Wyoming King Air as a National Facility
UW/NSF Cooperative Agreement 8 (CA8)
AGS-1917369: Year 1 Annual Report

Contents:

1. CA Status

The University of Wyoming King Air (UWKA), the Wyoming Cloud Radar (WCR), Wyoming Cloud Lidars (WCL), and associated instrumentation have been available to the broader NSF-funded science community through the NSF/GEO/AGS Lower Atmospheric Observing Facilities (LAOF) Program since 1988 (WCR was added in 2004, WCL was added in 2010). The UWKA facility is funded through a Cooperative Agreement (CA) between the University of Wyoming (UW) and NSF. The current CA, the 8th, began on 9/1/2019 and runs through 8/31/2024.

This report describes activities during Year 1 of CA8. It is noted here that Year 1 is not completed as of this writing. Where appropriate, planned activities for the coming 2 months are included.

Table 1 lists all projects supported during Year 1 of CA8. CHEESEHEAD, SPICULE, and SWEX are/were supported through NSF deployment pool (DP) funds. CHEESEHEAD had components that occurred during Year 6 of CA7 and Year 1 of CA8. SPICULE and SWEX were slated to occur during Year 1, but were postponed due to COVID19. DILBERT, funded directly through CA8 funds, is slated for the final two months of Year 1. Three projects (APART-Lite, MONARK, and HCPI-test) are non-NSF funded projects.

Table 1: Hours flown for project support during Year 1 of CA8

	HOURS FLOWN			
Project name	**Non-NSF Funded**	**CA8 Funded**	**NSF DP Funded**	**Total**
CHEESEHEAD			31.7	31.7
APART-Lite	10.7			10.7
MONARK	22.1			22.1
SWEX			1.8	1.8
SPICULE			-	0
DILBERT		12 (planned)		12
HCPI-test	10 (planned)			10
Grand Total				**88.4**

2. Projects Supported under NSF CA and Deployment Pool

Project: CHEESEHEAD

The ***Chequamegon Heterogeneous Ecosystem Energy-balance Study, enabled by a high density Extensive Array of Detectors*** (CHEESEHEAD) intensive field-campaign, addressed long-standing puzzles regarding the role of atmospheric boundary-layer responses to spatial heterogeneity in surface-atmosphere heat and water exchanges. Data collected during the three-month field campaign from summer to fall 2019 surrounding the Park Falls, WI, WLEF very tall tower, UWKA Facility, and Ameriflux supersite will be used to evaluate methods and models for scaling surface energy fluxes, testing the relationship between eddy covariance flux tower surface energy balance closure and mesoscale atmospheric properties, and analyzing how the planetary boundary layer (PBL) develops with complex spatial patterns of energy flux and comparing this to large eddy simulation. The three-month period allowed for observing vegetation senesces sequentially across the landscape. Three intensive observation periods were designed to span late summer to late fall and involved airborne sampling of spatial variability in fluxes to further substantiate hypotheses and parameterize models. Field support outreach and teacher training were planned to include via middle, high school, and undergraduate student involvement at nearby schools and colleges.

Outcomes:

The UWKA was deployed for three IOPs (one each in July, August and September) in 2019, during which 24 research flights were conducted. A total of 73 research hours were flown in support of CHEESEHEAD. The last IOP (IOP3) was conducted from September 22 through September 29. This was the only IOP that occurred during the time period covered under Year 1 of CA8. A total of 31.7 hours were flown during IOP3 in 8 research flight, 2 test flights, and 2 ferry flights.

Post-Project Critique/Debrief:

The Chequamegon Heterogeneous Ecosystem Energy-balance Study Enabled by a High-density Extensive Array of Detectors (CHEESEHEAD) project took place from July-September 2019, with the King Air deployed for three intensive operations periods (IOPs) from July 7-14, August 18-25, and September 22- 29. The King Air was based in Rhinelander, WI, for each IOP, with research flights taking place along predefined patterns and coordinated with various other project participants. Direct coordination regularly took place with regards to weather balloon launches, ground-based scanning lidar measurements, and UAV operations, as well as for occasional flights over the domain by an additional research aircraft.

The King Air research flights took place over a network of 60-100' tall instrumented towers centered around a ~1500' tall broadcast tower near Park Falls, WI. Before the first IOP, the King Air team worked with the investigators and relevant personnel (non-eyesafe ground-based lidar, UAV, and aircraft operators) to design three flight patterns that provided adequate clearance for flight operations around the instrumented towers, measurement platforms, and other hazards in the area (cell phone towers, the Park Falls airport). The patterns consisted of repeated passes stepping across the observation domain, nominally at 300' and 1300' AGL, with the passes' orientation (east-west, northwest-southeast, northeast- southwest) selected based on the expected wind direction for each active flight day.

Each IOP followed a similar schedule, with a new pilot and support crew swapping in each time. Following a test flight based in Laramie, the crew ferried the King Air to Rhinelander on a Sunday and flew a survey flight over the observation area on Monday, then four active research days between Tuesday and Saturday, and returned to Laramie on the subsequent Sunday. Research goals were met, with four pairs of morning and afternoon flights completed in each IOP. In total, 73 research flight hours were used over 24 research flights, with flights averaging 3 hours each allowing time to complete the flight patterns with occasional additional maneuvering for instrument calibration measurements.

Safety

As the project's science goals were focused on measurements in clear air, weather-related safety issues were expected to be secondary to the risks inherent in low-altitude flight operations around obstacles and in coordinating with other measurement platforms. To this end, the King Air group worked extensively with the project investigators to design and evaluate potential flight patterns, ensuring that the required maneuvers could be accomplished safely and that adequate clearance around obstacles would be maintained. Additionally, a daily project timetable was created, specifically defining the points along each King Air flight at which relevant operations on the ground (lidar scans, weather balloon and UAV launches) could safely occur. Regular communication via the chat interface between the system scientist and a mission coordinator on the ground ensured that this schedule was followed during each flight. The pilot also maintained radio communication with the UAV operators and with the other research aircraft during its occasional overflights of the observation area.

Along with allotting a day for each pilot to perform a survey flight prior to research operations and requiring visual meteorological conditions over the operations area, explicitly defining the flight patterns and coordination plans worked well to minimize safety risks. In particular, having a mission coordinator as the main point of contact on the ground worked very well and should be an expectation for similarly

complex projects in the future. No unexpected hazards or coordination issues occurred, and the only weather hazards (lower visibility due to wildfire smoke during IOP 1, occasional development of convective showers in or near the observation area) were easily dealt with. Other hazards included non- project air traffic, and birds flying at similar altitudes as the aircraft. These were encountered as expected, with risks mitigated by the crew (particularly the mission scientist) helping to scan visually for aircraft and birds, and the expectation that the pilot could deviate from the patterns as necessary.

