Letter of Interest

Project ICECHIP
In-Situ Collaborative Experiment for Collection of Hail In the Plains

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Summary: ICECHIP proposes a comprehensive, geographically targeted field campaign to study hail during 3 weeks in each of June 2023 and 2024. The primary scientific objectives of the project are focused on 1) characterizing the trajectory and fall characteristics of hailstones within hail-producing thunderstorms, 2) understanding the contributions of near and sub-cloud air masses to the development, growth, and melting of hail, 3) classifying surface properties of hailstones and identifying surface impacts and hailstone growth regimes, 4) fully capturing the characteristics and evolution of the convective updraft in relation to hail trajectories, and 5) improving the characterization of hail-radar relationships including scattering and melt. While these objectives have significant scientific merit, ICECHIP will also have wide-reaching broader impacts ranging from the training of undergraduate and graduate students, to the improved modeling of rimed ice resulting from extensive observations, to the significant economic benefit of better global hail forecasts across multiple sectors. Novel, emerging technology will also be a key highlight of this experiment. We anticipate that ICECHIP will be categorized by NSF as a “large” field campaign.

Motivation: Hail is the most consistently damaging impact of severe thunderstorms, producing CONUS losses alone in excess of $10 billion per year over the past decade. These impacts extend beyond the loss of individual homeowners, as commercial interests, renewable energy producers, both civilian and military aviation, and agriculture experience significant impacts during hailstorms, both in the United States and globally. Yet, with improved detection and prediction of severe hail and understanding of hail characteristics and impacts at the surface, a good portion of this monetary loss could be avoided: for example, aircraft could be moved or rerouted with better forecasts; stronger, hail-resistant building material could be created with better understanding of hail impacts; and communities would be prepared for specific hail types with improved radar detection. Uncertainties associated with such advances—and the economic impact of these storms—motivate the need for a greater understanding of the processes that produce these hailstones, the radar-derived structure of these storms, and the characteristics of the hailstones that reach the ground. In the nearly 40 years since the last dedicated U.S. hail research field campaign, the technology to understand these storms is now available to provide a significant leap forward for hail science. The hail research community has reached a point at which forward progress is being impeded without field observations. The implications of better understanding the processes that drive the generation of hail is all the more important in the context of a changing climate, which will modify when and where damaging hail occurs, highlighting the need to understand our capacity to predict and remotely assess these costly events.
Science Goals:

1. Characterizing the trajectory and fall characteristics of hailstones

Previous field campaigns focused on hailstone trajectories, including the National Hail Research Experiment (NHRE; 1972-1976) and the Cooperative Convective Precipitation Experiment (CCOPE; 1981), produced a wealth of seminal hailfall research. However, recent advances in technology in the intervening 40 years, including mobile dual-polarized radar systems, unmanned aerial systems (UASs), pseudo-Lagrangian drifters, three-dimensional printed hailstones, and others will allow a field campaign to produce an unprecedentedly detailed dataset to more fully understand hailstone trajectories. The campaign will seek to characterize hailstone trajectories and growth regions themselves using novel GPS-enabled passive tracers deployed at the surface, via UAS, and via aircraft, along with more traditional methods such as isotopic analysis. Experiments will also examine, for the first time, in situ observations of hailstone tumbling processes and shedding of meltwater via in-field and laboratory observations.

2. Understanding the contributions of near and sub-cloud air masses to the development, growth, and melting of hail

The successful development and growth of hail is, understatedly, a complicated process: embryos and supercooled water must coexist, hail trajectories themselves must traverse across the updraft, and updraft strength and volume must be appropriate for lofting hailstones for extended periods within favorable growth regions. All these factors are intricately tied to the environment in which the storm system forms. By fully characterizing the environmental characteristics of the far- and near-system air mass in both space and time around the hail-producing system, the relation of the environmental characteristics to hail trajectories can be better understood. Further, through observations of the sub-cloud air mass, the role of sub-cloud hail melt can be better understood, an important consideration in a warming climate with higher wet bulb zero levels. These results will naturally support objective (1); coupling knowledge of hailstone melting processes with that of the sub-cloud environment will allow full parameterization of these processes, coupled with tumbling, for the first time.

3. Classifying properties of hailstones reaching the surface to assist with identifying surface impacts and expansion of hail detection algorithms

Hail modeling and detection is naturally limited by the lack of surface validation data, particularly for characteristics beyond size: e.g., density, shape, mass, kinetic energy, and concentration. Each of these factors has significant societal impacts. For example, agricultural impacts are actually larger for storms producing large concentrations of small, wind-driven hail, as opposed to smaller concentrations of large hail, contrasting impacts for urban environments where larger hailstones are generally more important. By incorporating a full suite of observations of surface properties of hailstones, comprehensive data will be available for validating impact-based hail modeling for the first time.

