U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-16-054

ARM Unmanned Aerial Systems Implementation Plan

B. Schmid
M. Ivey

November 2016

ARM CLIMATE RESEARCH FACILITY

DISCLAIMER

DOE/SC-ARM-16-054

ARM Unmanned Aerial Systems Implementation Plan

B. Schmid, Pacific Northwest National Laboratory
M. Ivey, Sandia National Laboratories

A. Bendure, Sandia National Laboratories (SNL)
J. Hardesty, SNL
N. Hickmon, Argonne National Laboratory
K. Nitschke, Los Alamos National Laboratory
D. Dexheimer, SNL
F. Mei, Pacific Northwest National Laboratory (PNNL)
C. Sivaraman, PNNL
Contributors

November 2016

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AAF	ARM Aerial Facility
AMF	ARM Mobile Facility
ANAC	Autoridade Nacional de Aviação Civil, Portugal
ANL	Argonne National Laboratory
ARM	Atmospheric Radiation Measurement Climate Research Facility
ASR	Atmospheric Systems Research
ATC	Air Traffic Control
BER	Biological and Environmental Research
BRW	Barrow (now Utqiagvik)
CESD	Climate and Environmental Science Division
CIRES	Cooperative Institute for Research in Environmental Sciences
COALA	Coordinated Observations of the Arctic Lower Atmosphere
CU/B	University of Colorado, Boulder
DMF	Data Management Facility
DoD	Department of Defense
DOE	U.S. Department of Energy
EF	Extended Facility
ENA	Eastern North Atlantic
EPIC	Environmental Profiling and Initiation of Convection
ERASMUS	Evaluation of Routine Measurements using UAS
FAA	Federal Aviation Administration
ft	feet
FY	fiscal year
g	gram
GCM	Global Circulation Model
HF	high frequency
ICARUS	Inaugural Campaigns for ARM Research using Unmanned Systems
IMB	Infrastructure Management Board
IOP	Intensive Operational Period
IOPR	IOP Request
LANL	Los Alamos National Laboratory
LASSO	LES ARM Symbiotic Simulation and Observation
lbs	pounds
LES	large-eddy simulation
LW	longwave

m	meter
MIZOPEX	Marginal Ice Zone Observations and Processes Experiment
mm	millimeter
MOA	Military Operations Area
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NSA	North Slope of Alaska
OAM	Office of Aviation Management (DOE)
PECAN	Plaines Elevated Convection at Night
PNNL	Pacific Northwest National Laboratory
RFP	Request for Proposal
SBIR/STTR	Small Business Innovation Research/Small Business Technology Transfer
SC	Office of Science (DOE)
SGP	Southern Great Plains
SNL	Sandia National Laboratories
SW	shortwave
TBS	tethered balloon system
UAS	unmanned aerial system
UAV	unmanned aerial vehicle
VHF	very high frequency
VPN	virtual private network
XDC	External Data Center
W	Watts

Contents

Figures

Tables

1.0 Introduction

Recent advances in Unmanned Aerial Systems (UAS) coupled with changes in the regulatory environment for operations of UAS in the National Airspace increase the potential value of UAS to the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility. UAS include unmanned aerial vehicles (UAV) and tethered balloon systems (TBS). The roles UAVs and TBSs could play within the ARM Facility, particularly science questions they could help address, have been discussed in several workshops, reports, and vision documents, including:

- Ivey M, R Petty, D Desilets, J Verlinde, and R Ellingson. 2013. Polar Research with Unmanned Aircraft and Tethered Balloons: A Report from the Planning and Operational Meeting on Polar Atmospheric Measurements Related to the U.S. Department of Energy ARM Program Using Small Unmanned Aircraft Systems and Tethered Balloons, held July 24-26, 2013, Washington, D.C. U.S. DOE, Office of Science. DOE/SC-ARM-TR-135.
- DOE US. 2014. Atmospheric Radiation Measurement Climate Research Facility: Decadal Vision. U.S. DOE, Office of Science, Office of biological and Environmental Research. DOE/SC-ARM-14-029.
- Mather J. 2016. Decadal Vision Progress Report: Implementation Plans and Status for the Next Generation ARM Facility. DOE ARM Climate Research Facility. DOE/SC-ARM-16-036.
- Campos E and DL Sisterson. 2015. A Unified Approach for Reporting ARM Measurement Uncertainties Technical Report. DOE ARM Climate Research Facility. DOE/SC-ARM-TR-170.
- Verlinde H, J Harrington, J Mather, A McComiskey, M Shupe, and B Ellingson. 2015. ARM North Slope of Alaska Priorities Workshop September 10-12, 2014 Report. DOE ARM Climate Research Facility. DOE/SC-0176.
- de Boer G, B Dafflon, A Guenther, D Moore, B Schmid, S Serbin, and A Vogelmann. 2015. Climate and Environmental Sciences Division Aerial Observation Needs Workshop May 13-14, 2015 Report. DOE ARM Climate Research Facility. DOE/SC-0179.
- Hardesty, J, M Ivey, D Dexheimer, F Helsel, D Lucerno, and G de Boer. 2016. Opportunities for Sustained Arctic Observations and Scientific Collaborations at the US Department of Energy Atmospheric Radiation Measurement (ARM) Facilities on the North Slope of Alaska, 2016 Arctic Observing Summit (AOS) at Fairbanks, AK.