With a relatively intense flight schedule and substantial cabin heating anticipated due to the project payload, fatigue was a matter of concern ahead of time. This was particularly important for the pilots, with every flight consisting of extensive maneuvering at low altitudes. Fatigue levels were discussed and evaluated during the IOPs, and flight operations were able to be completed safely with flights averaging approximately three hours each and with adequate downtime between morning and afternoon flights. The possibility of having two pilots on site during the project was discussed; this was not required but is worth considering for similarly intense projects with longer deployments or more extensive flight patterns. For the support crew, fatigue was not an issue. Relatively light maintenance between flights was doable without approaching daily crew duty limits.

Two potential safety issues were noted following the deployments: in one IOP, the weather allowed the eight planned research flights to be completed without a hard down day, and the crew considered returning to Laramie a day early. Although this did not end up occurring, it would have required a waiver allowing the crew to work for seven consecutive days. Additionally, one of the crew exceeded the standard daily duty limit during the drive between Rhinelander and Laramie. Subsequent discussion by the safety committee resulted in a review of the expectation and requirements for exemptions to standard duty limits, and the establishment of more specific guidelines for crew driving to or from project deployments. These should also be discussed more explicitly in the future ahead of deployments.

Operations

Operations were conducted with a pilot, system scientist, technician and lidar scientist on site, with an additional engineer on site during the first IOP. The supply trailer was driven to Rhinelander beforehand, with the truck and trailer remaining on site between deployments. Although duties before and after flights were relatively light, it was useful to have the additional crew member early in the project to help deal with logistics and unexpected issues while starting project operations. Additionally, although the payload was light enough for the system scientist to operate the lidars from time to time, having a lidar scientist on site worked well to facilitate data processing and rapid evaluation of the lidar measurement quality.

Basing in Rhinelander generally worked well. The FBO easily accommodated the group's research operations as well as occasional visitors and student tours, and leaving a vehicle and trailer on site between deployments worked well. The main operational concerns were in the FBO having few staff on site – particularly during July and August, staff availability and fueling were occasionally concerns when the airport was unexpectedly busy. Advance planning and refueling immediately after landing helped mitigate this and keep subsequent flights on schedule. Starting and ending operations on a weekend also introduced some confusion as the weekday FBO staff were more familiar with the expected operations. With the extra days allotted before research operations, this did not significantly impact the project itself.

Another logistical issue occurred for research operations, in that the King Air could be staged for startup either by its hangar or by the main FBO building. During IOP 1, areas of access around the hangar were sometimes limited by commercial flight operations at the airport's main terminal; advance communication with the airport manager would have helped clarify the expected timing and impact on operations. For IOPs 2 & 3, the King Air was staged by the FBO building ahead of flights when possible. However, only one GPU was commonly in service; this was occasionally in use by other aircraft, moving King Air startup back to the hangar area. These were minor issues but some flexibility in planning was needed to ensure the research flights remained on schedule; with this noted the site worked well.

Base support during research flights worked well from Rhinelander, with no issues communicating between the aircraft and LOD during flights. The Emergency Response Plan was updated with local information, and project planning also included developing a contact sheet in the event the LOD needed to coordinate with any relevant instrument operators in the observation area. The satellite phone was tested in Laramie beforehand in case of difficulties communicating during the project; this did not become a concern, but testing it while airborne after arriving on site should be considered for future projects.

Finally, during pre-project planning, it was noted that obtaining the LONO for research lidar operations was particularly time-consuming, with alternate deployment strategies being discussed with the PI shortly before IOP 1 in case approval had not been obtained. For future projects, particularly those working away from Laramie, it was noted that all FAA waiver and approval requests (including final instrument and operations specifications) should be ready to submit 90 days ahead of the project to increase the certainty of approval by the start of research operations.

Instrumentation

The facility payload was relatively light, with the zenith lidar and Compact Raman Lidar the two most substantial additions. Heat mitigation in the cabin was a concern; using an air conditioner and shading the cockpit windows between the daily flights helped mitigate this, and the instruments were operated successfully. A few issues occurred with the lidars: the CRL computer's position in the cabin was moved prior to IOP 2 to mitigate possible interference observed during IOP 1. The CRL functioned well otherwise; its computer ran out of disk space once, briefly impacting data collection. This should be checked regularly during projects, and all personnel should be aware of the data recording strategy used to ensure sufficient disk space is available on each flight. Additionally, during IOP 1, the zenith lidar computer rebooted several times, briefly impacting data collection. This was subsequently replaced by the FOV computer, which functioned well. Disk space was also an issue, although it was checked regularly enough to not interrupt data collection. The zenith lidar laser locked out twice during IOP 3, once during turbulence and once during aircraft maneuvering. The usual mitigation strategies apply, ensuring that its water supply is topped off and that the operator is free enough to notice and correct issues quickly.

It was noted during the first IOP that the Licor 7000 was plumbed differently than the Licor 6262 previously used by the facility, likely decreasing its response and increasing the measurement lag. Discussion in the group and with the project PI decided to leave the installation unchanged until after the project to maintain consistency between IOPs. It was noted that in the future, care should be taken during similar instrument replacements to maintain as much consistency as possible in measurement strategy.

The EdgeTech chilled mirror hygrometer was the only instrument that developed major problems during the project. Following unusable measurements at the end of IOP 2 (RF 16), the mirror was cleaned prior to IOP 3. Although the hygrometer functioned during the final test flight in Laramie and the subsequent ferry to Rhinelander, it became stuck in a heating cycle immediately upon the IOP 3 survey flight and was unusable for that deployment. Troubleshooting and maintenance were limited due to the short deployment and limited crew; these issues were discussed with the PI to ensure they were aware, but the risk for this specific instrument was difficult to plan for or mitigate ahead of time.

Other instrument-related developments that did not impact research data collection included the front panel display computer rebooting sporadically during the project. This was not crucial for CHEESEHEAD as the system scientist typically used the tablet(s) in the rear seat, but will be corrected before the front display becomes more critical in future projects. Additionally, with the light payload, both facility PCASPs and a new Applanix IMU were flown at various times to take advantage of the flight hours. These were not deemed a significant issue to research data collection as they only required minor attention during startup and shutdown to collect data.

Education/Outreach

Due to basing at a different site than the other project participants, the King Air group did not directly engage in the project's public outreach events. Two student groups were brought in for tours and discussions with the project manager, pilots, and lidar scientists. These consisted of students in weather instrumentation classes at the University of Wisconsin – Madison and the University of South Carolina. Approximately 15 students were involved in this. Additionally, with the light payload allowing the system scientist to operate the lidars, several students were able to fly in the fourth seat during IOPs 1 & 2.

