Welcome!

On behalf of the steering committee, we would like to welcome you to the second North American Workshop on Hail and Hailstorms. Hail across the United States is now approaching a $20 billion dollars annual problem and represents 60 - 80% 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 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. As you will notice in this year's program, we wanted to highlight early career scientists who are helping lead the renaissance in hail research as well as bring the international perspective from across the globe to our second North American workshop. 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. We would like to thank the National Science Foundation and the National Center for Atmospheric Research. Without their support, this workshop would not have been possible. We would also like to thank Building Envelope Consultants Ltd., specifically David Balistreri, for their continued financial support of this event. We also would like to recognize Verisk and the Insurance Institute for Business & Home Safety. We hope you enjoy the workshop and have a wonderful time in the Boulder area!

Warm Regards,

Co-chairs:

Andrew J. Heymsfield
Becky Adams-Selin
Ian M. Giammanco

Workshop Steering committee:

John Allen
Jim Bresch
Julian Brimelow
Victor Gensini
Matthew Kumjian
Ted Mansell
Katharina Schröer
Bryan Wood
Robert Wright

Agenda

September 20

7:30 am to 12:00 pm	**Registration Open**
8:00 am to 8:10 am	**Opening Remarks**
8:10 am to 8:40 am	**Panel Discussion:** ***A New View: Hail Science through the Lens of Early Career Scientists*** **Moderator:** Becky Adams-Selin, *Senior Manager Science*, *Verisk Atmospheric and Environmental Research* **Panelists:** Brenna Meisenzahl – *Staff Scientist, Insurance Institute for Business & Home Safety* Cameron Nixon – *PhD Student, Central Michigan University* Bryn Ronalds – *Data Scientist - Risk Modeling, Zesty AI* Yuzhu Lin – *PhD Student, Penn St. University*
	Session 1: From Climatology to Climate Change: The Picture of Hail Risk **Session chair:** John Allen**,** *Central Michigan Univ***.**
8:40 am to 9:00 am	P1.1 Spaceborne Passive-Microwave Hail Detection: Global Climatologies, Validation, and Challenges Going Forward *Sarah Bang*, and Daniel Cecil* **Presenting author affiliation: NASA Marshall Spaceflight Center, Huntsville, AL*
9:00 am to 9:20 am	P1.2 A Radar-based Hail Climatology of Australia *Jordan Brook*, Joshua Soderholm, Alain Protat, and Hamish McGowan* **Presenting author affiliation: University of Queensland, Brisbane, Australia*
9:20 am to 9:40 am	P1.3 Continental Analysis of Hail Probability Trends in Australia 1979-2021 *Timothy H. Raupach*, Joshua Soderholm, Rob Warren, and Steven Sherwood* **Presenting author affiliation: University of New South Wales, Sydney, Australia*
9:40 am to 10:00 am	***Morning Break***
10:00 am to 10:40 am	**Panel Discussion: From Climatology to Climate Change: The Changing Picture of Hail and Hailstorms** **Moderator:** John Allen, *Assoc. Professor, Central Michigan University* **Panelists:** Victor Gensini, *Assoc. Prof. Northern Illinois University* Andreas Prein, *National Center for Atmospheric Research* Tim Raupach, *University of New South Wales* Susanna Mohr, *Karlsruhe Institute of Technology*

10:40 am to 11:00 am	P1.4 Contrasting Responses of Hailstorms to Anthropogenic Climate Change in Different Synoptic Weather Systems *Jiwen Fan*, Yuwei Zhang, Jingyu Wang, Jong-Hoon Jeong, Xiodong Chen, Shixuan Zhang, Yun Lin, Zhe Fang, and Rebecca Adams-Selin* **Presenting author affiliation: Pacific Northwest Laboratory, Richland, WA*
11:00 am to 11:20 am	P1.5 How do Severe Hail Occurrences Differ in Past Versus Projected Future Climate Regimes *Victor Gensini*, Jillian Goodin, Walker Ashley, Allison Michaelis, and Alex Haberle* **Presenting author affiliation: Northern Illinois University, Dekalb, IL*
11:20 am to 11:40 am	P1.6 Comparing U.S. Hail Risk Estimates Using Publicly Available Hail Data and Forensic Hail Data *Dylan Reif* and Daniel Betten* **Presenting author affiliation: Corelogic, Louisville, CO*
11:40 am to 1:00 pm	***Lunch Break***
	Session 2: Microphysics and Dynamics of Hailstorms **Session chair:** Kelly Lombardo, *Penn St. Univ.*
1:00 pm to 1:30 pm	**Keynote Presentation: Careers in Understanding Precipitation Processes** Andrew Heymsfield, *Senior Scientist, NCAR, Boulder, CO* Gerald M. Heymsfield, *Senior Research Meteorologist, NASA Goddard Space Flight Center, Greenbelt, MD*
1:30 pm to 1:50 pm	P2.1 The Stochastic yet Opportunistic Nature of Hail Growth *Rebecca Adams-Selin** *Presenting author affiliation: Verisk Atmospheric and Environmental Research*
1:50 pm to 2:10 pm	P2.2. Physical Assumptions About Non-Spherical Hailstones *Yuzhu Lin* and Matthew R. Kumjian* **Presenting author affiliation: Penn. St. University, University Park, PA*
2:20 pm to 2:40 pm	P2.3 Hail Embryo Type Tracking in Bulk Microphysics *Edward Mansell* and Jerry Straka* **Presenting author affiliation: NOAA National Severe Storms Laboratory, Norman, OK*
2:40 pm to 3:00 pm	P2.4 Impact of Microphysical Uncertainty on the Evolution of a Severe Hailstorm *Patrick M. Kuntze*, Corinna Hoose, Michael Kunz, Lena A. Frey, and Annette K. Miltenberger* **Presenting author affiliation: Johannes Gutenberg University Mainz, Mainz, Germany*
3:00 pm to 3:20 pm	P2.5 Exploring the Hail and Lightning Associated Convective Events in km-Resolution Simulations over the Alpine-Adriatic Region *Ruoyi Cui*, Nikolina Ban, Marie-Estelle Demory, and Christoph Schär* **Presenting author affiliation: ETH Zurich, Institute for Atmospheric and Climate Science*
3:20 pm to 3:40 pm	***Afternoon Break***

3:40 pm to 4:20 pm	**Lightning Poster Session #1** *(3-Minutes per presenter)* 1. The Hail Impact Monte Carlo Model – Version 2 *S. Strader and W. Ashley* 2. What is the Theoretical Limit for Hail Size *M. Kumjian, J. Brimelow, and J. Soderholm* 3. Revisiting Thermal Energy Transfer Coefficients for Nonspherical Hailstones *M. Kumjian, J. Soderholm, I. Giammanco, K. Lombardo, Y. Lin, and Z. Lebo* 4. How do Hail Return Intervals Scale Locally? *J. Allen* 5. Explicit Hail Prediction of a Moderate Hailstorm Case Using WRF-3DVar and Thompson-Eidhammer Microphysics *R. Li., J. Sun, Q. Zhang, A. Jensen, S. and Tessendorf* 6. Automated Processing of Hailstones in Free-Fall Using a High-Speed, High-Definition, Dual Camera Imager *S.Waugh, K. Ortega, and J. Synder* 7. Documenting and Digitally Preserving Giant Hailstones: The IBHS Record Hail Quick Response Team *I. Giammanco, C. Gropp, B. Maiden, and T. Brown-Giammanco* 8. An Updated 3D Radar-based Hail Statistic for Germany Including Further Characteristics *S. Mohr*, M. Schmidberger, M. Tonn, J.Wilhelm, and M. Kunz*
4:20 pm to 4:40 pm	P2.6 A Comparison of Hail Predictability with Different Initial Perturbations from Climatological Flow-Dependent and Aerosols Uncertainty *X. Li** **Presenting author affiliation: College of Urban and Environmental Sciences, Northwest University, Xi'an, Shaanxi Province, China*
4:40 pm to 5:00 pm	P2.7 Improving the Prediction/Simulation of Hail using an Advanced Bulk Microphysics Scheme *Jason Milbrandt*, Hugh Morrison, and Melissa Cholette* **Presenting author affiliation: Environment and Climate Change Canada, Dorval Quebec Canada*
5:00 pm to 5:20 pm	P2.8 A New Version of Thompson Microphysics Aimed at Better Simulation of Hail *Sarah Tessendorf*, Maria Frediani, Amanda Siems-Anderson, Lulin Xue, Kyoko Ikeda, Greg Thompson, and Anders Jensen* **Presenting author affiliation: NCAR, Boulder CO*
5:20 pm to 5:40 pm	P2.9 Simulation of RELAMPAGO IOP17 Using the New Hail Enable Thompson Microphysics Scheme *Lulin Xue*, Maria Fediani, Sarah Tessendorf, and Jenny Sun* **Presenting author affiliation: NCAR, Boulder, CO*
Adjourn	***Hosted Dinner on the Pavilion at NCAR Center Green***

September 21

8:00 am to 12:00 pm	Registration Open
	Session 3: Observing Hail – Unique Measurements & Observations **Session chair:** Ian Giammanco, *IBHS*
8:10 am – 8:30 am	P3.1 A Wind Tunnel Investigation on the Ventilation Coefficients of Hailstones *Alexander Theis*, Laura Werner, Subir Mitra, Stephan Borrman, and Miklós Szakál* **Presenting author affiliation: Max-Planck Institute for Chemistry, Mainz, Germany*

8:30 am to 8:50 am	P3.2 High-Speed, High-Resolution, Dual-Camera Imager for Photographing Naturally Falling Hailstones *Kiel Ortega*, Jeff Synder, and Sean Waugh* **Presenting author affiliation: Univ. of Oklahoma/CIWRO*
8:50 am to 9:10 am	P3.3 Automating the Analysis of Hailstone Layers *Joshua Soderholm* and Matthew Kumjian* **Presenting author affiliation: University of Queensland, Brisbane, Australia*
9:30 am to 9:50 am	P3.4 Characterization of Non-Soluble Particles Identified in Hailstones Collected in the Province of Cordóba-Argentina *Anthony Bernal Ayala** **Presenting author affiliation: University of Wisconsin, Madison, WI*
9:50 am to 10:10 am	P3.5 T-28 Research Aircraft and Polarimetric Radar Observations of Hailstorms *David Delene*, Andrew Detwiler, V Chandrasekar, Andrew Heymsfield, Aaron Bansemer* **Presenting author affiliation: University of North Dakota, Grand Forks, ND*
10:10 am to 10:30 am	***Morning Break***
10:30 am to 11:00 am	**Panel Discussion: Observing Hail – Unique Measurements & Instrumentation** **Moderator:** *Julian Brimelow - Western University, Northern Hail Project* **Panelists:** Kiel Ortega - *University of Oklahoma/CIWRO* Jeff French - *University of Wyoming* Sarah Bang - *NASA Marshall Spaceflight Center* Henry Reges – *Colo. St. Univ. / CoCoRaHS* Chandra V Chandrasekar – *Colo St. Univ.*
10:50 am to 11:10 am	P3.6. Hailstorms and Rainstorms vs. Supercells – A Comparison of Severe Thunderstorms in the Alpine Region *Monika Feldmann*, Marco Gabella, Alessandro Hering, and Alexis Berne* **Presenting author affiliation: Laboratoire de Télédétection Environnementale (LTE), EPFL, Switzerland*
11:10 am to 11:30 am	P3.7 View Inside a Hail Supercell over Southern Germany using C-Band Doppler Radar Spectra *Mathias Gergely*, Maximilian Schaper, Friedrich Seeger, and Michael Frech* **Presenting author affiliation: German Meteorological Service, Observatorium Hohenpeiseenberg, Germany*
11:30 am to 11:50 am	P3.8 On the Use of RaxPol for Studying Hail Processes in Convective Storms *Howard Bluestein* and David Schvartzman* *Presenting author affiliation: University of Oklahoma, Norman, OK*
11:50 am to 1:10 pm	***Lunch Break***
1:10 pm to 1:30 pm	P3.10 A First Insight into the Hail Distribution over Germany *Tabea Wilke*, Markus Schultze, and Katharina Lengfeld* **Presenting author affiliation: German Meteorological Service*

1:30 pm to 1:50 pm	P3.11 The Creation of a Hail Damage Swath Event Database and Follow on Applications *Jordan Bell*, Emily Wisinkski, Andrew Molthan, and Chris Schultz* **Presenting author affiliation: NASA Marshall Spaceflight Center, Huntsville, AL*
1:50 pm to 2:10 pm	P3.12 Advancements in Radar-Derived Hail Products for Estimating Hail Damage *Nick Guy*, Scott Ganson and Tory Farney* **Presenting author affiliation: Verisk*
2:10 pm to 2:30 pm	P3.13 Athenium Analytics Hail Products for the Insurance Industry *Kaitlyn Fons*, Jonathan Fairman, Justin Jones, and Amy Daniels* **Presenting author affiliation: Athenium Analytics*
2:40 pm to 3:20 pm	**Lightning Poster Session #2 (3-minutes per presenter)** **1.** Methodology and 2017 Results of Using Radar Observations to Evaluate Hail Mitigation by the Alberta Suppression Project *D.Delene, B. Bow, and A. Detwiler* 2. Hail Impacts on Stone-Coated Metal Tile Roof Systems *C. Sanders* 3. S-Pol Capabilities and a Potential Dual-Wavelength Upgrade for Enhanced Hail Studies *J.C. Hubbert, T. Weckwerth, M. Dixon, E. Loew, and J. Emmett* 4. Just What is Good? Musings on Hail Forecast Verification of FV3-HAILCAST Hail Forecasts *R. Adams-Selin, C. Kalb, T. Jensen, J. Hendersen, T. Supinie, L. Harris, Y. Wang, B. Gallo and A. Clark* 5. Validation of the Hail Differential Reflectivity using the Severe Hazards Analysis and Verification Experiment Dataset *J. Segall* 6. Exploring a Relationship Between Satellite-Derived Overshooting Top Area and Hail Severity *R. Trapp, M. Grover*, J. Goodnight, Y. Hong, E. Wolff, S. Nesbitt and L. Di Girolamo* 7. Seamless Coupling of Kilometer-Resolution Weather Predictions and Climate Simulations with Hail Impact Assessments (scCLIM) *Schmid et al.* 8. Athenium Analytics DexterHail – A Near Real-time Application of Hydrometeor Classification and Hail Size Discrimination Algorithms on NSSL MRMS MESH *J. Fairman, J. Jones, B. Putnam*
3:20 pm to 3:40 pm	**Afternoon break**
	Session 4: Field Campaigns Session chair: Andy Heymsfield, *NCAR*
3:40 pm to 4:00 pm	P4.1 The Northern Hail Project: A Renaissance in Hail Research in Canada *Julian Brimelow*, Greg Kopp, and David Sills* **Presenting author affiliation: Western University, London, Ontario, Canada*
4:000 pm to 4:20 pm	P4.2 Swabian MOSES – A Multidisciplinary Field Campaign to Investigate Severe Convective Storms and Hail *Michael Kunz*, Susanna Mohr, Jannik Wilhelm, and Andreas Weiser* **Presenting author affiliation: Karlsruhe Institute of Technology, Karlsruhe, Germany*
4:20 pm to 4:40 pm	P4.3 CHAT: The Colorado Hail Accumulation from Thunderstorms Project *Katja Friedrich*, Robinson Wallace, Bernard Meier, Wiebke Deierling, Evan Kalina, and Paul Schlatter* **Presenting author affiliation: University of Colorado, Boulder, CO*

4:40 pm to 5:00 pm	P4.4 Observations from Automated Hail Sensors in Switzerland: Estimations of the Hail Size Distribution and Comparison with Radar-based and Crowdsourced Data *Jérôme Kopp*, Alessandro Hering, Urs Germann, Olivia Martius* **Presenting author affiliations: University of Bern, Bern, Switzerland*
5:00 pm to 5:20 pm	P4.5 High-Resolution WRF Simulations of CONCH Hail Cases *Jim Bresch** **Presenting author affiliation: NCAR, Boulder, CO*
5:20 pm to 5:40 pm	P4.6 ICECHIP: Closing Critical Observational Gaps in Hail Research *Rebecca Adams-Selin*, John Allen, Victor Gensini, Andrew Heymsfield* **Presenting author affiliation: Verisk Atmospheric and Environmental Research*
Adjourn	**Reception at NCAR Center Green**

