) helped advance the Multi-Radar, Multi-Sensor (MRMS) system hail outputs. Other smaller field programs have helped fill gaps to keep research moving (Blair et al. 2011, 2017; Giammanco et al. 2015, 2017). By the mid-2000s a confluence of socioeconomic, geopolitical, and meteorological factors (see the sidebar) came together to alter the hail damage trend, increasing overall severe convective storm losses (Fig. 3).

As previously mentioned, the number of published papers in AMS journals (excluding the current decade) on hail has shown little increase relative to other hazards. Tornado research publications have shown a slow climb, while hurricane research publications have grown quickly. Scientific research, specifically regarding hailstones, showed a peak during the 1970s but had until the past decade slowly declined. As shown in Fig. 1, hail research has seen a small resurgence in the past 9 years despite no major research campaigns dedicated to hail. In 2018, the time

Fig. 3. Total annual insured losses in billions of dollars from severe convective storms since 2000. Data are adjusted for inflation. Data courtesy of AON.

was right to begin raising awareness of hail and the need for more research in North America.

Prior to this meeting, a workshop or conference dedicated solely to hail had not been held in North America. Meanwhile, our European colleagues have recognized the need to bring together relevant stakeholders and have hosted two workshops already and the third European workshop was originally scheduled to be held in 2020 but has been postponed as a result of the COVID-19 pandemic. Recognizing the importance of bringing this hazard back into focus, the National Science Foundation, along with NCAR, and the Insurance Institute for Business and Home Safety (IBHS), sponsored and organized this workshop.

Workshop

The workshop was held over the course of three days. It featured keynote lectures, traditional conference-style symposia, panel discussions, and poster sessions. Over 170 people from eight countries attended. The registration fee was waived for the 24 student attendees to help encourage participation. All 17 student presenters received travel grants because of the financial support from the National Science Foundation. The workshop was broken into five sessions spanning the following topics:

- convection and hail in a changing climate
- hail climatology, risk, and loss
- hail damage and mitigation
- hail detection and forecasting
- microphysics and dynamics of hailstorms

The first session featured a keynote lecture, a panel discussion, and several submitted presentations. It was effective in summarizing the state of using downscaled climate models to examine how hail may change with our changing climate. One common theme throughout the presentations was the potential increase in the volatility of hailstorm occurrences and shifting geographies. It was also clear that the likely increase in the melting-layer height due to a warming climate, will decrease the occurrence of small hail, with little effect expected on large hail. There is some evidence that convective intensity (as inferred from instability measures)

will increase, and, therefore, the frequency of large damaging hail may also increase. It is worth noting, however, that there does not appear to be a strong correlation between convective available potential energy (CAPE) and hail size prediction (Edwards and Thompson 1998).

The second workshop session focused on climatology, risk, and loss. Together, these topics present effective means to capture the overall picture of hail risk. This entails improved observational capability with a combination of active (radar-based, ground-based hail detection sensors), space-based sensing, crowdsourced reporting, and new detection technologies. Improved observations will lead to improved risk assessment. It was encouraging to hear from catastrophe modelers that they are actively working to improve how hail is represented within their respective models to better represent hail size distributions.

The European hail community continues to accelerate their collaborative efforts across the public and private sectors to study and mitigate the impacts of hail. They have begun to explore how to integrate more detailed information into hail reporting practices (i.e., duration, event statistics) using all available observation sources. The CoCoRaHS and mPING programs in the United States provide more thorough observations but unfortunately some of these unique data do not necessarily find their way into NOAA's Storm Events Database. Crowdsourced hail reports in Switzerland provide detailed observations of hail occurrence and are used to improve radar algorithms of hail occurrence (Barras et al. 2019). There is an urgent need for a more integrated approach across the North American weather enterprise to improve how hail is documented. Representatives from the private sector spoke regarding the alarming trend in the insured losses from hail.