Lodging, transportation, and shipping

Leaving the truck and trailer on site between IOPs worked well, given that the King Air only flew local test flights in these times. The only issue noted was some minor confusion regarding exact travel plans for drivers. These should be explicitly discussed beforehand to ensure that everyone has the same expectations, correct hotel reservations are made, and travel plans remain within safe duty limits.

Lodging worked out well, with a ~10 minute travel time to the airport. Two areas of concern were noted for future projects. Extra lead time for the site survey should be considered in similarly seasonally-busy areas; room availability was already decreasing quickly for IOPs 1 & 2 during the site survey, and last- minute additions or changes would likely not be possible. Additionally, inquiring about planned hotel maintenance should be considered during the initial survey. In this case, the hotel air conditioning was shut down on a seasonal basis prior to IOP 3 – not an issue given the weather occurring that week, but a potential concern if the transition to cooler fall weather had been delayed.

Summary

The project was a success overall. Operations during each deployment went well, with generally minor safety and operational issues outside of those inherent to the nature of the research flight design. Working extensively beforehand to establish flight patterns and coordination procedures along with establishing a mission coordinator for ground support were crucial in helping the actual deployments go smoothly despite the project's complexity. A similarly extensive level of advance planning and coordination should be used for future projects involving complex flight patterns and/or other measurement platforms.

The split deployment strategy worked well, given that there were no other research flight operations planned between IOPs. The short IOP schedule held some risk that the project would be impacted by unfavorable weather or instrument issues. The weather was mostly supportive, and instrumentation issues were generally small and dealt with quickly. The main exception, the EdgeTech hygrometer, was largely outside the scope what can be planned for or dealt with in a short deployment. In future planning, the main recommended change in procedure is to submit all necessary FAA paperwork 90 days ahead of time; while both the low-altitude waiver and lidar approval were obtained prior to IOP 1, the latter was close enough to first IOP to necessitate discussing last-minute changes to research flight strategies as a preemptive measure.

<u>Project: SWEX</u>

The **Sundowner Winds Experiment** (SWEX) is designed to investigate mechanisms driving downslope windstorms in the lee of the narrow Santa Ynez Mountains that are influenced by complex interactions with a cool, stable, and shallow marine boundary layer. The project was slated to occur from April 1 through May 15, May 2020. Ten flight days with two flights per day are expected (20 flights x 3.5 hours/flight = 70 research hours). An additional nine hours are needed for testing, eight for ferry, and two hours for pilot proficiency. A total of 89 hours are budgeted for support of SWEX.

Outcomes:

Preparations were well underway in early 2020 when the decision was made in mid-march to postpone the project until the same period in 2021. A site survey was completed in late 2019. Most of the instruments had been installed on the UWKA through late February and early March. One test flight had been conducted (1.8 hours flown). We anticipate beginning preparations for a SWEX 2021 in late February/early March of 2021 during Year 2 of CA8.

Project: SPICULE

The **Secondary Production of Ice in Cumulus Experiment** (SPICULE) is designed to use airborne in situ and remote observations to provide intensive measurements of microphysical and dynamic parameters that may, or may not, support suspected secondary ice production (SIP) in cumulus clouds. SPICULE uses two airborne platforms, the NSF/NCAR C-130 working subcloud and warm regions of cloud, and the SPEC Incorporated Learjet model 35A working the supercooled region of cloud. The C-130 will be equipped with in situ microphysical probes, aerosol measurements of CCN, IFP and biological aerosols, air motion sensors and the University of Wyoming cloud resolving radar (WCR).

Outcomes:

Early preparations were underway for SPICULE prior to the decision (in May) to postpone until 2021.

Since the last installation of WCR on the NSF/NCAR C130 for a field deployment in 2011 the radar went through a major upgrade to its 3rd generation (WCR3). The upgrade included hardware and software modifications which also led to the 3rd generation of radar quality control and products processing software as well as a need of installation changes. In preparation for SPICULE anticipated to take place in 2020 we worked on C130 installation setup using C130 radar rack kept at UW. After the new installation on the rack was finished it was used for ground testing and power calibration of the WCR3. The near nadir pointing antenna channel was calibrated using a corner reflector. WCR3 processing software for C130 also requires changes. Most of the software changes that could be completed before WCR3 flight tests and calibration on the C130 were implemented. The rest of the work in preparation for the field deployment during SPICULE in 2021 will be done about one to two months before the start of the experiment in 2021. In addition, we have finished the preparation of installing inertial reference system (IRS) on the C130 rack. During SPICULE we will collect data with this IRS in addition to the IRS data provided by the C130 aircraft data. The goal is to analyze the data and assess the possibility of improving the accuracy of the Doppler data corrected for aircraft motion contribution for the two WCR down-pointing antennas on the C130 ramp.

Project: DILBERT

The **Deployable Instruments, Laramie Based, Engineering Research Test** flights (DILBERT) is funded directly through hours programmed into CA8. The Research Engineering and Technical Support Group (RETSG) has been leading an effort to upgrade equipment on the University of Wyoming King Air (UWKA) over the past year, DILBERT is the flight program that will support that effort. The overarching objective of the program is to install the new equipment and test it in a way that would validate functionality of the equipment for use during an NSF funded project. Specifically objectives for the flights are to 1) test the in-flight functionality of the proposed equipment, 2) characterize the data received from the new instrumentation, and 3) compare results of old systems vs. new systems to identify potential problems prior to research.

Outcomes:

Flight operations will be based at the UW Flight Facility in Laramie, WY with a total of 12 hours allocated to accomplish the various mission profiles. Flights are expected to commence in July and August. A prioritized list of new equipment that is currently installed and will be tested during DILBERT includes:

1. King Air Display Stations
2. New Inverters (Main, Aux, Heat)
3. New Applanix IMU
4. Replacement Time Server
5. Static Pressure Sensor
6. HVPS Probe

All of the items above have been installed on the aircraft and we are currently in the process of being ground testing. The first flight for DILBERT should occur shortly after the week of July 4.

3. Projects Supported with non-NSF Funding

Project: APART-Lite

The ***Test Flights for Ammonia Phase Partitioning and Transport*** **(**APART-Lite) was a test campaign designed to identify and track gas-phase NH3 in agriculturally impacted air masses *in situ* using the University of Wyoming King Air (UWKA) research aircraft. The test campaign was proposed for the Colorado Front Range due to the large number of emission sources of NH3 from concentrated animal feeding operations and agriculture in that area. This project was funded from start-up resources provided to Prof. Dana Caulton at the University of Wyoming, and serve as a test bed for the complete APART project proposal that will be submitted to NSF at a later date.

The goals for APART-Lite were to 1) use measured NH3, CH4 (methane) and C2H6 (ethane) to identify and track NH3 emissions from concentrated animal and agricultural sources, 2) survey feedlots that are spatially separated from other feedlots to see if emissions from individual plumes can be isolated, 3) test which meteorological conditions and flight patterns are best for capturing short-range versus long-range transport of agricultural emissions, and 4) explore the utility of the ratio of CH4 to NHx in agricultural plumes for determining plume evolution and nitrogen deposition.

Outcomes:

A major accomplishment of APART-Lite was to install and successfully operate the demanding instrument payload proposed for the experiment, which included several user-supplied chemical instruments. A total of three flights were conducted during November of 2019, completing 10.7 research hours.

Project: MONARK

Project MONARK, funded by A3, a subsidiary of Airbus, was designed to test and advance the development of a GNSS-Radio Occultation payload and sensing strategies on aircraft platform to advance the technology readiness level of the sensor payload, aimed at improving forecasting accuracy. The data collected by the user-supplied instrument was augmented by standard meteorological data collected by instruments onboard the UWKA.

Outcomes:

During a one-week period in February, 2020, seven flights were conducted for a total of 22.1 flight hours. A wide variety of conditions were targeted including both clear air and precipitation, surface to 25,000 ft., and long (several hundred km) straight and level sections.

Project: HCPI-test

The Holographic Cloud Particle Imager Test experiment (HCPI-test) is funded through a contract with Radiation Monitoring Devices (RMD). RMD was awarded a DOE phase-II SBIR grant for the development and testing of the HCPI instrument. This program has the objective of installing and operating the RMD prototype HCPI instrument of the UWKA and collecting data in a variety of cloud and precipitation conditions. The UWKA-supported cloud instruments will be used to evaluate the performance of the HCPI during flight.

Outcomes:

HCPI-test is schedule to occur in early August, 2020. A total of five flights with 10 flight hours are expected. Preparations are underway for the installation of UWKA instrument payload. The HCPI has been ground tested for connectivity through the existing UWKA wing wiring.

4. Other Activities in Year 1

King Air Advisory Panel

The King Air Advisory Panel (KAAP) met twice during CA8, year 1. The KAAP is composed of five members, external to UW and represent both users and operators of aircraft for atmospheric research. Members serve on a voluntary basis for a five-year term. Current KAAP members include: Paquita Zuidema (U. Miami), Paul Shepson (SUNY-Stony Brook), Jeff Stith (NCAR/EOL/RAF-retired), Beat Schmid (DOE/ARM Aerial Facility), and Teresa Campos (NCAR/EOL). The committee meets nominally every 6 months via teleconference, with one meeting (every other year) in person. Both meetings during CA8, year 1 were through teleconferencing.

Materials presented to the KAAP during the October 18, 2019 meeting and the April 22, 2020 meeting are available on the web at: https://drive.google.com/drive/folders/1KAFjIxCJOkQ3MEFkLWww5qpl7NZWZGWx?usp=sharing. Additionally, KAAP provided a report that was emailed to UWKA PI-team and NSF LAOF program manager following the spring 2020 meeting. This report is also available through the above link.

Project Requests Reviewed

During the Fall 2019 and Spring 2020 Observing Facilities Assessment Panel (OFAP), a total of five requests for the UWKA/WCR/WCL Facility were reviewed and feasibilities presented. One (CHACHA) was reviewed during Fall 2019, the decision on that project is pending. Four

(APART, CAESAR, ESCAPE, RADFIRE2) were reviewed during Spring 2020. Of those, RADFIRE2 has been declined. APART and ESCAPE are still pending; CAESAR, a large campaign, is also pending, and if it moves forward a full flight request is due summer/fall 2020. Section 9 of this report includes a listing of the project queue for UWKA facilities for all funded and pending projects.

Development of New Capabilities/Instruments

Much work during year 1 has focused on in-house developments and testing and integration of recently acquired instruments and capabilities for the UWKA facility. All of these items highlighted below fit within the scope of 'Vision for the Facility in CA8' as outlined in the Section 4 of the CA8 proposal. These capabilities are also being developed in a way that they will be directly transferrable to the new aircraft (see section 5 of this report).

King Air Science Displays
There are several driving factors for the development of a new display system for users of the King Air. Instruments have become smaller and project payloads have become larger. Our system scientists routinely monitor eight displays on large projects from a single screen. Screen switching inefficiencies have led to operator fatigue and loss of data due to instrument failures that go unseen. The new display system has incorporated **three** 13-inch monitors into a single user station with a more robust computer for graphics and data visualization and touch screen capability. Furthermore, the RETSG FAA DER (Designated Engineering Representatives) have issued 8110-3 engineering compliance data to substantiate the aircraft installation. The new displays are now being integrated into the UWKA payload and will be tested during DILBERT flights later this summer.

Power Inverters
Three new DC-AC inverters were procured, installed and tested during CA8, year 1. Each 120V AC inverter is rated at 2000 Watts, giving a total capacity of 6000 Watts. This is an upgrade from the prior 4000-Watt capacity. The new inverters are ~10% more efficient than the ones they replaced, allowing for an increased electrical load for science payloads. Additionally, each inverter weighs half of the former and increases the available instrument payload, even after increasing the AC electrical load capacity. One inverter will be designated for "de-ice", further freeing up inverter capacity for additional scientific instruments.

Network Time Server
The timeserver on N2UW was upgraded due to the previous unit being end-of-life and having occasional problems synchronizing to the GPS constellation. The timeserver on N2UW provides the time reference for the data acquisitions system, IRIG timing signals for the Wyoming Cloud Radar and network time protocol (NTP) service for the Wyoming Cloud Lidars (WCLs) and various user supplied instruments. The new unit is natively DC powered and is one-half the size of the previous unit. Additionally, precision time protocol (PTP) and time-sensitive networking (TSN) are supported which will allow development of new data system capabilities utilizing distributed network-connected sampling nodes.

Development of UHSAS for UWKA

UWKA facility personnel led by Dr. Jeff Snider, Professor Dept. Atmospheric Science, continue work on the adaptation and evaluation of a DMT Ultra-High Sensitivity Aerosol Spectrometer (UHSAS) for operation within an aircraft cabin. Dr. Snider was part of a team that analyzed comparisons between an in-cabin and external UHSAS on the C130 during the 2016 ARISTO campaign. The UW-owned UHSAS has been altered to facilitate airborne operations. The modified UHSAS has been tested in an environmental chamber to simulate measurements during aircraft profiling. Dr. Snider provides specific recommendations for operation of the UW UHSAS in the UWKA in a draft report that is currently in preparation.