This document describes the implementation of a robust and vigorous program for use of UAV and TBS for the science missions ARM supports.

2.0 Laboratory Partnerships

Pacific Northwest National Laboratory (PNNL) manages the ARM Aerial Facility (AAF) for the DOE Office of Science (SC) Biological and Environmental Research program (BER). Sandia National Laboratories (SNL) manages the North Slope of Alaska (NSA) ARM facilities, including the Oliktok Point AMF3 installation. Argonne National Laboratory (ANL) manages the Southern Great Plains (SGP) facilities. PNNL and SNL collaborate to manage UAV and TBS operations at Oliktok Point. Experience gained at Oliktok Point is useful for UAS operations at other ARM facilities and at ARM-sponsored campaign locations. PNNL and ANL will collaborate to manage UAS operations at SGP. Similarly, PNNL and Los Alamos National Laboratory (LANL) will collaborate to manage UAS operations at other AMF sites. ANL, LANL, PNNL, and SNL will follow ARM Infrastructure Management Board established review and approval processes, including the Intensive Operational Period (IOP) Request Process for requests from the scientific community. Changes in baseline operations at Oliktok Point that involve UAS will be managed by the IMB using the Baseline Change Request process.

3.0 Oliktok Point, Alaska: A Unique Resource for Atmospheric Research

A number of long-term efforts associated with the third ARM Mobile Facility (AMF3) deployment at Oliktok Point are coming to fruition now, presenting a unique opportunity for the atmospheric research community. The AMF3 installation was completed in September, 2014. The following resources enhance the value of the AMF3 and make operation of UAV and TBS for research purposes at Oliktok Point possible:

1. Restricted Area R2204 at Oliktok Point is assigned to DOE and managed by SNL. R2204 enables unrestricted aerial operations within a 2-mile radius of Oliktok Point. It provides an important launching area for offshore operations, as was demonstrated during the MIZOPEX campaign in 2013 and the US Coast Guard Arctic Shield Search and Rescue exercise in 2015.
2. A Warning Area north of Oliktok Point has been approved by the Federal Aviation Administration (FAA). This Warning Area facilitates operations of research vessels and manned and unmanned aircraft in international waters north of Oliktok Point. It extends 40 nautical miles (nm) wide and 700 nm long across the Arctic Ocean toward the North Pole.

Figure 1. Restricted Airspace (R-2204, faint gray circle) centered on Oliktok Point.

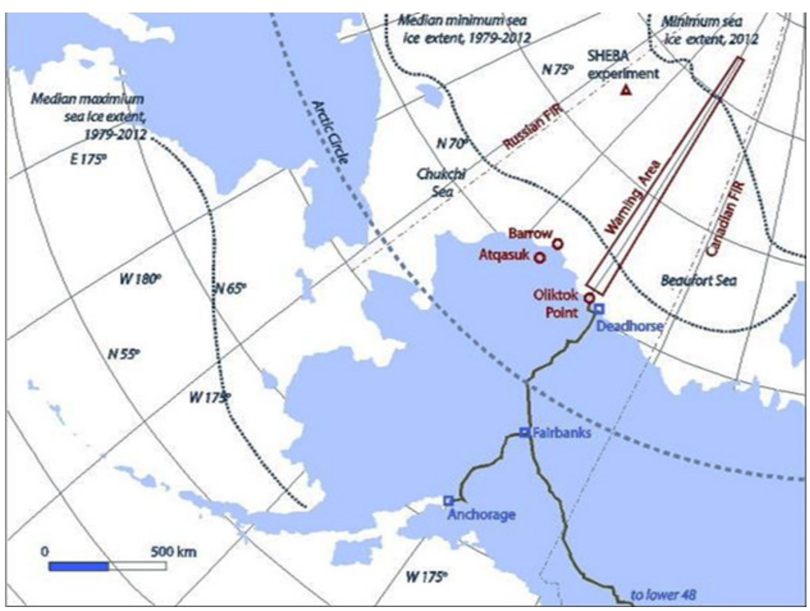

Figure 2. Warning Area (W-220) north of Oliktok Point.