4. Fully capturing the characteristics and evolution of the convective updraft in relation to hail trajectories

Accurate numerical simulations of convective updraft width and speed within convection-allowing models is still an active area of research: several observational comparison studies have found potential overestimation of vertical velocity by convection-allowing models. Yet the close relationship between hail trajectory and convective updraft characteristics drives the need to better depict the convective updraft. By using a suite of multiple radars, release of chaff, and pseudo-Lagrangian drifters to interrogate the convective updraft in time and space, its evolution can serve as a validation source for convective modeling. Such observations of the updraft can provide insights into its evolution and the overall updraft volume, and understand its links to hail size, amount, and swath distribution at the surface. By observing the hail trajectories and
convective updrafts in tandem, researchers can use the data to understand how modeled hail trajectories can be affected by errors in the modeled updraft. Observed updraft variability will be used to inform model errors.

5. Improved characterization of radar relationships including hail scattering and melt
All current hail warning and forecasting methods are validated by products using radar-hail size relationships due to the unavoidable lack of hail observations on the surface, yet these relationships have known deficiencies. By incorporating synchronous detailed radar and hail observations on the surface, along with knowledge of the below-cloud temperature profile and its melting impact, this campaign will allow for improved understanding of potential radar and hail size relationships. With the addition of surface hail density, kinetic energy, and concentration observations, the possibility of radar-hail relationships beyond merely hail size can also be explored for the first time.

Domain location and deployment strategy: This campaign is envisioned to take place during three weeks in late May-June over two successive years. The deployment strategy will be mobile and opportunistic, but with two specific geographical regions of focus. The first year (EOP1) will be focused along the Colorado and Wyoming Front Range with a goal of understanding hail production by orographically influenced convection. Use of this region will also be cost-efficient by taking advantage of the assets already housed there. The second year (EOP2) will be focused in southwestern Kansas, northwestern Oklahoma, and OK/TX panhandles, in alignment with the largest climatological frequency of significantly severe (>50 mm) hail. However, we foresee maintaining a largely mobile fleet of operations to obtain as many potential hailstorm datasets as possible, allowing us to expand the domain of EOP1 into the western High Plains (e.g., Nebraska Panhandle, far western Kansas). The mobile effort will be particularly emphasized during EOP2, expanding into the central, southern, and High Plains.

The observational fleet will include instruments focusing on (1) surface-based hail characteristics, (2) in-storm measurements, and (3) environmental/sub-cloud measurements. A full listing is provided in Appendix A, but NSF LAOF instrumentation requested includes the Univ. Wyoming King Air with W-band cloud radar and microphysics suite and NCAR’s S-POL (S-POL in EOP1 only). We are in close communication with Jeff French of Univ. Wyoming about the King Air upgrade schedule in 2023. In the event the King Air is not available for EOP1, we will request the NSF/NCAR C-130 aircraft. We have also discussed with John Hubbert of NCAR the proposed plans for upgrading the S-POL to dual frequency (S- and C-band). Even if the proposed effort is not funded, however, the S-POL will still provide high-quality radar measurements to interrogate hailstorms in the Front Range.

Following the timeline for large projects, EOP1 would take place in June 2023, and EOP2 during May/early June 2024. An Experimental Design Overview and Scientific Program Overview (EDO/SPO) will be submitted by 15 Jan 2021.

Project collaboration: We have partnered with an additional 14 collaborators with research groups with specific expertise beyond that of the steering committee in hail environmental characteristics, remote sensing of hail, in-situ hail measurements, hail impacts, microphysical modeling, and data assimilation. These collaborators and their areas of focus include Julian Brimelow (Environment and Climate Change Canada, ground observations), Jiwen Fan (PNNL, microphysical modeling and aerosol impacts), Katja Friedrich (Univ. Colorado, ground observations, hail growth in different regimes), Cameron Homeyer (Univ. Oklahoma, hail-radar relationships), John Hubbert (NCAR, SPOL radar), Evan Kuchera (557th Weather Wing, military impacts), Justin McMechan (Univ. Nebraska-Lincoln, agricultural impacts), James Pinto
(NCAR/FAA, aviation impacts), Alain Protat (Australian Bureau of Meteorology, 3D wind retrievals), Russ Schumacher (Colorado Climate Center, CoCoRAHS), Joshua Soderholm (Australian Bureau of Meteorology, in-storm hail observations), Yunji Zhang and Xingchao Chen (Penn State Univ., satellite data assimilation), and Conrad Ziegler (NSSL, multi-Doppler radar analysis and kinematic retrieval, radar-hydrometeor relationships).