The hail damage and mitigation session began with a diverse set of panelists from the private sector, including a shingle manufacturer, research scientists, and industry trade groups. The panel delved into the question: Can we develop and market better-performing roofing materials? A very large percentage of losses to homes and businesses from hail is due to the need for roof cover replacements. Within this session, results from several industry postevent damage investigations were presented, showing that hail damage severity was strongly tied to hail size, and not necessarily concentration. The size threshold for hail damage to roofs ranged widely from 1.25 to 2.00 in. (1 in. = 2.54 cm) This session also included presentations on how the private sector utilizes existing hail detection products from the National Weather

Growth, expansion lead to more hail damage

A major factor in the uptick in hail losses over the last decade can be attributed to the outward expansion of major metropolitan areas within the region referred to as "Tornado Alley" (e.g., Dallas–Fort Worth, Texas; Oklahoma City, Oklahoma; Denver, Colorado). This area experiences severe hail more regularly than any other part of the country (Cintineo et al. 2012). Since 2000, the population of Colorado has grown by 1.3 million people (2015 U.S. Census). Ashley et al. (2014) and Ashley and Strader (2016) described in detail the "expanding bulls-eye effect" and how vulnerability to geophysical hazards are governed by how population and the built environment are spread geographically. While Ashley et al. (2014) focused on this effect for tornadoes, it is certainly applicable to hailstorms. An additional factor contributing to higher hail losses is the changing housing landscape. In 1980 the median home size was approximately 1,500 ft² (~140 m²). By 2015, it had risen to nearly 2,500 ft² (~230 m²) (U.S. Census Bureau/Annual Housing Survey). Larger homes require more material to be replaced when damaged; thus, they cost more in material and labor. This leads to a larger loss than would have occurred 30 years prior. The housing market crash of 2008 and the subsequent economic recession also played a role in the apparent discontinuity in 2008–09 in the severe convective storm loss time history (Fig. 3). All of this has occurred during a lull in hail research activities. Vehicle damage is another large contributor to hail losses. In the 1980s the number of vehicles per household was approximately 1.8 and grew to a peak of 2.05 in 2006. The number of vehicles per person also reached a peak in 2006 of 0.786. While the number of vehicles per household has seen a slow decline, the number of vehicles per person showed a decrease through 2012 but has since rebounded and is on an increasing trend (Sivak 2017).

Unfortunately, losses have outpaced our ability to mitigate the damage hailstorms cause each year. Building material testing standards remain mired in old, obsolete science with little ability to predict real-world performance (Heymsfield and Wright 2014; Heymsfield et al. 2014; Brown et al. 2015; Brown-Giammanco and Giammanco 2018).

Service. The use of more data-driven analytics for hail damage assessment and claims processing will only grow. The validation of these new products underscores the need for quality hail observations on the ground.

Sessions 4 and 5 included overlapping topics covering hail detection, numerical weather prediction, and the dynamics and microphysics of hailstorms. With the upgrade of the NOAA NWS Doppler radar network to dual polarization (completed in 2013) and the upgrade of Environment and Climate Change Canada's radar network to dual polarization, the ability to more adequately detect and characterize hail events should lead to improved operational products. This in turn will cascade into the private sector, improving the outputs that rely on these data sources. Maximum estimated size of hail (MESH), vertically integrated liquid density (VIL D), and hail differential reflectivity (HDR) were shown to be the best combination of products for determining hail occurrence from the existing suite of WSR-88D algorithms. While in its infancy, machine learning was also shown to be a possible avenue for better identifying thunderstorms and characterizing their intensity. In addition to these nowcasting tools, new developments in numerical modeling from the academic and private sectors regarding hail parameterizations have taken shape. Updates to the HAILCAST one-dimensional, physically based hail forecasting model were presented. The model has been integrated into the convection-allowing models (CAM5) and has received an update to its physics. The updated version has shown greater skill over generic severe weather parameters in forecasting hail severity. The question was posed: Are current operational forecast models (i.e., WRF) capable of providing useful forecasts of hail occurrence and size? The requirements to achieve this were presented:

- improve the quality of observations/analyses
- attain sufficient horizontal resolution of models
- increase the capability of operational microphysics schemes to adequately represent the physics of hail growth

It was deemed that we are nearing the ability to provide meaningful skill; however, more in situ measurements both within the cloud and at the ground are needed to complete the puzzle.