September 22

	Session 5: The $20 Billion Dollar Problem: Hail Loss, Damage & Mitigation Session chair: Robert Wright, *Robert L. Wright and Assoc. Eng.*
8:10 am – 8:40 am	Panel Discussion: Trends in Hail Damage & Mitigation Moderator: Ian Giammanco, *Insurance Institute for Business & Home Safety* Panelists: Robert Wright, *Robert L. Wright and Assoc. Engineering* Chris Sanders, *Insurance Institute for Business & Home Safety* Greg Keeler, *Owens Corning* Emily Sambuco, *Liberty Mutual* John Sedgewick, *VDE Americas*
8:40 am to 9:00 am	P5.1 Mitigating Hail Damage Through Understanding Laboratory Testing, Certification, and Evaluation Programs *Dwayne Sloan* and Ian Giammanco** **Presenting authors affiliations: Sloan: Underwriters Laboratories, Giammanco: Insurance Institute for Business & Home Safety (IBHS)*
9:00 am to 9:20 am	P5.2 IBHS Testing of High Concentrations of Small Hail *Brenna Meisenzahl*, Tanya Brown-Giammanco, Ian Giammanco and Faraz Hedayati* **Presenting author affiliation: Insurance Institute for Business & Home Safety*
9:20 am to 9:40 am	P5.3 Electronic Hailpad with Telemetry System Using Accelerometers *Matt Phelps* and Andrew Heymsfield* **Presenting author affiliation: APEC Engineering & Laboratory*
9:40 am to 10:00 am	P5.4 A New Performance-Based Hail Engineering Method Shows that Impact-Resistant Roofing Avoids Up to 8 Times Its Cost *Keith Porter** **Presenting author affiliation: Institute for Catastrophic Loss Reduction (ICLR)*
10:00 am to 10:20 am	P5.5 An Overview of Hail Defense Operations in the Province of Styria, Austria *Satyanarayana Tani* and Helmut Paulitsch* **Presenting author affiliations: Graz University of Technology, Graz, Austria*

10:20 am to 11:00 am	***Morning Break & Formal Poster Viewing Session***
	Session 6: Advances & Challenges in Detecting & Forecasting Hail ***Session chair:*** Bryan Wood, *American Modern Ins. Group*
11:00 am to 11:20 am	P6.1 Hodographs and Skew-Ts of Hail Producing Supercells Using Self-Organizing Maps *Cameron Nixon* and John Allen* **Presenting author affiliation: Central Michigan University, Mount Pleasant, MI*
11:20 am to 11:40 am	P6.2 Searching for Predictability in the Environmental Conditions Preceding Large Hail *John Allen*, Cameron Nixon, and Matthew Kumjian* **Presenting author affiliation: Central Michigan University, Mount Pleasant, MI*
11:40 am to 12:00 pm	P6.3 Using a Deep Neural Network to Estimate Severe Hail Likelihood from Satellite Observations and Model Reanalysis Parameters *Benjamin Scarino*, Kyle Itterly, Kristopher Bedka, Cameron Homeyer, John Allen, Sarah Bang, and Daniel Cecil* **Presenting author affiliation: NASA Langley Research Center, Hampton, VA*
12:00 pm to 12:20 pm	P6.4 An Intercomparison of Real-Time Machine Learning Hail Guidance *David John Gagne*, Eric Loken, Amanda Burke, Nathan Snook, and Amy McGovern* **Presenting author affiliation: NCAR, Boulder, CO*
12:20 pm to 1:20 pm	***Lunch Break***
1:20 pm to 2:00 pm	**Virtual Keynote address: What's It Like to Fly Through a Hailstorm** **Wayne Sand**
2:00 pm to 2:20 pm	P6.5 Two Paradigms for Radar-Based Hail Size Estimation: Problems and Possibilities *Matthew Kumjian*, Robert Schrom, Ian Giammanco, Joshua Soderholm, Yuzhu Lin and Kelly Lombardo* **Presenting author affiliation: Penn. St. University, University Park, PA*
2:10 pm to 2:30 pm	P6.6 Operational Polarimetric NEXRAD Algorithm for Detection of Hail and Determination of its Size: Current Statis and Forthcoming Refinements *Alexander Ryzkhov*, Jeff Synder, and John Krause* *Presenting author affiliation: University of Oklahoma, Norman, OK*
2:30 pm to 2:50 pm	P6.7 A Convolutional Neural Network for the Detection of Hailstorms by Dual Polarimetric Radar *V. Forcadell*, C. Augros, K. Dedieu, and O. Caumont* **Presenting author affiliation: CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France*

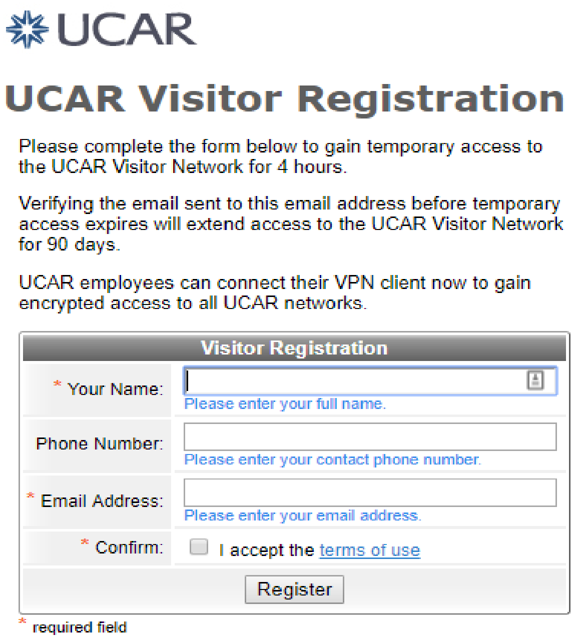
2:50 pm to 3:10 pm	P6.8 The Odds are Good: Using Hail Reports and Radar Indices to Probabilistically Understand Australian Hail *Isabelle Greco*, Steven Sherwood, Tim Raupach, and Gab Abramowitz* **Presenting author affiliation: University of New South Wales, Kensington, Australia*
3:10 pm to 3:30 pm	***Afternoon Break***
3:30 pm to 4:00 pm	**Virtual Panel Discussion: Future of Hail Forecasting** ***Moderator:*** Victor Gensini, *Northern Illinois Univ.* ***Panelists**:* Becky Adams-Selin, *Verisk* Ryan Jewell, *NOAA Storm Prediction Center* Jenni Pittman, *SOO NWSFO-Topeka*
4:00 pm to 4:20 pm	P6.9 Diurnal Cycle of Satellite Derived Hailstorms *Daniel J. Cecil* and Sarah Bang* **Presenting author affiliation: NASA Marshall Spaceflight Center, Huntsville, AL*
4:20 pm to 4:40 pm	P6.10 Hail Identification Algorithm for GPM DPR (version 7) and the Validation *V Chandrasekar* and Minda Le* **Presenting author affiliation: Colorado St. University, Fort Collins, CO*
4:40 pm to 5:00 pm	P6.11 Hail Growth Regions and their Identification with Radar *Andrew Heymsfield*, Michael Cecchini, Andrew Detwiler, Ryan Honeyager, and Paul Field* **Presenting author affiliation: NCAR, Boulder, CO*
5:00 pm to 5:10 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:



UCAR

UCAR Visitor Registration

Please complete the form below to gain temporary access to the UCAR Visitor Network for 4 hours.

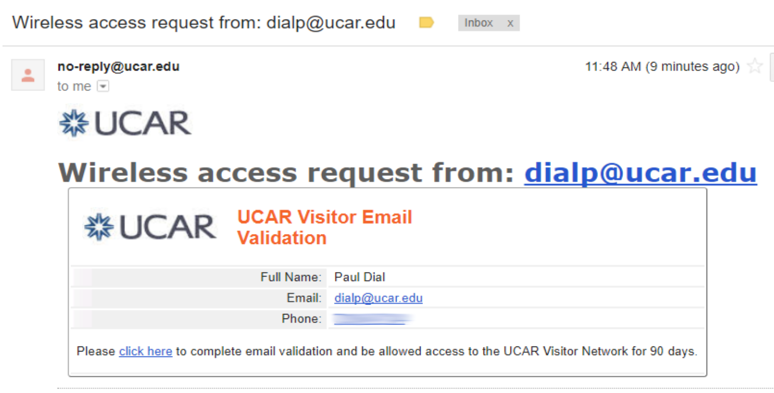
Verifying the email sent to this email address before temporary access expires will extend access to the UCAR Visitor Network for 90 days.

UCAR employees can connect their VPN client now to gain encrypted access to all UCAR networks.

Visitor Registration	
* Your Name:	Please enter your full name.
Phone Number:	Please enter your contact phone number.
* Email Address:	Please enter your email address.
* Confirm:	I accept the terms of use
Register	

* required field

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



Wireless access request from: dialp@ucar.edu Inbox x

no-reply@ucar.edu
to me

11:48 AM (9 minutes ago)

UCAR

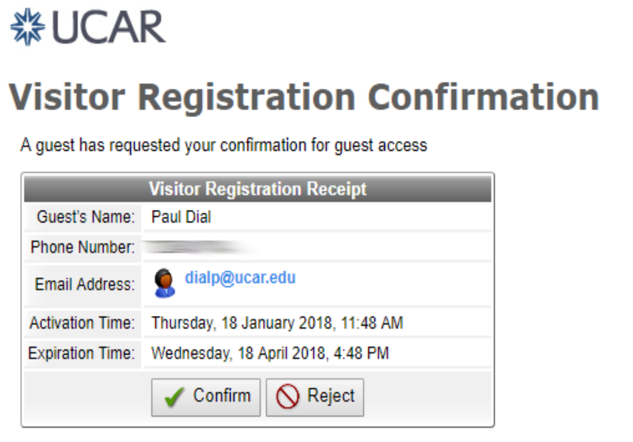
Wireless access request from: dialp@ucar.edu

UCAR UCAR Visitor Email Validation

Full Name:	Paul Dial
Email:	dialp@ucar.edu
Phone:	

Please click here to complete email validation and be allowed access to the UCAR Visitor Network for 90 days.

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:



UCAR

Visitor Registration Confirmation

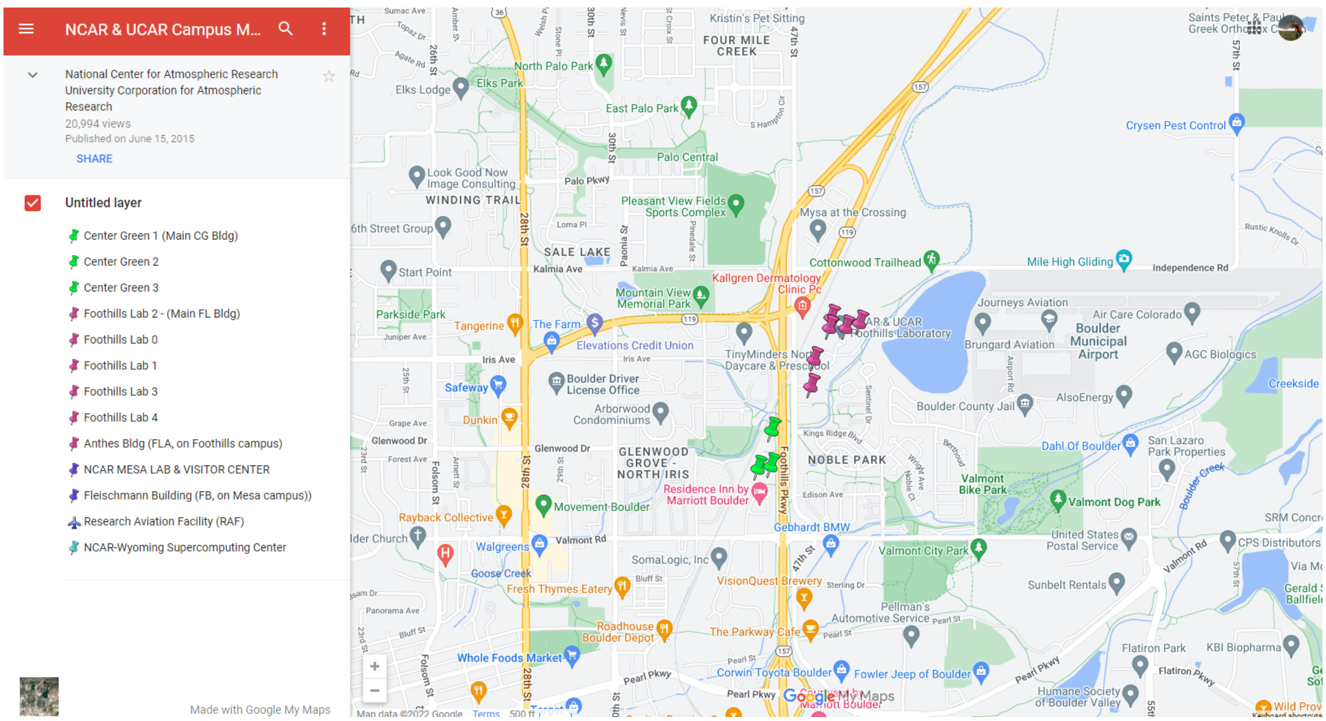
A guest has requested your confirmation for guest access

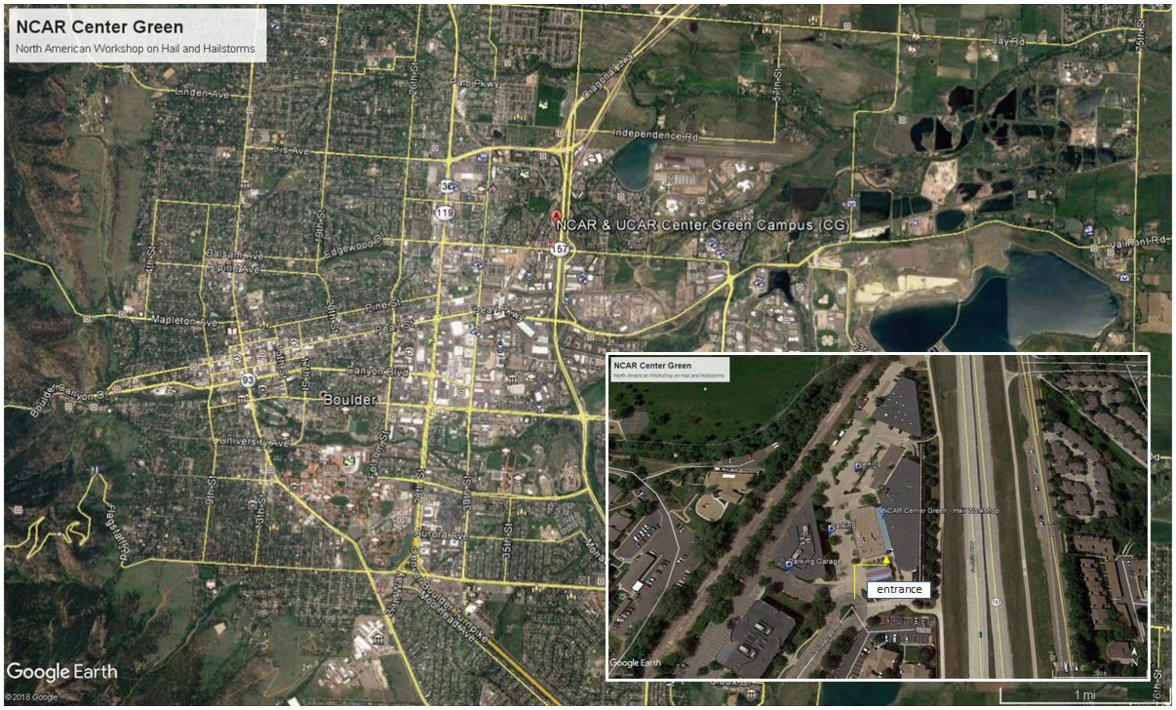
Visitor Registration Receipt	
Guest's Name:	Paul Dial
Phone Number:	
Email Address:	dialp@ucar.edu
Activation Time:	Thursday, 18 January 2018, 11:48 AM
Expiration Time:	Wednesday, 18 April 2018, 4:48 PM
	Confirm Reject

For more information on the UCAR Visitor wireless network, please see the UCAR Visitor Wireless FAQ.

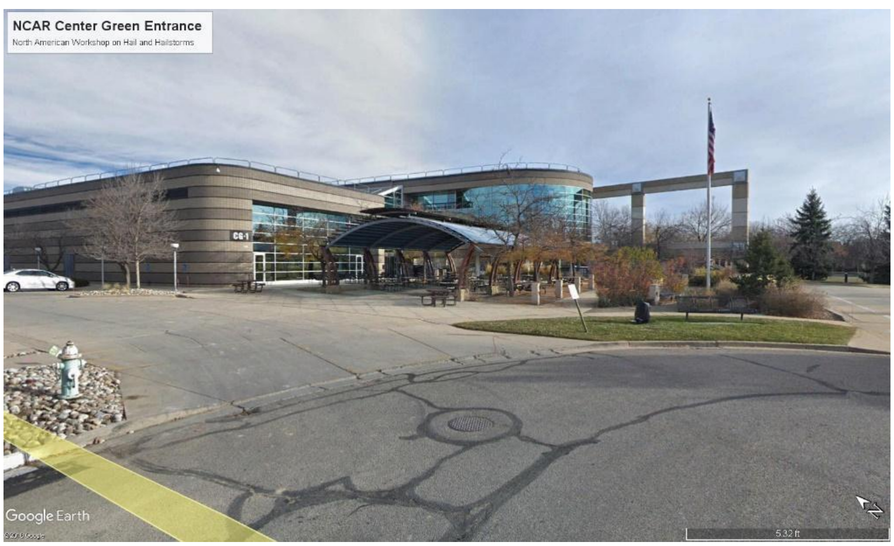
UCAR-NCAR Boulder Facilities Map

Center Green shown by green pins





- 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



Abstracts (By Order of Appearance at the Workshop)

Spaceborne Passive-Microwave Hail Detection: Global Climatologies, Validation, and Challenges Going Forward

Sarah D. Bang[1] and Daniel J. Cecil[1]
[1]*NASA Marshall Space Flight Center, Huntsville AL*

In addition to the myriad threats that severe hailstorms pose to society, infrastructure and agriculture, severe hail is difficult to measure in situ, and surface-based hail reporting and detection methods are inconsistent and vulnerable to nonmeteorological biases. This motivates the use of spaceborne remote-sensing platforms to retrieve hail and construct climatologies in a globally uniform way. We have developed a hail detection algorithm that leverages the sensitivity of spaceborne passive-microwave radiometers to scattering by hail, particularly in the channels from 10 to 89 GHz.

We use this retrieval to construct global passive-microwave climatologies of severe hail using the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), Global Precipitation Measurement Mission (GPM) Microwave Imager, Advanced Microwave Scanning Radiometer for EOS (AMSR-E), and Advanced Microwave Scanning Radiometer 2 (AMSR2) sensors and are working to extend into the pre-TRMM era to the Special Sensor Microwave Imager/Sounder (SSMI/(S)) data. Using coincident Global Precipitation Measurement (GPM) Ku-band precipitation radar, we assessed this retrieval and several others in the literature for their effectiveness and regional variability. We find that this retrieval, which leverages a signature in the Minimum 19-GHz polarization corrected temperature (PCT) combined with the 37-GHz PCT depression normalized by tropopause height constrains the radar reflectivity most tightly and gives the least appearance of regional biases compared to other passive-microwave approaches in the literature.

Satellite platforms offer consistent observations, even in remote, data-sparse, and oceanic regions that ground-based networks exclude. There are, however, potential disconnects between the processes identified aloft by the satellite and the resultant weather at the ground, leading to uncertainties in the retrievals that may propagate into satellite-based climatologies, particularly in the Tropics, where there are abundant strong - but not necessarily hailing - storms that are strongly represented in the current satellite climatologies. We will discuss ongoing efforts to assess and mitigate the contributing factors to these uncertainties, chiefly among them the effects of non-uniform beam filling in the passive-microwave footprint, and the relationships between the size distributions of hailstones aloft and the dynamic processes and environments with which they interact throughout their trajectories.

A Radar-Based Hail Climatology of Australia

Jordan Brook[1], Joshua Soderholm[2], Alain Protat[2] and Hamish McGowan[1]
[1]*University of Queensland, Brisbane, Australia*
[2] *Bureau of Meteorology, Melbourne, Australia*

Hailstorms pose a significant public safety and economic risk in Australia, where they are considered the most damaging natural hazard in terms of annual insured losses. Despite these impacts, the current climatological distribution of hailfall across the continent is still comparatively poorly understood. In this study, we aim to supplement previous hail studies in the region (such as those based on environmental proxies or satellite radiometer data) with more direct hail observations made by the Australian weather radar network. The Maximum Estimated Size of Hail (MESH) parameter is used to identify historical hailstorms in archived data for over 60 radars, resulting in the first nationwide, radar-based Australian hail climatology. We discuss how the spatio-temporal uniformity of the climatology is complicated by a number of factors, including the limited spatial coverage of the radar network, the varying accuracy of MESH estimates across different climatic regions, and variations in radar characteristics such as archive lengths, beamwidths and operating frequencies. We detail the application of various corrections to contend with these factors and ensure the uniformity of hail estimates throughout the archive. Finally, we illustrate the spatiotemporal distribution of hailstorms, including their physical characteristics, seasonal and diurnal frequency, and how these vary across different regions of the country.

Continental analysis of hail probability trends in Australia 1979-2021

Timothy H. Raupach[1], Joshua Soderholm[2], Rob Warren[2] and Steven Sherwood[1]
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Hail regularly causes hefty damages in Australia. It is expected that climate change will affect atmospheric factors that control hailstorm formation and maximum hailstone size, yet these changes in hailstorm "ingredients" are geographically inhomogeneous. This variability, combined with knowledge gaps in microphysical understanding, and offsetting effects between some changes, means that the effects of climate change on hailstorms remain highly uncertain. Hail is a relatively rare and small-scale process, meaning that it is difficult to observe for long enough for trend analyses, and computationally expensive to model at the high resolutions required to explicitly resolve convective storms. An alternative method to study hail is to use a hail proxy, which statistically relates larger-scale atmospheric properties to the likelihood of hail at the surface. In this study we use a newly-developed hail proxy for Australia to examine trends in hail-prone ingredients over the last four decades. European Centre for Medium-range Weather Forecasts (ECMWF) reanalysis 5 (ERA5) data provide the large-scale atmospheric conditions on which the hail proxy operates. To examine the reliability of the proxy results we compare them to trends in hail occurrence derived from shorter timeseries of radar data at several Australian cities. We examine the results in terms of seasonal trends and look at the factors driving changes in recent hail probability for Australia. The result is the first analysis of recent changes in hail probability at continental scale for Australia.

Contrasting Responses of Hailstorms to Anthropogenic Climate Change in Different Synoptic Weather Systems

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Hailstones and extreme precipitation generate substantial economic losses across the United States (US) and the globe. Their strong association with short-lived, intense convective storms poses a great challenge to predict their future changes. Here we conducted model simulations at 1.2 km grid spacing for severe convective storms with large hail and heavy precipitation that occurred in two typical types of synoptic-scale environments in spring seasons over the central US under both current and future climate conditions. We find that the responses of large hail (diameters > 2.5 cm) to anthropogenic climate change (ACC) are markedly different between the two types of synoptic-scale environments, with over 110% increase in large hail occurrences for the frontal systems, whereas less than 30% increase for the Great Plains low-level jet (GPLLJ) systems. This is explained by the larger increase in convective intensity and updraft width and a smaller increase in warm cloud depth in the frontal storms compared with the GPLLJ storms. Interestingly, the occurrences and intensity of heavy precipitation (rain rate > 20 mm h^{-1}) in both types of systems are similarly sensitive to ACC (e.g., 40% and 33% increases in the occurrences for the frontal and GPLLJ systems, respectively). These results might have important implications for predicting and managing risks for future hail and flash floods.

How do severe hail occurrences differ in past versus projected future climate regimes?

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Our understanding of how ongoing and future projections of climate change may impact hail frequency and severity is immature. We attempt to address this topic by using high-resolution (3.75 km horizontal grid spacing; 15 min interval output; 51 vertical levels) dynamically-downscaled regional climate simulations described in Gensini et al. (2022), driven by bias-corrected output from NCAR's Community Earth System Model (CESM). Simulations were performed for historical (1990–2005), midcentury (2040–2055), and end-of-century (2085–2100) epochs. Future epochs were simulated using an aggressive high-CO2 emission representative concentration pathway (RCP 8.5) and low greenhouse gas-emission (RCP 4.5) scenario to understand forcing sensitivities. This presentation will showcase

various results and analyses from these simulations, as well as compare the historical simulation epoch to remotely-sensed (e.g., MESH) and observed (e.g., reports) climatologies.

Comparing U.S. Hail Risk Estimates Using Publicly Available Hail Data and Forensic Hail Data

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Insurers need accurate weather data to manage their risk and understand property data. Without accurate size, date, and location information of severe hail events and severe hail risk potential, insurers may have a poor understanding of the overall hail risk at a property. In some cases, insurers use publicly available information such as the maximum estimated size of hail (MESH), severe reports from the Storm Prediction Center (SPC) or reports from the National Oceanic and Atmospheric Administration's (NOAA) *Storm Data* to assess the hail risk at a given location.

These publicly available products do not accurately estimate the hail risk and how this risk varies across different regions of the United States. We compare the risk estimate from these products to a risk estimate using CoreLogic's Hail Verification Technology (HVT) forensic data. HVT is a combination of quality-controlled hail reports and polarimetric radar data that estimates the hail path for hail larger than 0.75 inches in diameter. The hail risk for hail larger than 1 inch and larger than 2.5 inches in diameter are shown.

Insurers need to know the date of loss and severity of a hail event. To illustrate the differences between the publicly available data and CoreLogic's forensic hail data, example properties across different regions of the U.S. are chosen to assess the severity of a hail event and show differences in the date of loss estimate. By having the most accurate weather data, insurers can properly allocate resources to make better decisions and help their clients.

The stochastic yet opportunistic nature of hail growth

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Knowledge of common, predictable trajectory pathways hailstones take through a storm relative to its updraft would be useful in a variety of contexts, particularly including hail forecasting and hail growth parameterization. Unfortunately, recent research has suggested that identifying such pathways on an individual storm scale is highly difficult given their extreme variability.

This study uses a novel density-based clustering technique to determine possible hail growth trajectory pathways within a single pair of supercells over time. The CM1 cloud model was used to simulate a pair of left- and right-moving supercells using proximity soundings from the 29 May 2012 Kingfisher, OK storm observed during the DC3 field campaign. The ASZ16-HAILCAST hail trajectory model was fully embedded within CM1. A total of 10 million four-dimensional hail trajectories were calculated by seeding 1 million embryos across both supercells every 5 minutes from the time the storms reached maturity until just prior to dissipation, a total of 45 minutes. Hailstones from successive timesteps were not allowed to interact for the sake of computational efficiency. The resulting trajectories that resulted in non-negligible hail growth were then converted into an updraft-relative coordinate system to remove the time dimension. To further condense the data, a three-dimensional trajectory segment clustering technique based on a combination of the TRAjectory CLUStering (TRACLUS) algorithm and density-based DBSCAN was applied to group trajectory segments similar in location and orientation. A final step further grouped whole trajectories into "pathways" based on common segment clusters.

The resulting pathways varied widely between the two supercells as well as even temporally within the same supercell. Such results suggest that hail trajectory pathways on a storm scale should best be thought of as stochastic processes – understandable in the aggregate, but intrinsically non-deterministic on an individual scale. Further, while often as many as three pathways at one time in each supercell still produced large (>25 mm in equivalent spherical diameter) hail, these pathways did not follow a consistent spatial pattern. Thus, we conclude that hail growth, while stochastic, is also opportunistic: if a pathway to produce large hail can be found, hail will find a way.

Physical assumptions about nonspherical hailstone shapes

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Numerical modeling is valuable in hail research and forecasting. Physical assumptions regarding hailstones' shape, tumbling behavior, fall speed, and thermal energy transfer are applied in this process, be it explicit or inexplicit. However, many of these physical assumptions are uncertain. In this study, we investigate the effect of applying different physical assumptions in hail modeling using Cloud Model 1 to simulate supercell storms, coupled with the detailed 3D hail growth trajectory model by Kumjian & Lombardo (2020; hereafter KL20). We then examine the reason behind the variability in hail statistics produced with these assumptions.

Most microphysics schemes and hail models assume hailstones are spherical (e.g., Morrison et al. 2005; Adams-Selin & Ziegler 2016; KL20). Using hailstone shape data from Heymsfield et al. (2020) and Shedd et al. (2021), we establish a relationship between the hailstones' mass and the largest, smallest, and intermediate dimensions with reasonable degrees of randomness in consideration of hailstones' shape variability, capturing the observed distribution of tri-axial ellipsoidal shapes. We also incorporated explicit, random 3D tumbling of individual hailstones during each timestep of their growth to simulate the behavior of free-falling, non-spherical particles (Bagheri & Bonadonna 2016) and the resultant changes in cross-sectional area (which affects collection of cloud droplets). These physical attributes are then incorporated in calculating the hailstone's terminal velocity, using either empirical relationships such as that derived in Heymsfield et al. (2020), or analytical relationships from Bagheri & Bonadonna (2016) based on each hailstone's Best number and Reynolds number. Options for drag coefficient modification are added to characterize the hailstone's rough surface with varying degrees of "lobiness." The hailstone's shape and "lobiness," in turn, modify its thermal energy transfer coefficient (Macklin 1963; Bailey & Macklin 1968). We find the choice of terminal velocity scheme to have the strongest influence on final hail size. Using non-spherical, tumbling hailstones tends to reduce the number of large hail produced in our simulated supercell storms; applying shape-specific thermal energy transfer coefficients tends to increase final hail size by a small amount; the effect of lobes varies depending on the terminal velocity scheme used. We show that many of these physical assumptions, albeit adding complexity to hailstone growth modeling, can be parameterized efficiently and potentially used in bulk microphysics schemes.

Hail Embryo Type Tracking in Bulk Microphysics

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In this study, the general graupel species the NSSL bulk microphysics scheme, is split into separate categories of frozen drops ("FD"; from rain drops) and 'true' graupel (from rimed ice and snow). The hail species initiates new particles only from large graupel/FD. In the conversion process of larger FD and graupel to hail, the number of particles from FD is added as an extra hail variable, which propagates knowledge of the source particles after conversion.

The hail-source scheme is tested in two hail-producing storm environments so far: a southern Great Plains case (Oklahoma) and high plains case (Colorado STERAO case). The fraction of hail reaching the surface that originated from frozen drops vs. graupel can vary over time and storm-relative location. The overall results are consistent with the cloud base temperature relationship found by Knight (1981), where a higher-temperature cloud base generally has hail with a higher fraction of frozen drop embryos. Model results seem to favor frozen drop production via entrained raindrops from melted graupel rather than the collision-coalescence rain mechanism, at least for the STERAO case.

Impact of microphysical uncertainty on the evolution of a severe hailstorm

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Forecasting high impact weather events is a major challenge for numerical weather prediction. Initial condition uncertainty plays a major role but so do potentially uncertainties arising from the representation of subgrid-scale processese.g. cloud microphysics. In this project, we investigate the impact of these uncertainties on the forecast of cloud properties, precipitation and hail of a selected severe convective storm over South-Eastern Germany in 2019, that produced considerable amount of hail precipitation over the suburbs of Munich. Here, we focus the investigation on the effects of parametric uncertainty in a perturbed parameter ensemble, using the ICON model (with 2-moment cloud scheme, at 1 km grid-spacing). A latin hypercube sampling is used to generate systematic variations of selected microphysical parameters from an eight-dimensional parameter space. Considered processes include riming, diffusional growth of ice and snow, CCN and INP activation, as well as the mass-diameter and mass-velocity relations. First results show an especially large impact of INP concentrations on hail and precipitation. Further, CCN concentrations, graupel density and ice capacitance exhibit considerable influence. We will present a detailed analysis of the simultaneous influence of parameter perturbations on the cloud microphysical evolution of the storm. In a later stage of the project we will combine parameter and initial condition perturbations in a comprehensive ensemble to investigate the relative contribution and joint impacts of both uncertainty sources on forecast uncertainty.

Exploring the hail and lightning associated convective events in km-resolution simulations over the Alpine-Adriatic region

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The north and south of the Alps, as well as the eastern shores of the Adriatic Sea, are hot spots of severe weather events, including hail and lightning associated with deep convection. With advancements in computing power, it has become feasible to simulate deep convection explicitly (instead of relying on parameterization schemes) in climate models by decreasing the horizontal grid spacing to less than 4 km. These so-called convection-resolving models improve the representation of orography and reduce uncertainties associated with the use of deep convection parameterization. In this study, we assess changes in hail and lightning related severe convective events performed with the COSMO-crCLIM model (GPU version of the Consortium for Small-scale Modeling) at 2.2 km horizontal grid spacing over the Alpine-Adriatic region. We run multi-seasonal (April-September) simulations embedded with one-dimensional hail growth model HAILCAST and lightning potential index (LPI) under current and future climate conditions using the pseudo-global warming approach. We first evaluate the performance of hail and lightning under theurrentt climate using available observations. In addition, we investigate key variables for hail formation, including temperature, humidity, CAPE and CIN, bulk wind shear and updraft helicity. Furthermore, the behavior of 5 different embryos that initiated at different temperature levels are analyzed. The results indicate that the smaller hailstones will be more affected by the stronger updraft and increase in melting level height in the future, which lead to a broader hail size distribution compared to the larger hailstones.

Lightning Poster Session 1 Abstracts

The Hail Impact Monte Carlo Model (Version 2)

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Prior research has indicated that estimating the likelihood and severity of atmospheric hazard impacts requires an understanding of the dynamic relationship between hazard risk and societal vulnerability. This research illustrates the Hail Impact Monte Carlo (HailMC.V2) model which simulates hail events atop a user-defined spatial domain to estimate the possible impact on people, the built-environment, or other potentially vulnerable assets. Using a Monte Carlo approach, the model employs a variety of sampling techniques on observed hail event data to provide greater insight on the hail disaster potential for a user-defined geography. We demonstrate recent improvements to the HailMC.V1 that resulted in the HailMC.V2, including more accurate hail event spatial representations, improved impact estimation techniques, the incorporation of new cost surfaces (e.g., land use-land cover, land value, building footprint, critical infrastructure), etc. A sample HailMC.V2 application is illustrated by simulating hail events across eastern Colorado for three time periods: historical (1970); current (2020); and future (2070). Hail impacts on both the built-environment—as represented by housing units—and agricultural lands are provided. Outcomes emphasize the importance of developing versatile tools that capture better hail risk and vulnerability attributes to provide more precise estimates of disaster potential. Such tools can provide emergency managers, planners, insurers, and decision makers a means to advance mitigation, resilience, and sustainability strategies.

What is the theoretical upper limit for hail size?

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Recent cases of exceptionally large hail around the world have captivated many on social media. Such cases have occurred in the United States, Australia, Italy, Libya, and Argentina, the latter of which motivated a proposed new class for “gargantuan” (maximum dimension >15 cm) hail. Such extreme events have raised an intriguing question: What is the theoretical upper limit for hail size? We take a multifaceted approach to answer this question. First, we review the historical records for well-documented cases of extreme hail sizes, particularly those with reliable measurements of maximum dimension *and* mass. Second, we use a novel dataset of high-resolution 3D hailstone shapes from infrared laser scanning and digital photogrammetry to establish empirical relationships between hailstone volume, equivalent volume spherical diameter, maximum dimension, and new conceptual framework for characterizing their nonsphericity. These data are used to develop a simple parameterization that probabilistically maps hailstone mass to maximum dimension; though simple, the model is statistically robust and compares very well with an independent dataset of triaxial hailstone measurements. We then use this model to construct probabilities of maximum hail sizes for different assumptions about the upper limit for hailstone mass.

To test the reliability of our assumptions about maximum attainable hailstone mass, we employ simple updraft and hail-growth models, constrained by observed and simulated updrafts and storm environments associated with giant-to-gargantuan hail. Finally, we create a realistic rendering of the theoretical maximum hailstone and explore the conditions necessary for such extreme hail.

Revisiting Thermal Energy Transfer Coefficients for Nonspherical Hailstones

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Growth of severe hail involves a complex web of microphysical processes, many of which remain poorly understood. Hailstones acquire mass by collecting supercooled liquid water droplets as they pass through the parent storm’s updraft. As the collected supercooled liquid freezes and becomes a part of the hailstone’s ice mass, the associated enthalpy of freezing increases the hailstone’s surface temperature. The rate at which this excess thermal energy is dissipated to the surrounding air plays an important role in determining the growth regime (dry vs. wet) and, ultimately, the overall hailstone’s growth rate. This thermal energy dissipation rate is governed by the temperature difference between the hailstone and the surrounding air, as well as physical properties of the hailstone (i.e., size, fallspeed, shape, surface area, tumbling behavior, etc.). Because of the myriad of complex shapes natural hailstones exhibit, an empirically derived thermal energy coefficient (hereafter) is used in hail growth models. Most detailed hail growth models use a parameterization of as a function of hailstone Reynolds number based on a single wind tunnel study from 1968, which used artificial spherical hailstones. Given the limits of technology at the time, several assumptions were used and incorporated into the calculated values. Today, the advent of 3D laser scanning and 3D digital photogrammetry allows for detailed characterizations of hailstone shapes, including precise determination of hailstone surface area. In this study, we use a collection of over 200 digitized hailstone models to evaluate and refine the assumptions used in the oft-used parameterization, including updates for incorporating hailstones’ nonspherical shapes. The impacts of this refined parameterization on hail growth using our detailed hail growth model will be discussed.

How do Hail Return Intervals Scale Locally?

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Large hail can produce locally extreme damage and is the primary driver of insurance losses from severe convective storms in North America. Despite this, limited attention has been paid to local hail hazard variation, primarily due to challenges posed by observational records that could be utilized to extrapolate frequency. In prior work, the distribution and return periods of large hail on a 1.0˚ x 1.0˚ grid were characterized for the entire country. In this work, we assess how the frequency of large hail scales to a city-scale as well as smaller-scales. A blended, multi-observational dataset approach is used to derive return intervals at scales from cities down to a local 4 km grid, with major locations of hail risk considered including Denver, Oklahoma City, Dallas, Des Moines, St. Louis, Chicago, Indianapolis, Detroit, Nashville, Atlanta, Pittsburgh and New York City. Through this analysis, fitted extreme value models for well-observed locations using a Generalized Extreme Value model suggest a positive-shape parameter (i.e. a Frechet distribution), contrasting earlier work which showed the distribution was best modeled by a Gumbel distribution. These results highlight that, in some regions, the return rate locally is almost uniform between broader and local scales, whereas in others we see more notable decreases in risk as the area impacted decreases. The outcomes of this work will allow a better understanding of how often large hail can be expected at smaller scales, with relevance to major metropolitan areas or high-risk local assets such as photovoltaic utility scale plants. These findings shine a light on large hail risk from a financial standpoint and allows stakeholders to enhance preparation for hailstorms in the future, as well as develop approaches to mitigate damage and reduce losses.

Explicit Hail Prediction of a Moderate Hailstorm case using WRF-3DVar and Thompson-Eidhammer Microphysics

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Hailstones have large damage potential; however, their explicit prediction (including surface hail size and location) remains quite challenging. The uncertainty in model's initial condition and microphysics are two of the significant contributors to the challenge. This study therefore aims to investigate the impacts of improved initial condition and microphysics on surface hail size and location prediction for a moderate hailstorm occurred in Beijing on 10 June 2016 using the Weather Research and Forecasting (WRF) Model's three-dimensional variational data assimilation (3DVar) system and the latest revised Thompson-Eidhammer bulk scheme (MP38).

The role of initial condition on hail prediction is first explored by assimilating high-resolution radar and surface observations. Results indicate that data assimilation (DA) significantly improves the FSS score of hail size and location prediction by reducing errors in low-level vertical wind shears and moisture fields. However, even with more accurate initial condition provided by DA, hail prediction still can be affected by microphysical parameterization processes. Then, with DA applied, the role of microphysics (MP) is further discussed by comparing MP38 with two earlier schemes. MP38 is a newly revised two-moment hail-aware scheme that predicts graupel number concentration (N_g) and density. The results show that such modifications produced a smaller and more realistic forecast of hail size because of improved simulation of mass-weighted mean graupel diameter and radar reflectivity. However, it will significantly underpredict the hail size with only the revision of N_g, indicating both modifications are necessary for skillful hail size prediction in this case. The smaller hail size in MP38 further led to a stronger graupel melting process and cold pool, which inhibited the development of spurious convection at the north and improved hail location prediction. By assessing the efficiency of DA and the recently upgraded Thompson-Eidhammer MP scheme, the results of this work shed light on the importance of accurate representation of initial condition and microphysical processes in NWP models for explicit hail prediction.

Automated Processing of Hailstones in Free-Fall Using a High-Speed, High-Resolution, Dual Camera Imager

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Previous field and observational work regarding hailstones has provided numerous observations of hailstone shape, size, and density through impacts (hail pads, impact sensors), direct measurements (post impact), and post-impact image observations and three-dimensional scans. While invaluable, these observations generally fail to characterize the pre-impact state of hailstones in true free-fall. Limited studies using film cameras and stobe lights tried to address fall behavior of hailstones in natural free fall. To address limitations of imaging hail in natural free fall, a fully mobile, high-resolution, high-speed, dual-camera systems was designed and built by NOAA/NSSL and OU/CIWRO to observe hailstones in their natural state before impact in order to assess fall behavior (speed, orientation, canting angle, tumbling, etc.), size, shape, and density prior to impact and prior to any negative effects of melting and/or breaking. Each camera is capable of collecting ~300 fps at full 12 MP, 4k resolution, resulting in numerous high-quality images for even high-fall speed objects (20-50+ m s^{-1}). With the current system design, a large amount of data is collected over time periods as short as a few seconds, making analysis of objects tedious and time consuming. In order to automate processing of the large data sets collected by the hail camera vehicle, video analysis is being developed to automatically detect objects and provide accurate observations of their size, shape, velocity, density, and fall behavior while in complete free-fall. A preliminary analysis showing several example cases from recent deployments during the TORUS project will be presented along with observational characteristics of sampled hailstones.

Documenting and Digitally Preserving Giant Hailstones: The IBHS Record Hail Quick Response Team

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In 2015, the first hailstone was laser scanned using a hand-held, 3-D scanner and a precision digital model was created. In the years following, the application of this technology toward hailstones has led to research advances related to hailstone aerodynamics, the radar scattering properties of hail, and improved understanding of hailstone bulk densities and strength. The ability to create detailed digital models of individual hailstones made this technology perfectly suited for documenting and digitally preserving record-setting hailstones. The first record hailstone documented by the Insurance Institute for Business & Home Safety's (IBHS) quick response team was found by a home owner near Walter, Alabama in 2018. Through a rapid and ad hoc coordination with scientists from the University of Alabama at Huntsville and the National Weather Service Weather Forecast Office in Huntsville, the IBHS team was able to document and 3-D laser scan this record-setting hailstone. The Alabama state record hailstone also was the first hailstone record to include documentation of its volume in the National Center for Environmental Information record event database. The IBHS quick response team has now documented and digitally preserved the Colorado state record hailstone (2020) and the Texas state record hailstone (2021). The team also conducted a surveys in Arkansas in 2020, and another in Texas in 2022 that ultimately did not qualify as the state records. Record and other unique hailstones have also been 3-D printed for use in classroom settings, spotter training, and even used in vertical wind tunnel testing. The IBHS quick response team is committed to documenting and digitally preserving these unique and record-setting hailstones.

An updated 3D radar-based hail statistic for Germany including further characteristics

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Weather radars are the most powerful remote sensing tools for indirect hail detection. In particular, hail detection algorithms using volumetric (3D) radar reflectivity provide reliable estimates of hail on the ground (Allen et al., 2020). We present an update of an existing hail climatology for Germany (Schmidberger, 2018) by incorporating recent data (new period: 2005 – 2021). Using the cell tracking algorithm TRACE3D (Handwerker, 2002), 3D radar data from the Deutscher Wetterdienst (DWD) were analyzed regarding specific hail signatures. The detected potential hail cells were tracked in each consecutive 15 min time step and formed contiguous hail tracks. Furthermore, filtering methods for the identification of hail tracks were improved (e.g., false detections, split and merge artefacts etc.). Besides the spatial distribution of a gridpoint-based hail map, various characteristics of the hail tracks such as duration, length, width, and direction can be statistically evaluated for a 17-year period. In addition, the hail track dataset for Germany was combined with data from a mesocyclone detection algorithm of DWD in order to identify supercells and to examine their motion in detail. For this purpose, radar-derived supercell motion (based on the observational dataset) was compared with model data utilizing the parameterization according to the widely-applied method of Bunkers et al. (2000) with the aim to verify the applicability of the method for Germany (originally developed based on supercells in the USA). For this purpose, analysis data from the high-resolution numerical weather prediction model COSMO-EU were used to determine the wind direction, velocity and vertical wind shear in the surroundings of the supercells. First, the extent to which the Bunkers parameterization correctly reproduces the supercell motion determined by the cell tracking algorithm was investigated. Afterwards, the Bunkers method was adjusted for the supercell tracks separated into so-called right-movers and left-movers. For the whole sample of events as well as for the mentioned subdivision of the dataset, differences between the original and adjusted Bunkers parameterization and the radar-estimate tracks were investigated.

End of lightning poster session 1 abstracts

A comparison of hail predictability with different initial perturbations from climatological, flow-dependent, and aerosols uncertainty

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Hailstorms, a damaging phenomenon found in many areas of the world, are difficult to predict due to its sensitivity to small perturbations in initial conditions. This study provides an assessment of contribution of climatological, flow-dependent, and aerosol related uncertainty to hail predictability by varying both the initial cloud condensation nuclei concentration (CCNC) and the initial meteorological conditions based on WRF idealized ensemble runs. Climatological uncertainty profiles are obtained from ECMWF Atmospheric Reanalysis of the 20th Century (ERA-20C Project) and flow-dependent perturbations are derived from the European Centre for Medium-Range Weather Forecasting (ECMWF) operational ensemble. The analyses revealed that hail precipitation rate was very sensitive to small initial environmental perturbations both from climatological and flow-dependent perturbation, particularly in thermodynamic variables. Climatological perturbed ensemble presents a larger predictability with more random signals of climate change than flow-dependent perturbed ensemble, when the flow-dependent method generates more favorable conditions from the short-range forecasts and high-resolution analysis. Although meteorological perturbations produce large uncertainties in both hail and total precipitation, varying CCNC by an order of magnitude causes even larger uncertainties than the corresponding meteorological perturbations. Changing CCNC modifies the predictability of hail precipitation, with higher predictability in moderately polluted environments compared with very clean and polluted environments. Perturbing the initial meteorological conditions does not qualitatively change how aerosols affect hail and total precipitation. Constraining the initial meteorological perturbations helps reduce CCNC-caused uncertainty.

Improving the prediction/simulation of hail using an advanced bulk microphysics scheme

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The representation of hail and hail growth in numerical models is uniquely challenging for microphysics parameterization schemes. In addition to the complexity of modeling hail itself, a microphysics scheme must model everything from CCN activation to the riming of graupel – and everything in between – since almost every cloud microphysical process ultimately impacts the formation and growth of hail. Over the past several decades, microphysics schemes have advanced considerably and with that has come an increased capacity to model hail, including in NWP models. In 2015, we developed a new bulk scheme – the Predicted Particle Properties (P3) scheme – based on the concept of freely evolving generic ice-phase categories which in principle can represent any type of frozen hydrometeor. However, at the time of the last North American Hail Workshop in 2018, P3 had certain limitations in its capacity to model hail.