**Number of proposals planned to be submitted to NSF:** At least seven scientific proposals are currently planned, focusing on (1) hail embryo characteristics and formation, (2) validation of hail trajectory modeling using observations of hail riming, surface water retention, hail melt, and tumbling, (3) relationships among near/sub-cloud air mass characteristics, storm structure and evolution, and hail production, (4) relationships between surface hail characteristics and damage, (5) relationships between radar signatures and surface hail characteristics such as size, density, and kinetic energy, (6) understanding of predictability of hail production through ensemble sensitivity and data denial, and (7) hail growth and trajectory differences among Front Range, High Plains, and Central/Southern Plains storms. Given the different areas of expertise needed for each proposal subject, from observations to modeling to applications, we expect a minimum of three organizations involved in each science proposal. However, wherever possible we have attempted to limit the number of organizations involved to avoid additional expense.

**Expected involvement of other funding agencies, whether domestic or international:** PIs are in discussions with potential collaborators and funding opportunities from the FAA, the U.S. Air Force, the Australian Bureau of Meteorology, and Environment and Climate Change Canada. IBHS and the Community Collaborative Rain, Hail, and Snow Network (CoCoRAHS) have committed to providing resources.

**NSF Science Program to receive proposal:** Physical and Dynamical Meteorology (PDM)
Appendix A

NSF LAOF Instrumentation:
- Univ. Wyoming King Air with W-band cloud radar and microphysics observing suite; NSF/NCAR C-130 in EOP1 if King Air is unavailable
- NCAR’s S-POL (EOP1 only)

Non-NSF LAOF Instrumentation:
3 - Dual-pol, Dual-frequency mobile Doppler radars (2 X-bands and 1 C-band) (UI DOW Facility; CSWR)
15 - Surface mesonet/Pod instrumentation (some with Disdrometers) (UI DOW Facility; CSWR)
18 - Rapidly deployable hail impact acoustic disdrometers (IBHS)
Disdrometers have a 1 ft$^2$ impact surface based on the design of Lane et al. (2004). They employ a piezoelectric acoustic sensor to relate the area under the voltage signal curve to an impact kinetic energy. Individual impacts can be resolved at 500 Hz. Probes are calibrated using ice impact tests at IBHS. Each platform is also equipped with an aspirated thermodynamic instrument package (Variables: Temperature, RH, BP at 1 Hz sampling). Probes also all have mounts for GoPro cameras. IBHS currently has 9 GoPros for dedicated hail use, but will outfit the entire fleet for ICECHIP. Additional disdrometers can be built for use in ICECHIP.

2 - Handheld 3D laser scanner & associated mounts (IBHS)
IBHS maintains two handheld 3D laser scanners (Giammanco et al. 2017). ExaScan Unit and ArcTec Spyder scanner unit.

3 - Hail compressive strength test devices (IBHS)
Compressive strength test devices allow for hail strength to be tested in the field. Test can be conducted in less than 1 minute and uses a National Instruments LabVIEW data acquisition usb module and associated script for data collection. IBHS currently has 3 operational devices, but additional ones can be built for use in ICECHIP if needed.

1 - DJI Inspire drone (IBHS)
Quad-propeller drone equipped with gimbal camera mount. IBHS will likely add 1 or more DJI Mavic drones to our fleet which would be available for use in ICECHIP.

1 - Hail trajectory probe system (Australia BoM)
A novel radiosounding system designed to deliver simultaneous free-falling hailstone-shaped probes to the updraft region of severe thunderstorms (developed by the Bureau of Meteorology, Penn State and Bonn). Probes are designed to have analogous aerodynamic properties to hailstones, while limiting the accretion of ice. High frequency measurements of GPS location and pressure provide a unique validation dataset of storm dynamics and modelled hailstone trajectories.

1 - DJI Phantom 4 Pro V2.0 drone (Australia BoM)
Quadcopter equipped with a mechanical shutter camera is required for capturing distortion-free survey imagery for retrieving hailstone size and concentration (BoM, Soderholm et al. 2019). Operated by 1 person.
2 - iMet-3050A 403 MHz portable sounding systems (NIU and CMU)
Compact, high performance, full-range sounding systems for meteorological field research.

1 - VAISALA rawinsonde unit (CU)
Rawinsondes provide vertical profiles of temperature, dew point temperature, and wind. They will be deployed outside the thunderstorm to characterize the environmental conditions prior and during the storm.

3 - Robust Autonomous Aerial Vehicle – Endurant and Nimble (RAAVEN) UAS (CU)
The RAAVEN is a small unmanned aircraft based on a custom-built airframe from RiteWing RC. With a wingspan of about 2m, a typical launch weight is 6.5kg, depending on the instrumentation and battery configuration. The RAAVEN unmanned aircraft system (UAS) includes a pneumatic launcher configurable for either ground launch or launch from the roof of a SUV (Ford Explorer). Typical endurance is 2.5-3h with a 630Wh battery pack. Instrumentation includes: Black Swift Technologies 3D multi-hole probe (relative wind measurement), VectorNav 200/300 inertial navigation system (INS), Pixhawk GPS and magnetometer, Vaisala RSS-421 (RS-41) pressure, temperature, relative-humidity sonde (carries 2 for redundancy), data-logger with real-time telemetry. During the 2019 TORUS campaign, the RAAVEN fleet was additionally equipped with small HD action cameras (Mobius). During the 2020 ATOMIC campaign, the RAAVEN was additionally equipped with a fine-wire turbulence probe and up-down looking radiometers. Super RAAVEN is a recent addition to the fleet, that doubles the size of the RAAVEN with about a 50% increase in endurance.

High-speed videography and hail collection (ECCC)
Focus will be on the collection and analysis of hail data, using an approach called Position, Deploy, Retreat and Retrieve (PDRR) to deploy instrumentation in advance of approaching hailstorms. This will require multiple storm intercept teams deploying between 5 and 10 hailpads and hail disdrometers (separated by ~1 km) at right angles to the direction of the approaching storm. Disdrometers will sample an area of 0.2 m² (~2 ft²) at 50 kHz and can distinguish between rain and hail. Hail surveys will be conducted at each site where hail is observed—this will include photographing, measuring and weighing hailstones in the vicinity of the sensors. Up to three PDRR sites per intercept will be “supersites” collocated with a high-speed videography rig (GoPro High-definition video recorded at 240 frames per second, or faster) and a device to collect and preserve hailstones from the hail fall.

1 - 12-channel microwave radiometer (CU)
The radiometer provides temperature, humidity, and liquid water profiles from the surface to 10 km and both integrated water vapor and liquid water every minute. It also records surface temperature, relative humidity and pressure and includes a zenith infrared sensor that records cloud base. It will be deployed outside of the thunderstorm precipitation core to characterize the inflow and outflow environmental characteristics.

2 - Optical disdrometers (CU)
The Parsivel optical disdrometers measure particle size distributions between 0.06-24.5 mm within a sampling area of ~50 cm². Parsivel disdrometers will be placed in the path of the thunderstorms measuring raindrop size and hail distributions. This technique has been successfully tested during VORTEX2.

1 - Hail machine (UNL)
A hydraulically driven simulated hail machine, designed to simulate hail damage on a planted crop, was recently completed based on a previous machine built in 1986 by the UNL engineering
department in collaboration with the National Crop Insurance Service. The new hail machine is outfitted with a number of instruments to record various parameters during a hail application. A pitot-static tube and two pressure static sensors measure wind velocity and air pressure in real-time. In addition, wind speeds can be adjusted through three fine adjustment hydraulic valves. Three-quarter inch diameter ice is held in a hopper and fed into the machine by a metal auger driven by an electric motor with a variable rate controller. Ice is supplied by an Ice-O-Matic 1406FR housed at the Eastern Nebraska Research and Extension Center that is capable of producing 1,400 lbs of ice per day. Ice application rates are monitored through an optical RPM sensor on the drive shaft of the auger. Data collected from the sensors are stored on an Arduino system that can be downloaded via USB.

**IBHS Hail Impact Testing Laboratory**

IBHS at its South Carolina Research Center maintains laboratory capabilities to test both roofing and siding products for hail impacts using a pneumatic propulsion system that can meet speeds and kinetic energies of natural hailstones. The IBHS laboratory facility also has a hail manufacturing system that can produce ice spheres, in large quantities, at densities and strengths that match that of natural hail. The laboratory manufactured hailstones mimic the impact mechanics of natural hailstone impacts allowing for exploration of both hard and soft hail impacts and the influence of ice density on damage. IBHS has the capability to produce hail sizes from 0.75 - 3.5 inches.

**Hailpad network (CoCoRaHS)**

A unique, non-profit, community-based network of volunteers of all ages and backgrounds working together to measure and map various forms of precipitation.

**Streamsondes (NCAR)**

Small, 6 by 10 cm 9-g packages, each with attached balloon, which can be released via airplane dropsonde tube. Each contains a GPS tracker, accelerometer, and temperature, relative humidity, and pressure sensors. Once detached from the balloon, falls at a terminal velocity of 3 m/s.