<u>High Volume Particle Sampler (HVPS)</u>
A SPEC, Inc., HVPS was acquired in late 2019. This instrument is replacing the PMS 2DP for measuring and imaging precipitation particles and completes the suite of next-generation Optical Array Probes (OAPs) on the UWKA that already include a CIP-25 grayscale and SPEC 2DS, which both came online during CA7. The HVPS has been ground-tested on the UWKA through the existing wing wiring and is set for test flights during DILBERT. Flights will include direct comparisons between the HVPS and the 2DP (which will be retired once the HVPS demonstrates its capability) as a way to demonstrate consistency with existing data sets.

<u>LWC-301</u>
The longstanding Droplet Measurement Technologies (DMT) LWC-100 liquid water instrument failed in 2019. The instrument was no longer supported by the manufacturer and not repairable by UW King Air facility personnel. DMT's current hot-wire liquid water probe, the LWC-301, was purchased in early 2020. The new probe is more robust and alleviates the problem of overheating sensing elements in low airflow conditions. The LWC301 is interfaced to the existing King Air data acquisition system through serial and analog data channels. As the facility moves to limit analog data channels for the replacement aircraft data system, serial interfaces will become more prominent along with network-based instruments. Thus, the LWC-301 is a test of new instrument interface software. The LWC-301 will undergo flight tests starting in July 2020.

<u>Winds and Network Data Acquisition</u>
Development efforts have started on deterministic network-based data acquisition utilizing a replacement air-motion (wind) system as the test instrument. Sensors have been procured to replace the existing N2UW noseboom sensor configuration and add an additional differential and static pressure measurement to the system. The high-speed transducers have serial interfaces and measurements need to be made simultaneously and timed precisely. These development and test efforts lay the groundwork for sampling distributed data sources over a network infrastructure – a technique that will be essential for increasing instrument payload capacity in the new Wyoming King Air.

<u>Single Particle Soot Photometer (SP2)</u>
A new Single Particle Soot Photometer - Extended Range (SP2-XR) was acquired from Droplet Measurement Technologies in early 2020. This instrument will enable measurements of black carbon along with improved measurements of the sub-micron aerosol size distribution. UW personnel have been trained in the operation of the SP2-XR and a new graduate student has been recruited (funded through CA8, beginning with year 2) who will conduct an in depth analysis of the performance of the SP2 on the ground and during flight. UW is working with DMT to develop and test an instrument software modification to allow the instrument to broadcast data over a local area network. This will allow real-time correlation of SP2-XR data with existing data streams on the King Air.

<u>*OAP Processing Software Development*</u>

As the UWKA facility is bringing new/modern OAPs online for cloud and precipitation measurements (see HVPS in previous section), a parallel activity is the development of new OAP processing software. The new software, based on the University of Illinois OAP Processing

Software (UIOPS), developed by Dr. Greg McFarquhar, will better handle shattering artifacts and partially imaged small particles that are more readily detected with the new generation of OAPs which contain better optics and faster-response electronics. The new software package will also provide robust algorithms for determining hydrometeor shape classification that can be used to rudimentary phase discrimination. This effort is being led by PI Jeff French and an MS-level graduate student who began in January 2020. The new software is expected to come online and be adopted by the UWKA in 2021.

WCL-specific Developments

WCL Supplemental Type Certificate (STC) and FAA Issue Paper

Good progress has been made on the supplemental type certificate (STC) for certifying the Wyoming Cloud Lidar Two Field-of-View (WCL-2-FOV). An issue paper regarding the laser aspects of the lidar installation is nearly complete and facility personnel have had multiple interactions with the FAA to complete the paper. Outstanding items for the STC are being addressed and UW is optimistic that the process will be completed in 2020. Issuance of this STC by the FAA will go a long way towards the development of lidar STC's for the next generation King Air.

WCL Data Set Processing

The design of the WCL(s) provide no output laser energy monitor, yet variation in the laser output can at times be significant impacting the calibration. Generation of a calibrated attenuated backscattering coefficient for the Level 1 WCL dataset is desirable and necessary for the development of higher level products such as extinction coefficient-based retrieval. Utilizing data from several campaigns (aerosol focused and cloud focused) new WCL operational routines and data processing code have been developed to provide reasonably reliable Level 1 dataset for upward and downward WCLs.

WCL measurements from the 2018 BBFLUX campaign have utilized this new processing methodology to determine calibrated attenuated backscatter that in turn has been used to identify aerosol boundaries (aerosol mask) within the 2D vertical cross sections. Based on this mask, the aerosol extinction coefficient is retrieved using the Fernald backward iteration method. To investigate the fire plume injection height, the smoke aerosol vertical structure is reconstructed with consecutive but repeating flight legs at different heights.

Webpage Development

As per comments from reviewers of the CA8 proposal, the UWKA is striving to provide more easily accessible information to users and potential users of the facility. This includes both data access as well as information about the facility itself, its instrumentation, and capabilities. This is a large effort, and we decided to begin by revamping the facility website with a structure in place that will allow for a seamless integration as newly developed documents are produced. We are working with an outside consultant/developer on this effort that is funded through the 'information specialist' person within CA8.

The facility website is now in the process of being redesigned and updated to provide up-to-date information describing the facility and its research capabilities, with a particular focus on providing information for investigators who have utilized the King Air (or may in the future) for research data collection. As part of this process, the main facility webpage (https://www.uwyo.edu/atsc/uwka/) has been updated along with several new pages providing summary information about the facility's history and uses, and the planned acquisition and modification of a newer King Air, in order to provide basic overview information for website visitors. Additional plans underway include migrating and updating the existing pages to this newer format, and developing a more extensive set of information describing the aircraft, its instrumentation, and the associated research data sets. These will be developed in the form of guides describing each aspect in detail, e.g., an investigator handbook and a description of basic processing and usage for research measurements.

5. Personnel Support of MSRI-specific Developments and Next Generation UWKA

Development of the replacement King Air is a significant effort outlined in the CA8 proposal. The NSF Mid-Scale Research Infrastructure grant awarded to the University of Wyoming for the development of the next generation King Air (UWKA-2) relies upon personnel time from the CA8 dedicated to the new aircraft development. Below we provide a summary of the personnel, supported through CA8, who have dedicated a <u>portion of their funded CA8 effort</u> towards the MSRI effort. Reporting on the outcomes of the MSRI is beyond the scope of this report.

Seven persons funded through CA8 have expended significant effort towards the development of UWKA-2. These include

- Jeff French, PI, CA8 (co-PI, MSRI Award) – roughly 50% of Dr. French's effort towards the CA8 award in Year 1 has focused on the development of the new aircraft. His efforts included: development of a 'Scope of Work' Document and associated budget that defines the modifications and certifications to be accomplished on the new aircraft, acquisition of the baseline aircraft including working with the UW administration for UW approvals and reporting, developing and finalizing contracts with companies outside of UW that are required for the development of UWKA-2, development of the project execution plan (PEP) for the new aircraft development portion of the MSRI award.
- Bart Geerts, co-PI, CA8 (PI, MSRI Award) – roughly 85% of Dr. Geerts' effort towards the CA8 award in Year 1 has focused on the development of the new aircraft. This principally focuses on the overall management of the MSRI award, reporting requirements for that award, and working with the UW administration towards the acquisition of the new aircraft.
- Matt Burkhart, Senior personnel CA8 (co-PI, MSRI Award) – approximately 50% of Mr. Burkhart's effort towards the CA8 in Year 1 has been directed to the MSRI effort. He is the overall project manager for the MSRI and is therefore responsible for the development of the full PEP, encompassing all 5 MSRI sub-projects. Mr. Burkhart is also project lead for the development of the enhanced air-ground communications sub-project, and the technical lead for all electrical modifications and upgrades to the new aircraft.
- Nick Mahon, Senior Personnel CA8 (senior personnel MSRI Award) – Mr. Mahon has spent approximately 35% of his CA8 time allocation supporting the MSRI award. He is the UW technical lead for structural upgrades to the new aircraft and provides oversight of UWs fabrication and installation team. General activities include aircraft specifications and selection, collaboration on the project execution plan with focus on the risk register and technical data exchange with the aircraft modifiers. A significant effort has been placed on the generation of Interface Control Documents (ICD) for certain structural modification areas of the aircraft.
- Brett Wadsworth, Chief Pilot UW – Mr. Wadsworth has played an active role in the selection and evaluation of the baseline aircraft, defining the avionics requirements for

the new aircraft, and evaluating (specifically non-research) modifications that should be required for UWKA-2. This has accounted for 25% of his CA8, year 1 effort.

- Brett Spiker, Chief Mechanic UW – Mr. Spiker has also been heavily involved in the selection of the baseline aircraft, including performing a 2-day inspection on the aircraft when it was in Laramie. Additionally, Mr. Spiker is responsible for ensuring that the proposed modifications and certifications that are in the design process will be serviceable in practice for the new aircraft. Roughly 10% of his CA8, year 1 has focused on support of the MSRI.
- Samuel Haimov, Senior Personnel CA8 (co-PI MSRI Award) – One of the sub-projects within the MSRI is the upgrade of WCR. This includes hardware and software upgrades and a repackaging of the radar in order to be installed on UWKA-2. AS the sub-project lead, Dr. Haimov expended about 20% of his CA8, year 1 effort to complete the MSRI PEP for this project, communicate with vendors, develop a statement of work, etc. Much of this latter work has been accomplished in collaboration with ProSensing, Inc. the contractor responsible for the re-packaging of WCR4.

6. Spending Summary for Year 1

Table 2 lists spending in Year 1 by category. Actual amounts are through May 31, 2020 (first 9 months of year 1). Indirect costs (IDC) are encumbered immediately at the beginning of year, and released back to the grant for items that were not charged IDC but were budgeted. Salaries through the final three months have been encumbered. A number of specific items are expected to be charged through the summer including: equipment/facility upgrades including the acquisition and development of a new Rosemount 858 gust probe to replace the existing probe, insurance due in July, mechanic and pilot training, and test flights (to fund the DILBERT project described in section 2 of this report). Items such as data system and instrument maintenance and supplies were significantly underspent in year 1 due to the lack of NSF deployment, resulting from COVID-19. Unspent year 1 funds will be carried to year 2.

Table 2: Spending by Category during CA8 year 1, through May 31, 2020

Category	Year 1 Allocation	Encumbered	Expended	Unspent
Equipment	$45,000.00	$0.00	$0.00	$45,000.00
Fringe	$432,759.00	$93,353.26	$222,966.14	$116,439.61
Indirect Cost	$715,642.00	$342,890.16	$367,965.88	$4,785.96
Insurance	$30,000.00	$0.00	$0.00	$30,000.00
Data System Maintenance	$25,000.00	$0.00	$0.00	$25,000.00
Instrument Maintenance	$30,000.00	$0.00	$0.00	$30,000.00
Mechanic Training	$4,000.00	$0.00	$0.00	$4,000.00
Pilot Training and Physicals	$24,000.00	$14,611.00	$1,840.55	$7,548.45
Publications	$5,000.00	$0.00	$0.00	$5,000.00
Safety Program	$10,000.00	$0.00	$752.00	$9,248.00
Safety Training	$5,000.00	$0.00	$0.00	$5,000.00
Salary	$954,625.00	$235,618.23	$589,058.47	$129,948.30
Salary - GA	$22,800.00	$0.00	$8,397.00	$14,403.00
Software License	$2,000.00	$0.00	$0.00	$2,000.00
Supplies	$20,000.00	$0.00	$3,654.73	$16,345.27

Test Flights	$13,500.00	$0.00	$0.00	$13,500.00
Travel	$29,500.00	$0.00	$370.69	$29,129.31
Tuition and Fees	$9,784.00	$0.00	$4,436.47	$5,347.53
Subtotal:	**$2,378,610.00**	**$686,472.65**	**$1,199,441.93**	**$492,695.43**

Table 3 lists the distribution of salaries for all persons funded through CA8. Column 2 – "CA Salary (% of Total Salary)" lists that percent of the total salary budgeted for year 1 and the last column shows the percent of the budgeted amount that has been used. This is current as of May 31, 2020 (nine months, or 75% of the way through year 1). Stotler, Executive Business Manager, was hired in April, 2020. West, Technician, was hired in January, 2020. Information Manager is an open position, funds are presently being used to fund an outside contractor for webpage development. Other are funds being used to support an undergraduate student. This table does not include distribution of fringe.

Table 3: Distribution of Salaries during CA8 year 1, through May 31, 2020

Name/Title	CA Salary (% of Total Salary)	CA Salary ($ Available)	CA Salary ($ Used)	Percent CA Salary Used
Burkhart, Research Scientist Sr., ETT	75%	$74,412.00	$40,694.72	55%
Deng, Lidar Scientist	75%	$67,632.00	$51,789.78	77%
Drew, Research Pilot	75%	$71,451.00	$53,692.19	75%
French, PI	33%	$29,792.00	$0.00	0%
Geerts, Co-PI	11%	$15,500.00	$0.00	0%
Glover, Master Technician	75%	$50,769.00	$36,975.95	73%
Haimov, Radar Scientist	75%	$74,116.00	$56,484.00	76%
Kuestner, Machinist	75%	$44,964.00	$30,911.57	69%
Little, Technician	75%	$35,001.00	$17,267.76	49%
Mahon, Engineer, Sr.	75%	$67,437.00	$51,522.75	76%
Morgan, Engineer/Systems Analyst	75%	$40,140.00	$31,357.64	78%
Oolman, Project Manager/Scientist	75%	$74,060.00	$55,222.20	75%
Plummer, Project Manager/ Scientist	75%	$47,727.00	$36,547.29	77%
Rodi, Co-PI	33%	$46,667.00	$20,510.00	44%
Shaffer, Graduate Student 1	100%	$22,800.00	$8,397.00	37%
Snider, Senior Personnel	8%	$10,757.00	$0.00	0%
Spiker, Chief A/C Mechanic	75%	$64,152.00	$32,124.56	50%
Stotler, Exec Business Manager	8%	$4,792.00	$0.00	0%
Wadsworth, Chief Research Pilot	75%	$78,561.00	$58,818.87	75%
West, Technician	75%	$35,001.00	$14,014.66	40%
Information Manager	29%	$21,000.00	$0.00	0%
Other		$0.00	$1,536.00	0%

7. Budget and Plans for Year 2

Table 4 lists the planned spending for Year 2. The 'unbudgeted rollover from previous year' includes the sum of the unspent and unencumbered funds remaining as of May 31, 2020 from year 1. Most of these funds will be expended by the start of year 2, during the last 3 months of year 1 and are not included in the Grand Total Budget for Year 2.

Table 4: Year 2 Budget Estimate: Sept 1, 2020 to August 31, 2021

PERSONNEL	$/Month	NSF Mo/Yr	Salary
Burkhart, Research Scientist Sr., ETT	$8,557	9.0	$77,016
Deng, Lidar Scientist	$7,778	9.0	$70,002
Drew, Research Pilot	$8,217	9.0	$73,952
French, PI	$10,279	3.0	$30,836
Geerts, Co-PI	$16,043	1.0	$16,043
Glover, Master Technician	$5,838	9.0	$52,546
Haimov, Radar Scientist	$8,523	9.0	$76,709
Kuestner, Machinist	$5,171	9.0	$46,538
Little, Technician	$4,025	9.0	$36,226
Mahon, Engineer, Sr.	$7,755	9.0	$69,797
Morgan, Engineer/Systems Analyst	$4,616	9.0	$41,545
Oolman, Project Manager/Scientist	$8,517	9.0	$76,653
Plummer, Project Manager/ Scientist	$5,489	9.0	$49,397
Rodi, Co-PI	$16,100	3.0	$48,301
Shaffer, Graduate Student	$1,900	12.0	$22,800
Snider, Senior Personnel	$14,845	0.8	$11,134
Spiker, Chief A/C Mechanic	$7,377	9.0	$66,397
Stotler, Exec Business Manager	$4,960	1.0	$4,960
Wadsworth, Chief Research Pilot	$9,035	9.0	$81,311
West, Technician	$3,968	9.0	$35,714
Information Manager	$6,210	3.5	$21,735
Grad Student 1	$1,900	12.0	$22,800
Other	$0	0.0	$0
TOTAL Months/Year		162.3	**$1,032,412**
FRINGE			**$385,585**
TOTAL PERSONNEL			**$1,417,997**
OTHER CATEGORIES			
Facility Upgrades			$45,000
Maint: Data System			$25,000
Mechanic Training			$4,000
Instrument Maintenance			$30,000
Supplies			$20,000
Safety Program			$10,000
Safety Training			$5,000
Calibrate/Test Flight			$13,500
Pilot Training/Physicals			$24,000
Insurance			$30,000
Software License			$2,000
Travel			$29,500
Publications			$5,000

GA Tuition and Fees			$19,568
TOTAL OTHER			**$262,568**
Indirect Cost	44.5%		**$727,826**
GRAND TOTAL for Year 2 Budget			**$2,408,391**
Previous Year Funds not encumbered and/or spent as of May 31, 2020			$1,179,168

8. Status of Supplemental Deployment Pool Funding

Table 5 lists the status of deployment pool funding (supplement to CA8) as of May 31, 2020. A supplemental award in the amount of $285,620 was made to UW on Feb 13, 2020. This award was to partially fund the deployment of the UWKA and/or WCR for SWEX and SPICULE in spring/summer 2020.The remaining cost for deployment was to be supplied through funds remaining in the deployment pool funding supplement to CA7 (currently in a no-cost extension). Expenses incurred in preparation for SWEX-2020 and SPICULE-2020 were charged to the CA7 supplement, but due to the postponement of both projects due to COVID-19, the CA7 supplement was not exhausted. No charges have been yet made to the CA8 supplement. The full amount continues to be available for the expected deployment of SWEX and SPICULE in 2021 (year 2).

Table 5: Status of Deployment Pool Funding Account, supplement to CA8

	Sum of Receipts	Sum of Encumbered	Sum of Expended	Sum of Available
16101-1004405A-1 NSF Deployment CA8 END: 8/31/24	$285,619.47	$89,391.71	$0.00	$196,227.76
Aircraft Operations	$107,325.00	$0.00	$0.00	$107,325.00
Data Processing	$9,825.00	$0.00	$0.00	$9,825.00
Ferry	$11,402.56	$0.00	$0.00	$11,402.56
Fringe	$2,600.70	$0.00	$0.00	$2,600.70
Indirect Cost	$89,391.71	$89,391.71	$0.00	($0.00)
Purchased Services	$17,980.00	$0.00	$0.00	$17,980.00
Salary	$6,119.30	$0.00	$0.00	$6,119.30
Trailer Deployment	$4,070.08	$0.00	$0.00	$4,070.08
Travel	$31,392.68	$0.00	$0.00	$31,392.68
WCR Install	$5,512.44	$0.00	$0.00	$5,512.44

9. Project Queue

Table 6 lists the project queue for NSF-funded projects utilizing the UWKA/WCR/WCL facility. A number of projects are pending and decisions are expected in the coming weeks. The project queue, as listed, extends into year 3 of CA8.

Table 6: Queue for funded and pending NSF projects for the UWKA/WCR/WCL facility.