Since that time, the P3 scheme has been further developed and is now capable of modeling hail in detail. P3's "ice" categories can now represent mixed-phase particles by predicting (and retaining) the liquid fraction of hail undergoing wet growth or melting; it has 3 independent parameters to describe the size distribution, thus predicting the relative spectral dispersion (and allowing for a diagnostic of the maximum hail size); and it allows for a user-specified number of free ice categories. In this presentation, high-resolution mesoscale model simulations of an observed hailstorm will be presented and the capacity of P3 to model hail will be examined. Results from sensitivity tests will be shown to illustrate the impacts on modeling hail of the various new developments to the P3 scheme.

A new version of Thompson microphysics aimed at better simulation of hail

Sarah Tessendorf, Maria Frediani, Amanda Siems-Anderson, Lulin Xue, Kyoko Ikeda, Greg Thompson, and Anders Jensen

The Thompson bulk microphysics scheme (Thompson et al. 2008, Thompson and Eidhammer 2014) utilizes a single-moment hybrid category to represent both graupel and hail, with a constant density of 500 kg/m^3 (a value in between that expected for graupel and hail). A new two-moment and predicted density graupel category has been implemented into the scheme, which predicts mass mixing ratio, number concentration, and the density of rimed ice particles in order to better represent the variations between graupel and hail in this hybrid hydrometeor category. The new version of the scheme was evaluated for its ability to predict hail sizes compared to observed hail sizes from storm reports and estimated from radar in a mesoscale convective system case study (Jensen et al. 2022). The two-moment and predicted density graupel scheme was shown to better predict a wide variety of hail sizes at the surface, including large (>2-inch in diameter) hail that was observed. A more complete evaluation of this scheme has been conducted over the 30-day period of May 2019 in the central U.S. plains. This presentation will describe the new scheme, illustrate its performance in the 30-day evaluation period compared to surface reports and radar data, including compared to the radar-derived Maximum Estimated Size of Hail (MESH). This presentation also will provide an update on how this scheme has been implemented into the Weather Research and Forecast (WRF) model code so that interested users can access it.

Simulation of RELAMPAGO IOP17 using the new hail-enable Thompson microphysics scheme

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The unique combination of the steep and complex topography, interactions of moist air masses from surrounding oceans, and the Amazon forests makes the southern Andes and associated downwind plain a hotspot for strong organized convective storms that produce severe hail damages. To improve our understanding of the physical processes associated with these unique strong convective systems, the Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations (RELAMPAGO) and Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaigns were conducted in the Sierras de Córdoba Mountain range of north-central Argentina from 2018 summer to 2019 spring.

The Intensive Observing Period (IOP) 17 of RELAMPAGO (2018-12-13 22:00 to 2018-12-14 03:00) observed a unique type of convective storms seen in South America with back building and fast upscale growing features. Flooding, strong winds, large hail, and a tornado (near San Francisco east of Cordoba) were all reported during this event. This presentation will show results of 1-km WRF simulations of this IOP using the recently developed hail-aware Thompson microphysics scheme with special emphasis on storm dynamics, microphysical properties and hail precipitation features.

A wind tunnel investigation on the ventilation coefficients of hailstones

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The rate of change of mass of a hailstone by diffusion is affected by its motions. In a stationary pure diffusive case, the water vapor distribution around a spherical hailstone is spherically symmetric having rather weak water vapor gradients. However, when a hailstone falls in the air, the flow field and hence the water vapor distribution around the hailstone is asymmetric showing much stronger water vapor gradients which are high at the upstream side and lower at the rear side of the hailstone. When averaged over the whole surface area of the hailstone the mass transfer to or from the falling hailstone surface is always higher compared to a pure diffusive case. This convective enhancement is given by the ventilation coefficient. Thus, to reliably quantify growth or sublimation rates of falling hailstones with models, it is necessary to know their ventilation coefficients. The rate of change of mass is proportional to the rate of change of heat. Therefore, the growth or sublimation of hailstones has not only implications on the humidity of the ambient air but also the vertical temperature profile of the atmosphere and consequently cloud and storm dynamics. However, there is a lack of experimental studies on the ventilation coefficient of spherical hailstones in the literature. There are just three experimental studies available – all dating back to the 1960's – which investigate the heat and mass transfer of spherical and oblate hailstones, but all were measured under accretional growth and melting conditions, respectively.
Therefore, experiments in the Mainz vertical wind tunnel were carried out to determine ventilation coefficients of spherical hailstones in the diffusion mode. We investigated stones with diameters between 1 and 3 cm or, equivalently, Reynolds numbers between 10.000 and 45.000. The spherical hailstones were produced by freezing water in molds and introduced into the wind tunnel. While freely floating at their terminal velocities the hailstones lost

mass due to sublimation. The temperature was set to -5°C and relative humidities were rather low, i.e. between 30 % and 50 % with respect to ice, to facilitate sublimation. The mass of the hailstones was measured before and after the wind tunnel measurements by weighing them. During the measurement in the tunnel, the hailstones were photographed using a high-speed camera at 500 frames per second. From these images the size of the stones and thus their mass as well as the rate of change of mass in the convective case were derived. The recordings of temperature and dew point were used to calculate the rate of change of mass for the pure diffusive case. The ratio of these rates is by definition the ventilation coefficient, which were calculated and parameterized.

A High-Speed, High-Resolution, Dual-Camera Imager for Photographing Naturally Falling Hailstones

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Although previous field campaigns and research have provided numerous observations of hailstone sizes and shapes, these observations typically are made at the time of impact (e.g., hailstone hitting a hail pad or impact sensor) or after the hailstones have fallen (e.g., collecting hailstones off the ground for measurement and scanning). Since hailstones are often not spherical, how hail “looks” to weather radar, both for operational use (e.g., severe weather warnings) and in numerical simulations (e.g., through the use of a polarimetric radar forward operator), depends on the hail’s orientation and fall behavior (e.g., mean canting angle and tumbling behavior). Although previous field efforts have examined the fall behavior of mostly small hail (generally < 2.5 cm in diameter), the fall behavior of large hail has been examined using lab-created pseudo-hailstones and “idealized” hailstones tested in wind tunnels and used in theoretical calculations. However, there is a dearth of observations about the fall behavior of naturally falling large hailstones in real conditions. To fill this gap, we have developed a high-speed (~300 fps), high-resolution stereographic camera imager designed to image natural hailstones, and in particular large hailstones, in free fall. This new imager improves on a previous, dual-camera (non-stereographic) prototype tested in 2019. Because large hailstones have comparatively high fall speeds (20–50+ m s-1 in the lower troposphere), a high frame rate is required to capture multiple images of the hailstones as they fall in order to get information on the tumbling behavior and fall speed. The typically low number concentration of large hail requires a large sampling volume, which in turn requires a high-resolution sensor in order to provide sufficient resolution to estimate hailstone size. This presentation introduces the new imager and presents preliminary observations collected in several convective storms in the central U.S. in Spring 2022. We intend for this work to improve radar-based detection of large hail and lead to more accurate representation of large hail by polarimetric radar forward operators.

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Automating the Analysis of Hailstone Layers

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Hailstone size, shape and internal structures are the result of growth conditions within the parent thunderstorm updraft. Size and shape are effectively the aggregate product of these processes, while internal structures preserve the growth evolution. The most characteristic internal structure are opaque and clear ice layers that present an onion-like appearance. The abrupt transitions between layers are the result of the freezing rate, which is very sensitive to hailstone surface temperatures near 0° C, leading to the wet and dry growth regimes that result in clear and opaque ice, respectively. Effectively, hailstone layer opacity is a record of the microphysical conditions during growth. Recent improvements in hail growth modelling and high-performance computing permits the simulations of millions of individual hailstones, including the contribution of wet and dry growth regimes; however, evaluation of these exciting new datasets is lacking. A new technique for automating the two-dimensional measurement of hailstone layers from thin sections is demonstrated. This technique is designed to provide reduce labor and potential errors while increasing the benefits of analyzing thin sections. Outputs are demonstrated for a collection of 40 hailstones from Melbourne, Australia, including the representation as equivalent circular cross sections for direct model comparison. Further, a sample of simulated hailstones is analyzed to provide a first look at evaluating a hail growth model using observed layers.

Characterization of non-soluble particles identified in hailstones collected in the province of Córdoba-Argentina

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Córdoba Province in Argentina is a region where some of the most severe storms in the world occur, with frequent hail that has damaging impacts on property and agriculture. A challenge in forecasting hail comes from an incomplete understanding of the main environmental and storm internal controls on hail occurrence and size, including for different storm modes and in different regions of the world, as well as limited verified hail reports. In a previous study (Bernal Ayala et al. 2022), verified hail collected in the mountainous Córdoba region was correlated with GOES-16 satellite data, showing promise in satellite-based proxies for hail detection in multiple environments for different storm modes. The next goal is to identify possible source regions from which these particles were transported to further our understanding of hail formation in this region. For this study, non-soluble particulates are identified in a hail sample from the 8 February 2018.

T-28 Research Aircraft and Polarimetric Radar Observations of Hailstorms

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The armored T-28 research aircraft operated by South Dakota School of Mines and Technology created a unique set of in situ hail observations while conducting 9 different campaigns. The T-28 aircraft sampled in convective storms producing hail to obtain hail number concentrations and size distributions, as well as two-dimensional shadow images. Concurrently with aircraft observations, there is S-band dual-polarimetric radar observations. The T-28 aircraft's 18 hail encountering missions provides a large data set for documenting in-situ hail observations with the polarimetric radar signatures. The dataset enables computing expected polarimetric radar signatures for comparison with of the observed radar signatures to determine radar signatures of hailstorms. Varying the approximations and parameters used in the calculations and comparing the calculated to the actual radar returns provides insight into how hail shapes, orientation, sizes and concentrations influence radar signatures.

Hailstorms and Rainstorms vs. Supercells - a Comparison of Severe Thunderstorms in the Alpine Region

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Using six years of radar-based thunderstorm data in the Swiss radar domain, we classify them as ordinary thunderstorms, rain or severe rain storms, hail or severe hail storms and supercells. After investigating the overlap between rain storms, hail storms and supercells, we examine their intensity life cycles. This analysis allows us to identify predictors of intensification within the life cycles of severe storms. A particular focus lies on the occurrence of hail in the intensity lifecycle of supercells. We then subdivide the radar domain into regions of differing topographical complexity, ranging from the Po Valley, the Southern Prealps, the main Alpine ridge, the Northern Prealps, the Swiss Plateau, to the Jura. An examination of the intensity distribution of storms in each region shows an evident intensity decrease for the most severe storm types over the main Alpine ridge, intermediate values over the moderately complex foothills of the Alps, and peak values for the flat Po Valley and the Swiss Plateau. This contrasts the overall frequency distribution, where both Prealpine regions show the highest occurrence of convection. These analyses compare several categories of hazardous thunderstorms and examine the influence of increasingly complex terrain on different types of severe convection from an observational perspective.

View inside a hail supercell over southern Germany using C-band radar Doppler spectra

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Since spring 2021, Doppler (power) spectra are saved continuously from the vertically pointing birdbath scans of the 17 operational radars in the German C-band radar network to gain further insight into precipitation processes. Potential applications of these radar data are first tested with the DWD research radar that is quasi-identical to the operational radar systems and installed at the observatory Hohenpeissenberg in pre-alpine southern Germany. Here, we present first results for using the Doppler spectra obtained from the operational birdbath scan strategy to analyze a hail cell that passed over the observatory in spring 2021. Birdbath scans are repeated every 5 min for a duration of 15 s (within the operational radar scanning cycle) and deliver a height profile of the radar echo of the hail cell at a resolution of 25 m. For all height levels, the Doppler spectra further subdivide the radar echo into many spectral contributions that reflect the different fallspeeds of the precipitation particles present at that altitude. Due to the strong dependence of particle fallspeed on precipitation type and particle size, these Doppler spectra provide a unique view into the structure and progression of the hail supercell. In the heart of the supercell, we find complex multimodal precipitation fields of hail and rain with combined radar reflectivity of up to 60 dBZ and typical hailstone fallspeeds of about 18 m s^{-1} near the ground. The profiles of Doppler specra that capture the hail growth region of the supercell indicate that hail growth occurs within the updraft region while large hailstones simultaneously fall through the same atmospheric region from above. Overall, the recorded sequence of birdbath scans indicates distinct stages in the progression of the hail cell with a very pronounced transition from rain to hail at the ground that is in line with simultaneous in situ observations collected by a hail sensor and rain gauges.

On the use of RaXPol for studying hail processes in convective storms

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RaXPol is a mobile, rapid-scan, X-band, polarimetric, Doppler radar, which has been used for over a decade to study tornadoes and tornadogenesis in supercells. It has also been used recently to study precipitation processes in snowstorms in the Northeastern U. S. While the main focus of our scientific studies has been to learn more about tornado structure, formation. and evolution in supercells, it has also serendipitously captured the production of large hail in many cases. Most recently, we have collected raw, I/Q data in supercells, which have been used to compute polarimetric spectra in a few supercells in the Southern Plains. When collecting and recording raw data, the frequency-hopping capabilities, which allow for rapid scanning, must be disabled for coherent spectral processing, so that only slow, sector scans are collected in this mode of data collection. Future radars, however, will allow for rapid-scan data collection of raw data. In this presentation polarimetric spectra from a supercell that had recently produced a tornado on 12 October 2021 in western Oklahoma will be shown and compared with analyses of moment data. In addition, data collected in a tornado-warned supercell in the Texas Panhandle on 22 April 2022 will also be shown. It will be demonstrated how polarimetric spectra might be used to enhance our understanding of hail production processes in convective storms by providing information not only on the type of hydrometeors present, but also on their size distribution. Our plans for future field programs will then be discussed.

First insight into the hail distribution over Germany

Tabea Wilke[1] , Markus Schultze[1] , and Katharina Lengfeld[1]
German Weather Service, Germany

Since major hail events are quite rare in Germany, there is a lack of information in hail occurrence, size and its spatiotemporal distribution. As hailstorms are often locally very limited events, the hail distribution is hard to analyze precisely. Hail reports can only give a first intuition about the amount of hail overall. There might be a bias in the amount of reports towards too many reports in highly populated areas, which could lead to an underrepresentation of reports in rural and sparsely populated areas. Areal information from weather radar networks can overcome this issue with a high spatio-temporal resolution. The German radar network consists of 17 dual-polarimetric radar systems, which cover Germany more or less completely. First of all, a hydrometeor classification (HYMEC) is applied to the radar data to check if the occurrence of hail is reasonable. From that, a hail distribution over Germany can already be derived. For the analysis of the hail sizes, the Maximum Expected Size of Hail (MESH) and a method based on Vertical Integrated Ice (VII) are used to estimate the hail size in those regions where hail is probable. The results of

MESH and VII are finally compared to the eyewitness reports sent to the ESWD and the WarnWetter-App.

The Creation of a Hail Damage Swath Event Database and Follow On Applications

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Severe and intense thunderstorms impact agricultural crops with damaging winds, hail, and tornadoes during the prime summer growing season annually across the Great Plains and Midwest. In certain thunderstorm events, damaging winds and hail can leave behind large swaths of damage, known as 'hail damage swaths' or 'hail streaks'. These hail damage swaths can be up to several hundred kilometers long and tens of kilometers wide, which allow them to be frequently seen from satellite remote sensing platforms. While these damage swaths can represent hundreds of millions to billions of dollars in damage annually, there is very little official documentation of their occurrence. In order to better understand the annual occurrence and spatial extent of these hail damage swaths, a hail damage swath event database was created. The database was constructed using daily Storm Prediction Center Storm Reports and daily NASA Moderate Resolution Imaging Spectroradiometer (MODIS) True Color Imagery. The research team identified suspected hail damage swaths, associated metadata (swath occurrence, first appeared in imagery), and a geospatial outline of the suspected perimeter of the swath. Ancillary datasets such as archived NEXRAD data and archived severe thunderstorm warnings were used to validate potential damage swaths into the final database. This paper will discuss in-depth the creation of the hail damage swath event database while also presenting geospatial and temporal analysis of the event database. We will also outline future research in how this database will be updated, how the database is contributing to improved remote sensing mapping techniques of the hail damage swaths, and how the database is contributing to developing machine learning algorithms of automated detection of hail damage swaths.

Advancements in radar-derived hail products for estimating hail damage

Nick Guy[1], Scott Ganson[1], and Tory Farney[1]
[1]Verisk

Traditionally weather radar-estimate maximum hail size has been used as the primary, and often only, product to relate potentially damaging hailstorms to insurance claims. These estimates are commonly based upon a relationship to equivalent radar reflectivity. Past research has shown that while hail size alone does a decent job relating where damaging hail will occur, there is room for improvement. The Verisk hail algorithm is a fully polarimetric-based algorithm that yields a hail size as well as hail impact energy. Moving away from only maximum hail size in favor of hail impact energy results in a product better suited to capture the true effect of a high impact storm. The combination of the hail size and impact energy yields a robust correlation to the spatial distribution of historical insurance claims data when compared to standard hail size or hail kinetic energy products. Future improvements in the underlying representation of the distribution and characteristics of hail stones will act to further improve these estimates and capture a broader range of storm morphologies and characterizations.

Athenium Analytics Hail Products for the Insurance Industry

Kaitlyn Fons[1], Jonathan Fairman[1], Justin Jones[1], Amy Daniels[1]
[1]Athenium Analytics

Storms producing hail, typically severe convective storms (SCS), are among the top costliest perils for the insurance industry. Understanding the distribution of hail risk across the U.S., learning from past events, and access to a tool for post-event forensics is necessary for property insurers to optimize their exposure to hail. Athenium Analytics is an industry leader in natural hazard and internal risk analytics, and has multiple products dedicated to understanding hail for both the claims and underwriting sides of the insurance workflow. These products include: a near-real-time

updating DexterHail product, Daily Historic Hail GIS layers, and GaugeHail risk maps. Dexter is a post-event verification tool that uses automated algorithms to track severe events with latencies of 90 minutes from storm occurrence. The DexterHail layer is used by insurance claims teams to understand their exposure after a storm, and is derived from patent-pending algorithms that adjust and correct data from the NSSL Multi-Radar Multi-Sensor (MRMS) MESH product to produce consistent hail results at 1 km resolution. Applying knowledge from DexterHail, in 2020 Athenium partnered with AON to produce a catalogue of historic event footprints, which included hail and other SCS perils such as straight-line wind and tornadoes. These daily layers utilize historic radar information to produce records for all days with severe weather reports from 1995-2019, oriented in a GIS-centric layering structure. Athenium recently used the hail footprints to update the GaugeHail risk map, a product that is used during the underwriting process to understand hail frequency and severity across the contiguous U.S. The GaugeHail update utilized both the results of DexterHail during the MRMS era and the historic retrievals of hail size from the Daily Historic Hail GIS layers. This poster will present highlights from these three different datasets and demonstrate how Athenium Analytics translates information of hail occurrence into actionable products that our customer base can easily use.

Lightning poster session 2 abstracts

Methodology and 2017 Results of using Radar Observations to Evaluate Hail Mitigation by the Alberta Hail Suppression Project

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[1]University of North Dakota
[2]Weather Modification International

The Alberta Hail Suppression Project is an operational glaciogenic cloud seeding program designed to reduce hailstone-induced property damage in the metropolitan areas in the lee of the Rocky Mountains of southern Alberta, Canada. The operations area includes the cities of Calgary and Red Deer. This evaluation uses data from a project C-band radar located at the Olds-Didsbury Airport, approximately half-way between Calgary and Red Deer, and an Environment Canada radar at Strathmore, about 40 km east of Calgary. Effectiveness in hail reduction is evaluated using indicators of Maximum Vertically Integrated Liquid (MaxVIL) and storm area greater than or equal to 60 dBZ (Ar60) to relate observations before and during the project's cloud seeding operations. The MaxVIL indicator is more sensitive to the size of large hail, while the Ar60 indicator is more sensitive to the area of hail. Several different seeding effectiveness metrics are evaluated using 21 hail cases from 2017. The Increasing Hail Ratio metric is 0.12 (1.0 is highest possible value) for both MaxVIL and Ar60 indicators, which indicates a reduction in damaging hail. The number of cases could be increased using the project radar data recorded for other seasons between 2014 to 2021 to determine if the statistical significance changes appreciably. Automated data-processing scripts have been developed; therefore, it would be relatively straightforward to analyze additional storms once preliminary radar data review determines the suitable analysis times and locations for each season.

Hail Impacts on Stone Coated Metal Tile Systems

Chris Sanders
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Hail causes $10 billion dollars in property damage each year in the United States. Roofs are the first line of defense against severe weather events and the hazards they present. Although asphalt shingles are the primary roof cover used on residential roofing, other roof cover types have begun to gain popularity. One product gaining popularity is a roofing system referred to as stone coated metal which use a series of coatings to adhere granules to the surface of metal tiles. The goal of this study was to identify and if possible, quantify the damage that occurred to these metal tile systems through laboratory hail impact testing. Panels were tested using 2-inch laboratory manufactured hailstones using the IBHS hail impact test protocol.

S-pol Capabilities and a Potential Dual-Wavelength Upgrade for Enhanced Hail Studies

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Vast improvements in radar technology have been achieved since the last hail experiments in the 1980s. Processors are fasters, real time identification and filtering of ground clutter echoes, increased receiver dynamic range, automated particle identification, time-series recording for complete flexibility in data post processing, rapid scanning technology and algorithms, and perhaps most importantly, dual-polarization technology, which has dramatically increased the detection of particle scattering information and thus our ability for microphysical information retrievals. For microwave penetration with minimal attenuation through large hailstorms, long wavelength radars, such as NCAR's S-Pol and Colorado State University's CSU-CHILL, are very desirable for microphysical identification and high data quality. Presently S-Pol is the only S-band radar that is available to the NSF research community via the LAOF supported by NCAR. This presentation will first review an example of S-Pol measurements through a sever hailstorm.

It is well known that the combination of S- and C-Band wavelengths can significantly increase the information as to the type and phase of precipitation particles in a resolution volume. This has been demonstrated before, for example, in several studies using OU-Prime data (C Band operated by the University of Oklahoma) and KOUN data (S Band, NEXRAD). There have also been many modeling studies comparing precipitation particle scattering at S and C Band. These studies show that different sized particles have significantly different radar signatures. These different scattering signatures can be leveraged to glean more information about the precipitation particles thereby enhancing not only resolution volume composition estimation but also general storm structure and dynamics. A limitation of previous S- and C-band comparative studies was the matching of the S- and C-band resolution volumes in both time and space. NCAR has begun an investigation into eliminating the issue of finding S- and C-band data from separate radars that are matched well enough to make possible meaningful comparisons.

This issue could be solved if a radar, such as S-Pol, could simultaneously broadcast both S- and C-band wavelength using a single feedhorn while maintaining matched main beams in the far field. However, the main antenna beamwidth, according to antenna theory, is proportional to the wavelength divided by the diameter of the parabolic reflector, i.e., one would expect that the C-band beamwidth would be about half of the S-band beamwidth. Through advanced design techniques the far-field main beams of the S- and C-band frequencies can indeed be matched. NCAR has obtained such a designed feed horn and has verified via modeled data that the far field main beams are well matched. This dual-wavelength capability would greatly expand the study of hail microphysical processes and therefore advance our understanding hail storms.

Just what is "good"? Musings on hail forecast verification through evaluation of FV3-HAILCAST hail forecasts

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The CAM-HAILCAST pseudo-Lagrangian hail size forecasting model was implemented in the Limited Area Model of the Unified Forecast System Finite Volume 3 (FV3) dynamical core. The performance of the FV3-HAILCAST implementation was evaluated using two different verification methods over three different spatiotemporal scales during the 2019, 2020, and 2021 NOAA Hazardous Weather Testbed Spring Forecasting Experiments. Subjective evaluation of all the verification methods was solicited as well as the participants' thoughts on the content of a ``good'' hail forecast. Results recommend use of multiple verification methods tailored to the type of forecast expected by the end-user interpreting and applying the forecast.

Evaluation of FV3-HAILCAST over both 1-h and 24-h periods found continued improvement from 2019 to 2021. The improvement was largely a result of wide intervariability among FV3 ensemble members with different microphysics parameterizations in 2019 lessening significantly during 2020 and 2021. A combination of both upscaling neighborhood verification and an object-based technique that only retained matched convective objects was necessary to understand the improvement. For example, a member of the 2019 ensemble overproduced convection, resulting in poor upscaling neighborhood verification scores. However, where convection was correctly forecast, FV3-HAILCAST forecasts were skillful, resulting in high object-based scores. Verification over varying spatiotemporal scales also showed where convective and/or hail size forecast overprediction was most common during the diurnal cycle; these peaks in overprediction did not occur at the same time. Overprediction throughout the diurnal cycle lessened by 2021.

Validation of the Hail Differential Reflectivity using the Severe Hazards Analysis and Verification Experiment Dataset

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Hail is responsible for billions of dollars in damages in the United States annually. However, many challenges still exist not only in forecasting these events, but in accurately determining what is happening within an ongoing storm as well. As such, the need for tools and/or algorithms to help forecasters differentiate between storms with hail and those without, in addition to helping estimate the potential size of the hail within, has risen. One proven avenue for assisting forecaster's is the use of dual-polarization Doppler weather radar. Indeed, polarimetric radar has been used in many different ways over recent years to try to infer more information on ongoing processes within the storm that may be indicative of enhanced hail production. The Hail Differential Reflectivity parameter (H_{DR}), however, has not received much, if any, attention since the national network of WSR-88D radars were upgraded to polarimetric capabilities. Derived from disdrometer measurements, H_{DR} employs a simple Z_H-Z_{DR} relationship to diagnose radar gates within a storm as potentially containing hail. However, it is not yet known if any reliable size information can be interpreted from H_{DR} values. In this study, we compared single-radar, polarimetric output from various algorithms within the Multi-Radar Multi-Sensor (MRMS) suite of products to the output of H_{DR}. Ground-truth observations available from the Severe Hazards Analysis and Verification Experiment (SHAVE) dataset are used to evaluate the information provided by the H_{DR} output, and the feasibility of incorporating H_{DR} into currently available products will be addressed.

Exploring a relationship between satellite-derived overshooting-top area and hail severity

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Recent idealized modeling studies have established physical links between hail severity and updraft area, and updraft area and an associated "overshooting top" area (OTA). Motivated by these physical links, we are exploring a potential relationship between hail severity and OTA in GOES-16 data. OTs are detected using a new algorithm developed by Hong et al. (2022), and then OTA is quantified following the method introduced by Marion et al. (2019) and subsequently modified by Grover et al. (2022). Hail severity is quantified using the U.S. hail report dataset maintained by the NOAA National Centers for Environmental Information. The reports are filtered such that the largest hail size for a given event is identified. The largest hail size is then attributed to the nearest OT, if one exists.

Thus far we have limited our study to mesoscale domain sector (MDS) areas and periods, to exploit the associated high temporal resolution. Our preliminary results for 2018-2021 show a modest linear relationship between OTA and hail size, which is consistent with a manual analyses of a small subset of events. At the workshop we will present a stratification of these results by season, geographical region, and other OT attributes. We will also discuss the limitations of this approach, as well as our future work.

Seamless coupling of kilometer-resolution weather predictions and climate simulations with hail impact assessments for multiple sectors (scClim)

Schmid et al.

Hail constitutes one of the top damage drivers of property insurance in Switzerland, with hail damage ranking first (48.2% of total damage 2009-2018) in the damage statistics of Swiss property insurers as well as in agricultural insurance. Addressing hail damage is challenging, because hail is related to severe thunderstorms, one of the most complex atmospheric phenomena due to its small spatial scale, vigorous development and the intricate physical interactions. Furthermore, hail damage occurs in various sectors and its quantification requires detailed knowledge about vulnerabilities and exposure with high spatial and temporal resolution. The project scClim, funded by the Swiss National Science Foundation, has set out to address these challenges in a unique inter- and transdisciplinary fashion with the goal of seamlessly coupling kilometer-resolution weather predictions and climate simulations with hail impact assessments for multiple sectors. To achieve this, we use data from the newest generation kilometer-scale weather and climate models on GPU-based supercomputing systems (which explicitly resolve convective processes), a unique radar-based hail track climatology for Switzerland, novel ground observation systems (e.g., sensors and crowd-sourcing), abundant damage data (especially agriculture, buildings, and vehicles), and the open-source and -access impact modeling platform CLIMADA that integrates multi-sectoral damage assessment components in a probabilistic manner. A close dialogue with key stakeholders and partners from the public and private sector enables us to explore the potential of impact-based warnings and to assess hail risk today and in a changing climate. This spanning of weather to climate scales will advance our understanding of the meteorological-climatological variability of hail occurrence and its impacts. Likewise, it is essential to inform sectoral adaptation strategies to strengthen societal resilience against hail risk. This contribution will introduce the scClim endeavour and present first results from the five subprojects, showcasing a range of initial joint case studies from the weather modeling, climatological, and impact modeling perspectives.

Athenium Analytics DexterHail – A near real-time application of hydrometeor classification and hail size discrimination algorithms on NSSL Multi-Radar Multi-Sensor MESH

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The National Severe Storms Laboratory (NSSL) Maximum Estimated Size of Hail (MESH) real-time product has been a gamechanger in terms of real-time hail size analysis. However, due to its real-time nature, there are several post-processing techniques available that can add value to the base product with the aim of increasing the probability of detection of severe hail (hail size greater than 1.0"). In April 2020, Athenium Analytics released an update to its DexterHail product, increasing the probability of detection of severe hail for post-storm forensics. DexterHail has latencies of around 90 minutes from storm occurrence and applies several different correction algorithms to the raw NSSL MESH data. The DexterHail algorithm first corrects for any radar site-related issues by filling points closest to the radar, performing temporal clustering, and identifying spurious hail retrievals by masking from the NSSL precipitation retrieval to further remove any radar-related clutter from the base product. Then, the national MRMS layer is decomposed into NEXRAD site-range domains and matched with three-dimensional atmospheric data from the NOAA HRRR model to perform additional hydrometeor classification algorithms and hail size discrimination from raw dual-polarization Level II NOAA NEXRAD radar volumes. After correction of each radar site is completed, a storm-motion-vector-following joining scheme is applied at various hail size thresholds to produce GIS-ready shapefiles for customer use. Application of all these parts increases the probability of detection of severe hail (>1.0 inches) at the site location by 7% compared to the base NSSL MESH product and detection of larger hail (>2.0 inches) by around 5% when comparing to NOAA SPC hail reports. By applying this system in a dynamic cloud computing environment overall processing time, even on days where nationwide hail is present, is on the order of minutes. This presentation will discuss the details of the DexterHail product, covering details of its formulation, cloud computing techniques applied, specific case studies, overall validation of the product, and various applications that have led to improving hail identification and risk across the Athenium Analytics weather product suite.

End of lightning poster session 2 abstracts

The Northern Hail Project: A renaissance in hail research in Canada

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With ever-rising losses caused by extreme weather, the majority of which are associated with severe convective storms (SCS), it is of national importance to advance our understanding of hail occurrence and damage impacts across Canada and improve the means for managing our risk and vulnerability to hail. It has been almost 40 years since the Albert Hail Project wrapped up. Although the AHP left a valuable legacy for future research initiatives to build on, the break in substantive hail research in Canada since its cessation has led to critical observational and knowledge gaps related to SCS occurrence and their impacts in Canada. It is thus essential that we address the key

data and knowledge gaps and provide opportunities to train the next generation of scientists and engineers to work on SCS and their impacts. To this end, the University of Western Ontario has recently launched the Northern Hail Project (NHP). We will provide the background, rationale and expected outcomes for the NHP and will also present observations from our first field season in Alberta. The philosophy of the NHP is to undertake world-class and transformative research that is data driven and has real-world applications. This includes deploying Canada's first hail disdrometer and weather station network in Calgary (located in Canada's Hail Alley), installing hailpad networks, sampling and preserving hail collected from hail swaths for analysis, monitoring vegetation health following hailstorms using multi-spectral cameras mounted on UAVs and super-high-resolution satellite imagery. Valuable data will also be collected from a portable testbed comprising a dual-polarization Doppler radar, a lightning mapping array, a surface station mesonet, a mobile mesonet, upper-air soundings and remote-controlled cameras. One of the foci of the portable testbed is to improve the detection and quantification of hail size (and tornado intensity) using radar and other remote sensing tools. Collectively these data, and the analysis thereof, are expected to have significant benefits for Canada and internationally. In the long term, detailed data for damaging-hail events over both agricultural land and urban areas will help stakeholders mitigate damage. The climatology of damaging hail events developed from our data will allow improved risk and catastrophe models for the insurance sector. The improved understanding of how hailstorms form will allow for better warning systems. In the short term, the data obtained will be useful for stakeholders, such as emergency managers, who will have access to our damage maps and surveys.

Swabian MOSES – a multidisciplinary field campaign to investigate severe convective storms and hail

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Convective storms and associated phenomena such as wind gusts, heavy rain, or hail are localized yet destructive weather systems that can cause significant damage to buildings, vehicles, infrastructure, and agriculture. These events and the associated process chain from their triggering to amplification to impact on the ground were the focus of the Swabian MOSES[1] measurement campaign lead by KIT, carried out from May to September 2021 in southwestern Germany – a Germany-wide hotspot of hailstorms.

The main objectives of Swabian MOSES 2021 were, among several others, to explore causes of the frequent occurrence and usually poor predictability of severe thunderstorms and hailstorms in the study area, to investigate reasons for the inhomogeneity of the precipitation and soil moisture distribution, and to gain a better understanding of the formation and evolution of hail, including the influence of aerosols. In order to tackle these objectives, researchers from ten partner institutions and various disciplines established and equipped more than 25 temporary ground-based stations with state-of-the-art in-situ and remote sensing observation systems, such as lidars, dual-polarization X-band Doppler weather radars, radiosondes including stratospheric balloons, an aerosol cloud chamber, masts to measure vertical fluxes, and networks of disdrometers, soil moisture and hail sensors. These fixed-site observations were supplemented by mobile observation teams, such as a storm chasing team launching swarmsondes in the vicinity of hailstorms.

Seven intensive observation periods (IOPs) were conducted on a total of 21 operating days. An exceptionally high number of convective storms, including both unorganized and organized thunderstorms such as supercells, occurred during the study period, particularly from June to mid-July, and were well captured by the installed instruments. Our presentation gives an overview of the Swabian MOSES field campaign and show some observational highlights for the IOPs with large hail occurrence. Trajectories of swarmsondes launched in the vicinity of a supercell, for example, were directed into the cell's updraft almost perpendicular to the general wind speed and the propagation of the cell. The wind direction in the lowest 400 to 600 m above ground level was almost constant, and also wind speed as well as equivalent potential temperature did not vary much, indicating that the sondes approximately followed the air parcel displacements.

CHAT – the Colorado Hail Accumulation from Thunderstorms project

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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 results from the project, which include building a hail depth database and radar-based hail accumulation algorithm for operational application, presenting ways to identify and study characteristics of thunderstorms producing hail accumulations on the ground using radar and lightning observations, and discussing ways to now- and forecast these events based on environmental conditions.

Observations from automatic hail sensors in Switzerland: estimations of the hail size distribution and comparison with radar-based and crowdsourced data

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In summer 2021, a series of exceptionally widespread and intense hailstorms occurred over Switzerland, causing historical damages as recorded by several insurance companies. While those events caused major impacts, they also present a unique research opportunity because several measuring platforms were capturing the hailstorms:
1. a newly set-up network of automatic hail sensors that report the size and kinetic energy of individual hailstones with very high temporal and size resolution.
2. the crowdsourcing function of the MeteoSwiss app through which users can report the largest hailstone size, the presence of a hail layer and information on potential damage along with their position, timestamp, and a picture.
3. two operational hail products of the Swiss weather radar network: the probability of hail (POH) and the maximum expected severe hailstone size (MESHS).

A first look at the data collected from those observing systems during the summer of 2021 showed that they give a coherent and comprehensive picture of both the hail footprint and hailstones diameters. However, the data is numerous and remains to be fully exploited in more detailed studies.

The automatic hail sensors make it possible to capture the local duration of a hailstorm, to precisely record the timing of hailstone impacts and to infer the hailstones diameter from their measured kinetic energy. We present a first estimation of hailstone size distributions and kinetic energy flux derived from the automatic sensor measurements, including recent observations from summer 2022, and compare those estimations with previous studies. We also relate the measurements of the sensor to neighboring crowdsourced reports and compare them to local MESHS values and to the polarimetric radar-based hydrometeor classification HYDROCLASS at the sensor's location during a hail event. The exploitation of data from automatic hail sensors is a new research avenue which is at an exploratory stage and any feedback from the hail community would be valuable to us.

High-resolution WRF simulations of CONCH hail cases

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The Coordinated Observations of Northern Colorado Hail experiment (CONCH) was conducted in June and July of 2021 to gain experience in the use of new tools and instruments for future hail observation experiments. One component of CONCH was a post-experiment modelling effort using a high-resolution (1-km grid spacing) configuration of Advanced Research WRF (WRF-ARW). While drought conditions over Colorado limited the opportunities to observe large hail, numerical results from multiple CONCH cases will be described. It was found that forecasts were sensitive to the initial conditions and moisture distribution in particular. Cases where either initiation or intensity of convection is marginal have limited predictability.

ICECHIP: Closing critical observational gaps in hail research

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The In-situ Collaborative Experiment for the Collection of Hail In the Plains (ICECHIP) field campaign is proposed over a two-year period to close critical observational knowledge gaps in hail research. Year 1 of ICECHIP will collect geographically targeted observations from the Colorado and Wyoming Front Range during the period 1–30 June 2024. Year 1 will focus on a spatial and temporal climatological peak of hail exceeding 25 mm and leverage domain-fixed assets to maximize data collection, quality, and efficiency. Year 2, from 15 May–5 June 2025, will turn attention to a larger domain in the south-central Great Plains to gather observations of significant hail (>50 mm) in convective regimes characterized by relatively larger convective instability, higher boundary-layer average mixing ratios, and warmer sub-cloud temperature profiles. ICECHIP will address 5 major research themes: 1) embryo development and hailstone growth and fall behavior; 2) in-storm hail trajectory and convective updraft relationships; 3) environmental impacts on hail processes and predictability; 4) surface properties of hailstones and associated impacts; and 5) relationship of hailstone physical properties and growth processes to radar observations. The field campaign design includes the University of Wyoming King Air, NCAR's S-Pol and Colorado State University's CHILL radars, the University of Illinois mobile Doppler radars, unpiloted aerial systems, modern surface and upper-air instrumentation, and a large suite of deployable surface hail collection and observation instrumentation.

Many gaps remain in our understanding of hail science. Examples include minimal understanding of how embryo hydrometeor type, size, and location are connected to environmental conditions and impact subsequent hail production in real-world environments, how thunderstorm updraft characteristics and evolution can modify in-storm hail trajectories and surface hail production, and how hail swath characteristics relate to storm kinematic and microphysical evolution and the background convective environment. ICECHIP's science themes and associated testable hypotheses will permit a generational leap forward for hail science by obtaining novel and comprehensive observations of hailstones, their parent storms, and associated damage swaths. ICECHIP will also establish physically based links between surface hail characteristics and agricultural and property damage, many for the first time, which will directly lead to improvements in materials and disaster science. ICECHIP will be the first comprehensive field campaign to study hail in over 40 years, and without its observations from cutting-edge instrument platforms, our understanding of hail will continue to have critical uncertainties.

Hail is the costliest hazard produced by severe thunderstorms in the U.S. and billion-dollar losses from single hailstorms are becoming commonplace globally. Results from the ICECHIP field campaign will improve radar detection and monitoring of hail, provide critical ground-truth information for materials science, and improve our ability to predict hailstorms. Annual losses from hail are so large that it is possible just one successful hail forecast and associated mitigation efforts enabled by ICECHIP would completely offset the investment in ICECHIP. The nation's numerical weather prediction and forecast capabilities will be directly improved through diverse collaboration amongst academic, government, private sector, and international partners. ICECHIP domains experience hail environments similar to others globally and knowledge gained from the campaign will be directly transferable. In addition to the significant societal benefits, ICECHIP will promote educational efforts through training of undergraduate and graduate students across several U.S. universities and publicize results using open-houses, agricultural field days, social media, and formal conference presentations to both academia and industry to maximize outreach.

Mitigating Hail Damage and Insurance Losses Through Understanding Laboratory Testing, Certification, and Evaluation Programs

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Since the early 1990's, UL worked with roofing manufacturers and the insurance industry to naturally evolve from longstanding testing and certifications for fire performance of roofing products to addressing concerns due to hail damage, specifically for asphalt shingles. Through a study of impact energies based on terminal velocity of hailstones, a UL Standard was published in 1996 – UL2218, *Impact Resistance of Prepared Roof Covering Materials*. This standard uses steel balls ranging in diameters from 1-1/4 in. to 2 in. in diameter to impact roofing assemblies, resulting in impact Classifications of 1, 2, 3, or 4. Since that time to today, impact testing and certification of roofing products for hail damage to these types of Standards, using either steel balls or projected ice balls, has been the primary means of helping insurance and consumers understand hail performance and has positively assisted in mitigating losses.

However, in more recent years, IBHS and its insurance company members recognized the continuing growing problem of hail damage in large regions of the United States. Hail has become a near $20 billion dollar in property loss issue annually. It has been transformed from an insurance industry economic nuisance to a much broader societal concern. There was a clear need to further explore the science of hail damage on roofing products in order to better align the damage modes to the assessments that would result in insurance claims. IBHS sought to expand on the foundational work from laboratory testing and certifications to UL2218 (using steel balls) and FM4473 (using ice balls), to gain a deeper understanding towards improvements in this area.

Towards this objective, researchers gathered, weighed, measured, and 3-D scanned thousands of hailstones in the field to garner needed data on the physical characteristics of hail, and then successfully replicated those characteristics in large volumes to manufacture realistic laboratory hailstones. Laboratory and field research has shown that the impact energy and material properties of laboratory hailstones can successfully correlate to typical natural hailstones in non-wind driven conditions. While these tests do not exactly replicate natural hailstone impacts, they do certainly provide a way to compare relative product performance in controlled, repeatable laboratory tests. In June 2019, IBHS released a new test protocol, called *Impact Resistance Test Protocol for Asphalt Shingles* – this is a machine-vision, objective damage assessment that results in a product scorecard. The test protocol informs shingle performance ratings that differentiates product performance across three damage modes, including deformations, breach, and granule loss. This method is largely based on UL2218 and FM4473 but contains important technical differences. To date, IBHS has tested the impact resistance of commercially available asphalt shingles using both 1.5- and 2.0-inch diameter laboratory manufactured hailstones using the IBHS hail impact testing protocol. To conduct testing, IBHS bought widely purchased impact-resistant shingles from standard distribution channels accessible to consumers, brought them to the lab, and tested them under scientifically replicated real-world conditions. The results offer unprecedented insights into the Impact-Resistant Shingle Performance of shingles labeled as impact resistant.

Since 2015, UL and IBHS have cultivated a strong partnership to utilize the strengths of each organization for the benefit of consumers, insurance, and manufacturers related to building constriction. To help meet increasing demand for testing, as the roofing industry continues to improve asphalt shingle design, UL has added the capacity for research and exploratory testing of asphalt shingles to the IBHS protocol. They will soon begin serving roofing manufacturers by testing new asphalt shingles to the standard as part of their product development phase. Under an agreement, UL will also test impact-resistant labeled products available in the marketplace as IBHS continues to fulfill its commitment to refresh its Roof Shingle Hail Impact Ratings periodically. New testing will result in adding new products to the ratings program as they are introduced to the market. Leveraging UL's capacity to run exploratory tests for manufacturers and tests for IBHS to refresh public ratings will also enable IBHS to remain focused on ongoing and new research to further identify ways to reduce avoidable loss from severe weather.

IBHS Impact Testing of High Concentrations of Small Hail

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High Plains hailstorms tend to produce more hailstones per square foot than those in the Southern Plains. However, these "snowplow" hail events typically produce sub-severe to marginally severe hail sizes (1-inch and below). Hundreds to thousands of hailstones could fall on a single area within a given storm but the effects have not been studied in detail. A roof could experience multiple snowplow hail events over its lifetime because the roof is not replaced since it is assumed to be undamaged. The Insurance Institute of or Business and Home Safety conducted an experiment investigating whether large quantities of sub-severe hail could lead to notable granule loss on asphalt shingles, accelerating the decline of a roof's service life. Six brands of shingles were selected for this study, including impact resistant (IR) and non-IR shingles. Two large test panels (50" x 66") of each product were constructed, one panel was placed in the IBHS aging farm for one year to naturally weather while the other panel was stored in a conditioned space. After the one-year period, pre-photos were captured of each panel before being subjected to three hundred 0.67-inch hail stones and two hundred 1-inch hail stones (500 total impacts). Post-photos were collected prior to placing panels back in original locations for another year of aging/storage. A machine vision algorithm was developed to assess granule loss over an entire test panel. The testing process was repeated a second time. Following the second test, all panels were run through the IBHS Hail Impact Standard Test for 2-inch hail stones. Shingles were analyzed through our HIPS Photo Analysis Program for comparison of previous IBHS research results on the same products. Granule loss could be seen with the naked eye for some of the natural weathered products after testing. These visible inconsistencies could have the potential to trigger a claim. For most products, it would take more than 150 2-inch hail impacts from the IBHS test method to match the individual or patch granule loss associated with 500 sub-severe impacts. We are objectively investigating the HIPS results as the damage occurring from the sub-severe test panels is significantly greater than that of the same products from previous IBHS research of 2-inch impacts alone. This testing is an example of a mild high concentration case; the damage could shorten the overall life of the roof cover while also making it more susceptible to future hail events.

Electronic Hail Pad with Telemetry System Using Accelerometers

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We use a Sentinel Systems, LLC electronic hail impact sensor equipped with accelerometers to measure hail impact values and convert them to kinetic energy values. We measured impact values with a ADXL372 200g 3-axis accelerometer with an Arduino Uno REV3 processor equipped with a standard SD data card and cell phone or satellite connectivity. The unit is battery powered and maintained by a solar panel. The test unit is mounted to a hard roof mount and can operate autonomously or as part of a node with in a network that can map hail information for any area. The sensor is covered with a polycarbonate clear lens that is adhesively bonded to a metal frame. The accelerometer is bonded to the underside of the lens in the center. The lens was painted, and individual areas marked and numbered to measure impacts using the UL 2218 steel ball drop test. To reduce damage to the polycarbonate lens wood balls were substituted for metal. Impacts were aimed at individual areas and the values recorded from the accelerometer. Wood balls fell through a calibrated ballistic chronograph (minimum speed detected is 20 ft/s) and the impact speed was recorded with the accelerometer impact value. The balls were weighed, and the kinetic energy was computed for each impact. Kinetic Energy (KE) values were regressed against the accelerometer values and the regression equation used to compute KE for each accelerometer reading. Impact was at the same location for each ball drop. Ball drop height varied from 15 to 20 feet such that the accelerometer range to readings covered the manufactures stated range of accuracy. Five impacts were made each from 15, 16, 17, 18, 19 and 20 feet drop heights. Three accelerometers located equidistant from the outside edge of the round hail tile and were used to triangulate the impact location on the lens. By triangulation we can measure the impact location relevant to the accelerometer located in the center of the lens and correct for distance from the center accelerometer such that each impact will be relevant to the center location.

A New Performance-Based Hail Engineering Method Shows that Impact-Resistant Roofing Avoids up to 8 Times Its Cost

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Hail is among Canada's most expensive natural hazards at CAD $370 million per year on average, sometimes exceeding $1 billion, and capable of causing a $10 billion loss, much of it to repair roofs. Hailstorms are inevitable and the climate crisis will aggravate them. But adaptation measures can ameliorate economic catastrophes. One can adopt better building cladding systems such as impact-resistant asphalt shingle roofs. ICLR developed what seems to be a novel performance-based engineering method to estimate the costs and benefits of hail mitigation. We applied it to impact-resistant roofing and found that impact-resistant shingles add 50% to the cost of a roof, about $3,400 for an average roof, but save up to 8 times their cost. In terms that interest insurers, the resilient system reduces the frequency of damage by 15 times and the severity by half. In Calgary, considering hailstorm frequency, the shingles save $10,000 over the 20-year life of a roof, for a benefit-cost ratio of 3 to 1. The shingles pay for themselves in 5 years, on average. An insurer with a 90% retention rate would save $4,200 over the life of the policy. Costs and benefits scale with roof size, and location matters. The shingles are cost effective anyplace with at least 0.8 hailstorms per year, which comprises much of western Canada. Places with more frequent hailstorms get more benefit. The work sets the stage to model other hail mitigation measures and for improved impact-resistance tests.

An overview of hail defense operations in the province of Styria, Austria

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Crop hail damage is a significant challenge for the Styrian agriculture sector. Hail prevention experiments have been conducted for many years in Styria to reduce agriculture damage against hail. The history and recent advances in the operational framework will be illustrated. A total of eight aircraft and two radars are utilized for the hail defense platform. Weather forecasts, radar data, aircraft tracking, data transmission and Tablet-PC display system mounted in the aircraft are available for operational planning and implementation. The novel pilot visual interface communication system was implemented for better coordination. The daily operational planning includes the number of aircraft and pilot allotment and the expected mission start based on synoptic meteorological conditions and weather forecast status. The Weather Information System (WIIS) software system supports operational activities. The HAILSYS software developed for post-analysis of daily operations and radar-derived parameters over time and associated changes due to cloud seeding will be present. The crowdsourcing platform (HeDi: Hail event Data interface) was developed and used for near real-time hail reports. An overview of hail prevention operations, coordination, latest developments and challenges will be explained in detail.

Hodographs and Skew-Ts of Hail-Producing Supercells using Self-Organizing Maps

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The environments associated with severe hailstorms, compared to those of tornadoes, can be less apparent and familiar to forecasters. Recently, longer and straighter hodographs with weaker low-level shear have been recognized as being more favorable for severe hail. However, this leaves many questions. First, how much variety exists within the full shapes of the hail hodographs? Second, how do thermodynamics impact this variety, and is there a balance between CAPE and shear like has been noted with tornadoes? Thirdly, and more broadly, what synoptic regimes should forecasters be looking for to anticipate significant hail events? We address all of these questions to move toward a more complete conceptual model.

In this study, we use a self-organizing map algorithm and ERA-5 modeled proximity soundings to determine the most common hodographs associated with a large sample of severe hail reports. These shear profiles are cross-matched with their respective skew-Ts to better assess the relationship between thermodynamics and kinematics. We find that a large subset of severe hail cases features low-level shear that most forecasters would not consider to be "weak", in contradiction to our current understanding. Consequently, we closely examine the scenarios where severe hail is still possible without weak low-level shear, and whether or not these were likely cases of "elevated" storms. For a broader understanding, we explore where the various hodograph shapes are most commonly found throughout the U.S., and what this may mean for the necessary synoptic pattern there. To better understand the corresponding surface

patterns, we examine spatial maps of hodographs and skew-Ts and assess the influence of fronts. With this comprehensive analysis, we hope that analog forecasting will become more commonplace in hail forecasting, and that "classic" severe hail environments will become more readily recognizable amongst forecasters and modelers.

Searching for Predictability in the Environmental Conditions preceding Large Hail

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Expected hail size is a poorly forecast quantity. Hail predictions have been explored on a variety of timescales through both modeling and statistical approaches, though relatively few skillful predictors have been identified. This limitation to predictors has led to challenges in understanding why a given parameter may inform the expected occurrence of hail or its absolute diameter. Previous approaches have focused around bulk metrics or coarse parameterizations of storm processes. However, these efforts have been hampered by a failure to focus on the representativeness of hail size observations, inappropriate use of nulls, and fixating on parameters that may be poorly related to hail processes. This presentation will focus on new insights and parameters identified through modeling, discriminant analyses, self-organizing maps and clustering. We leverage a data-informed approach to better characterize the relationship between the ambient storm environment and resulting hail diameter. We find that key to addressing this problem is consideration of synoptic regime, regional differences, seasonality and storm mode.

Parameter importance is tested through the use of ERA-5 pseudo-proximity soundings to a blended dataset of hail profiles from multiple observational records, that include the Storm Prediction Center (SPC) Storm Data, the SPC Storm Mode Dataset, Community Collaborative Rain, Hail and Snow Network (CoCoRAHS) and Meteorological Phenomena Identification Near the Ground (MPING), in combination yielding some 75,000 reliable cases. These cases allow assessment of the relationship between hail and its environment for a variety of sizes ranging from 0.25 to >4.00 inches in maximum diameter. Through this analysis, the importance of data cleansing and choice for obtaining robust predictors will be illustrated. Results highlight that many common associations between parameters (e.g. CAPE and hail size) are ill-posed, as hail production exhibits multiple environmental pathways or requires different parameters, or can be driven by storm dynamics. These suggest that a multi-model and profile-aware approach is necessary to obtain reliable environmental-based predictions of hail size.

Using a Deep Neural Network to Estimate Severe Hail Likelihood from Satellite Observations and Model Reanalysis Parameters

Benjamin Scarino, Kyle Itterly, Kristopher Bedka, Cameron R. Homeyer, John Allen, Sarah Bang, and Daniel Cecil

Geostationary satellite imagers provide historical and near-real-time observations of cloud top patterns that are commonly associated with severe convection. Furthermore, environmental conditions favorable for severe weather are thought to be well represented by reanalyses. Predicting exactly where convection and costly storm hazards like hail will occur using models or satellite imagery alone, however, is difficult if not impossible. The multivariate combination of satellite-observed cloud patterns with reanalysis environmental parameters, linked to radar-estimated Maximum Expected Size of Hail (MESH) using a deep neural network (DNN), enables estimates of potentially severe hail likelihood for any given storm cell. These estimates are specifically designed to make hail likelihood distinctions based on satellite-indicated points of deep convection within environments favorable for storm development.

Statistical distributions of convective parameters from satellite and reanalysis highlight non-severe/severe class separation for well-known hailstorm predictors, e.g., overshooting cloud top characteristics, deep-layer wind shear, mid-level lapse rate, and convective inhibition. These complex, multivariate predictor relationships are exploited within a DNN to produce a hail likelihood metric with a critical success index of nearly 0.55 and Heidke skill score exceeding 0.36. Furthermore, applications of the DNN to select case studies demonstrate good qualitative agreement between hail likelihood, satellite-detected severe convection regions, and MESH. Climatological aggregation of these hail likelihoods is beneficial to those interested in improved understanding of hail frequency and severity, especially in regions without adequate radar coverage and storm reporting.

An Intercomparison of Real-Time Machine Learning Hail Guidance

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Hail continues to be a challenging severe storm hazard to predict due to the confluence of environmental and storm scale factors necessary for hail formation and sustenance. A growing number of machine learning hail guidance products at day-ahead lead-times have been developed over the past 8 years to assist in diagnosing convection-allowing model output for large hail potential and assist NOAA Storm Prediction Center forecasters in crafting hail outlooks. In this presentation, we compare the predictions from three machine learning hail guidance products along with the SPC hail outlook for a period from 3 May to 15 August 2021 over the conterminous United States. The algorithms are the Loken Random Forest, the Burke Random Forest, and Burke U-Net. While there is some overlap in the choice of ML model, key differences in how the input data are processed and how the ML model outputs are combined result in very different forecasts from the ML models. In the presentation we examine bulk verification statistics regarding discrimination and reliability for all methods and then examine model performance conditioned on different environmental factors. The results provide more insight into when the different ML methods should be expected to perform well or struggle.

Two Paradigms for Radar-Based Hail-Size Estimation: Problems and Possibilities

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There is an essential need for remote sensing in determining the location of damaging hailfall and in characterizing the degree of the hail threat. Radar provides the best tool for mapping hail-bearing storms, which is useful for operational warnings and nowcasting, as well as post-storm hail swath analyses. Despite this critical need, however, radar-based hail size estimation has been a long-standing challenge.

Traditionally, there have been 2 main paradigms for radar-based hail size estimation: (1) direct size estimation from hailstones' backscattering properties, and (2) indirect estimation based on storm structural features and/or proxies for storm strength. In this presentation, we will review the traditional approaches to radar-based hail-size estimation, as well as the limitations of these approaches informed by recent hail research. As an example of the first paradigm, algorithms based on hailstone backscattering properties often employ simplified assumptions about hailstone shapes (e.g., spheres or spheroids). We will show results from state-of-the-art, three-dimensional hailstone scanning that now allows for direct calculation of the hailstones' electromagnetic scattering properties, and how these differ from simpler shape assumptions. We also demonstrate how resonance scattering effects for significantly severe (> 5 cm) hail confound the relationship between radar reflectivity and hailstone size, and, when considering typical hailstone number concentrations, renders reflectivity factor effectively useless for hail sizing.

As an example of the second paradigm, there is widespread use of vertically integrated reflectivity metrics (e.g., VIL, MESH, MESHS) or the altitude attained by significant reflectivity values to estimate hail size, which implicitly assumes that taller, stronger storms produce larger hail. We will show recent hailstorm simulations that demonstrate this assumption is flawed, and how these metrics are uncorrelated to simulated hail production. Recent research has also suggested the Doppler radar-inferred strength of the mesocyclone in supercell storms is correlated to hail size; here, we show that mesocyclone strength is correlated to CAPE, which drives the observed relationships to hail size rather than being related to a physical process favorable for hail growth. Finally, possible avenues to improved radar-based hail-size estimation for both paradigms will be presented, informed by recent research results.

Operational polarimetric NEXRAD algorithm for detection of hail and determination of its size. Current status and forthcoming refinements.

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The existing polarimetric radar algorithms for hydrometeor classification (HCA) and hail size determination (HSDA) implemented on the WSR-88D network have been designed almost a decade ago and need substantial modifications. For example, the current version of HCA / HSDA does not capitalize on the polarimetric signatures of hail above the melting layer (ML) and does not link relevant signatures at lower and higher antenna elevations. In this presentation, we will discuss forthcoming refinements of the operational hail algorithm. One of them will utilize a clear link between very large / giant hail at the surface and such polarimetric signatures aloft as negative Z_{DR} and anomalously low ρ_{hv} above the top of the Z_{DR} column that indicates a convective updraft. The existing HCA / HSDA does not utilize specific differential phase K_{DP} for classification of hail. Recent studies show that large melting hail in low concentration is characterized by very high Z and low K_{DP} whereas small melting hail in high concentration may have anomalously high K_{DP}. This motivates incorporating the K_{DP} membership function in the HCA / HSDA fuzzy logic algorithm. It was also found that intense tropical rain is often misclassified as “small hail” in the existing HCA / HSDA because both are characterized by a combination of high Z and low Z_{DR}. We plan to distinguish between tropical rain and hail using vertical gradient of Z below the ML, the magnitude of Z above the ML, and the total concentration of raindrops N_t retrieved from the combination of Z and Z_{DR}.

A Convolutional Neural Network For The Detection Of Hail Storms By Dual-Polarization Radar

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Hailstorms have a substantial economic impact on businesses and populations over the world. This year, convective storms producing large hailstones have already been responsible for an estimated loss of $3.9 billion in France alone, and the 2022 hail season is not yet finished. The potential of radar data has been studied over the past decades to develop computational methods capable of detecting hail and estimating hailstone size. Probability of hail-based algorithms, hydrometeor classification using fuzzy logic or new methods using machine learning have been explored to locally quantify the presence of hail in storms. With recent studies suggesting specific spatial signatures within hailstorms (Kumjian et al., 2021), methods that have the potential to see those signatures appear of great interest to detect hail. This work aims to present the performances of a Convolutional Neural Network for the detection of hailstorms using dual-polarization radar data. Based on a dataset of storms with and without hail in Southwestern France from 2017 to 2020, the binary classifier is trained and tested. A comparison is made with existing state of the art radar-based hailstorm detection techniques. Results show a significant improvement in all performance metrics and particularly false alarms, even with simple features and a basic network layer structure.

The odds are good: Using hail reports and radar indices to probabilistically understand Australian hail.

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Responsible for Australia’s costliest insured weather event, hailstorms pose a serious threat to lives, property, and agriculture in Australia and globally. Understanding the climatology of hailstorms around Australia is therefore of critical importance to understanding climate risks today and in a future warmer world. Unfortunately, the requisite data for this pursuit is scarce. Whilst reanalysis products can indicate when an atmosphere is hail-prone they struggle to reliably indicate whether hail fell at that time or not. Radar-derived indices, like the maximum expected size of hail (MESH), are more trustworthy, but can only be applied over the relatively small part of Australia covered by the radar network. Finally, due to Australia’s low population density and the underutilization of the reporting system, hail reports in Australia are infrequent and error-prone, but also our most certain evidence of genuine hail fall. In this talk, we outline a probabilistic framework linking MESH and these citizen hail reports in order to predict hail fall and suggest how this might be applied Australia-wide.

Diurnal Cycle of Satellite-Derived Hailstorms

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Passive microwave sensors on low-earth orbiting satellites have been used to infer near-global climatologies of severe hailstorms. These sensors do not directly measure hail, but empirical relationships have been constructed between the 19- and 37-GHz brightness temperatures and the likelihood of having large hail reported at the surface in the USA. Some of these sensors have been on satellites that progress through the diurnal cycle, others have been on sun-synchronous satellites. Properly incorporating data from the sun-synchronous satellites requires accounting for the diurnal cycle. We will use data from the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Mission (GPM) satellites to estimate the diurnal cycle of likely hailstorms, and how that varies in different regions. Initial results suggest the estimated hailstorm frequency peaks from late afternoon through late evening in most hail-prone regions, although the amplitude of the diurnal cycle does vary between regions.

Hail Identification Algorithm for GPM DPR (version 7) and the Validation

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Hail has raised interest due to its huge impact to human activities. In the new version of GPM DPR algorithm (version 7), a new Boolean hail product is developed to identify hail along each DPR vertical profile. The novelty of this algorithm, for the first time, offers the potential of retrieving a uniform and homogeneous hail dataset on the global scale from radar sensors. The algorithm is built upon the precipitation type index (PTI) which is a value calculated for each dual-frequency profile with precipitation observed by GPM DPR. The dual-frequency ratio slope with respect to height, the maximum of reflectivity and storm top height are three key ingredients composing PTI value. PTI has been approved to be effective in separating various precipitation types such as snow, graupel and hail profiles.

In this research work, we focus on validation of hail identification algorithm by analyzing and cross-validating hail observations from various sources including individual hailstorm and on a global scale. Our algorithm will be validating with hailstorms observed by ground validation radar NEXRAD, GMI based hail identification and multiple scattering effect from Trigger module output of DPR level-2 algorithm. The global scale analysis is essential for satellite-based products. We validate this hail product with various global hail maps using radar, radiometer-based algorithms and reports. The study includes the global distributions of hail and the seasonal transition features.

Hail Growth Regions and their Identification with Radar

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In this study, we draw upon data from the South Dakota School of Mines and Technology T28 hail penetrating aircraft. Microphysical measurements, including hail size distributions and environmental conditions (state parameter, air vertical velocity), were collected between 1969 and 2003 but only recorded digital data after 1995 are used. Those data, synthesized by Detwiler et al. (2012), and an analysis conducted by Field et al, (2019) are used in this study. The Field et al. (2019) were then used by Cecchini et al. (2022), who used 3D scans of natural hailstones and Discrete Dipole Scattering (DDSCAT) code to simulate the radar reflectivity of the hailstones at multiple radar wavelengths. We use the Field et al (2019) study to examine the relationship of the hail maximum diameter to the air vertical velocity and the liquid water content. As a means of identifying the microphysics of these regions, the Cecchini et al. (2022) analysis is used to characterize the hail microphysics, including the properties of the particle size distributions and hail kinetic energy, as a function of the radar reflectivity and the radar dual wavelength ratio.

The most interesting aspect of our work is an evaluation of the MESH algorithm. Parameterizations are drawn between the hail microphysics and radar reflectivity that will be useful for identifying hail microphysics and kinetic energy, and hail microphysics and measurements from radar, that will be very useful for future studies of hail growth regimes.