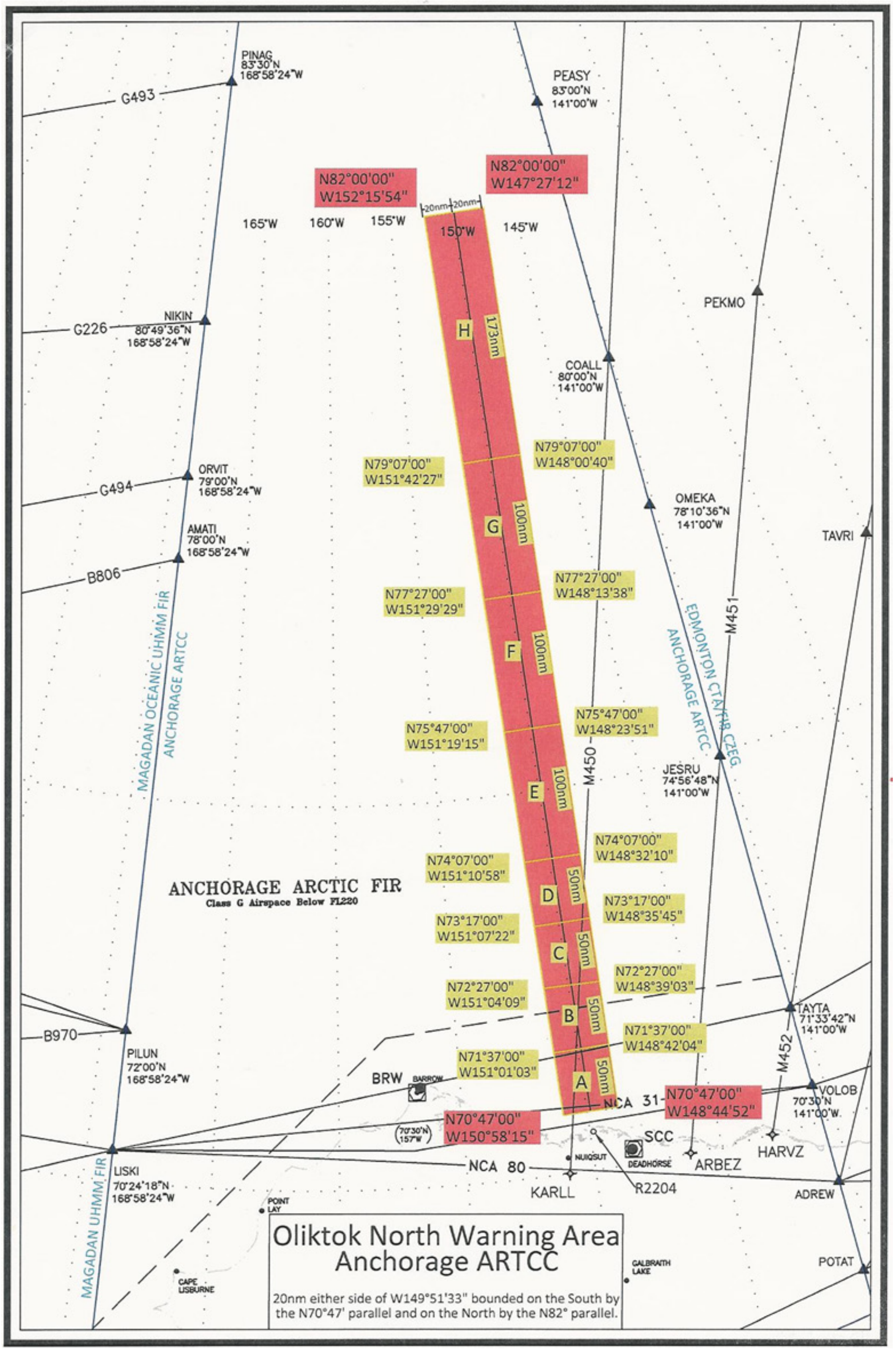

Figure 3. Detail of the Warning Area (W-220) north of Oliktok Point with the capability of activating individual segments.

3. SNL and ARM are working with the FAA to obtain access to long-range radar and air traffic information for the Oliktok Point area. This information is essential for operations beyond line of sight at Oliktok Point. International airspace W-220 starts about 12 miles offshore from Oliktok Point.
4. Baseline ARM measurements provide important information for flight operations in the Oliktok Point area, including upper air wind speeds, cloud height, dew point, cloud type, and related information. Making these data available in near-real time will assist aerial operations.

Figure 4. AMF3 at Oliktok Point.

5. Oliktok Point has road access and connects to the trans-Alaskan (the “haul” or “pipeline”) road. The ability to ship equipment via truck to Oliktok Point is a major logistical advantage over sites that have only air or ocean shipment options.
6. A network of collaborating organizations has been established that can provide important services for UAS operations and field campaigns (e.g., medical facilities in the event of an emergency).
7. Prior campaigns hosted at Oliktok Pont (e.g., MIZOPEX, Arctic Shield 2015) have established important precedents and proven processes for offshore UAS operations there. The DOE-controlled Warning Area (W-220) has effectively facilitated operations in international waters north of Oliktok Point.

Figure 5. (a) NASA Sierra UAV at Oliktok Point during MIZOPEX, and (b) use of the ScanEagle UAV in W-220 International Warning Area during US Coast Guard Arctic Shield 2015 search-and-rescue exercise.

4.0 Southern Great Plains, Oklahoma

The Southern Great Plains Site (SGP) is extensively instrumented with a network of intermediate and extended facilities that provide information over a domain intended to represent a Global Circulation Model (GCM) grid box. In 2016, SGP added additional instrumentation and configured the layout to support observation assimilation through the LES ARM Symbiotic Simulation and Observation (LASSO) Workflow. Campaigns early in this configuration have used the SGP as a hub or anchor point for integrated field campaigns. The Plains Elevated Convection at Night (PECAN) experiment extended from

SGP to northern Kansas, seeking to improve the understanding and simulation of processes that initiate and maintain convection and convective precipitation at night over the central U.S. Great Plains. The Enhanced Soundings for Local Coupling Studies addressed how ARM could better observe land-atmosphere coupling to support the evaluation and refinement of coupled weather and climate models through high-temporal-resolution measurements of surface turbulent heat fluxes and boundary-layer properties.