Future directions

This workshop demonstrated that hail science is difficult, and challenges and opportunities abound. The final size of hail on the ground or when it impacts our built environment is determined by a myriad of processes occurring across a wide range of spatiotemporal scales. Across the globe, reliable hail observations are lacking both at the surface and especially within hailstorms. What has been lacking for hail research since the retirement of the SDSMT T-28 aircraft has been a hail-penetrating aircraft that would provide the data necessary to evaluate and improve dual-polarization radar retrievals of hail size and kinetic energy, better microphysical probes to characterize hail size distributions and shape, and hailstorm dynamics. There is also a need for increased coordinated and collaborative research.

Improvements to radar hail detection and characterization could help reduce fraud, expedite claims processing, and add skill to severe weather warnings for damaging hail. Improvements in hail forecasting could help reduce automobile damage by providing enough time to protect vehicles. Building and material science research in hail impacts can help update standard material testing to more accurately represent hail and to push manufacturers to develop more resilient building products. It is the organizers' hope that this workshop will inspire a more collaborative environment across all sectors. Despite the lack of attention this hazard receives, there is an emerging hail and hailstorms research community in both the private and academic sectors. Figure 4 shows a possible path forward for a more targeted and strategic approach to hail research.

The research community can conduct meaningful research and integrate that information into actionable products both in the academic and private sectors. Some of the emerging positive outcomes demonstrated by this resurgence in hail research include

- improvements of the microphysical parameterizations and coupling to storm dynamics in weather forecast models—CAMs, including WRF and HAILCAST, among others, and thereby the growth and resultant trajectories and fall of hail
- MRMS products and climatologies
- operational WSR-88D hail size discrimination algorithm

Hail mitigation has also taken a step ahead with improved impact testing of roofing materials using more realistic test protocols based on better hailstone characteristics data, such as the recently released IBHS Roof Shingle Hail Impact Ratings (<https://ibhs.org/hail/shingle-performance-ratings/>). Shingle manufacturers have quickly pivoted to begin developing more resilient products as a result. In 2019, Fort Collins, Colorado, became the first community to incorporate hail mitigation into their local building code, requiring new roof covers

Fig. 4. Graphical depiction of a possible path ahead for a more collaborative and coordinated approach to hail research. Figure adapted from Julian Brimelow’s keynote lecture titled “Bridging Knowledge Gaps in Hailstorm and Hail Research,” which opened the workshop.

Table 1. Table of acronyms.

Acronym abbreviation	Full name/description
CAMS	Convection-allowing models
CCOPE	Cooperative Convective Precipitation Experiment
CoCoRaHS	Community Collaborative Rain, Hail and Snow Network
HDR	Hail differential reflectivity
IBHS	Insurance Institute for Business and Home Safety
MESH	Maximum estimated size of hail
MRMS	Multi-Radar Multi-Sensor
mPING	Meteorological Phenomenon Identification Near the Ground
NHRE	National Hail Research Experiment
NCAR	National Center for Atmospheric Research
PECAN	Plains Elevated Convection at Night campaign
SDSMT	South Dakota School of Mines and Technology
STEPS	Severe Thunderstorm Electrification and Precipitation Study
TORUS	Targeted Observations by Radar and Unmanned Aerial Systems in Supercells
UL	Underwriters Laboratories
VORTEX/VORTEX 2	Verification of the Origin of Rotation in Tornadoes Experiment (2)
VIL D	Vertically integrated liquid density
WRF	Weather Research and Forecasting Model

to be impact rated according to the Underwriters Laboratory (UL) testing program. To slow the loss curve, contributions and open collaboration from all the sectors represented at this workshop are needed.

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