Cat	Project	Facilities	Time Frame	Location	PI	Status	NSF Science Program
FY 2020							
S	SWEX	WYKA, ISFS, ISS	1 Apr–15 May 2020 **POSTPONED**	California	Calvalho	Funded	AGS/PDM
S	SPICULE	NSF/NCAR C-130, WCR	Spring/Summer 2020 **POSTPONED**	Colorado	Lawson	Funded	AGS/PDM
FY 2021 and beyond							
S	**SWEX**	**WYKA, ISFS, ISS**	**1 Apr–15 May 2021**	**California**	**Calvalho**	**Funded**	**AGS/PDM**
S	**SPICULE**	**NSF/NCAR C-130, WCR**	**Spring/Summer 2021**	**Colorado**	**Lawson**	**Funded**	**AGS/PDM**
S	**ESCAPE**	**NSF/NCAR C-130 w/ WCR, COW, DOWs, soundings**	**summer 2021**	**Texas**	**Kollias**	**PENDING**	**AGS/PDM**
S	**APART**	**UWKA**	**Late summer/fall 2021**	**WY & CO**	**Fischer**	**PENDING**	**AGS/ATC**
S	**CHACHA**	**UWKA, AVAPS**	**15 Feb–16 Apr 2022**	**Utqiaġvik, AK**	**Shepson**	**PENDING**	***OPP & AGS/ATC***
L	**CAESAR**	**NSF/NCAR C-130, AVAPS, HAIS, WCR, WCL, ISFS**	**23 Feb–7 Apr 2022**	**Sweden or Norway**	**Zuidema**	**EDO under review**	**AGS/PDM**

10. Other Funding Support for Key Personnel

Table 7 lists all external, non-CA8 support received by senior personnel on the CA8 award during year 1. Senior personnel receiving no additional external support are not listed.

Table 7: External Support for Key Personnel.

Name	CA8 Yr 1 NSF Salary Available (%total)	CA8 Yr 1 NSF Salary Used (% total)	Other Support	Year 1 Non CA8 External Support (% of total salary)
French, PI	33%	0%	NSF SNOWIE- 6.89%	6.89%
Rodi, Co-PI	33%	14.65%	NSF CA7- 5.07%	5.07%

Geerts, Co-PI	11%	0%	USGS- 6.34%	6.35%
Snider, Sr. Personnel	8%	0%	NSF Hotplate- 6.45%	6.45%
Burkhart, Research Scientist, ETT	75%	55%	BLM- 2.3% NSF Hotplate- 7.3% MSRI- 7.4% EDF- .88%	17.88%

***NOTE: Rodi is part-time un-benefitted. His 'total' salary represents the salary he would draw if working a full 12 months.

11. Publications in 2019-20 Resulting from UWKA/WCR/WCL

The following is a list of publications in 2019 and 2020 resulting from NSF LAOF support of the UWKA facility. Included in the 2020 list are known publications that are currently under review.

2020 Publications to date

Butterworth, B. J., and co-authors, 2020: Connecting Land-Atmosphere Interactions to Surface Heterogeneity in CHEESEHEAD19. *Bull. Amer. Meteor. Soc.,* submitted.

Chipilski, H. G., X. Wang, and D. B. Parsons, 2019: Impact of assimilating PECAN profilers on the prediction of bore-driven nocturnal convection: A multi-scale forecast evaluation for the 6 July 2015 case study. *Mon. Wea. Rev.*, **148**, 1147:1175. https://doi.org/10.1175/MWR-D-19-0171.1

Grasmick, C., and B. Geerts, 2020: Detailed dual-Doppler structure of Kelvin–Helmholtz waves from an airborne profiling radar over complex terrain. Part I: Dynamic structure. *J. Atmos. Sci.*, **77**, 1761:1782. https://doi.org/10.1175/JAS-D-19-0108.1

Jensen, A. A., P. T. Bergmaier, B. Geerts, H. Morrison, and L. S. Campbell, 2020: Sensitivity of convective cell dynamics and microphysics to model resolution for the OWLeS IOP2b lake-effect snowband. *Mon. Wea. Rev.*, in press. https://doi.org/10.1175/MWR-D-19-0320.1

Majewski, A. and J. R. French, 2020: Supercooled drizzle development in response to semi-coherent vertical velocity fluctuations within an orographic-layer cloud. *Atmos. Chem. Phys.*, **20**, 5035–5054. https://doi.org/10.5194/acp-20-5035-2020

Yang, J., Z. Wang, A. J. Heymsfield, K. J. Suski, and D. W. Toohey, 2020: High ice concentration observed in tropical maritime stratiform mixed-phase clouds with top temperatures warmer than -8°C. *Atmos. Res.*, **233**, 12 pp.

2019 Publications

Bernstein, B. C., R. M. Rasmussen, F. McDonough, and C. Wolff, 2019: Keys to Differentiating between Small- and Large-Drop Icing Conditions in Continental Clouds. *J. Appl. Meteor. Climatol.*, **58**, 1931-1953.

Gaudet, L. C., K. J. Sulia, F. Yu, and G. Luo, 2019: Sensitivity of Lake-Effect Cloud Microphysical Processes to Ice Crystal Habit and Nucleation during OWLeS IOP4. *J. Atmos. Sci.*, **76**, 3411-3434.

Haghi, K. R., B. Geerts, H. G. Chipilski, A. Johnson, S. Degelia, D. Imy, D. B. Parsons, R. D. Adams-Slin, D. D. Turner, and X. Wang, 2019: Bore-ing into nocturnal convection. *Bull. Amer. Soc.*, **100**, 1103-1121.

Juliano, T. W., M. M. Coggon, G. Thompson, D. A. Rahn, J. H. Seinfeld, A. Sorooshian, and Z. J. Lebo, 2019: Marine boundary layer clouds associated with coastally-trapped disturbances: Observations and model simulations. *J. Atmos. Sci.*, **76**, 2693-2993.

Lin, G., B. Geerts, Z. Wang, C. Grasmick, X. Jing, and J. Yang, 2019: Interactions between a nocturnal MCS and the stable boundary layer, as observed by an airborne compact Raman lidar during PECAN. Mon. Wea. Rev., **147**, 3169-3189.

Rauber, R. M., B. Geerts, L. Xue, J. French, K. Friedrich, R. M. Rasmussen, S. A. Tessendorf, D. R. Blestrud, M. L. Kunkel, and S. Parkinson: Wintertime orographic cloud seeding - A review. 2019, *J. Appl. Meteor. Climatol.*, **58**, 1931-1953.

Tessendorf, S., and Coauthors, 2019. A transformational approach to winter orographic weather modification research: The SNOWIE Project. *Bull. Amer. Meteor. Soc.*, **100**, 71-92. https://doi.org/10.1175/BAMS-D-17-0152.1