To advance understanding about these types of research questions, scientists have begun seeking a UAS component to vertically extend in situ observations. Both CLOUD MAP and the Environmental Profiling and Initiation of Convection (EPIC) Cal/Val campaigns involve multiple UAS platforms capable of carrying payloads from <1 to 15 lbs. Proposed campaigns show increased need for UAS and high potential for collaborative campaigns.

The SGP Central Facility (CF) is hosting fixed-wing and rotor UAV with varied take-off and land locations. Extended facility (EF) and intermediate facility (IF) needs are assessed specific to the proposal needs. EF and IF instrumentation have a minimal footprint requiring coordination with land owners for UAS operations.

Most of SGP resides under FAA Wichita Air Traffic Control (ATC) airspace, with U.S. Air Force Military Operations Area (MOA) above 7000 feet. Users are expected to obtain all necessary aviation permissions for flight operations.

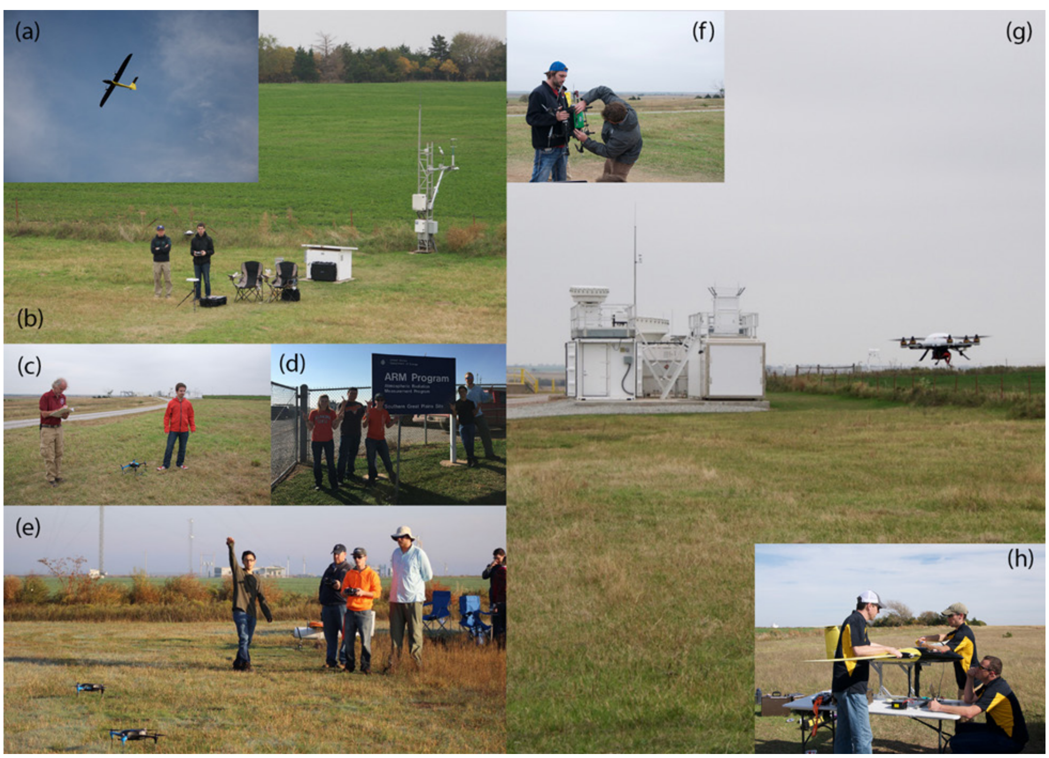

Figure 6. (a) CLOUDMAP University of Colorado TTwister, (b) EPIC Meteomatics participants and Meteodrone, (c) EPIC University of Oklahoma participants, (d) CLOUDMAP Oklahoma State University participants, (e) CLOUDMAP Oklahoma State University and IRIS, (f), EPIC University of Oklahoma participants and CopterSonde, (g) Meteomatics Meteodrone, and (h) University of Colorado participants and TTwistor.

5.0 ARM Mobile Facilities (AMF) and Eastern North Atlantic (ENA) Sites

ARM operates the ENA fixed facility on Graciosa Island, Portugal. Operational since 2013, the site adjacent Graciosa Aeroporto may be able to provide support for UAS use following UAS regulatory approvals from the airport operators and from Portuguese National Institute of Civil Aviation (Autoridade Nacional de Aviação Civil; ANAC). The ENA Site Manager will facilitate and coordinate requests to operate UAS with the relevant Portuguese authorities. Additional consideration should be given to the time required to request Portuguese regulatory approval.

The ARM AMF provide a unique opportunity for the scientific community to leverage AMF deployment capability in often remote and climatically under-sampled locations. The necessary steps to obtain UAS operations approval will vary considerably depending on location. Proposals for UAS support will be considered on a case-by-case basis. The AMF Site Manager will facilitate and coordinate requests to local authorities; however, in-country support given to foreign (US) UAS operations may be problematical and require significant lead times.

6.0 Implementation

The implementation will be multi-pronged.

1. ARM will continue to host UAV and TBS activities at NSA and SGP. These include:
   a. Collaborative operations with federal agencies
   b. Collaborative operations with academic institutions and industrial partners.
2. ARM will build up in-house UAS capabilities. These capabilities will be used to establish a robust observations program at NSA followed by other ARM sites. As each of these capabilities mature, they will become available to the scientific community through the IOPR process.
3. Sandia National Laboratories (NSA Mega-Site Management) and Pacific Northwest National Laboratory (AAF) will jointly implement the ARM UAS Program.
4. ARM intends to host UAS activities at ENA and at AMF sites. These include:
   a. Collaborative operations with federal and foreign agencies
   b. Collaborative operations with academic institutions
   c. RM AAF UAS activities.

6.1 Platforms of ARM UAS Program

We plan to build capabilities based on a range of platforms: tethered balloons, small UAV (FAA 107 designation[1]) and Group 3 (DoD designation[2]) fixed-wing UAV.

---

[1] https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=20516

[2] https://en.wikipedia.org/wiki/U.S._military_UAS_groups

6.1.1 Tethered Balloons

Instrumented tethered balloons have been operated at Oliktok Point as part of ARM operations since 2004. Tethered balloons offer a safe, affordable, and proven means to place instrumentation inside mixed-phase or icing clouds. In fall of 2014, a short engineering evaluation (Coordinated Observations of the Arctic Lower Atmosphere; COALA) in conjunction with University of Colorado/Boulder Cooperative Institute for Research in Environmental Sciences (CIRES) demonstrated the value of tethered balloons. In this 2014 exercise, tethered balloons were operated concurrently with a small UAV for enhancement of the final data set value. Concurrent flights and data collection have continued at Oliktok Point during 2015 and 2016, with TBS operations also conducted at Utqiagvik (formerly known as Barrow; BRW) in 2016.

In particular, TBS and (and sUAV, see next section) observations were carried out under an ARM engineering activity called Inaugural Campaigns for ARM Research using Unmanned Systems (ICARUS). The science goals and mission parameters of ICARUS were defined as an outcome of the Oliktok Point Summer 2016 UAS/TBS Activities Planning Meeting by the Oliktok Point Science Team, ARM representatives and Oliktok Point Operators, 26-27 January 2016 in Boulder, Colorado. During ICARUS, TBS and sUAV collected in situ measurements of the vertical profile as well as near-surface measurements in the region around Oliktok Point. TBS flights were also conducted in Utqiagvik, Alaska, in July 2016.

Table 1. ICARUS TBS activity summary.

Month	Total Flight Duration	Baseline Instruments	Non-baseline instruments	Comments
April 2016	11 hrs	All	Distributed Temperature Sensing (DTS), iMet radiosonde B (RSB)	First use of DTS at Oliktok Point.
May 2016	14 hrs	All	DTS, iMet RSB	Flights conducted high-vertical-resolution characterization of thermodynamic state, and other properties, of the cloud top region.
June 2016	24 hrs	All	DTS, iMet RSB	Operational strategy similar to May 2016 with the addition of simultaneous DataHawk UAS flights.
July 2016	10 hrs	None	iMet RSB, Printed Optical Particle Spectrometer (POPS), miniSASP	Ten hours of TBS flights were conducted at the ARM NSA site in Utqiagvik.

July 2016	7.5 hrs	All	DTS, iMet RSB, POPS	First use of POPS at Oliktok Point.
October 2016	33 hrs	All	DTS, iMet RSB, POPS Video Ice Particle Sampler (VIPS), Turbulence Pod	Cloud, wind, and aerosol profiling flights were conducted. Solid precipitation particle microphysics measurements and cloud turbulence measurements were also collected. Simultaneous DataHawk UAS flights were conducted. First use of TBS for AMF3 radar calibration.

SNL has and will continue to enhance ARM's tethered balloons capability at Oliktok Point leading to routine observations as much as meteorological conditions allow. This includes coordination to develop and fly new sensors and systems with ARM partners and researchers.

(a) 

(b) 

(c) 

(d) 


(e)

Figure 7. Tethered balloon operations at Oliktok Point: (a) launch of a helikite TBS, (b) concurrent flights of an aerostat balloon (high altitude) and DataHawk small UAS (low altitude), (c) concurrent preparations for flight of aerostat balloon and a Pilatus small UAS, (d) three balloon sizes at Oliktok Point (L-R): Helikite, sonde and aerostat, e) image of aerostat above Oliktok Point. The image was taken by a camera on the small DataHawk UAV.

6.1.2 Small Fixed-Wing UAV

PNNL has procured 4 DataHawk small UAV (including a ground-control station) built by the University of Colorado/Boulder (CU/B). The DataHawk is a small (wingspan 1 m), light (700 g), and relatively inexpensive UAV. It has a static 80-g payload measuring location, altitude, pressure, temperature, humidity, wind speed, turbulence, and surface temperature. The DataHawk can be launched in different ways: by hand, from a portable bungee launcher, or dropped from a balloon. The DataHawk has an endurance of about 40 minutes and in some ways can be viewed as a steerable radiosonde.

AAF pilots have been trained in DataHawk operations and have commenced a routine flying program with DataHawks at Oliktok Point called ICARUS (see above). Under ICARUS 2016, AAF carried out six weeks of DataHawk operations in the summer of 2016 at Oliktok Point. A large data set of boundary-layer observations (including the parameters mentioned above) were obtained in over 60 science flights, on 23 days, with a total flight time of more than 36 hours. The data are available from the ARM Archive. Additional AAF conducted DataHawks flights are planned at Oliktok for the summer of 2017. The science community will be asked for input to the design of this mission at the ARM/ASR PI meeting in spring 2017. Beginning in 2018, DataHawk missions may be proposed to ARM as part of the large facility call to augment data at any of the ARM fixed sites or AMF locations.

It should be mentioned that for ARM, AAF, and PNNL, the DataHawk project has had the additional benefit of being a pilot project paving the way for the successful procurement and operations of larger, more complex and expensive UAV.

SNL has also hosted DataHawks flown by CU/B at Oliktok Point in several campaigns: MIZOPEX (2013), COALA (2014), and ERASMUS (2015, 2016).

Figure 8. A DataHawk small UAV on a desk.

6.1.3 Group 3 UAV

UAV are ideal to address a subset of the science questions spelled out in the reports listed in section 1 if they have the capacity to carry and power the appropriate instrumentation. A Group 3 UAV is most desirable to address this need. A large number of platforms from different vendors are available in this segment. PNNL published a Request for Information on the FedBizOps website. This allowed potential vendors to express their interest to receive a Request for Proposal (RFP). The specifications used in the RFP were derived from the science requirements defined in the reports listed in Section 1 and in meeting with the ARM UAS Advisory Group (see below). On Feb 16, 2016 PNNL signed a contract with Navmar Applied Sciences Corp. for a TigerShark XP system modified for arctic conditions (dubbed ArcticShark). AAF should be in possession of the entire package (including pilot and maintenance training, and acceptance testing) by January 2017.

Our vision is to implement regular flights anchored at Oliktok Point. Eventually, ArcticShark observations should connect the BRW and AMF3 sites and extend an equal distance out over the Arctic Ocean. AAF is in the process of acquiring and testing baseline instruments for the ArcticShark (see below). Eventually investigators will be able to propose guest instruments and science missions using the ArcticShark.

Figure 9. AAF ArcticShark on runway at Griffiss Airport, Rome, NY.

Table 2. Technical specifications of AAF ArcticShark.

Wingspan	21' 3"
Length	14' 3"
Empty Weight	427 lbs
Max Gross Take-off Weight	625 lbs
Max Payload	100 lbs
Payload Power	2,500 W
4 Underwing Hardpoints	
Max Altitude	15,000 ft
Endurance	10-12 hours
Iridium SatCom (Beyond-Line of Sight Ops)	

6.2 Elements of ARM UAS Program

Figure 10. Elements of the proposed ARM UAS Program.

6.2.1 Advisory Board

We have established a small ARM UAS Advisory Board of roughly five members. This board reports to ARM management. This advisory board helps establish priorities for procurements, resource allocation, and flight operations based on science needs.

6.2.2 Safety and Risk Management

A strong aviation safety culture exists at ANL, LANL, PNNL, and SNL and is essential to the safe execution of UAS operations. All four labs have an Aviation Safety Point of Contact. The DOE Site Offices at the four labs also have a DOE Aviation Safety Officer. The labs work closely with the DOE Office of Aviation Management (OAM).

A separate document "Unmanned Aerial System Operation Safety at ARM Sites" is under review by the DOE Office of Aviation Management (OAM) and the DOE Aviation Safety Officers at the partner labs.

6.2.3 Training and Qualification

Training and qualification requirements for UAS crew members are defined in the "Unmanned Aerial System Operation Safety at ARM Sites" document.

6.2.4 Maintenance

A maintenance program is being provided by the vendor of the ArcticShark Group 3 UAV and is being attended by AAF Aircraft Mechanics. Maintenance for small UAVs and TBS is typically performed by crew members onsite. If significant repairs are required, equipment is generally returned to the manufacturer.

6.2.5 Instrumentation

For TBS and the Group 3 UAV, payloads can be designed based on science needs (see categories in Table 3). Such instruments have to be highly miniaturized and fully autonomous. We have started procurement of instrumentation based on availability and measurement needs outlined in the foundational documents on which this report is based. UAS instruments for imaging, radiometry, and to measure atmospheric state variables are widely available. UAS instruments to measure clouds, aerosols, and gases are coming online rapidly. Instruments procured/planned are shown in Tables 4, 5, and 6. We have tested and characterized the acquired UAS instrumentation in the lab as well as on the AAF Gulfstream-1 manned aircraft by comparing their measurements with those made by their established traditional-size siblings. Instruments currently in development can be added later either as guest instruments or as baseline instruments. Developing the next generation of UAS sensors through the Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) program has been ongoing for some time and needs to be well integrated with the ARM UAS Program outlined here. In addition, ARM will periodically sponsor targeted UAS instrumentation calls. ARM has successfully used this process for hardening/maturation of instrumentation for manned aircraft.

Integration of instrumentation onto UAS poses challenges quite different from doing so for the much larger manned aircraft. However, UAS vendors and their industrial partners are quite interested in collaborating with ARM on integration tasks.

Table 3. Categories of UAS instrumentation of interest to ARM.

Category	Measurement
1	Atmospheric thermodynamics
2	Radiation (broad band and spectral, SW and LW)
3	In situ aerosol properties
4	In situ cloud properties
5	In situ gas phase
6	Passive remote sensing (imaging, non-imaging, any wavelength)
7	Active remote sensing (any wavelength)

Table 4. Instruments currently available for TBS.

Measurements	Instrument	Manufacturer	Weight (kg)	Comment	Category
Meteorological sensor	Tethersondes	Anasphere	0.74	Weight with batteries; measures P, T, RH, wind speed	1
Water phase	Supercooled Liquid Water Content (SLWC)	Anasphere	0.2	Weight with batteries	4
Liquid water	Wetness Sensor	Campbell Scientific	0.14	Weight with batteries	4

Table 5. Instruments in development for TBS.

Measurements	Instrument	Manufacturer	Weight (kg)	Comment	Category
Aerosol Size Distribution	Printed Optical Particle Spectrometer (POPS)	Handix	0.8	140-3000 nm	3
Temperature	Oryx Distributed Temperature Sensing (DTS)	Sensornet	0.027/ m of fiber	Temperature every 1m along tether	1
Aerosol optical depth profile	Mini Scanning Aerosol Solar Photometer (MiniSASP)	NOAA	2.7	Clear-sky operation only	3

Ice particle size distribution and habit	Video Ice Particle Sampler (VIPS)	NCAR	2.7	High-resolution imagery of particles up to 1 mm	4
Turbulent motions involved in fundamental cloud processes	Turbulence Pod	University of Leeds	3.2	Motion-corrected earth-relative turbulent winds and derived turbulence quantities	4
Meteorological Sensor and Data Transmission for Varied Sensors	iMET-1-RSB Radiosondes	International Met Systems	0.26	Measures P, T, RH and transmits SLWC and POPS data	1

Table 6. Baseline instruments for Group 3 UAV.

Measurements	**Instrument**	**Manufacturer**	**Weight [kg]**	**Comment**	**Category**
Meteorological sensor	Aircraft-Integrated Meteorological Measurement System (AIMSS-30)	Aventech	1.1	RH, P, T, Wind speed and direction	1
Radiometry	Upwelling SW (no mask) (SPN-1)	Delta-T Devices	1.4		2
	Downwelling SW (1 unit with/1 without mask) (SPN-1)	Delta-T Devices	2.8		2
	Upwelling IR (IR20)	Huskeflux	1.5		2
	Downwelling IR (IR20)	Huskeflux	1.5		2
Aerosol number concentration	Mixing Condensation Particle Counter (MCPC-1710)	Brechtel	2.7	$D_p > 7$ nm	3

Aerosol Chemical Composition	Multi-Channel Chemical Sampler (CHEM)	Brechtel	0.5	8 channels, sample flow 3 lpm	3
Aerosol Size Distribution	Printed Optical Particle Spectrometer (POPS)	Handix	0.8	140 - 3000 nm	3
	Optical Particle Counter	Brechtel	1.4	0.1-10 µm	3
Aerosol Light Extinction	Single-channel Tricolor Absorption Photometer	Brechtel	0.9	Wavelengths: 450, 525, 624 nm	3
Cloud Droplet Size Distribution	Cloud Droplet Probe (CDP-2)	Droplet Measurement Techniques (DMT)	1.4	2-50 µm	4
Gases	CO_2 and H_2O	LICOR LI-840 a	1.0		5
Remote sensing	Video camera (multiband)	TBD			6
	IR imager	TBD			6

6.2.6 Operations

6.2.6.1 Planning and Review Process

Following IMB approval, any and all proposed UAV and TBS operations at any ARM site must undergo a detailed planning and review process. Details are provided in “Unmanned Aerial System Operation Safety at ARM Sites”.

6.2.6.2 TBS Operations

Typical staffing required: 1 operator, 1 observer, 1-3 balloon handlers (during launch and retrieval, varies with balloon size and wind condition), 1 Range Safety Officer, 1-2 payload scientists (if required for new sensors, etc.). Multiple roles are typically performed by the same individual.

TBS operations conducted by SNL are planned again for the summer of 2017 at Oliktok Point. Beginning in 2018, TBS missions can be proposed to ARM as part of the large facility call to augment data at the Oliktok Point site.

6.2.6.3 Small UAV Operations

Typical staffing required: 1 operator, 1 observer, 1 Range Safety Officer.

DataHawk operations conducted by AAF are planned for the summer of 2017 at Oliktok Point. Beginning in 2018, DataHawk missions may be proposed to ARM as part of the large facility call to augment data at any of the ARM fixed sites or AMF locations.

6.2.6.4 Group 3 UAV

Typical staffing required: 2 UAV operators, 1 UAV technician, 1 Range Safety Officer, and 1 -2 payload scientists. Additional staffing is usually needed to set up the UAV and its payload.

The main steps to arriving at a robust flying program with a Group 3 UAV are depicted in the milestone table below.

Table 7. Milestones for Group 3 UAV (ArcticShark).

Milestone	Date
Maintenance Technician Training for (2) on TigerShark by NASC, Rome NY	Nov/Dec 2016
Pilot training for (3) on TigerShark by NASC, Rome, NY	Nov/Dec 2016
Acceptance and flight testing of TigerShark XP by NASC, Rome, NY	Jan 2017
Delivery and Acceptance of TigerShark XP, Pasco, WA	Jan 2017
Training flights (no payload), Pendleton, OR	Feb/Mar 2017
Complete lab testing of AAF owned UAS instrumentation	Jul 2017
Complete integration of initial payload onto TigerShark XP	Aug 2017
TigerShark XP engineering/test flights (Pendleton, OR) with small payload	Sep through Nov 2017
Science/engineering flights Oliktok, AK	May+Aug 2018
TigerShark XP available for missions proposed (Oliktok)	May through Aug 2019

6.2.7 Data Management

The ARM Data Management Facility (DMF) currently receives and processes raw data collected from the four fixed sites and three mobile facilities hourly. The proposed plan is to integrate the UAV and TBS data flow with the routine data flow of the ARM Facility. Raw and processed data will be packaged and sent to the ARM Data Archive, after initial quality assurance, for distribution to the scientific community. The DMF will also be responsible for running ingests that will convert the raw data to a standard format. Value-Added Products can be developed to combine and merge data sets. The DMF will work closely with developers, mentors, and site scientists for UAV and TBS IOPs to ensure processes are run efficiently and monitored. The DMF will leverage existing ARM tools to monitor the data and alert UAS operators when data flow is disrupted.

Monitoring the data flow helps in early detection of malfunctioning instruments. Integrating data flow with routine ARM products will help in easy discovery, data assimilation, and real-time analysis of data. Storing data in the archive will also help in providing notification to the users when a data set has been reprocessed.

Most of the current AAF data is arriving at the archive through the External Data Center (XDC). To take advantage of the services and processes of the DMF outlined above, we are migrating AAF data sets from the XDC to the DMF where routine data collected by ARM is deposited. For the UAS and TBS data, we intend to use the DMF route from the onset as described above.

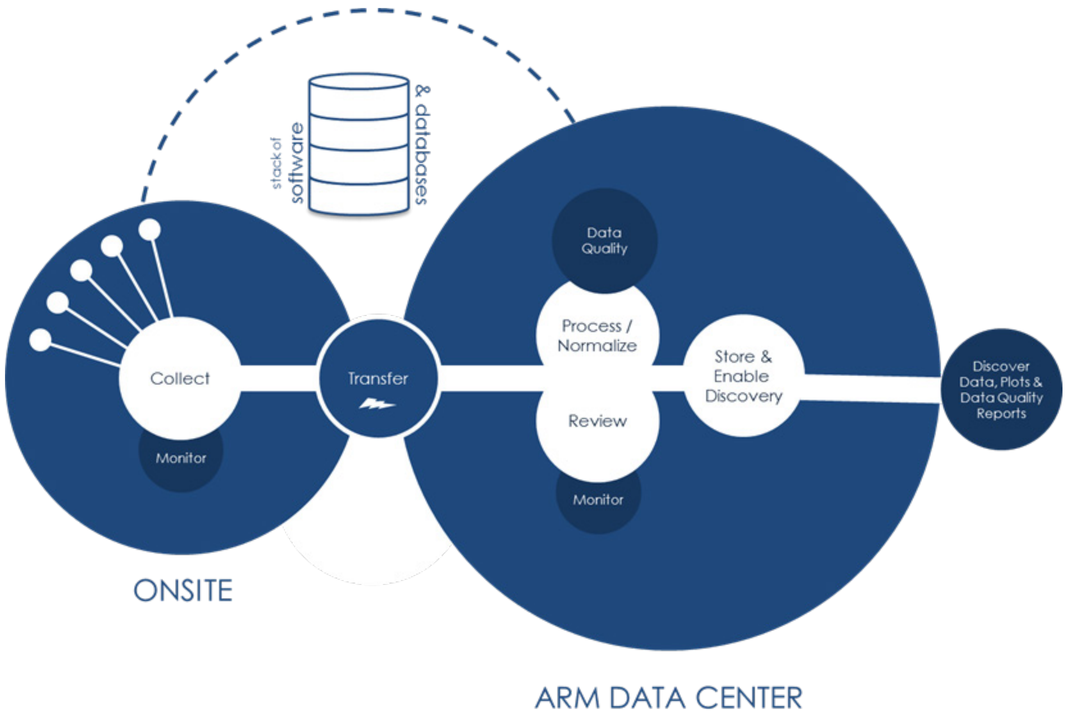

Figure 11. