Welcome!

On behalf of the steering committee we would like to welcome you to the first North American Workshop on Hail and Hailstorms. Hail across the United States accounts for nearly $10 billion dollars in annual property losses each year and represents nearly 70% of the annual average loss from severe convective storms. Unfortunately, our ability to forecast, detect, and mitigate against hailstorms has lagged the increasing impact these events are having.

We have assembled a wide-ranging and diverse group of invited keynote speakers, expert panels, and plenary talks covering all facets of hail and hailstorms. It is our goal to bring together all stakeholders who care deeply about the impact of hailstorms and the science behind them. We hope you will find our three-day workshop to be informative and provide a view of the current state of hail science. We encourage each one of you to engage with our diverse group of attendees and to discuss ways we can improve our ability to forecast, detect, and mitigate against hail and hailstorms through new pathways of collaboration.

First, we would like to thank the National Science Foundation. Without their support through agreement M0856145 to the National Center for Atmospheric Research, this workshop would not have been possible. We would also like to thank the Insurance Institute for Business & Home Safety and Building Envelope Consultants Ltd. for providing additional support for our student presenters.

We hope you enjoy the workshop and have a wonderful time in the Boulder area!

Warm Regards,

Ian M. Giammanco  Andrew J. Heymsfield
## Agenda at a glance

| Time               | Event                                                                 |
|--------------------|----------------------------------------------------------------------|
| 7:30 am to 12:00 pm| Registration Open                                                    |
| 8:00 am to 8:10 am | Opening Remarks                                                       |
| 8:10 am to 8:30 am | Keynote presentation: “Bridging Knowledge Gaps in Hailstorm and Hail Research”  
  Julian Brimelow, Environment Canada |
| 8:30 am to 9:30 am | **Session 1: Convection & Hail in a Changing Climate**               |
| 9:30 am to 9:50 am | P1.1 “Hail Occurrence Under Anthropogenic Climate Change as Investigated with Convection Permitting Dynamical Downscaling”  
  Jeff Trapp*, Kim Hoogewind, Sonia Lasher-Trapp  
  *Presenting author affiliation: University of Illinois, Champaign-Urbana, Illinois |
| 9:50 am to 10:10 am| P1.2 “Hail Production Under Anthropogenic Climate Change Investigated with a “Pseudo-Global Warming” Approach”  
  Sonia Lasher-Trapp*, Jeff Trapp  
  *Presenting author affiliation: University of Illinois, Champaign-Urbana, Illinois |
| 10:10 am to 10:30 am| Morning Break                                                        |
| 10:30 am to 10:50 am| P1.3 “Severe Convective Storm Losses in the United States: What the Hail is Happening?”  
  Steve Bowen*  
  *Presenting author affiliation: AON Benfield, Chicago, Illinois |
| 10:50 am to 11:10 am| P1.4 “The Intensity and Evolving Risk of Damaging Hailstorms in the U.S.”  
  Brian H. Tang*  
  *Presenting author affiliation: SUNY-Albany, Albany, New York |
| 11:10 am to 12:00 pm| Expert Panel: “Catastrophe Models: Assessing Hail Risk & Vulnerability Today and into the Future”  
  Moderator: Jason Butke, Travelers Insurance  
  Jurgen Grieser, Risk Management Solutions  
  Eric Robinson, AIR-Worldwide  
  David Smith, CoreLogic  
  Steve Drews, AON Benfield/Impact Forecasting |
| 12:00 pm to 1:00 pm| Lunch Break                                                          |
| 1:00 pm to 1:30 pm | Keynote presentation: “An Inside Look at Hailstorms”                 |
  Paul Smith, South Dakota School of Mines and Technology, Rapid City, South Dakota |
| Time          | Session                                                                                     |
|--------------|--------------------------------------------------------------------------------------------|
| 1:30 pm to 1:50 pm | P1.5 “Changes in the Convective Population and Thermodynamic Environments in Convection-Permitting Regional Climate Simulations Over the United States”  <br>Kristen Rasmussen*, Andreas Prein, Roy Rasmussen, Kyoko Ikeda, Changhai Liu, Erin Dougherty  <br>*Presenting author affiliation: Colorado State University, Fort Collins, Colorado |
|               | **Session 2: Hail Climatology, Risk, and Loss**                                                   |
|               | **Session Chair: Jason Butke**                                                                   |
| 1:50 pm to 2:20 pm | Keynote presentation: “Hail Observations: Limitations, Oddities, and Impacts”  <br>John T. Allen, Central Michigan University, Mount Pleasant, Michigan |
| 2:20 pm to 2:40 pm | P2.1 “Seasonal and Monthly Forecasting of US Hail Activity”  <br>Chiara Lepore*, Michael K. Tippett, John T. Allen  <br>*Presenting author affiliation: Columbia University, New York |
| 2:40 pm to 3:00 pm | P2.2 “CHAT-The Colorado Hail Accumulation from Thunderstorms Project”  <br>Katja Friedrich*, Robinson Wallace, Bernard Meier, Weibke Deierling, Evan Kalina, Paul Schlatter  <br>*Presenting author affiliation: University of Colorado, Boulder, Colorado |
| 3:00 pm to 3:20 pm | P2.3 “Eastern Colorado Severe Hail Climatology Conundrums”  <br>Samuel Childs*  <br>*Presenting author affiliation: Colorado State University, Fort Collins, Colorado |
| 3:20 pm to 4:00 pm | **Afternoon Break & Poster Session 1**                                                          |
| 4:00 pm to 4:20 pm | P2.4 “Using Spaceborne Sensors to Detect Hailstorms and Build Climatologies”  <br>Daniel J. Cecil*,  <br>*Presenting author affiliation: NASA Marshall Spaceflight Center, Huntsville, Alabama |
| 4:20 pm to 4:40 pm | P2.5 “The Swiss National Hail Climatology Project – Overview and First Results”  <br>Katharina Scherz*, S. Trefalt, C. Schwierz, U. Germann, A. Hereng, T. Schlegel, L. Nisi  <br>*Presenting author affiliation: MeteoSwiss |
| 4:40 pm to 5:00 pm | P2.6 “A New Era of Hail Monitoring, Forecasting, and Climatology in Switzerland”  <br>Simona Trefalt*, H. Barras, N. Besni, A. Hereng, L. Nisi, K. Schroer, C. Schwierz, D. Wolfensberger, U. Germann  <br>*Presenting author affiliation: MeteoSwiss |
| 5:00 pm to 5:20 pm | P2.7 “Using > 50,000 Crowdsourced Hail Reports for the Verification of Radar Based Hail Products”  <br>Helene Barras*, A. Hereng, U. Germann, O. Martius  <br>*Presenting author affiliation: University of Bern, Bern, Switzerland |
| 5:20 pm to 5:40 pm | P2.8 “Hail Frequency in Central Europe Estimated from Single-Pol Radar Reflectivity and the Relation to Local- and Large-Scale Environmental Conditions”  <br>Michael Kunz*, Jan Wandel, Sven Baumstark, Elody Fluck, David Piper  <br>* Presenting author affiliation: Karlsruhe Institute of Technology, Center for Disaster Management and Risk Reduction Technology, Karlsruhe, Germany |

**Adjourn**

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**August 15**

| Time          | Session                                                                                     |
|--------------|--------------------------------------------------------------------------------------------|
| 8:00 am to 12:00 pm | Registration Open                                                                            |
|               | **Session 2 Continued**                                                                     |
| 8:00 am to 8:20 am | P2.9 “The May 8, 2017 Metro Denver Hailstorm: One of the Costliest in U.S. History”  <br>Paul Schlatter*  <br>*Presenting author affiliation: National Weather Service Forecast Office Boulder, Colorado |
| Time          | Session                  | Presenter/ Affiliation                                                                 |
|--------------|--------------------------|----------------------------------------------------------------------------------------|
| 8:20 am to 9:10 am | Keynote Presentation: “Hail Kinetic Energies & Test Protocols: Where are We & How did We Get Here”  
Andrew J. Heymsfield, National Center for Atmospheric Research  
Robert Wright, Robert L. Wright & Associates  
Ian M. Giammanco, Insurance Institute for Business & Home Safety |
| 9:10 am to 9:30 am | P3.1 “History of Underwriters Laboratory’s Impact Testing Program and Certification”  
Dwayne Sloan*  
*Presenting author affiliation: Underwriters Laboratory, Chicago, Illinois |
| 9:30 am to 9:50 am | P3.2 “RICOWI Hail Investigation Program: April 11, 2016 North Texas Hailstorm”  
*Richard Herzog  
*Presenting author affiliation: Haag Engineering, Burnsville, Minnesota |
| 9:50 am to 10:10 am | P3.3 “A Non-Destructive Hail Test Model”  
Matthew Phelps*  
*Presenting author affiliation: Texas Tech University, Lubbock, Texas |
| 10:10 am to 10:30 am | Morning Break |
| 10:30 am to 10:50 am | P3.4 “Automated Hailswaths – Claims and Damage Ratios in the Insurance Industry”  
*Andrew Siffert  
*Presenting author affiliation: BMS Group |
| 10:50 am to 11:10 am | P3.5 “Modeling Hail Impact: How Many Hailstones of What Size?”  
Jurgen Grieser*  
*Presenting author affiliation: Risk Management Solutions, London, England |
| 11:10 am to 11:30 am | P3.6 “Hail Hazard and Hail Risk Modeling for Germany Based on a Combination of Radar and Insurance Data”  
Manuel Schmidberger, James E. Daniell, Michael Kunz*  
*Presenting author affiliation: Karlsruhe Institute of Technology, Karlsruhe, Germany |
| 11:30 am to 11:50 am | P4.1 “HAILCAST Hail Forecasting Performance during the NOAA/Hazardous Weather Testbed Spring Forecasting Experiments”  
Rebecca Adams-Selin*  
*Presenting author affiliation: AER, Offutt AFB, Nebraska |
| 11:50 am to 1:30 pm | Lunch Break |
| 1:30 pm to 2:30 pm | Expert Panel: “Hail Resiliency – Can We Get There?”  
**Moderator:** Tanya Brown-Giammanco, Insurance Institute for Business & Home Safety  
Heather Estes, Insurance Institute for Business & Home Safety  
Greg Malarkey, Sr. VP Malarkey Roofing  
Ellen Thorp, EPDM Roofing Association  
John Gimble, RICOWI & Gimble Consulting Engineering |
| Time          | Session                                                                                           |
|--------------|---------------------------------------------------------------------------------------------------|
| 2:30 pm to 2:50 pm | **P4.2 “Observations of Supercells Containing Large Hail Using a Rapid-Scan X-band, Mobile, Polarimetric Doppler Radar (RaXPol)”**  
Howard B. Bluestein, Jeffrey Synder, Jana Houser, Zach Wienhoff, Dylan Reif, Kyle Thiem  
*Presenting author affiliation: University of Oklahoma, Norman, Oklahoma* |
| 2:50 pm to 3:10 pm | **P4.3 “Hail Research at CIMMS/NSSL Using the SHAVE and MYRORSS Databases”**  
Kiel L. Ortega*,  
*Presenting author affiliation: CIMMS - University of Oklahoma, Norman, Oklahoma* |
| 3:10 pm to 3:30 pm | **Afternoon Break**                                                                                 |
| 3:30 pm to 4:30 pm | **Expert Panel:** “Future Applications in Hail Detection and Forecasting”  
Moderator: Matthew Kumjian, The Pennsylvania State University  
David John Gagne, PhD, National Center for Atmospheric Research  
Daniel Betten, PhD, CoreLogic / Weather Fusion  
Alex Kubicek, Understory  
William Ramstrom, Verisk Weather Solutions |
| 4:30 pm to 4:50 pm | **P4.4 “Development of a Post-Event Tool for the Spatiotemporal Analysis of Hail Events”**  
Justin E. Jones*, Leigh A. Munchak  
*Presenting author affiliation: Weather Analytics, Dover, New Hampshire* |
| 4:50 pm to 5:10 pm | **P4.5 “Hail Detection and Prediction Using 1-Minute GOES 14 & 16 Satellite Imagery and Ground-Based Dual Polarization Radar”**  
Elisa Murillo*, Cameron Homeyer, Kristopher Bedka, Thea Sandmael  
*Presenting author affiliation: University of Oklahoma, Norman, Oklahoma* |
| 5:10 pm to 5:30 pm | **P4.6 “Real-time Hail Prediction Using Machine Learning Algorithms with HREFv2”**  
Amanda Burke*, Nathan Snook, Amy McGovern, David John Gagne  
*Presenting author affiliation: University of Oklahoma, Norman, Oklahoma* |
| 5:45 pm to 7:00 pm | **Information Exchange at Center Green**                                                             |
| **August 16** |                                                                                                |
| 8:00 am to 8:20 am | **P4.7 “The Operational Application of the Lightning Jump Algorithm for Hail Nowcasting in Catalonia”**  
Carme Farnell*, Tomeu Rigo, Oriol Puig  
*Presenting author affiliation: University of Barcelona and Meteorological Service of Catalonia, Barcelona, Spain* |
| 8:20 am to 8:40 am | **P4.8 “A Comparison of the Lightning Jump Algorithm Using Total Lightning Versus Cloud-to-Ground Flashes”**  
Tomeu Rigo*, Carme Farnell  
*Presenting author affiliation: Meteorological Service of Catalonia* |
| 8:40 am to 9:00 am | **P4.9 “Continental Scale Hail Frequency Estimation from Geostationary Satellite Data”**  
“Heinz Jurgen Punge*, Kristopher M. Bedka, Michael Kunz  
*Presenting author affiliation: Karlsruhe Institute of Technology, Karlsruhe, Germany* |
| 9:00 am to 9:20 am | **P4.10 “Hail Detectability Using Backscatter Differential Phase by X-Band Dual Polarization Radar”**  
Takeshi Maesaka*, Shin-ichi Suzuki, Yukari Shusse, Koyuru Iwanami  
*Presenting author affiliation: National Research Institute for Earth Science and Disaster Resilience, Japan* |
| Time           | Session/Activity                                                                 |
|---------------|----------------------------------------------------------------------------------|
| 9:30 am to 10:30 am | **Morning Break & Poster Session 2**                                              |
|               | **Session 5: Microphysics & Dynamics of Hailstorms**                             |
|               | Session Chair: Hugh Morrison                                                     |
| 10:30 am to 11:00 am | Keynote Presentation: “Microphysics and Dynamics of Hail-Producing Thunderstorms”  
|               | Zachary Lebo, University of Wyoming, Laramie, Wyoming                            |
| 11:00 am to 11:30 am | Keynote Presentation: “Features of Hailstones and their Formation”               
|               | Charles Knight, National Center for Atmospheric Research, Boulder, Colorado       |
| 11:30 am to 11:50 am | P5.1 “Hail Prediction in the Canadian 2.5-km NWP system using the P3 Microphysics Scheme”  
|               | Jason Milbrandt* Presenting author affiliation: Meteorological Research Division/Environment and Climate Change, Canada |
| 12:00 pm to 1:30 pm | Lunch Break                                                                      |
| 1:30 pm to 1:50 pm | P5.2 “Potential Impacts of Aerosol Pollution on Hailstorms”                      
|               | William R. Cotton*, Adrian M. Loftus, and Gustavo G. Carrio                     
|               | *Presenting author affiliation: Colorado State University, Fort Collins, Colorado |
| 1:50 pm to 2:10 pm | P5.3 “Investigating the Characteristics of Hail Accumulating Thunderstorms”     
|               | Robinson Wallace*, Katja Friedrich, Bernard Meier, Wiebke Deierling, Evan Kalina, Paul Schlatter  
|               | *Presenting author affiliation: University of Colorado, Boulder, Colorado         |
| 2:10 pm to 2:30 pm | P5.4 “High-Resolution EnKF Analyses and Forecasts of the 8 May 2017 Colorado Severe Hail Event”  
|               | Jonathan Labriola*, Nathan Snook, Youngsun Jung, Ming Xue                      
|               | *Presenting author affiliation: University of Oklahoma, Norman, Oklahoma         |
| 2:30 pm to 2:50 pm | P5.5 “Subtropical South American Hailstorm Storm Characteristics and Environments”  
|               | Zachary S. Bruck*, Kristen L. Rasmussen, Daniel J. Cecil                      
|               | *Presenting author affiliation: Colorado State University, Fort Collins, Colorado |
| 2:50 pm to 3:10 pm | Afternoon Break                                                                  |
| 3:10 pm to 3:30 pm | P5.6 “Interpretable Deep Learning Representations of Hail Growth Processes”     
|               | David John Gagne* Presenting author affiliation: National Center for Atmospheric Research, Boulder, Colorado |
| 3:30 pm to 3:50 pm | P5.7 “Improving Graupel and Hail Treatment in the Thompson Microphysics Parameterization”  
|               | Greg Thompson*, Sarah Tessendorf, Kyoko Ikeda, Andrew Heymsfield               
|               | *Presenting author affiliation: National Center for Atmospheric Research, Boulder, Colorado |
| 3:50 pm to 4:10 pm | P5.8 “Characteristics of Hail Events Near the Sierras de Cordoba, Argentina”    
|               | Jeremiah Otero Pietsante*, Deanna Hence, Sarah Tessendorf, Roy Rasmussen       
|               | *Presenting author affiliation: Hobart and William Smith Colleges, Geneva, New York |
| 4:10 pm to 4:30 pm | P5.9 “Comparison of Hailstorm Properties Between China and the United States”    
|               | Qinhong Zhang*, Xiang Ni, Chuntao Liu, Daniel J. Cecil                        
|               | Presenting author affiliation: Peking University, Beijing, China                |
| 4:30 pm to 4:50 pm | P5.10 “The Role of Initial Cloud Condensation Nuclei Concentration in Hail Using the WRF-NSSL 2-Moment Microphysics Scheme”  
|               | Xiaofei Li*, Presenting author affiliation: Peking University, Beijing China    |
| 4:50 pm to 5:00 pm | Closing Remarks                                                                  |
|               | Adjourn                                                                          |
UCAR Visitor Wireless: How it works

The UCAR Visitor wireless network (SSID) is an open, unencrypted wireless network that uses a "captive portal" to require registration before full access is enabled. The registration form is displayed on devices by redirecting web browser requests to authentication servers. Most newer operating systems will detect the presence of a captive portal and immediately pop open a login page. In the remainder of cases, an unregistered user is redirected when attempts are made to browse the web.

Once the registration page is adequately filled in and "Register" button is clicked, the device will have four hours of access. At the same moment, a registration email containing a link is sent to the email address entered on the registration form.

Here's the registration page users see when first accessing the network:

Upon submission of the form, the user should soon receive an email that looks like this:

Clicking the "click-here" link in the confirmation email opens a receipt page confirming the 90 days of access, but the user must click the "Confirm" button here to complete the process:
For more information on the UCAR Visitor wireless network, please see the UCAR Visitor Wireless FAQ.
Parking is available around Center Green, both in the garage to the west and surface parking around the facility.

The entrance to the Center Green Conference Center is past the pavilion and on the left.
## Detailed Agenda & Abstracts

**Tuesday August, 14**

| TIME                                      | Session                                                                 |
|-------------------------------------------|-------------------------------------------------------------------------|
| 7:30 am – 12:00 pm                       | Registration                                                           |
| 8:00 am – 8:10 am                        | Opening Remarks – Ian Giammanco, Andy Heymsfield                         |
| Tuesday, 8:10 am – 8:30 am               | **Keynote presentation**                                                |
|                                           | "Bridging Knowledge Gaps in Hailstorm and Hail Research"               |
|                                           | Julian Brimelow, PhD                                                    |
|                                           | *Physical Sciences Specialist, Meteorological Services of Canada, Environment and Climate Change Canada* |
|                                           | **Abstract**                                                            |
|                                           | Of all precipitation types, hail prediction is probably subject to the largest uncertainties, and the reasons for this are many and varied. The growth of hail, and especially large hail, requires the alignment of several key ingredients, and the final size of hail on the ground is determined by a myriad of processes occurring across a wide range of spatio-temporal scales. |
|                                           | There have been important advances in our understanding of hail, but incomplete knowledge of certain key processes means that hail science still faces significant challenges. Even so, it has been over 30 years since the last field program dedicated to hail science was undertaken, and with the exception of work undertaken by List and others in the 1990s, virtually no concerted effort has been made to continue ice tunnel experiments. |
|                                           | Here we identify some of the key gaps in our understanding of hailstorms and hail growth, while also proposing potential solutions. The advent of new technology (e.g., electronic disdrometers, miniaturization of sensors and remote-sensing techniques) and increased use of social media mean that the time is ripe for a resurgence of hail research and advancing our understanding of hailstorms and hail. A road map for how such a breakthrough might be achieved is proposed. |
| Tuesday, 8:30 am – 9:30 am                | **Expert Panel Discussion**                                             |
|                                           | "Convection and Hail in a Changing Climate"                             |
|                                           | **Description:** This panel brings together experts in the relationship between climate change and severe convective storms with a focus on hail. Implications for the reinsurance and insurance sectors will also be explored. |
|                                           | **Moderator:** John T. Allen                                            |
|                                           | *Assistant Professor of Meteorology, Central Michigan University*        |
|                                           | **Panelists:**                                                          |
|                                           | Julian Brimelow, PhD                                                    |
|                                           | *Physical Sciences Specialist, Meteorological Service of Canada*        |
|                                           | Victor Gensini, PhD                                                     |
|                                           | *Assistant Professor of Geographic and Atmospheric Sciences, Northern Illinois University* |
|                                           | Mark Bove                                                               |
|                                           | *Senior Research Meteorologist, MunichReinsurance America Inc.*         |
|                                           | Andreas Prein, PhD                                                      |
|                                           | *Project Scientist, National Center for Atmospheric Research*           |
Tuesday, 9:30 am – 9:50 am

“Hail Occurrence Under Anthropogenic Climate Change as Investigated with Convection Permitting Dynamical Downscaling”
Jeff Trapp*, Kim Hoogewind, Sonia Lasher-Trapp

*Presenting author affiliation: University of Illinois

Abstract
Herein we use dynamical downscaling with a high-resolution, convection-allowing grid over the entire contiguous United States (CONUS) to investigate possible future changes in hail occurrence under anthropogenic climate change (RCP8.5). Specifically, simulations from the Geophysical Fluid Dynamics Laboratory Climatic Model, version 3 from the Coupled Model Intercomparison Project phase 5 have been dynamically downscaled by Hoogewind et al. (2017) over historical (1971-2000) and future (2071-2100) time periods using the Weather Research and Forecasting (WRF) model, version 3.6.

As quantified in terms of days using exceedances of WRF-predicted hail/graupel mixing ratios, we find statistically significant future increases in occurrences of “large” hail over large areas of the CONUS, during all four seasons. Notably, an increase of up to 5 large-hail days during each of the summer months are projected over the late 21st Century for locations within the Great Plains. Future increases of 1-2 days of “significant” hail are also found, but limited to the central CONUS during spring and summer.

Our flexible downscaling approach lets us further investigate individual events during the 30-y future and historical time slices. We identified the top 10 large hail events in both time slices, and re-simulated each event with WRF using the in-line version of HAILCAST, and also using three additional microphysical parameterization schemes. The hail sizes generated by HAILCAST correlate strongly with the WRF-predicted mixing ratio variables and associated diagnostics. The microphysics experiments provide us confidence that our overall conclusions are robust.

Our ongoing efforts to quantify other convective-storm attributes to help us better understand these changes in hail occurrence will be discussed at the workshop.

Tuesday, 9:50 am – 10:10 am

“Hail Production Under Anthropogenic Climate Change Investigated with a Pseudo-Global Warming Approach”
Sonia Lasher-Trapp*, Jeff Trapp

*Presenting author affiliation: University of Illinois

Abstract
Over North America, climate-model projections indicate widespread increases in frequency and magnitude of convective available potential energy (CAPE) throughout the 21st Century. The CAPE increases have, in turn, been used to suggest the likelihood of more frequent and intense thunderstorms, and by extension, more frequent and intense hailstorms. CAPE alone, however, is a poor proxy for predicting intense thunderstorm occurrence, as well as hail occurrence.

Here, we pursue a “pseudo-global-warming” (PGW) approach, which provides a flexible framework for experimentation and examination of cause and effect in the relevant dynamical and microphysical processes that create large hail events. A recent high-end severe convective storm event in the U.S. that produced over 150 reports of severe hail over a 12-h period is used. This event is simulated both in its true environment, as well as an environment modified by a projected climate-change “delta” (encompassing temperature, humidity and vertical wind profiles). Specifically, we use global climate model simulations under historical and future (RCP8.5) conditions to modify the initial and boundary conditions of these WRF model simulations. We conduct the WRF simulations at very high resolution (100-meter grid spacing) to capture more detail. For both the historical and PGW simulations, we create multiple realizations, using different multi-moment microphysical parameterizations available in the WRF model. Initial lower resolution results suggested hail swaths from this event in a PGW environment would be fewer and shorter, possibly due to the effects of the lower-shear environment in reducing updraft size. Different microphysical schemes also produced increases or decreases in the hail swath intensity. With the new high-resolution runs, the effects of differences in representation of the microphysical processes among the parameterizations are examined, providing additional insight into the coupling of microphysics and convective dynamics that may possibly drive differences in hail production in the PGW environment.
Tuesday, 10:10 am – 10:30 am

MORNING BREAK

Tuesday, 10:30 am – 10:50 am

“Severe Convective Storm Losses in the United States: What the Hail is Happening”

Steve Bowen*, AON Benfield

Abstract

Severe convective storms (SCS) have become an increasingly costly peril for the insurance industry in North America. While much of the public focus is often on the frequency and severity of tornadoes, the reality is that the primary driver of loss from SCS events has become hail. In the United States alone, annual hail losses are now estimated to account for at least $10 billion in payouts by public and private insurers due to widespread damage to residential, commercial and agricultural property. During a recent 10-year stretch from 2007-2016, SCS was the costliest peril for the industry in the U.S. – highlighting the annual consistency of these types of events. Many of these events in recent years have left billion-dollar costs in major metro areas such as Dallas-Fort Worth, San Antonio, Denver, and Minneapolis.

This session will focus on the short and long-term evolution of hail and SCS loss in the United States, identify some of the primary drivers causing the continued increase of losses, and highlight what the current trends suggest for the future.

Tuesday, 10:50 am – 11:10 am

“The Intensity and Evolving Risk of Damaging Hailstorms in the U.S.”

Brian H. Tang*, University of Albany - SUNY

Abstract

In order to better assess the intensity of past hailstorms and assess evolving and future hail risk in metropolitan areas, we develop a catalog of 55 hailstorms that incurred at least $100 million in insured losses. For each hailstorm, the potential damaging hailfall area (PDHA) is defined to be the intersection of two radar-derived areas: the cumulative 1.5-km hail kinetic energy (HKE) ≥ 250 J m$^{-2}$ and the maximum estimated size of hail (MESH) ≥ 2.5 cm with a 10-km buffer. An algorithm to fill in the gaps between successive radar scans, using a dense optical-flow technique and semi-Lagrangian advection scheme, generates more continuous PDHAs.

Since 10 of the 55 events occurred in the Dallas/Ft. Worth, TX area, we focus on the evolving and future hail risk there. U.S. Census data from 1990 to 2010 indicates substantial increase in housing units in suburban areas surrounding Dallas/Ft. Worth, which is projected to continue to increase in the next couple decades based on local government studies. As a result, the risk exposure may increase dramatically, assuming hailstorms are a stationary random process. Similar patterns of urban sprawl in other major metropolitan areas (e.g., Denver, St. Louis, and Minneapolis) have increased hail risk exposure in these areas too.

The catalog is publicly assessible for research and educational use. Potential uses are discussed.
Tuesday, 11:10 am – 12:00 pm

Expert Panel Discussion
“Catastrophe Models: Assessing Hail Risk and Vulnerability Today and into the Future”

Description: This expert panel discusses the current state of severe convective storm catastrophe modeling, focusing on the contribution of hail. It will also cover the scientific needs of the industry to examine risk and vulnerability to hailstorms in a more granular fashion.

Moderator: Jason Butke
Director and Meteorologist for Catastrophe Strategy, Travelers Insurance Inc.

Panelists:
Jeff Waters
Senior Product Manager, Risk Management Solutions

Eric Robinson
Principal Scientist, AIR-Worldwide

David Smith
Senior Director for Model Development, CoreLogic

Steve Drews
Director, AON Benfield Impact Forecasting

Tuesday, 12:00 pm – 1:00 pm

LUNCH BREAK

Tuesday, 1:00 pm – 1:30 pm

Keynote presentation
“An Inside Look at Hailstorms”

Paul Smith, PhD
Professor Emeritus, South Dakota School of Mines & Technology

Abstract
The armored T-28 storm penetrating aircraft (SPA) operated for more than thirty years in hailstorm and thunderstorm research projects around the U.S as well as in Canada and Switzerland. The concept of an SPA that could safely penetrate hail-bearing storms was put forth by Paul MacCready during the 1966 “Project Hailswath” and brought to fruition a few years later with support from the National Science Foundation. Initial operations during the National Hail Research Experiment based in northeast Colorado developed the guidance for bringing back useful data on updrafts, turbulence and microphysics of the storm interiors. Later projects added studies of storm electrification and chemistry.

The talk will present some examples of T-28 observations and discuss some of the scientific contributions. The latter include helping to dispel the idea that hailstones grow by multiple up-and-down cycles inside the storms, and demonstrating that the Russian conceptual model of a “big-drop zone” in the storms where large hailstones grow is not applicable, at least in the storms in Switzerland. Observations from the T-28 have helped to better understand the hail signatures in polarimetric radar data.

The aircraft was retired from service in 2004 and is being reassembled at the National Weather Museum in Norman, Oklahoma. Efforts to modify an A-10 “Warthog” for service as a next-generation SPA are on hold due to an unresolved problem with anti-icing sections of the wings.

Tuesday, 1:30 pm – 1:50 pm

“Changes in the Convective Population and Thermodynamic Environments in Convection-Permitting Regional Climate Simulations Over the United States”
Kristen Rasmussen*, Andreas Prein, Roy Rasmussen, Kyoko Ikeda, Changhai Liu, Erin Dougherty

*Presenting author affiliation: Colorado State University

Abstract
Convection-permitting regional climate simulations over the U.S employing the pseudo-global warming approach are used to investigate changes in the convective population and
thermodynamic environments in a future climate. The simulations match the observed precipitation diurnal cycle, indicating that they reproduce organized convection that most climate models cannot adequately represent. Results from this analysis suggest that weak to moderate convection will decrease and strong convection will increase in frequency in a future climate. Analysis of the thermodynamic environments supporting convection shows that both convective available potential energy (CAPE) and convective inhibition (CIN) increase downstream of the Rockies. Although some previous studies suggest that CAPE will increase in a warmer climate, a corresponding increase in CIN acts as a balancing force to shift the convective population by suppressing weak to moderate convection and also provides an environment where CAPE can build to extreme levels and may result in more frequent severe convection. Finally, hail reports from the National Centers for Environmental Information (NCEI) database will be used to identify days when large hail (>1 inch) occurred across the U.S. from 2000-2013. Analysis of the storm characteristics, graupel/hail hydrometeor concentrations, and thermodynamic environments in both the current and future climate hailstorms will be presented.

**Keynote presentation**

"Hail Observations: Limitations, Oddities, and Impacts"

John T. Allen, PhD

Assistant Professor of Meteorology, Central Michigan University

**Abstract**

What do we really know about the characteristics of hail observations? What are the limitations and uses of these data, and how can we get around these issues? Just how big has the largest observed hail been? In this presentation, the characteristics of United States hail observations will be discussed, including the drivers of the intricacies of the dataset and the statistical limitations that these challenges present.

To illustrate these issues, climatological characteristics of frequency in the dataset are explored, including spatial clustering toward non-meteorological boundaries, rendition of seasonal cycle and intra-annual trends. For example, observations of hail size in the US show heavy quantization toward fixed diameter reference objects and are influenced by spatial and temporal biases similar to those noted for occurrence. Large portions of the continent have experienced hail in excess of 12.5 cm in the past 30 years, with the remainder having seen hail in excess of 2.5 cm in that same time period. Maximum-recorded hail sizes have been growing larger in the most recent decade mainly in response to improved records of these events and increasing report frequency rather than as a result of actual increase in hail size. To overcome these limitations, the spatial return interval for US hail size will be discussed. The results reveal that large hail sizes in excess of 10 cm are likely for return periods between 10-20 years for much of the region east of the Rockies, and at periods of less than 5 years in the Central Plains.
Tuesday, 2:20 pm – 2:40 pm

“Seasonal and Monthly Forecasting of US Hail Activity”
Chiara Lepore*, Michael K. Tippett, John T. Allen

*Presenting author affiliation: Columbia University

Abstract
We will present two methods for extended range prediction of US hail activity as measured by hail events, which we define to be three-hourly periods with one or more reports of hail greater than one inch in diameter. The first method produces spatially-resolved March-May probabilities of below-normal, normal and above-normal hail activity conditional on the previous December-February (DJF) ENSO state. Forecasts are validated using the Brier skill score, which is also used to select the level of spatial smoothing. Numbers of hail events are predicted skillfully in the southern U.S. including parts of Texas, Oklahoma, Kansas, Louisiana and Arkansas. Skill and overall hail activity is higher in the cool phase of ENSO (La Niña-like). We extend the lead-time with only a modest reduction in skill by using the predicted DJF ENSO state from NMME forecasts initialized in October of the previous year, instead of the observed DJF ENSO state. The second method produces monthly deterministic forecasts of the number of hail events and is based on forecasts of a Hail Environmental Index (HEI), which is a function of monthly-averaged storm relative helicity (SRH), convective precipitation (cPrcp), and convective available potential energy (CAPE). Forecast values of the HEI are computed from Climate Forecast System, version 2 outputs. HEI forecasts match well the annual cycle of hail events at the CONUS and regional levels (South, Northeast, Central, Upper Midwest, Plains). Rank correlations between forecasts and numbers of hail events are statistically significant in some NOAA regions and months of the year. ENSO modulates the CFSv2-based HEI forecasts and, to a lesser extent, their skill, during March-May, with more activity and higher skill during cool ENSO conditions, consistent with the other forecast method. Much of the skill of the monthly forecasts appears to derive from the first two weeks of the forecast.

Tuesday, 2:40 pm – 3:00 pm

“CHAT – The Colorado Hail Accumulation from Thunderstorms Project”
Katja Friedrich*, Robinson Wallace, Bernard Meier, Weibke Deierling, Evan Kalina, Paul Schlatter

*Presenting author affiliation: University of Colorado

Abstract
In recent years, deep hail accumulations from thunderstorms have occurred frequently enough to raise the attention of the National Weather Service, the general public, and news agencies to this phenomenon. Despite the extreme nature of these thunderstorms, no mechanism is currently in place to obtain comprehensive reports, measurements, or forecasts of accumulated hail depth. To better identify and forecast hail accumulations, the Colorado Hail Accumulation from Thunderstorms (CHAT) project has been initiated with the goals of collecting improved and more frequent hail depth reports on the ground as well as studying characteristics of storms that produce deep hail accumulations in Colorado. The presentation will cover highlights and first results from the project, which include building a hail depth database, presenting ways to identify and study characteristics of thunderstorms producing hail accumulations on the ground, as well as discussing ways to nowcast these events.

Tuesday, 3:00 pm – 3:20 pm

“Eastern Colorado Severe Hail Climatology Conundrums”
Samuel J. Childs*, Colorado State University

Abstract
The Front Range and eastern Plains of Colorado experience some of the most frequent and intense hail storms in the country. The area’s location in the immediate lee of the Rocky Mountains, as well as often near the interface of a cold continental air mass from the north and a warm and moist air mass originating from the Gulf of Mexico, make it a favored location for all forms of severe weather. Hail is of particular danger due to the elevated terrain supporting hail stone growth via intense updrafts and colder in-cloud temperatures, and hail stone fallout in closer proximity to the ground. Other unique topographical features across eastern Colorado, such as the Palmer Divide and Cheyenne...
Ridge, provide additional sources of lift and moisture for deep convection and cyclonic vorticity for intense, rotating supercells. For example, the Denver Cyclone, and related Denver Convergence Vorticity Zone, often forms when southerly flow is stretched over the Palmer Divide, generating cyclonic vorticity that is tilted into the vertical, which promotes tornadoes and severe hail storms. In fact, eastern Colorado is prone to both heavy hail storms of generally small stones in which snow plows must be activated for their removal as well as hail storms with isolated giant stones, such as the devastating May 2017 storm near Denver.

It is of worth, to the public but especially to emergency management officials, meteorologists, city leaders, and the insurance industry, to know whether (and if so, where) the risk for severe hail is increasing over time. Unfortunately, this question is difficult to answer due to inhomogeneities in the hail data record. For example, hail data is known to have a large population bias, as reports are highly correlated to cities and highways (i.e., where people live and frequently travel). As such, the upward trend in hail reports in the past decades is at least in part attributable to population growth. In less populated places, hail often goes undocumented. Further, reported hail stone sizes are often clustered around the thresholds used by the Storm Prediction Center to delineate quarter- (1.00”), golf-ball- (1.75”), and baseball-sized (2.75”) hail. The change in the threshold for severe hail changed from 0.75” to 1.00” in 2010, causing another inhomogeneity in the data record.

Given the aforementioned hail maximum in eastern Colorado, this study investigates the hail data record for a 28-county region east of the foothills of the Rocky Mountains. Since the Front Range urban corridor of Colorado is one of the fastest growing places in the U.S., it is hypothesized that population will have a large effect on hail report frequency and density. In fact, it is shown that the number of both severe hail reports and hail days has increased substantially since 1955, although the magnitude of increase is dependent upon the size threshold chosen. When only the years 1997–2017 are considered, which represents a more reliable data record, a large increasing trend in reports and days still exists, especially for a 1.0”+ size threshold. Interestingly, the increasing trend is not found domain-wide, but rather is correlated with trends in population during the 1997–2017 period, with counties seeing rapid population growth amassing more hail reports in general and counties with stagnant or decreasing population showing on average fewer hail reports. These findings are potentially complicated by the fact that hail can be reported by a non-resident of a particular county (e.g., a storm chaser). However, an analysis of hail report sources shows that almost 80% of reports are attributed to trained spotters and the public, with storm chasers, law enforcement, and social media playing a much-reduced role. Hail reports are also distinctly clustered along major highways in eastern Colorado, highlighting the dearth of navigable roads in much of the rural eastern Plains. Finally, it is found that almost all severe hail reports stem from discrete cellular storms, either isolated or in clusters, as opposed to linear convection, with relatively high shear and low-level moisture and marginal surface-based CAPE compared to climatological values. The findings provide a current landscape of severe hail events across eastern Colorado that can serve as a basis for projections of future changes in severe hail risk due to meteorological and societal elements.
“Using Space-borne Sensors to Detect Hailstorms and Build Climatologies”
Daniel J. Cecil*, NASA Marshall Spaceflight Center

Abstract
Despite numerous studies on hail conducted in countries across all continents (except Antarctica), cohesive pictures of hailstorm distributions on scales larger than individual nations have been rare. Measuring and reporting standards vary from nation to nation, within nations, and also across eras. In the last decade, several studies have used satellite data to attempt to detect hailstorms with standardized approaches applied on near-global scales. This limits some of the geographic biases associated with varying reporting standards, although the satellite-based detection methods likely have their own biases related to meteorological regimes. Microwave sensors in low Earth orbit seem especially well suited to identifying severe thunderstorms with large hail. The temporal sampling from low Earth orbit may not be suitable for operational warnings, but can be suitable for constructing climatologies and for comparing regions that have different standards for ground-based observations.

The satellite-based sensors do not directly detect hail, but instead detect storm characteristics that tend to be associated with hail. Some studies focus on relationships with large hail (>2.5 cm diameter) reaching the surface, some include the more numerous reports of smaller hail (1 cm and less), and some involve retrievals of hail aloft that may melt before reaching the surface. These studies usually have to choose between a low false alarm rate with a low probability of detection, a high probability of detection with a high false alarm rate, or an optimized skill score when considering both detections and false alarms.

This presentation will focus on how to interpret some recent satellite-based studies in light of these considerations, and discuss some ideas for subsequent studies and applications.

“The Swiss National Hail Climatology Project – Overview and First Results”
Katharina Schroer*, S. Trefalt, C. Schweierz, U. Germann, A. Hering, T. Schlegel, L. Nisi

*Presenting author affiliation: MeteoSwiss

Abstract
In Switzerland, hail is one of three major meteorological phenomena that cause expensive and substantial damages (the other hazards being wind storms and flooding). In the building sector, hail is related to over a third of the costs incurred through natural hazards, other vulnerable sectors include infrastructure, vehicles, agriculture and viticulture. Moreover, devastating flooding events can occur as a consequence of hail due to drains/run-offs being blocked by foliage or hail itself. A single hail event can lead to tens of thousands of claims and cause damages of the order of several tens of millions of USD. On average, the yearly damages in Switzerland have been estimated to amount to several hundred millions of USD.

Thus, there is a large interest and need for accurate information on hail, not only in terms of real-time warning, but also in terms of climate information for planning, prevention and the implementation of adaptation measures. Currently, there is a range of products available for planning and regulations by the administration, the insurance and other private sectors, but no universally accepted planning basis exists. The available hail products that are widely used date back partly to the 1980s or 1990s. Since then, more data, novel measurement technologies and new statistical methods have become available.

To improve the situation, a larger group of stakeholders under the lead of MeteoSwiss, the Swiss Federal Office for Meteorology and Climatology, has launched a cooperation to create a commonly accepted hail climatology to support planning and implementation of measures. The development and execution of the project is based on a continuous dialogue and co-design with the stakeholders to best meet their needs. Implementation by MeteoSwiss ensures that the climate service can be delivered in an operational and sustainable fashion. The project started in May 2018.

In this paper, the Swiss Hail climatology project will be presented, explaining its challenges and opportunities, the stakeholder interactions and the scientific goals. These include improvement of the radar hail data basis, detection of different hail parameters and hail events, operational production and analyses of a range of hail climatologies and the
development of methods to calculate return periods. Some first results will also be discussed.

Tuesday, 4:40 pm – 5:00 pm

“A New Era of Hail Monitoring, Forecasting, and Climatology”
Simona Trefalt*, H. Barras, A. Hering, L. Nisi, K. Schroer, C. Schweierz, D. Wolfensberger, U. Germann
*Presenting author affiliation: MeteoSwiss

Abstract

The Prealpine regions of Switzerland are some of the major hail hotspots in Europe, where hail causes substantial damage on a yearly basis. As a natural consequence, there is a strong need for accurate information on hail on all time scales, going from real-time hail identification and automatic hail warnings to day-one forecasts and hail return-period statistics and climatology. This has triggered a new wave of hail activities at MeteoSwiss and other institutions in Switzerland.

At MeteoSwiss radar- and NWP-based hail algorithms to identify hail occurrence (POH) and estimate its maximum size (MESHS) on a 1km$^2$ scale have been operational for many years. These algorithms take advantage of the full vertical and temporal resolution of the five C-Band radars scanning 20 elevation sweeps every 5 minutes. The upgrade to dual-polarization capabilities lead the way to a now operational hydrometeor classification scheme which, includes classes for ice hail, melting hail, and graupel. Such indirect hail information is naturally best when verified by hail observations on the ground. To this purpose, in 2015 a hail-reporting function was added to the MeteoSwiss smart phone and tablet App, which allows to report hail sizes in six distinct classes or actively report the absence of hail. We received over 50'000 reports in the first three years. Moreover, for verification purposes, but also to gain insight into hail storm dynamics and microphysics, we deployed a pilot network of digital hail sensors, which measure the kinetic energy of individual hail stones. This network will be expanded to over 80 sensors in the next years, covering the main hail hotspots of Switzerland. The verified occurrence of hail and size information can be employed as the basis from which to compute statistics on the return-period of hail of different sizes. Hail around the Swiss Alps is furthermore interesting from a meteorological point of view, since the hail climatology differs between the northern, more continental, and southern side of the Alps, where the influence of the Mediterranean sea is strong. These regions however are only a few hundreds of km apart. The identification of the prevalent atmospheric conditions on hail days north and south of the Alps will complement the now operational automatic alerts based on radar thunderstorm tracking of convective cells, by regional day-one forecasts of hail risk based on NWP.

The combination of new hail observation databases and large data archives from radar and NWP offers great conditions for hail research in one of the major hail producing areas of Europe.

Tuesday, 5:00 pm – 5:20 pm

“Using > 50,000 Crowd-sourced Hail Reports for the Verification of Radar-Based Hail Products”
Helene Barras*, A. Hering, U. Germann, O. Martius
*Presenting author affiliation: University of Bern

Abstract

Three years ago, in 2015, the Swiss National Weather Service (MeteoSwiss) added a crowdsourcing function to their weather app that invites users to report hail stone size observations. Users can choose between six different hail size classes such as “coffee bean”, “1 CHF” and “5 CHF” coin sizes or “golf ball” and one “no hail” class. The app is widely distributed in Switzerland and there are 500'000 users every day (the total population of Switzerland is 8.4 million). The crowd-sourced hail report data set is unique in its high number of reports (> 50'000 since May 2015) for a comparatively small area (considering the Alps, less than a third of the 41’000 km$^2$ area of Switzerland is populated).

The nature of the crowd-sourcing data requires that the reports be filtered for inaccurate reports, which was done with radar maximum reflectivity fields, a user blacklist and a neighborhood method. As an example application, we used the filtered reports to verify the two operationally produced radar hail detection algorithms POH (probability of hail) and
MESHS (maximum expected severe hail size). We observe a positive correlation between the reported hail size and the radar-based size estimates but also significant variability of the radar-based MESHS values for each reported hail-size class. The results further show that the app users do not differentiate between graupel and hail and that the largest hail size class is reported disproportionally often. As a reaction, the size categories were updated in September 2017 to include a “tennis ball” size class which should facilitate the removal of false reports from users that are boasting about their hail experience. With this contribution, we will present the MeteoSwiss hail crowdsourcing reports, their strengths, weaknesses and some statistics, as well as the verification of the radar hail detection algorithms.

Tuesday, 5:20 pm – 5:40 pm

“Hail Frequency in Central Europe Estimated from Single-Pol Radar Reflectivity and the Relation to Local- and Large-Scale Environmental Conditions”
Michael Kunz, Jan Wandel, Sven Baumstark, Elody Fluck, David Piper
*Presenting author affiliation: Karlsruhe Institute of Technology, Center for Disaster Management and Risk Reduction Technology

Abstract
Tracks of severe convective storms (SCS) have been estimated from 2D radar data over a long-term period from 2005 and 2014 for several European countries such as France, Germany, Luxembourg, and Belgium. The event set comprising more than 21,000 individual SCS tracks shows a high spatial variability of the tracks caused by the interaction of large-scale climatology and local-scale flow dynamics. While the frequency of SCS is lowest near the Atlantic coastal regions, it is highest over and downstream of mountain ranges such as the Massif Central (France) or Black Forest (Germany).

In order to scrutinize the relation between hail events and prevailing ambient conditions, the large event set is combined with ERA-Interim reanalysis and detections of cold fronts based on the same reanalysis. Additionally, hail reports from the European Severe Weather Database (ESWD) are used to extract a subset of events that provides information about the observed hail diameter. While most of the hailstreaks over the almost flat terrain in northern Germany require a cold front as trigger mechanism, only between 10 and 20% of the streaks have been identified as prefrontal events over the rolling terrain in the south. Composite environmental conditions based on two different reanalyses show a clear separation between different hail size classes when considering thermodynamical quantities such as Lifted Index or Lapse Rate. Dynamical quantities such as Wind Shear or Storm-Relative Helicity, however, separate best when considering length of tracks. Interestingly, not only the local-scale absolute value, but also the mesoscale spatial distribution of these parameters turns out to distinguish well between the corresponding event classes. For the separation between small hail/short storm tracks and large hail/long tracks, quantitative evaluation based on categorical verification and logistic regression reveals that Storm-Relative Helicity has a much higher prediction skill compared to Wind Shear.
### Registration

**“The May 8, 2017 Metro Denver Hailstorm: One of the Costliest in U.S. History”**

*Paul Schlatter*, National Weather Service Forecast Office, Boulder Colorado

**Abstract**

Hailstorms across the High Plains of the U.S. east of the Rocky Mountains are more common than just about anywhere else in the world. In Colorado, the metropolitan Denver area sees anywhere from 11-13 severe hail storms each year. The Denver metro area has also become more vulnerable to the impacts of hailstorms over the past 30 years, pun intended. The reason is rapid population growth; in 1990 the population was around 1.3 million people. Today, the population of metro Denver is estimated to be over 3.5 million people, increasing the damage potential of those hailstorms. On July 11, 1990 a hailstorm packing baseball to softball size hail moved from Estes Park to Boulder and then across a good portion of Denver, causing $1.2B in damages (adjusted for 2017), which was the costliest in U.S. history at the time. On July 20, 2009 a hailstorm across the western part of metro Denver caused $890M adjusted for 2017. Both storms pale in comparison to the hailstorm on May 8, 2017, when up to baseball hail occurred west to east across metro Denver, causing an estimated $2.2B in damages (NCEI estimate). The May 8 hailstorm is one costliest in U.S. history for purely hail damage, similar in cost to the “Tri State Hailstorm” on April 10, 2001. This presentation will detail the near-storm environmental conditions before and during hail fall, the radar and satellite observations, the warning operations in the NWS Boulder office, and finally discuss an unanticipated surprise event that occurred at about the same time as the giant hail. We will also discuss why the damages were so great and compare/contrast this storm to the other costliest storm in U.S. history.

### Keynote presentation

**“Hail Kinetic Energies & Test Protocols: Where are We & How Did We Get Here?”**

Andrew J. Heymsfield, PhD  
*Senior Scientist, National Center for Atmospheric Research*

Robert L. Wright  
*Robert L. Wright and Associates*

Ian M. Giammanco, PhD  
*Lead Research Meteorologist, Insurance Institute for Business & Home Safety*
"History of Underwriters Laboratory's Impact Testing Program and Certification"
Dewayne Sloan*, Director of Principal Engineers and Regulatory Services for the Building and Life Safety Technologies Underwriters Laboratory

Abstract
Over the past few years, the roofing and insurance industries have seen a steady increase in hail damage activity to roofing products and systems. Hail damage is pervasive and complex. Understanding the nature of hail damage, the testing and certification approaches, and the overall impact of hail damage is critical to roofing manufacturers, contractors, building owners, Code officials and insurance stakeholders. Information will be presented towards an understanding of hail impacts on the roofing and insurance industries, with a focus on testing and certification.

Participants of this session will be able to:
- Identify the U.S. hail risk and vulnerabilities
- Understand prevalent roofing impact test standards
- Identify hail damage modes
- Describe how the use of roofs tested and certified for impact can help mitigate damage

"RICOWI Hail Investigation Program: April 11, 2016 North Texas Hailstorm"
Richard F. Herzog*, Haag Engineering Co.

Abstract
The Roofing Industry Committee on Weather Issues, Inc. (RICOWI) performed a field research project in the northern Dallas-Fort Worth area to inspect widespread damage from a hailstorm that occurred on April 11, 2016, and caused an estimated $250 million in damage to property. A total of 178 residential and commercial roofs were inspected that were struck by hailstones ranging from less than 1-inch diameter to greater than 3-inches in diameter. The objective of the Hail Investigation Program (HIP) project is to investigate field performance of roofing assemblies after major hail events, to factually describe roof assembly performance and modes of damage, and to formally report the results for substantiated hail events. The RICOWI HIP teams were balanced with representation from manufacturers, academia and researchers, designers, technical consultants, the insurance industry, and contractors. The data will be of interest to consultants, engineers, building owners, climatologists, catastrophe modelers, and risk managers.

"A Non-Destructive Hail Test Model"
Matthew Phelps*, Texas Tech University

Abstract
Many aspects of hail have been studied for years, with most of the published literature focusing on the meteorological aspects of hail. Many reports are on ice which in part, infers hail information. Schulson (1999), reports "Over the past ten years alone (since 1999) more than 10,000 papers on ice have appeared in the scientific and engineering literature." Without an understanding of the physical and engineering properties of freezer ice balls, simulated and natural hail stones, meaningful understanding of hail hardness, strain rate response, or compressive strength, remains unresolved. One of the barriers to hail mechanics investigations are destructive test methods. A non-destructive test method that facilitates mathematically relationships of various hail physical, engineering and materials properties will allow researchers to relate more hail aspects without destroying the test sample.

Transmissivity is the measure of light transmitted through a material. In this method transmissivity was measured in 108 freezer icecballs, 108 simulated hailstones and 108 natural hailstones. Each hailstone was evaluated for the percent light passing through the hailstone (vs light without the hailstone) for each of the seven colors of the visible spectrum. Each color dominate wavelength was measured with a photo spectrometer.

Illuminance (measured in Lux) was measured before and after the hailstones were in place. The difference being the percentage of light passing through the hailstone. The highest percent passing through the hails with the longest wavelength were the value (dominate wavelength and color)
reported for each stone. To create separation between the seven colors and their associated wavelengths the selected wavelength was multiplied by the percent passing for each stone. The purpose of this examination is to establish if subsequently collected data has a correlation to the transmissivity and if the correlation is unique to a specific wavelength. Since transmissivity is a nondestructive test method it can be used as a proxy for other properties such as compressive strength allowing the hail stone to be preserved for other investigations.

The base light illuminance was measured for each color and then compared to the illuminance for each wavelength color for each hail stone. The light system operating temperature was maintained by a dual set point thermostat. Operating temperature of electrical devices effects the amount of resistance in the circuitry. Pilot test indicated that the selected temperature range had the lowest Standard Deviation of all temperature data sets.

To test the compressive strength of stones the specimen is placed in a zip lock baggie and placed on the 0,0 mark on the tempered glass base inside the hydraulic press. A GoPro camera is placed beneath the glass base to record the deformation of the stone against the glass base. Loads are applied by a hydro pneumatic jack and the force was measured. Vertical compression and horizontal (lateral) expansion was measured. The test environment temperature was about 25 °F. Transmissivity values were regressed against compressive strength and compressive pressure and a linear curve fit to the data.

Wednesday, 10:10 am – 10:30 am

MORNING BREAK

Wednesday, 10:30 am – 10:50 am

“Automated Hailswhaths – Claims and Damage Ratios in the Insurance Industry
Andrew Siffert*, Vice President and Senior Meteorologist BMS Group

Abstract

On an inflation-adjusted basis, 2017 was the second costliest year on record for thunderstorm-related damage in the U.S. Most of the insured losses resulted from hail damage not associated with tornado losses, thus highlighting that hail and straight-line winds are often the predominant severe convective storm loss driver. Due to increasing awareness over the last several years regarding the increase in insured hail losses, insurance companies have been arming themselves with analytics; hail swath report maps which now seem to be a dime a dozen are widely used by insurance companies. But, such maps are just one tool that an insurance company can use to improve customer satisfaction and profitability during these costly catastrophic events. BMS RE US is drawing upon its broad, national client-base to provide important insights to insurance companies, helping them better understand and utilize the information in hail swath reports. In this talk, we will discuss how insurance claims data from destructive hail events adds value beyond the standard hail swath maps by offering improved claims rate and exposed loss ratios.

Learning Objectives:
- Understand Claim Rate:
  - Its magnitude on event response
  - Internal vs external (3rd Party) adjusters
  - Where to mobilize
- Understand Exposed Loss Ratio:
  - Expected loss severity
  - Mobilization of resources
  - Anticipated reinsurance utilization
  - Reinsurer notification

Wednesday, 10:50 am – 11:10 am

“Modeling Hail Impact: How Many Hailstones of What Size?
Jurgen Grieser*, Risk Management Solutions

Abstract

A variety of aggregated variables are used in order to characterize the potential impact of hail on property and vehicles. Maximum hailstone size and hail-kinetic energy are two of them. However, the maximum hailstone size need not to be the largest contributor to losses. And large hail kinetic energies can be generated by many small or few large stones. While many small stones may not cause damage to property at all, few large stones can just miss small objects at risk like cars or solar panels. We aim to characterize hail events by less aggregated variables than maximum hailstone size or hail-kinetic energy.

To do so we analyze the 22,000 hail observations from the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS). These data provide minimum, mean and maximum hailstone size, duration of hail and overall hailstone number density at the ground.
We use this data to fit a Marshall-Palmer distribution that allows modelling the rate of hail stones hitting the ground per unit area, time and hailstone size bin during the passage of a hail storm. One result of the model is that event hail-kinetic energy goes approximately with the squared maximum hailstone size. This is in line with observations by Auer (MWR, 1972). As a validation experiment the results of this model are compared to observations of hail kinetic energy and maximum hailstone size in Southern France published by Fraile et al. (AR, 2003). The model can be used for Monte-Carlo simulations of hail fall on various components of subjects at risk.

Wednesday, 11:10 am – 11:30 am

“Hail Hazard and Hail Risk Modeling for Germany Based on a Combination of Radar and Insurance Data”
Manuel Schmidberger, James E. Daniell, Michael Kunz*

*Presenting author affiliation: Karlsruhe Institute of Technology, Center for Disaster Management and Risk Reduction Technology

Abstract

Germany with a substantial hazard potential for buildings, cars, crops and even for human life. Due to the lack of appropriate direct hail observations, radar data are used as a proxy for hail. The combination of radar data and the cell-tracking algorithm ‘TRACE3D’ is used to create a unique radar-based hail climatology for Germany. Additionally, TRACE3D provides an event set for historical events with information on every single potential hail track between 2005 and 2017.

In combination with reports of hailstone sizes which are collected in the European Severe Weather Database (ESWD) the historical hail event dataset forms the basis for a new hail model to quantify the hail risk in Germany. A new approach based on the Gutenberg-Richter recurrence law known from earthquake modeling is used to combine the return period of hailstorms on a 1 x 1 km² grid with historical hailstone sizes from the ESWD. Based on this stochastic event set, polygons are created to represent the stochastic hail tracks in the model. The polygons form the basis for the calculation of a probable maximum loss (pml) for a given portfolio. Detailed vulnerability studies of historic hail events lead to vulnerability functions for different building classes. This calibrated vulnerability functions are used to combine the hazard and vulnerability to a risk for every stochastic hail track. Over a cumulative distribution, a mean damage ratio is quantified for each object, which leads to the expected damage. A second version of this model was developed to estimate loss in near-real time after a severe hailstorm.

Wednesday, 11:30 am – 11:50 am

“HAILCAST Hail Forecasting Performance during the NOAA/Hazardous Weather Testbed Spring Forecasting Experiments”
Rebecca Adams-Selin*, AER

Abstract

HAILCAST is a one-dimensional hail growth model currently integrated into the WRF-ARW model and designed to predict hail size on a convective scale. During the past five NOAA Hazardous Weather Testbed (HWT) Spring Forecasting Experiments (2014-2018), HAILCAST was run within the NSSL WRF-ARW Ensemble, the CAPS Storm-Scale Ensemble Forecast (SSEF), the Community Leveraged Unified Ensemble (CLUE), and the NCAR WRF ensemble. Subjective and objective feedback from HAILCAST’s performance each year was used to drive improvements in the hail model physics, including constant embryo sizes, parameterized horizontal motion across the updraft, and adiabatic liquid water profiles. HAILCAST’s performance was also compared to hail size forecasts generated using surrogate severe fields including updraft helicity, maximum column updraft speed, and column-integrated graupel, as well as Day 1 convective outlooks issued by the Storm Prediction Center. A range of thresholds for the surrogate severe fields were used for verification. Evaluation efforts revealed the importance of multiple verification metrics, including both object-based and more traditional grid-based neighborhood verification. Future plans for incorporation into HAILCAST of environmental parameter information descriptive of three-dimensional updraft structure and volume will be presented.

Wednesday, 11:50 am – 1:30 pm

LUNCH BREAK
Wednesday, 1:30 pm – 2:30 pm

**Expert Panel Discussion**

**“Hail Resiliency: Can We Get There?”**

*Description:* A sizable percentage of the monetary impact of hailstorms is driven by damage to roofs, both for residential and commercial structures. This panel brings together experts in the roofing industry and scientific testing communities to explore the question: can we reduce hail damage roofs through improved products and testing.

**Moderator:** Tanya Brown-Giammanco, PhD

*Vice President for Research, Director of Hail Research, Insurance Institute for Business & Home Safety*

**Panelists:**

- Heather E. Estes
  *Research Scientist and Research Manager, Insurance Institute for Business & Home Safety*

- Greg Malarkey
  *Senior Vice President, Malarkey Roofing Inc.*

- Ellen Thorp
  *Associate Executive Director, EPDM Roofing Association*

- John Gimble
  *Gimble Consulting Engineering, RICOWI*

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Wednesday, 2:30 pm – 2:50 pm

**“Observations of Supercells Containing Large Hail Using a Rapid-Scan X-Band Mobile, Polarimetric Doppler Radar”**

Howard B. Bluestein*, Jeffrey Synder, Jana Houser, Zach Weinhoff, Dylan Reif, Kyle Theim

*Presenting author affiliation: University of Oklahoma*

**Abstract**

Since the spring of 2011, my research group has been probing supercells in the Plains of the U. S., with a rapid-scan (volume scans taking < 15 – 25 s), X-band, mobile, polarimetric Doppler radar (RaXPol). While the main foci of our studies have been tornadogenesis and tornado structure, we often find that large hail is reported in our radar volume. In this presentation, we will show polarimetric radar data from three supercells during which hail > 7.5 cm was reported during data collection. These cases include: 23 May 2011 (near Mountain View, OK), 31 May 2013 (near El Reno, OK) (Witt et al. 2018, in review), and 24 May 2016 (near Dodge City, KS). We will report on the ability of the radar to identify regions of very large hail in these storms.

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Wednesday, 2:50 pm – 3:10 pm

**“Hail Research at CIMMS/NSSL Using the SHAVE and MYRORSS Databases”**

Kiel L. Ortega*, CIMMS - University of Oklahoma

**Abstract**

The Severe Weather Application Technology and Transfer Group at CIMMS/NSSL has been engaged in activities for over a decade dedicated to collecting a research-quality hail verification database paired with comprehensive radar information for the events. The first activity was the Severe Hazards Analysis and Verification Experiment, which was a remote hail report collection project that involved operators calling after thunderstorms to collect reports of hail along a storm’s path. SHAVE was unique in that the goal was to collect reports with ~2 km spacing between reports, much higher than Storm Data; further, reports of ‘no hail’ and non-severe reports were also collected along the path of the storm, whereas such reports are not readily available elsewhere. The primary sampling strategy was to begin the verification phone calls near the start of a storm and work backwards to determine the approximate areas hail began falling at the surface. The verification phone calls would then continue downstream behind the storm until storm dissipation or more than 2 hours had passed since the storm had passed. The project ran from 2006 through 2015, primarily during the summer months. During the 10 years of operation, over 250,000 phone calls were made, yielding over 74,000 reports of a variety of hazards, including hail. The hail reports totaled over 54,000, with most of the hail reports being ‘no hail’ and non-severe sizes. Cases from the decade of
operations were reviewed and 735 events that had good report swath resolution were kept for further research. The cases ranged from storms that produced no hail at all to long-track storms producing large swaths of hail exceeding 50 mm. These events yielded 32,341 total SHAVE hail reports. Of these 735 events, 427 had at least 1 polarimetric WSR-88D within 150 km of the report swath and yielded a total of 19,411 SHAVE hail reports that can be used in polarimetric radar studies.

SHAVE hail reports have been used to help develop a polarimetric Hail Size Discrimination Algorithm (HSDA) that is now operational on the WSR-88D network. The SHAVE database has also been used to evaluate the capabilities of the Multi-Radar, Multi-Sensor (MRMS) system to diagnose surface hailfall characteristics. Radar data from single-polarization cases have been hand-analyzed to compile a data set that can better relate radar outputs, including subjectively determined signatures like a bounded weak echo region, to hailfall downstream. A similar effort is planned for the dual-polarization data. Finally, individual hail reports have been paired to polarimetric data in the immediate area surrounding the report. These sub-images are being used to explore machine- and deep-learning capabilities for hailfall diagnosis.

The second activity ongoing that contributes towards furthering hail science is the Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS). This effort involves processing the entire WSR-88D archive through the MRMS system, producing both reflectivity-derived and Doppler-velocity derived products. The data are merged onto a CONUS-wide latitude-longitude grid with an approximate spacing of 1-km (500-m for the velocity products), with 35 vertical levels and at 5-min time steps. As of April 2018, the years 1998 through 2011 have been completed and efforts were underway to continue processing, including merging polarimetric moments, for the remaining years. MYRORSS data, combined with findings from the SHAVE investigations, can be used to develop a radar-based hail climatology and provide a very large data set for use in developing machine- and deep-learning techniques using MRMS data to diagnose hailfall.

3:10 pm – 3:30 pm

Sophisticated Break

Wednesday, 3:30 pm – 4:30 pm

Expert Panel Discussion

"Future Applications in Hail Detection & Forecasting"

Description: This panel discussion delves into future applications that may come from improvements in hail detection and forecasting. It covers both the public and private sector needs and where our panelists see new computational abilities and technologies contributing.

Moderator: Matthew Kumjian, PhD
Assistant Professor of Meteorology, The Pennsylvania State University

Panelists:
Alex Kubicek
Founder and CEO, Understory Inc.

David John Gagne, PhD
Research Scientist, National Center for Atmospheric Research

Daniel Betten, PhD
Principal Research Scientist, CoreLogic

William Ramstrom
Director of Weather Applications, Verisk Weather Solutions

Wednesday, 4:30 pm – 4:50 pm

"Development of a Post-Event Tool for the Spatiotemporal Analysis of Hail Events"
Justin E. Jones*, Leigh A. Munchak

*Presenting author affiliation: Weather Analytics

Abstract

Detection of hail events and estimation of hail size from weather radar data are considerable scientific challenges; however, these problems are of critical importance to insurers, so that they can most efficiently deploy claims adjusters to the field following a severe weather event and better anticipate future claims by understanding the frequency and severity of hail events at a property location. Weather Analytics’ Dexter hail product is a post-event analysis tool that allows insurers and claims adjusters to verify historical and near real-time hail events. It provides both a historical database of hail events and a web-based display tool to view the spatial distribution of hail sizes for selected dates across the continental United States at 1-km resolution. The tool uses multiple hail data sources to produce the hail size estimates, including the Multi-Radar/Multi-Sensor System.
(MRMS) radar-derived hail size products, Storm Prediction Center (SPC) reports of human observed hail sizes, and Level 3 hail size and polarimetric radar data archived by the National Climatic Data Center (NCDC). The Dexter hail size data is produced operationally within a cloud computing environment every hour with a maximum latency of 120 minutes.

In the development of this tool, several deficiencies with current publicly available hail data sources have been identified. Weather Analytics has developed unique, proprietary methods to improve the quality of radar-derived hail data as well as disseminate the data in formats that are easily used by insurers. This talk will provide a high-level overview of the usage of the tool, as well as the scientific and technical methods that have been employed to ensure quality and improve the accuracy of the publicly available hail data.

Wednesday, 4:50 pm – 5:10 pm

“Hail Detection and Prediction Using 1-Minute GOES 14 & 16 Satellite Imagery and Ground Based Dual-Polarization Radar”

Elisa Murillo*, Cameron Homeyer, Kristopher Bedka, Thea Sandmael

*Presenting author affiliation: University of Oklahoma

Abstract

Large hail can lead to significant agricultural and property loss. Due to historical limitations of reporting and other factors, these events have not been studied as extensively as other hazards such as tornadoes. In the contiguous US, real-time analysis and detection of severe storms is largely based on information gathered by the ground-based NEXRAD (Next-Generation Radar) network, which obtains volumes at about 5-min intervals. Since 2013, the NEXRAD network has provided radar observations at dual-polarization, which has provided better indications of hydrometeor types and of hail events. After the launch of GOES-16 in November of 2016, the spatial and temporal resolution of geostationary satellite imagery over the US is now greater than that of the NEXRAD network. It is expected that this data will enable improvements in severe weather prediction. Previous studies have found several satellite signatures associated with deep and severe convection. For example, overshooting tops (OTs) show a clear and distinct updraft in visible imagery with a corresponding local minimum in infrared brightness temperatures, indicative of high cloud tops. Severe storms are commonly associated with OTs, but only ~1% of OT-producing storms are severe. On the other hand, above-anvil cirrus plumes, which are collocated with OTs and produce the cloud-top IR signatures referred to in older literature as the “enhanced-V” or “cold-ring”, have recently been shown to be one of the most powerful satellite-based indicators of severe weather. Mesoscale atmospheric motion vector (mAMV) products have recently been used with 1-min GOES imagery to diagnose unique cloud-top motions that often precede severe weather. These satellite products, from both GOES satellites, may show improvement in identifying and predicting severe storms. However, to date, an assessment of a broad range of radar- and satellite-based products’ ability to identify and predict hail events has been incomplete.

This study aims to determine the ability, from a statistical approach, of numerous satellite- and radar-based products to detect and predict large hail events. First, radar-based products are evaluated based on hail reports to determine the best radar indication of hail occurrence. Second, both reports and the most skillful radar-based indicator will be used to assess the value of radar and satellite products for hail identification and prediction. Using 5-min NEXRAD data from more than 20 recent severe weather events (2013-Present) and more than 5,000 storms, we will show that combinations of radar reflectivity at horizontal polarization and differential reflectivity above the melting level can be confidently used as a proxy for severe hail occurrence. The predictive skill of additional radar- and satellite-based products will also be shown relative to both the hail reports and radar-based hail indication.

Wednesday, 5:10 pm – 5:30 pm

“Real-time Hail Prediction Using Machine Learning Algorithms with HREFv2”

Amanda Burke*, Nathan Snook, Amy McGovern, David John Gagne

*Presenting author affiliation: University of Oklahoma

Abstract

Severe hail is a weather hazard that, on average, results in more than a billion dollars of damage within the continental United States each year. Thus, timely and accurate operational hail forecasts are vital in allowing the public to take action. These forecasts rely on correctly representing the processes and environment responsible for hail production. Currently, multiple operational models predict hail based on discrete environmental data. The models use a variety of microphysical schemes and methods for parameterizing or simulating hail growth. This abundance of data can lead to cognitive overload for forecasters attempting to predict hail and other severe weather hazards.
Machine learning (ML) synthesizes multiple datasets to obtain an optimal configuration for predicting hazardous weather, including severe hail. Hail growth is predicted using classification ML models, with input from the High-Resolution Ensemble Forecast version 2 (HREFv2). The HREFv2, provided by the Storm Prediction Center (SPC), is an eight-member ensemble that uses a mixture of microphysical parameterizations. Twenty-seven environment and storm scale variables, determined via preliminary testing as optimal for predicting severe and significant severe hail, are used from each ensemble member. Maximum Estimated Size of Hail (MESH), a Multi-Radar Multi-Sensor (MRMS) product, was used as an observation dataset to train and verify the ML model. Preliminary results suggest that the ML hail forecasts accurately predict severe hail over spatially similar regions, as compared to observed hail from SPC hail reports. In addition, the ML models identified temperature at 1000 and 500 hpa, dew point temperature at 500 hpa, and hourly maximum updraft strength as the most important variables for hail growth. Further analysis of ML models will be conducted to investigate model performance metrics.

**Thursday August, 16**

**TIME**

**Thursday, 8:00 am – 8:20 am**

“The Operational Application of the Lightning Jump Algorithm for Hail Nowcasting In Catalonia”
Carme Farnell*, Tomeu Rigo, Oriol Puig

*Presenting author affiliation: University of Barcelona*

**Abstract**

Farnell et al. (2017) and (2018) showed the high relationship between the triggering of a warning by the Lightning Jump (LJ) algorithm and the occurrence of severe weather (large hail, strong wind gusts, downbursts, and/or tornadoes). More than 80% of the alerts were associated with at least one register in the area of study. This percentage may be even larger due to the lack of observations in some events that took place in low-density population areas or at night. The algorithm has been set into operation in the Meteorological Service of Catalonia (SMC), considering lightning data exclusively. The LJ warnings have two levels: the lower one is commonly associated with heavy rainfall and small hail, but can be used as a precursor of severe weather occurrence. On the contrary, the higher level has a higher degree of correlation with severe weather, mainly large hail. It is planned that in the near future, the higher level alerts will be used to warn population about severe weather.

In order to collect surface data for improving the information associated with the phenomena occurring in severe thunderstorms, we have started a citizen participation campaign (called “Plega la pedra”, translated as “Catch the hail”) using social networks (mainly twitter #meteocatpedra- and a whatsapp line). Thanks to the large contribution of the citizenry, the number of registers in 2017 was higher than usual, despite the year presented fewer hailstorms than the median of the previous 2 decades.

This presentation shows the results of the campaign and an analysis of different cases, including the importance of the spotters’ contribution when validating the characteristics of the alerts: lead time, distance, or maximum hail registered.

**Thursday, 8:20 am – 8:40 am**

“A Comparison of the Lightning Jump Algorithm Using Total Lightning Versus Cloud-to-Ground Flashes”
Tomeu Rigo*, Carme Farnell

*Presenting author affiliation: Meteorological Service of Catalonia*

**Abstract**

The Meteorological Service of Catalonia (SMC) has developed a database of severe weather phenomena, with registers since 2004. This database has been used for identifying the regions of Catalonia most prone to be affected by severe hail (diameter larger than 2 cm) and small hail. In
addition, the SMC has lightning data from its own detecting network (XDDE), which is capable to discriminate between intra-cloud (IC) and cloud-to-ground (CG) flashes, another feature of the XDDE is that the flash path can be detected using a single point or several ones (fact defined as multiplicity). These data are available since 2006.

Using the spatial distribution of hail observation for the period 2007-2016, we have offline run the lightning jump algorithm for the same period, considering the different configurations of the lightning data: using only CG and non-multiplicity (CGNM), CG and multiplicity (CGWM), total lightning without multiplicity (TLNM), and total lightning with multiplicity (TLWM). The alerts obtained for the four configurations have been plotted in the same style as the hail registers’ map of the data base, in order to compare them.

The results show how the use of CG flashes is not enough for reproducing the behavior of the hailstorms, with a poorer map of occurrences than the ground base. On the contrary, the TL configuration shows a high degree of correlation with the data base at surface.

Thursday, 8:40 am – 9:00 am

“Continental Scale Hail Frequency Estimation from Geostationary Satellite Data”
Heinz Jurgen Punge*, Kristopher M. Bedka, Michael Kunz

*Presenting author affiliation: Karlsruhe Institute of Technology

Abstract

Hail is a prominent peril in many parts of the world and across most insurance markets, but is not adequately captured by ground detection. To fill this gap, by analyzing long time periods of remote sensing information, we can now construct meaningful hail climatology that describe spatial and temporal features of the hail distribution affecting damage expectations. One remote sensing product that can serve as an effective proxy for severe convective events is satellite derived cloud overshooting top (OT) detection. Compared to products from ground-based devices, this method presents the advantage of high spatial homogeneity and geographical coverage, avoiding calibration biases. However, the occurrence and intensity of specific hazards associated to these extreme weather events, such as large hail, heavy rain, or severe wind, depend on the local and regional atmospheric conditions. An OT-filter specific to large hail as reported in storm event databases was designed using ERA-INTERIM reanalysis data in the vicinity of these events.

For Europe, we used reports from the European Severe Weather Database (ESWD) and an 11-year OT database from Meteosat Second Generation geostationary satellite data. In particular, detections with absent convectively available potential energy or elevated freezing level are unlikely to be related to large hail on the ground---these represent a significant fraction of the OTs over the sea and mountainous parts of southern Europe and neighboring Northern Africa, respectively. Hail hotspots in Europe are found in foothill regions of the Alps and in mountain ranges such as the Pyrenees, the Massif Central, and the Carpathians. The resulting hail hazard map for Europe is found to be in good agreement with major regional and national scale climatological studies. For Australia, a 10-year database of OTs has been obtained from Japanese MT-SAT imagery and filtered using Australian Severe Storm Archive hail reports in the same way. Hail is found to be most frequent in the South-Eastern parts of Australia, whereas the large majority of OTs detected in the North are unlikely to be related to hail on the ground due to very high freezing levels and low wind shear. The findings match existing large-scale hail frequency estimates for Australia from coarser satellite or model based methods well, but offer greater detail. Our analysis of seven years of 3D-data from the Bureau of Meteorology weather radar network covering most larger settlements shows a similar overall pattern, but appears to suffer from large calibration deficiencies. The radar-based findings can however be used to resolve small scale variations of hail frequency due to orography and land-sea contrast. Further improvements can be obtained when undetected capped situations with lower cloud top level but still significant convective potential in sounding data are accounted for.

Thursday, 9:00 am – 9:20 am

“Hail Detectability Using Backscatter Differential Phase by X-Band Dual Polarization Radar”
Takeshi Maesaka*, Shin-ichi Suzuki, Koyuru Iwaami

*Presenting author affiliation: National Research Institute for Earth Science and Disaster Resilience, Japan

Abstract

Classification of precipitation, particularly hail detection, using weather radar has been usually based on lookup table, fuzzy logic, or neural network so far. However, it is difficult to collect “teaching data” (simultaneous observations of radar echo and hydrometeor) to improve these methods, and these methods sometimes depend on other factors, such as seasons, climatic zones, and storm types. Some radar parameters, such as radar reflectivity (ZH) and differential reflectivity (ZDR) play an important...
role in these methods, but precipitation attenuation affects ZH and ZDR in X-band dual-polarization radar. On the other hand, propagation differential phase (Φ DP), which is one of radar parameters, is not influenced by the precipitation attenuation, because it is not an amplitude but a phase. Now Φ DP is used for precise Quantitative Precipitation Estimation (QPE) in Japanese X-band weather radar network (XRAIN). The observed Φ DP is contaminated by a noise and backscatter differential phase (δ), which is caused by large precipitation particle like a hailstone. The elimination of the noise and δ is a key technique in QPE using Φ DP. Maesaka et al. (2012) proposed a method to retrieve the ΦDP from the observed differential phase under the assumption that the Φ DP is a monotone increasing function of a distance from radar in rainfall. With this method, it is possible to estimate the δ inversely. In this presentation, the δ and hail report are compared, and the hail detectability using δ is discussed.

Thursday, 9:30 am – 10:30 am
MORNING BREAK & POSTER SESSION #2

Thursday, 10:30 am – 11:00 am
Keynote Presentation
“Microphysics and Dynamics of Hail-Producing Thunderstorms”
Zachary J. Lebo, PhD
Assistant Professor of Atmospheric Science, University of Wyoming
Abstract
A brief overview of hail microphysics is provided for single hailstones. These processes are extended to bulk and bin microphysics frameworks for use in 2D and 3D dynamical frameworks, and the pros and cons of bulk and bin microphysics schemes in the context of hail are discussed in detail. A review of recent studies using both types of microphysics schemes to examine the role of various assumptions related to hail growth and demise is presented. Finally, the connection between convective storm dynamics and the microphysics of hail is discussed, focusing on recent advancements using numerical models and observations.

Thursday, 11:00 am – 11:30 am
Keynote Presentation
“Features of Hailstones and Their Formation”
Charles Knight, PhD
Senior Scientist Emeritus, National Center for Atmospheric Research
Abstract
Observations are presented from several decades of collecting hailstones, examining and recording them, and trying to understand their structures and the storms that produce them. The research started with systematic hail collection in the National Hail Research Experiment in NE Colorado, before 1970. NHRE included a test of a hail suppression technique, and evidence from the hailstones themselves contributed to the conclusions about the Soviet method of hail suppression. The wide range of natural hailstone shapes, sizes, and internal structures is illustrated, and possible implications for a better understanding of hailstorms are discussed.

Thursday, 11:30 am – 11:50 am
“Hail Prediction in the Canadian 2.5-km NWP System Using the P3 Microphysics Scheme”
Jason Milbrandt*, Meteorological Research Division/Environment and Climate Change, Canada
Abstract
The Meteorological Services of Canada (MSC) currently runs a deterministic numerical weather prediction (NWP) over a pan-Canadian domain with a 2.5 km horizontal grid spacing. While this is somewhat coarse with respect to what is needed to fully resolve convective circulations in hailstorms, the model is able to simulate sufficiently realistic storms such that explicit hail forecasting – where the predicted hail is a direct model output – becomes feasible. Later this year, the 2.5 km NWP system will be upgraded and, amongst other improvements currently being tested, will use the recently developed Predicted Particle Properties (P3) microphysics scheme. P3 is a detailed multi-moment bulk scheme based on a fundamentally new approach to represent ice-phase hydrometeors. In contrast to traditional microphysics schemes which partition the ice phase into several predefined particle types, such as “snow”, “graupel”, etc., P3 introduces the concept of “free” ice categories. With this approach, each ice category has several prognostic variables...
and allows the smooth evolution of various physical properties, such as mean size, bulk density, rime mass fraction, etc. Consequently, there are no artificial ‘conversion’ processes between categories, as in traditional schemes. Even with a single free ice category, P3 can represent any type of frozen hydrometeor, including hail.

An overview of the P3 microphysics scheme will be presented along with simulation results illustrating the capacity of MSC’s high resolution NWP system to forecast hail explicitly.

Thursday, 11:50 am – 1:30 pm

LUNCH BREAK

Thursday, 1:30 pm – 1:50 pm

“Potential Impact of Aerosol Pollution on Hailstorms”
William R. Cotton*, Adrian M. Loftus, Gustavo G. Carrío

*Presenting author affiliation: Colorado State University

Abstract
In this talk we focus on investigations of the potential impacts of aerosol pollution on hailstorms. By aerosol pollution we are talking about small hygroscopic aerosol particles emitted by gasoline and diesel vehicles, power generation with hydrocarbons, refineries, and many industries. Previous studies examined the impacts of high concentrations of cloud condensation nuclei (CCN) on hail with conflicting results. Noppel et al. (2010) used two-moment microphysics and found high CCN concentrations lead to more numerous, but smaller hailstones, and reduction in hail accumulations at the surface. Khain et al. (2011) used a full-bin microphysics scheme in a two-dimensional cloud model and large CCN concentrations lead to an increase in total hail mass and sizes of hailstones. Interestingly, these studies were for the same storm.

Here we focus on recent simulations of CCN impacts on hailstorms by Loftus and Cotton (2014). In that study a triple-moment hail model was used to examine hail impacts on the 29 June 2000 STEPS supercell hail-producing storm. It was found that high CCN concentrations lead to greater predicted hail sizes and amounts of large diameter hail, whereas the general storm dynamics and evolution are relatively insensitive to changes in CCN. Additionally, most hydrometeor distributions as well as hail formation and growth processes respond non-monotonically to increases in CCN, with the response changing sign above a threshold CCN value around 600 cc\(^{-1}\) for the particular environment and storm type examined. Fewer numbers and less hail mass are generated in simulations with extremely low (100 cc\(^{-1}\)) and very high (3000 cc\(^{-1}\)) values of CCN compared to cases initialized with CCN amounts between these two extremes. The results of this study agree qualitatively with recent results of Eliotoviz et al., (2016) using full bin microphysics in a two-dimensional cloud modeling framework.

We then discuss the results of a large number of hailstorm simulations by Carrío et al., (2014) in which cloud base temperature is varied. Clouds with high cloud base temperatures produce larger amounts of liquid water contents in the lower parts of the cloud which favors precipitation formation by collision and coalescence. On the other hand, clouds with lower base temperatures have smaller distances between cloud base and zero degree centigrade, thus warm-rain collision and coalescence is less dominant. It is found that for storms with colder cloud base temperatures or higher cloud bases, and with smaller distances between cloud base and freezing level(D), large CCN concentrations favor larger predominant hail sizes and concentrations, greater integral masses of hail, and greater hail precipitation. In contrast, hailstorms forming in airmasses with warmer cloud base temperatures, and greater D, the response to high CCN concentrations is weak.

Thursday, 1:50 pm – 2:10 pm

“Investigating the Characteristics of Hail Accumulating Thunderstorms”
Robinson Wallace*, Katia Friedrich, Bernard Meier, WeiBke Deierling, Evan Kalina, Paul Schlatter

*Presenting author affiliation: University of Colorado

Abstract
Hail accumulations from thunderstorms, sometimes as large as 60 cm, have significantly affected the populations across the High Plains of Colorado and Wyoming by creating hazardous road conditions and endangering lives and property. Our work shows how 20 quality-controlled hail depth reports obtained during the Colorado Hail Accumulation from Thunderstorms (CHAT) project can be used to validate a hail accumulation algorithm for operational application. The validated algorithm, using WSR-88D radar data, shows marked improvement over a previous algorithm presented in Kalina et al. (2016). Furthermore, using the improved algorithm, and lightning and dual-polarization radar data from a set of 32 thunderstorms, we assess the relative importance of in-cloud hail production, storm speed, and melting rates in determining the amount of hail accumulation observed on the ground. Our results show radar-derived in-cloud hail production is the most correlated to hail accumulation (r=0.93).
In contrast, while storm speed and melting rates show little to no correlation to hail accumulation, both are determined to be important when comparing storms that experience similar in-cloud hail production.

High Resolution EnKf Analyses and Forecasts of the 8 May 2018 Colorado Severe Hail Event
Jonathan Labriola*, Nathan Snook, Youngsun Jung, Ming Xue
*Presenting author affiliation: University of Oklahoma

Abstract

Hail causes more than $1 billion in damage annually in the United States. Explicit hail prediction using high-resolution (500 m grid spacing) numerical weather prediction models can potentially extend severe weather warning lead times and mitigate hail damage. In this study an ensemble Kalman filter (EnKF) is used to assimilate surface and radar observations of the 8 May 2017 Colorado hail event into ensembles run using either a double moment (DM) or variable density rimed ice DM microphysics (MP) scheme. Although multi-moment MP schemes predict a large number of microphysical fields (12-17 variables), microphysical state of the hailstorms is improved when all precipitation variables are updated via the assimilation of reflectivity. Results also indicate that choice of MP scheme impacts how background dynamic and microphysical variables are updated during assimilation, impacting the subsequent hail forecast.

0 – 90 minute hail size forecasts are verified against radar derived hail size discrimination algorithm output and surface based hail size reports. Although all forecast experiments are initialized from accurate analyses, the variable density rimed ice DM scheme is the only MP scheme that predicts the coverage and size of hail with skill.

Subtropical South American Hailstorm Characteristics and Environments
Zachary S. Bruick*, Kristen L. Rasmussen, Daniel J. Cecil
*Presenting author affiliation: Colorado State University

Abstract

Subtropical South America has some of the deepest convective storms (Zipser et al. 2006; Houze et al. 2015) and most frequent large hail (Cecil and Blankenship 2012) on Earth. Hail in this region has been known to cause extensive damage to property and agriculture (e.g., wineries, soybean and wheat crops) due to its large size and frequency, especially in central Argentina near the Andes foothills (Rasmussen et al. 2014). These storms frequently form near complex terrain and often grow upscale in place (Rasmussen and Houze 2011, 2016; Rasmussen et al. 2014), producing deep hail accumulations in addition to large hailstones. While convection initiates over and near the foothills of the Andes, similar to convective initiation near the foothills of the Rocky Mountains and Palmer Divide in Colorado, the frequency of large hail in the immediate foothills of the Andes in subtropical South America is more similar to the frequency found in the central Great Plains of the U.S. A dearth of research investigating why such large hail forms in the immediate foothills of the Andes limits our understanding of the microphysical and dynamical processes supporting these extreme storms. This is primarily due to a historical lack of observations in this area, such as dense radiosonde or ground-based radar networks that would enable better identification of hail-producing environments and storms. As a result, this study makes novel use of the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) passive microwave radiometer and Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar instruments aboard the Aqua and TRMM satellites, respectively, to identify convection and the likelihood of hail production, in order to better understand how these hailstorms are unique. ERA-Interim reanalysis data is utilized to discern changes in mesoscale and synoptic environments between hail-producing and non-hail-producing convection. Results will be presented on hailstorm characteristics and associated synoptic environments that improve our understanding of hail production in subtropical South America and around the world.
“Interpretable Deep Learning Representations of Hail Growth Processes”
David John Gagne*, National Center for Atmospheric Research

Abstract
Large hail growth depends on positive feedbacks among multiple atmospheric processes within the three-dimensional structure of a storm. Statistical machine learning models often struggle to encode spatial structures without extensive manual pre-processing. Deep learning models, in particular convolutional neural networks, can learn to encode multi-dimensional spatial structures into an internal representation that is optimized for prediction. These internal representations can be interpreted through feature optimization and activated analog techniques. Feature optimization utilizes the neural network optimization procedure to generate an input field that maximally activates a particular neuron or set of neurons in the network. Activated analog techniques submit a set of examples through the network and return the examples that most activate each neuron. The purpose of this presentation is to analyze the features identified by convolutional neural networks trained on storm-scale numerical weather prediction model output that are associated with large hail and compare them with our existing knowledge of hail growth processes.

This study uses 3-km-grid-spacing numerical weather prediction model output from the NCAR convection-allowing ensemble and deterministic WRF model output with a similar configuration run over a 7 year period on major storm event days. Hourly maximum upward vertical velocity is used to identify strong updrafts in the model runs, and a 96-km-wide box is extracted around each storm. Temperature, dewpoint, geopotential height, and winds are extracted at multiple pressure levels to capture the thermodynamics within the hail growth region of each storm. Simulated radar reflectivity is also used as an input to analyze how neural networks associate storm mode with different hail chances. The networks are trained to predict the probability of 25 mm diameter hail based on the microphysics-simulated maximum hail size at the surface. This perfect model experiment setup maximizes the strength of the association between storm structures and surface hail.

The feature optimization process reveals that the convolutional neural networks encode multiple processes associated with large hail growth. Feature optimization and activated analogs reveal that isolated and training supercell radar signatures positively contribute to the probability of severe hail. Disorganized convection is associated with a low probability of severe hail. Feature optimization on the thermodynamic fields identifies wind shear, strong lapse rates, mid-level rotation, and strong horizontal flow through the hail growth zone as contributing to severe hail chances. Some networks also encode interactions between storms in which graupel ejected from one storm is seeded into the updraft of a downwind storm. The geographic and diurnal distributions of when different features are activated are also explored.

“Improving Graupel and Hail Treatment in the Thompson Microphysics Parameterization”
Greg Thompson*, Sarah Tessendorf, Kyoko Ikeda, Andrew Heymsfield

*Presenting author affiliation: National Center for Atmospheric Research

Abstract
The talk will present recent improvements to the treatment of graupel and hail within the WRF model’s Thompson microphysics parameterization using three predicted moments. By using three moments, graupel/hail particle density can vary rather than be constant, which results in particle fall speeds more correctly matching observations. In addition, a diagnostic maximum hail size metric was developed to compare model forecasts against observations.
Thursday, 3:50 pm – 4:10 pm

“Characteristics of Hail Events Near the Sierras de Cordoba, Argentina”
Jeremiah Otero Piersante*, Deanna Hence, Sarah Tessendorf, Roy Rasmussen
*Presenting author affiliation: Hobart and William Smith Colleges

Abstract
Argentina is a global hotspot for severe hailstorms, especially within the vicinity of the Andes Mountains and the Sierras de Córdoba. This hail activity results in substantial damage and economic loss in both urban areas and farms in the region. The RELAMPAGO (Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations) field campaign, which will take place during the austral summer of 2018, aims to deepen the understanding of the lifecycle of the region’s convective storms through direct observations. To assist in locating equipment and personnel for the project, this study presents a hail climatology which addresses the diurnal, annual, and spatial patterns of the region’s hail. Trends in hail size and the type of damage are also discussed. To create this climatology, meteorological surface station data between 1 June 1987 and 31 May 2017 from 20 stations in the Mendoza, San Luis, and Córdoba provinces were supplemented with online newspaper and social media reports from 1 June 2013 to 31 May 2017. Both datasets show that hail peaked in the summer for Mendoza and San Luis, but in the spring for Córdoba, which was the province with the most hail reports. The combined effects of topography and population likely influenced the spatial distribution of hail reports. The two datasets disagree on the time of day hail most frequently occurred, however. This, in addition to the role of population density in hail reporting, highlights the potential for bias among the results.

Thursday, 4:10 pm – 4:30 pm

“Comparison of Hailstorm Properties Between China and the United States”
Qinghong Zhang*, Xiang Ni, Chuntao Liu, Daniel J. Cecil
Presenting author affiliation: Peking University

Abstract
The United States and China are located within a similar latitude range, but with quite different hailstorm climatology. The maximum hail occurrence was found in Central Plain of United States and Tibetan Plateau of China. The differences might largely be influenced by the different surface hailstorm observation systems in the two regions. U.S. hail reports are dominated by cases with hail size greater than 19 mm from public reports that could be biased toward high population regions, while hail reports in China cover all hail size above 2 mm on weather stations. Therefore, comparison of the hail datasets in the two countries and constructing a universal observation method would advance our understanding in regional and global hail climatology. To achieve this goal, a 16-yr record of hail reports over the southeast U.S. and from weather stations in China are collocated with Precipitation Features (PF) derived from the Tropical Rainfall Measuring Mission (TRMM) radar and passive microwave observations. The fraction of PFs collocated with hail reports (hail PFs) reaches 3% in the plains of the U.S. In China, the fraction is higher in high elevation regions than low elevation regions. Hail PFs in the U.S. show lower brightness temperatures, higher lightning flash rates, stronger maximum reflectivity, and higher echo tops than those in China, consistent with the larger hail diameters in the U.S. reports. The average near surface maximum reflectivity of hail PFs at high elevations (≥ 2000 m) in China is about 5 dB smaller than those at low elevations. Despite the distinguish differences, larger hail is reported with PFs having stronger maximum reflectivity above 6 km in both counties. Based on these results, efforts are made to find threshold to detect hail with size > 19 mm using collocated hail reports in the U.S. The threshold is applied to global hail distribution discussion and reveals well matched results with ground observation. The method is further validated with three-year observation of Ku-band radar aboard GPM core observatory, especially in China and United States.

Thursday, 4:30 pm – 4:50 pm

“The Role of Initial Cloud Condensation Nuclei Concentration in Hail Using the WRF-NSSL 2-Moment Microphysics Scheme”
Xiaofei Li*, Peking University

Abstract
The effects of the initial cloud condensation nuclei (CCN) concentrations (100–3000 mg⁻¹) on hail properties were investigated in an idealized non-severe hailstorm experiment using the Weather Research and Forecasting (WRF) model, with the National Severe Storms Laboratory 2-moment microphysics scheme. The initial CCN concentration (CCNC) had
obvious non-monotonic effects on the mixing ratio, number concentrations, and radius of hail, both in clouds and at the surface, with a CCNC threshold between 300 and 500 mg\(^{-1}\). An increasing CCNC is conducive (suppressive) to the amount of surface hail precipitation below (above) the CCNC threshold. The non-monotonic effects were due to both the thermodynamics and microphysics. Below the CCNC threshold, the mixing ratios of cloud droplets and ice crystals increased dramatically with the increasing CCNC, resulting in more latent heat released from condensation and frozen between 4 and 8 km and intensified updraft volume. The extent of the riming process, which is the primary process for hail production, increased dramatically. Above the CCNC threshold, the mixing ratio of cloud droplets and ice crystals increased continuously, but the maximum updraft volume was weakened because of reduced frozen latent heating at low level. The smaller ice crystals reduced the formation of hail and smaller clouds, with decreased rain water reducing riming efficiency so that graupel and hail also decreased with increasing CCNC, which is unfavorable for hail growth.

POSTER SESSION #1
AUGUST 14, 3:20 – 4:00 pm

"Properties of Hailstorms over the United States from Multi-Radar Multi-Sensor System Data"  
Nana Liu*, Chuntao Liu, Andrew Heymsfield, Ian Giammanco  
* Presenting author affiliation: Texas A&M University at Corpus Christi, Corpus Christi, Texas

Abstract  
One year (2017) small-size hail events (< 19 mm) from the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) and large-size hail events (> 19 mm) from the National Oceanic and Atmospheric Administration (NOAA) are combined and examined together in this study. To explore the properties of storms that produce hail, hail reports are temporally and spatially collocated with Precipitation Features (PFs) derived from Multi-Radar/Multi-sensor system (MRMS) data. The PFs are defined by grouping the continuous area of high-resolution MRMS precipitation (1 km, 2 min). With no surprise, PFs with larger size of hail have a stronger maximum radar reflectivity profile and a larger area of 50 dBZ radar reflectivity at -10°C, -20°C. The area of 50 dBZ radar reflectivity at -20°C is found to be well correlated to the hail sizes. Analysis of PFs with large hail report suggests that PFs with > 60 dBZ of maximum radar reflectivity at -20°C yields the highest Critical Success Index (CSI) and Heidke Skill States (HSS). The geographical distribution of potential hail PFs identified using these criteria is consistent with the distribution of the hail reports over the United Stated.

"The Regional Risk Perception of Extreme Weather Events: The Example Hail in Germany"  
Susanna Mohr*, Martin Doring, Frauke Feser, Tina Kunz-Plapp, Beate Ratter, Reimund Schwarze, Michael Kunz  
* Presenting author affiliation: Karlsruhe Institute of Technology, Center for Disaster Management and Risk Reduction Technology, Karlsruhe, Germany

Abstract  
Damages to buildings, infrastructure and even human life caused by extreme weather events have significantly increased during the last decades. This has happened due to the interaction of several factors such as increases in assets, increases in vulnerability of infrastructure and people, or changes in patterns and the frequency of extreme events. Seen from a social perspective, this increase is basically connected to and framed as a direct consequence of global warming. Hence, extreme weather events such as heavy hailstorms are phenomena, which call for an inclusion of the social dimensions in the context of reliable mitigation and adaptation measures and risk actions to be taken in the case of extreme events.

Within the frame of the interdisciplinary project "Regional risk cultures of weather extremes", scientists from different disciplines such as meteorology, sociology, and economics merge their conceptual and methodological expertise to investigate hazardous weather events (HWE) from an integrated perspective. Emphasis is put on the social perception and assessment of HWE as well as on actions taken regarding HWE such as heat waves, floods, winter storms, storm surges, and – in the present context – hail. The aim of the project consists in gaining a better and regionalized understanding of the societal and cultural dimensions of risk in the context of HWE. For this purpose, street surveys were conducted at locations specifically affected by certain types of hazards in Germany. In addition to regions with an increased probability of a certain hazard such as hail, regions with a low likelihood of occurrence were considered for comparative purposes.

In the project, we address the following research questions concerning HW (here: for hail):
• How are HWE perceived, explained and evaluated?
• What role does climate change play in the interpretation of HWE?
• What are the regional differences between risk perception, assessment and action in relation to experience and knowledge about an HWE?
• What protective measures have been, are or will be taken, and why?
• Can regional-specific risk cultures be identified and how are they structured?

“Temporal Variability of Severe Convective Storms Connected with Hail Events Across Europe and Their Relevant Drivers”
Susanna Mohr*, David Piper, Jan Wandel, Olivia Martius, Michael Kunz
*Presenting author affiliation: Karlsruhe Institute of Technology, Center for Disaster Management and Risk Reduction Technology, Karlsruhe, Germany

Abstract
Due to a lack of long-term, reliable, and consistent information about the occurrence of severe convective storms (SCS) in Europe – especially those connected with hail events – we have developed a methodology that enables to indirectly estimate thunderstorm and hail probability from numerical weather prediction or climate models. One approach is represented by a logistic hail model that estimates the number of days with hail-favoring conditions from the combination of appropriate hail-relevant meteorological parameters such as convective indices and moisture content. The other approach estimates SCS probability on a specific day using a weather type classification scheme trained to distinguish among convection-favoring and -inhibiting situations. Using these two approaches, we investigated the temporal and spatial variability of convective predisposition and hail potential over past decades and identified large-scale atmospheric processes (e.g., teleconnection patterns, SST, blocking) that determine the spatio-temporal variability of SCS. Using downscaled reanalysis data (NCEP/NCAR1) available for a long-term period of 60 years, the potential hail index (PHI) obtained from a logistic model shows a high spatial correlation at different sites across Europe and high annual and multiannual variability, but no trend over the whole period. To identify potential drivers for convective days, typical upper-level flow patterns associated with a high convective predisposition were deduced using principal component analysis. While all over central Europe the most prominent pattern for high convective activity is given by a southwesterly flow type over the respective area, distinct regional discrepancies regarding further favorable flow types are observed. Furthermore, we identified two regions (Northeast Atlantic and Scandinavia) that show a correlation between blocking and convective activity over Europe. The crucial role of large-scale flow is further studied by assessing the impact of atmospheric teleconnection patterns on the annual variability of SCS. It is found that positive phases of the North Atlantic Oscillation (NAO) go along with a significant reduction of convective activity in most of the European regions investigated.

“Trends in Environments Conducive for Large Hail”
Brian H. Tang, SUNY-Albany, Albany, New York

Abstract
The large hail parameter (LHP) is used to assess 39-year trends (1979–2017) in environments conducive for large hail. The LHP is a composite index, used to differentiate environments conducive for significantly severe hail (≥ 5 cm) versus smaller hail, that is comprised of three thermodynamic parameters and three kinematic parameters that are associated with hail growth. We define a LHP-day as any day (12 UTC – 12 UTC) that has a maximum LHP that exceeds 5.8, 10.6, and 18.4, representing the 25th, 50th, and 75th percentile of past environments that coincided with significantly severe hail. Using the lowest threshold (5.8), there has been an significant increasing trend in LHP-days in the central Plains (3–5 more LHP-days per decade) and in the northeast U.S. (1–3 more LHP-days per decade). There has been a significant decreasing trend in LHP-days in the immediate lee of the Colorado Rocky Mountains (3–5 days per decade). Using the higher thresholds (5.8 and 18.4), there has been an significant increasing trend in LHP-days in the central and southern Plains (1–4 more LHP-days per decade). These trends are attributed to changes in the thermodynamic parameters of the LHP. The results suggest that there is has been increasing hail risk due to an increasing frequency of days that are conducive for significantly severe hail over the time period examined.

“Hailstorms in Surrogate Climate Change Simulations Over Switzerland”
Andrey Martynov*, Olivia Martius
*Presenting author affiliation: University of Bern, Bern, Switzerland

Abstract
The summer season of 2015 has been simulated over the Central Europe using the Weather Research and Forecasting Model (WRF) model, driven by the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analysis. A surrogate climate change experiment has been performed with biased surface and boundary forcings, corresponding to climate changes expected towards the end of the XXI century (RCP 8.5 scenario). The sensitivity of hailstorms to atmospheric humidity has been studied by using two different relative humidity bias levels. Hailstorms over the densely populated Swiss Plateau region in unbiased and biased
simulations have been compared, using the WRF-simulated radar reflectivity and hail size estimations from the Hailcast-1D model, coupled with WRF.

"Comparing Hail Estimation with Warnings in 2017"
Tomeu Rigo*, Carme Farnell, Oriol Puig

*Presenting author affiliation: Meteorological Service of Catalonia

Abstract

The Meteorological Service of Catalonia (SMC) 6-minutely runs an algorithm of probability of hail (POH) based on the Waldvogel et al. (1979) technique, generating hourly and daily POH maps at the time of the thunderstorm (diagnosis tool). The algorithm compares the isozero output of the WRF model with the echo top of radar reflectivity over 45 dBZ. Moreover, the SMC works on hail nowcasting (between 30 and 120 minutes in advance) through the Lightning Jump tool (Farnell et al., 2017).

This study has compared the regions of POH over 85% of probability (this is the threshold that, based on our experience, has been considered for selecting hail over 1 cm of diameter) and the warnings of the LJ tool for each event occurred during 2017. Considering the trajectories of the thunderstorms identified using the radar network, it is possible to integrate both types of information (nowcasting and diagnosis) in the same data base.

We have calculated the skill scores of the LJ algorithm and the main characteristics of the warnings related to the diagnosed observations (lead time, distance between warning and observation, among others), for the campaign of 2017.

"Environmental and Radar Characteristics of Gargantuan Hail-Producing Storms"
Rachel Gutierrez* Matthew R. Kumjian

*Presenting author affiliation: Penn State University, State College, Pennsylvania

Abstract

Large hail can be extremely destructive to crops, infrastructure, and vehicles, and it can also cause severe injuries or even death to livestock and people caught outside. Individual hailstorms can be responsible for billions of dollars’ worth of insured losses. In this study, we investigate storms producing gargantuan hail (defined here as hail ≥ 6 inches in maximum dimension) to improve the understanding of how and why extremely large hail is formed. To accomplish this, we investigate the radar and environmental characteristics of extremely large hail events and look for similarities, differences, or any unique features that may be indicative of a gargantuan hail threat. The main goals of this study are to: (i) determine any reliable radar signatures indicative of gargantuan hail, and (ii) determine if any unique environmental characteristics are conducive to gargantuan hail production. Through preliminary analysis of 9 cases, we found that 6 of the storms have expansive bounded weak echo regions (BWERs) at high elevations. Additionally, we have found 4 cases of large three-body scattering signatures at low and high elevations. It is interesting to note that the gargantuan hail typically falls outside the region of the highest radar reflectivity factor at low levels. Also, the supercells associated with these gargantuan hail cases do not always have the classical “hook” shape typical of tornadic storms. Near-storm environments from these cases tend to reveal large storm-relative flow magnitudes at low levels. Further details on the quantitative analysis of storm structures will be discussed at the meeting. It is our hope that this research may be able to improve the forecasting and nowcasting of impactful hail events.

"CoCoRaHS: A 20-year Hail Data Repository for the United States and Canada"
Henry Reges*, Russ Schumacher, Nolan Doeskin, Noah Newman, Julian Turner, Dani Talmadge

*Presenting author affiliation: Colorado State University

Abstract

CoCoRaHS - The Community Collaborative Rain, Hail and Snow network (www.cocorahs.org), is an international network of over 20,000 citizen scientists collecting precipitation measurement at their locations on a daily basis. The network has been collecting hail data since 1998 and has become one of the largest repositories of hail information in both the United States and Canada. Data is also collected for Puerto Rico, the U.S. Virgin Islands and the Bahamas. Volunteers report hail as it falls (duration, size, depth, characteristics of the hail - hard, clear, white, damage, etc.), giving real-time information to the National Weather Service via AWIPS, which may meet the criteria for issuing severe weather warnings within their forecast areas. In addition to the reports, observers can deploy aluminum covered Styrofoam hail pads which provide researchers with a footprint of the hailstones that fell and clues to the storms themselves (https://cocorahs.org/ViewData/ListDaysWithHail.aspx). All data and hailpad photos are archived by date and free for the public to access via the website.

From an educational aspect, the network promotes an annual "Hail Week" each April to raise awareness of hail, how to report it and how to measure it. The network's training resources on hail provide an easy to follow "Measuring Hail" animation (https://youtu.be/0HvRGa09_uq) going over everything an observer would need to know about taking a hail observation, as well as a
section on other things to know about hail (https://cocorahs.org/Content.aspx?page=hail). This CoCoRaHS poster will take a look at the hail aspect of the network and give examples of significant hail events.

“Global Wind Oscillation and Hail Activity in the U.S.”
Victor A. Gensini

*Presenting author affiliation: University of Northern Illinois

Abstract
Changes in Earth relative atmospheric angular momentum can be described by an index known as the Global Wind Oscillation. This global index accounts for changes in Earth’s atmospheric budget of relative angular momentum through interactions of tropical convection anomalies, extratropical dynamics, and engagement of surface torques (e.g., friction and mountain). It is shown herein that U.S. hail events are more (less) likely to occur in low (high) atmospheric angular momentum base states when excluding weak Global Wind Oscillation days, with the strongest relationships found in the boreal spring and fall. Severe, significant severe, and giant hail events are more likely to occur during Global Wind Oscillation phases 8, 1, 2, and 3 during the peak of U.S. severe weather season. Lower frequencies of hail events are generally found in Global Wind Oscillation phases 4–7 but vary based on Global Wind Oscillation amplitude and month. In addition, probabilistic anomalies of atmospheric ingredients supportive of hail producing supercell thunderstorms closely mimic locations of reported hail frequency, helping to corroborate report results.

“Real-Time Hail Warning and Community Outreach in the CASA DFW Urban Network”
Venkatachalam Chandrasekar*, Hainan Chen, Brenda Phillips

*Presenting author affiliation: Colorado State University

Abstract

POSTER SESSION #2
AUGUST 16, 9:30 am – 10:30 am

“Life Cycle Analysis of Potentially Destructive Convective Cells for Nowcasting Purposes in Consideration of Atmospheric Environment Conditions”
Jannik Wilhelm*, Ulrich Blahak, Kathrin Wapler, Roland Potthast, Michael Kunz

* Presenting author affiliation: Karlsruhe Institute of Technology, Karlsruhe, Germany

Abstract
Severe damages to property, large economical losses and even loss of life may crop up within a very short time scale in conjunction with severe convective storms associated with heavy precipitation, hail, strong winds and, in a few cases, with tornadoes. Over recent decades, several nowcasting procedures have been developed with the objective of a more sophisticated on-line prediction of the evolution of convective cells. A large number of these methods is based on radar- or satellite-derived cell detection and tracking techniques. The representation of the cells’ life cycle, however, has not reached a satisfying state yet. Though, from the perspective of warning and precaution management, it is crucial to have spatially and temporally accurate predictions of the intensity including the tendency of a convective cell available, from which the potential threat can be estimated.

The ultimate goal of the project is to design a multi-sensor nowcasting method, which combines statistical information about the cell life cycle and ( thermo-) dynamic parameters determined from the latest high-resolution NWP model forecast. We present statistical analyses of historical two-dimensional cell tracking data based on radar reflectivity from German Weather Service. Physicalmathematical approaches useful for the integration of model environment parameters into a future nowcasting procedure predicting track, intensity and potential threat associated with the cells in a probabilistic manner would be most desirable and are therefore part of the current research. The cell tracking dataset covering Germany and parts of its neighboring countries will be described. Moreover, comprehensive statistical analyses with respect to life cycle characteristics such as intensity evolution, cell organization and spatial distribution, also with respect to possible hail occurrences, will be shown. These analyses will be supplemented by depictions and preliminary findings of a first approach to a simple prediction scheme including high-resolution model information from reanalysis fields. Last, future perspectives of the nowcasting method will be presented and discussed.
“Hail Pore Air Volume and Relative Ice, Water, and Air Analysis”
Matthew Phelps, Texas Tech University, Lubbock, Texas

Abstract
To better understand and define structural damage to building envelopes that is caused by hail there is a need to better understand physical properties and engineering mechanics of hail. The physical properties of our primary concern are the structural type and quantity of air, water, and ice within a hailstone. To measure the amount of entrained air and dissolved gases trapped inside hailstones, they were melted, and the air bubbles collected, and the volume measured. Hailstones were placed in a clear glass container filled with distilled water that had been previously saturated with dissolved gases (atmospheric air). The hailstones were placed inside an inverted glass funnel (maximum diameter four in.) and the funnel stem was fitted with a rubber balloon. The water temperature was monitored with a digital thermometer. As the hailstones melted the air bubbles floated up through the stem into the rubber balloon. After the hailstone was completely melted, air bubbles adhered to the sides of the glass funnel were freed by wiping the inside of the funnel. The balloon, partially filled with air, floated inside the water column. A hypodermic needle and syringe were used to remove and measure the volume of air contained in the balloon. The syringe measured volumes in 0.1 mL units. The rubber balloon did not leak when punctured or when the needle was extracted. The volume of air collected was compared to the total volume of the stone. Before melting, stone volumes were measured using the “Archimedes method” by immersing the stone in liquid silicone and measuring the volume of the displaced liquid. The liquid silicone is not reactive with water or ice and was refrigerated to -40°F before use. Stones were weighed on a digital scale with 0.1 g units. Porosity of the stones was computed by dividing the stones density by the density of pure ice (at the same temp.), then subtracting the result from one. The volume of the voids is equal to the porosity. The volume of ice is the volume of the stone less the volume of the voids. The measured volume of air was then subtracted from the volume of voids, with the difference being the volume of liquid water. The stones ice, air and liquid water volumes were summed to confirm unity. To determine the relationship between the relative volumes of air, water and ice in a hailstone, the USDA soil textural triangle was modified to create an air, liquid water, and ice triangle based upon the relative percentages of each of the three constituents. Date were plotted on the three-sided graph and values of other stone properties were contoured on the graph. This method shows the relationship of the physical constituents to other stones engineering properties by structural type. By using transmissivity as a surrogate, destructive test such as compressive strength can be plotted on the graph and provide a description of how the relative percentages of ice, water and gases will affect the compressive strength for a given structural type. This method does not account for hail stone structural type or other physical properties; therefore, a family of graphs are being created to account of structural differences that are not limited to relative constituent percentages.

“Development of a Relative Hailstone Hardness Scale”
Matthew Phelps, Texas Tech University, Lubbock, Texas

Abstract
The American Society of Testing and Materials (ASTM), now ASTM International standard E833-92 Standard Practice for Determining Resistance of Solar Collector Covers to Hail by Impact With Propelled Ice Balls, reports “no direct relationship has been established between the effect of impact of [freezer] ice balls and hailstones.” In determining the mathematical relationship between these categories of stones we have simultaneously developed a hail relative hardness scale system that will allow practitioners to relate kinetic energy content to relative impact energy. Without knowing the compressive strength, such a system would be no better than a guess. To determine the mathematical relationship between ice balls and natural hailstones, a common unit of measure between the two is necessary. This common link must also be non-destructive such that the sample remains intact for compressive strength and other testing.

In this investigation, transmissivity measurements of 36 ice balls from three freezing methods and data of density and surface hardness were tested. These results will be compared to natural hailstones of similar transmissivity measurements. The results are plotted, and a curvilinear fit made for each of four structural types of hailstones. The hypothesis for the difference is that of structural difference. Support for this hypothesis comes from the numerical analysis of 879 hailstones that were grouped by size (0.25 in. increments) and found that both average (R² = 0.9508) and max (R² = 0.9739) compressive pressure decreased with increased diameter over the range from 0.25 to 2.75 in. The data show that the standard deviation decreased from over 582 to 12 over the same range, R² = 0.947. These data suggest that as size increases both compressive pressure and variability (SD) decrease. Our hypothesis of structure specifies that as hail stones grow (from wet or dry growth) that cyclic structure tends to make compressive strength less variable; thus, the cyclic structure reduces variance and compressive pressure. In this study the compressive strength (Ibf) increased with increasing diameter; however, as the cross-sectional diameter increased at a greater rate then compressive strength the compressive pressure was reduced. To assess the relationship between freezer iceballs and natural hail the compressive strength values by transmissivity values were plotted for structural type, producing a family of curves that represent the mathematical relationship between ice balls and natural hail. The natural hailstone relative compressive strength is set to 1.0 for the value of the hardest hailstone recorded (487.38 Ibf) plus three standard deviations (SD = 83.69) of dataset from which the hailstone belonged. The value of 738.46 Ibf was considered the theoretical hardest natural hailstone. The theoretical softest hailstone was water (value 0 Ibf). This provides us with a relative impact energy model by hardness scale that can be computed by multiplying the hardness coefficient by the calculated kinetic energy that results in relative impact energy. This model will allow all the features of kinetic energy and will also account for the estimated compressive strength of the hailstones. Estimated compressive strength comes from the relationship between transmissivity and compressive strength. Transmissivity provides us a non-destructive test method that we can regress against compressive strength and other material mechanics.
Hail presents an ongoing challenge for Australia where a majority of the population is situated along hail-prone subtropical east coast. A renewed focus on hail research has been motivated by the ongoing dual-polarization upgrade of the national radar network and increasing interest by industry groups to improve the long-term understanding and real-time mapping of hail impact. The following paper presents efforts towards developing the next generation of tools, data and research for both the radar community, and non-specialists research and industry users.

To promote the development and application of hail retrievals, an open source hazardous weather toolkit is under development in the python language, built upon the functionality of the Py-ART radar library. Hail and mesocyclone retrieval techniques are implemented and can be easily interfaced with Py-ART ingest, analysis and plotting modules. An application of this toolkit is demonstrated through a preliminary verification of hail retrieval techniques against surface hail datasets collected from a recent citizen science and field campaign in Southeast Queensland, Australia.

Alongside the toolkit, a public archive of Australian operational weather radar data is currently under development. The hazardous weather toolkit will be applied to generate a hail and mesocyclone products from Doppler wind and satellite-calibrated reflectivity, with records extending more than 20 years for multiple capital cities. Preliminary work is also underway to explore improvements to historical single-pol hail retrievals through the use of terrain models and dual-pol retrievals using 3D-wind advection and melting considerations.

The SMC runs an algorithm that, using volumetric radar data, identifies, characterizes, tracks and forecasts thunderstorms. Each convective cell is tracked throughout its life-cycle, and the information of all the positions of the trajectory is stored in a database. The algorithm gives very valuable information to the forecasters, in terms of the past and future trajectories, and the trend of different parameters. Moreover, combined with the Lightning Jump tool (which considers only lightning data and warns of severe weather), it helps to identify the areas with higher probability of being affected by the most active thunderstorms in the immediate future.

The present analysis has focused on crossing information of two types: the lightning jump warnings and the thunderstorm trajectories. The main goal has been to identify those key parameters associated with the cells that produce at least one severe weather alert. Some of the cell parameters have been: position, the height of the top, the height of the centroid, the maximum and medium reflectivity, the vertically integrated liquid, and the cloud-to-ground and intra-cloud flash rates, among others. We have normalized several parameters in order to make all cells equivalent regarding their life-cycle. Then it is possible to discriminate between two categories: with and without lightning jump warning. The current work has been made considering the data from 2017, with more than 2000 thunderstorms analyzed, 164 of them with at least one warning.

Finally, and continuing with the work started in Farnell et al. (2018), we have selected only those thunderstorms with LJ warnings, in order to determine their convective mode and the vertical profile of reflectivity at the time of the warning. This has allowed the identification of those thunderstorm categories most commonly associated with severe weather, and also their vertical profile.

Hail nowcasting and climatology efforts currently rely on projecting hail detected aloft directly onto the ground underneath. When surface hail swaths produced in this manner are compared to surface hail observations, significant deviations are observed, likely due to storm generated advection of hail as it falls. This effect is particularly apparent for loss reports, motivating the need to improve hail retrievals for fine scale assessment by the insurance industry. The method proposed in this study uses a physical model to calculate hail trajectories in order to estimate where and when each detected hail particle above the freezing level will fall to the ground. Either a maximum hail size or hail intensity parameter is produced for each grid-point on the ground based on hail trajectories. Dual-polarized hail detection techniques are employed and considerations are made for changes in terminal velocities and size due to melting below the freezing level. A 3D wind field is calculated from Dual-Doppler wind retrievals and acts as the only forcing mechanism to calculate the trajectories. A dual-polarized hail classification algorithm is also used at low elevations to verify trajectories in example cases. In addition to improving impact mapping of hail events, this technique is aimed at improving operational nowcasting by providing a better indication of where hail will land with a lead-time sufficient to issue warnings. Additionally, the work is of significant importance to...
emergency services and the private sector to better guide post-storm assistance efforts and provide more accurate climatology information.

“In Situ Hail Observations Using a Rapidly Deployable Network of Hail Impact Disdrometers”
Ian M. Giammanco*, Tanya M. Brown-Giammanco

*Presenting author affiliation: Insurance Institute for Business & Home Safety, Richburg, South Carolina

Abstract

The use of in-situ adaptive instrument networks has been successful in documenting storm-scale environments near and within supercell thunderstorms. Most instrument systems designed to capture hydrometeor distributions are not sufficiently rugged to survive repeated exposure to large hail or are cost prohibitive for use in a large, adaptive network. The Insurance Institute for Business & Home Safety (IBHS) developed a low-cost, rapidly deployable hail impact disdrometer probe which built upon previous work by Lane et al. (2002). The instrument employs an impact plate, piezoelectric disk, and a low-cost robotics microcontroller. The probe captures hail impact kinetic energies which are used to estimate approximate hail sizes. Probes can resolve hailstones of approximately 0.5 cm and larger. IBHS maintains a network of 18 probes, eight of which are equipped with thermodynamic measurement capability. The network of impact disdrometers was deployed in 2017-2018 during the annual IBHS hail field research program. The work presented here summarizes the in-situ observations from the impact disdrometers and physical hail measurements from four supercell thunderstorms. In each case the spatial extent of the swath of hail was captured and provided a detailed picture of kinetic energy flux, estimated hail size, and hail concentrations and how these quantities evolved both spatially across the swath of hail and due to storm-relative location.

“Deployment of a Novel Automated Hail Sensor Network in Switzerland”
Daniel Wolfensberger*, H. Barras, A. Berne, A. Berne, A. Hering, O. Martius, L. Nisi, K. Schroer, C. Schwierz, S. Trefalt, U. Germann

*Presenting author affiliation: MeteoSwiss Division for Radar, Satellite, and Nowcasting, Switzerland

Abstract

Hailstorms are characterized by small spatio-temporal scales. As such the measurement of hail is often performed indirectly, with algorithms based on specific radar reflectivity levels and the freezing level height from a NWP model, estimating its occurrence (Probability of Hail, POH) and its maximum size (Maximum Expected Severe Hail Size, MESHS). As with all indirect retrieval methods this requires validation and calibration with in-situ observations of hail to yield meaningful results. In the last twenty years, in Switzerland, sampling of hailstones has been performed manually on isolated events, which is tedious, prone to human error, and raises the issue of limited representativeness. Even though MeteoSwiss has been receiving thousands of crowdsourced hail reports from their app users, which are a fantastic source of observations, they need to be complemented by a more reliable and precise description of individual hailstones.

In this light, we introduce a novel fully automatic hail sensor network. Comprising more than 80 instruments which are currently being installed in three climatological radar-derived hail hotspots in Switzerland, this network will be able to provide real-time observations of individual hailstone fall velocity and diameter derived from the recorded kinetic energy. Measurement of hailstone kinetic energy relies on a piezo-element placed underneath a robust Plexiglas plate, which vibrates upon impact. The sensors are entirely autonomous thanks to the use of solar panels for power and mobile broadband for communication. The sensor network will continuously gather data for 8 years, providing vast perspectives in terms of POH and MESHS validation, as well as refinement of hail climatology in the complex topography of Switzerland. In a broader context, hail measurements from the sensors will in future also be presented to the public in quasi real-time on the MeteoSwiss smart phone application.

The focus of our paper will be the description of the sensor network and some preliminary comparisons of hail observations from the hail sensors with radar-based hail algorithms (POH and MESHS).

“Hailstone Stable Isotope Measurements as Indicators of Storm Environment Conditions”
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Abstract

In the evening of April 12th, 2016, northern Bexar County (San Antonio) Texas was hit by a hailstorm that caused an historic $1.4 billion worth of insured losses to vehicles, homes, and businesses. A call for hailstones collected from the hailstorm was made on social media, and several people donated their collected hailstones to this study. We collected and photographed 20 hailstones, displaying characteristics of spherical, conical, and curvilinear triangular shapes, clear and cloudy ice, smooth and rough textures. A cold room at the Southwest Research Institute was used, where we set up a band saw to cut the hailstones. Sections of the hailstones mounted on glass slides were viewed and photographed between crossed polaroid sheets in order to examine each hailstone’s crystal structure. A closer examination of the crystal structure was conducted on certain hailstones by cutting ice thin sections of the cross...
sections. A second slice across the hailstone was cut into about ten 2x5mm subsections and each subsection was melted in a separate container to sample from the inside to the outside of the hailstone for stable isotope analysis. Stable oxygen and hydrogen isotope measurements of these subsamples were conducted on a Picarro L2130-isotopic Water Analyzer (cavity ring-down laser spectroscopy technology) in the Center for Water Research, University of Texas at San Antonio. The isotopic analysis of the hailstone subsamples, together with their crystal structures, are examined here to provide information on the vertical profile of the moisture content, cloud droplet sizes, and temperature of the clouds in which the hailstones formed.

“Experimental measurement of large hail terminal velocity in the free atmosphere at air pressures from 550 to 1000 millibars”

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Abstract

Using a collection of 3D printed hailstones that were created from 3D scans of hailstones collected for other projects, we investigated the variability of large hailstone terminal velocity at different air pressures. Using a 2 meter slingshot, we launched the artificial hailstones up to an estimated 100 meters above ground level and used 30 frame per second video to image their descent and were thus able to determine their fall speed. Theoretical estimates suggest that the artificial hailstones should have been at between 90 and 95% of their true terminal velocity. With the help of students and volunteers participating in a research expedition organized by a non-profit organization, the American Climer Science Program, we launched the 66 artificial hailstones at 4 locations ranging from 1000 millibars (Bellingham, Washington) to 550 millibars (at 5150 meters in the Peruvian Andes). Measured fall speeds were similar to terminal velocities measured in a vertical wind tunnel at 1000 millibars. But using the standard conversion (the square root of the ratio of the air pressures) to predict the fall speed at a different pressure rarely agreed with the observations. We are investigating possible reasons for this mismatch.

“Development of a hail monitoring algorithm using X-band polarimetric radars in and around the Tokyo metropolitan area, Japan”

Yuakri Shusse*, Shin-ichi Suzuki, Hitoshi Yokoyama, Takeshi Maesaka, Kaori Kieda, Koyuru Iwanami, Kohin Hirano

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Abstract

In the vicinity of the Tokyo metropolitan area in Japan, hailfall events occur several times a year, sometimes causing significant damage to urban and public infrastructures, agricultural crops, resilient-owned ground objects, and other things. The largest hail diameter may exceed 5 cm, and the hailstones may accumulate more than 10 cm in the depth on the road. However, it has been difficult to continuously obtain evidence of hailfall on the ground, since hailfall occurs suddenly and locally. On the other hand, operational and research X-band polarimetric radars are densely installed in and around the Tokyo metropolitan area. Therefore, development of hail monitoring techniques utilizing the X-band radar network is expected.

With the information obtained from the reporting system, questionnaire survey, field survey, etc., we were able to confirm hailfall for 4 days during the warm season in 2017 in this area. A remarkable hailfall case occurred in central Tokyo on 18 July 2017. Hail with a maximum diameter of about 7 cm was observed on the ground, and a strong rain also fell with hailstones. The hailfall area was about 100 km2. The intense convective storm related to this hail event was observed by the X-band polarimetric radar network. This study demonstrates characteristics of polarimetric radar measurements around hailfall area and develops hailfall monitoring techniques by analyzing this hailfall event.

“A Hail Detection Algorithm using X-Band dual-polarization radar observation network in Japan and its Comparison with Field Survey Results”

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Abstract

X-band dual-polarization radars are increasingly employed for meteorological use in Japan since specific differential phase shift, KDP, in X-band is an excellent indicator for estimating the precipitation rate of heavy rainfall. Ministry of Land, Infrastructure, Transport and tourism, MLIT, constructed an X-band dual-polarization radar observation network (XRAIN) to reduce damage from localized heavy rain and torrential downpour. We are developing a hail detection algorithm, which distinguish a hail area from a strong rainfall area, using horizontal reflectivity factor, ZH, and KDP in X-band. Several hailstorms damaged agricultural crops, small structures and
other things in the summer season of 2017 in and around Tokyo. We applied our algorithm to these cases using XRAIN observation data and examined them by comparing with the results of field surveys.

“Hail Precursors and Predictability in Regions North and South of the Swiss Alps”
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Abstract
From April to September severe storms regularly affect the Prealpine region. Heavy precipitation, wind gusts and hail may cause substantial damage and represent high costs for insurance companies, since even quite small hail, that is relatively frequent, poses a risk to sectors such as agriculture. It is therefore of great interest to forecast these phenomena with a lead time as high as possible. Especially in the case of hail, there is big potential for damage mitigation, since much of the damage usually affects vehicles that can easily be moved to ‘safe’ locations.

To this day explicit forecasting of hail at the right location remains a challenge for operational numerical weather prediction (NWP). As an alternative to explicit forecasting of hail, prediction of hail potential through statistical models relying on atmospheric parameters and indices, especially those readily deducible from radio sounding observations, have widely been used in the past as well as today. The temporal and spatial representativity of radio soundings, which are launched between one and four times a day from a network of about 50 sites across continental Europe, is however too limited, to optimally describe the state and evolution of the atmosphere. NWP model analyses, with assimilated observational data from e.g. ground weather stations, radar and radio soundings, comprise information on both higher spatial and temporal scale. They are thus an interesting alternative data source to identify and study atmospheric indicators of daily hail probability, such as CAPE, moisture availability and triggering mechanisms as e.g. areas of (low-level) horizontal convergence.

A simple statistical model, specifically a binary regression model, is proposed for daily hail probability in two distinct regions North and South of the Swiss Alps. Predictors are retrieved from the NWP model (COSMO2, 2.2km resolution), while the binary predictand (observations of hail vs. no hail) are determined from the Probability of Hail (POH) algorithm based on radar reflectivity and NWP freezing level height. Moreover, the predictability of hail is addressed by verifying the statistical model in forecasting runs with lead time ~24h. Results of these analyses will be presented at the workshop.

Next-Day Hail Size Forecasts for the 8 May 2017 Colorado Severe Hail Event Using a Convection Allowing Model
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Abstract
Long range (20 – 22 hour) convection allowing model forecasts are performed for a severe hail event on 8 May 2017 using several different partially and fully two-moment microphysics (MP) schemes. Storm surrogate and explicit hail size forecasting methods are used to predict severe and significant severe hail in the model forecasts. The storm surrogate updraft helicity predicts the spatial coverage of hail with the most skill because it identifies strong, rotating storm updrafts that are capable of producing large hail. The Thompson hail algorithm predicts the coverage of hail with a high level of skill, but underpredicts hail size. MP schemes that predict a high-density rimed ice category (i.e. hail) produce the most realistic surface hail forecasts in terms of size and spatial coverage. MP schemes with low-density rimed ice underpredict the size but over predict the spatial coverage of hail, this is because small rimed ice particles are advected far downstream of the storm updraft.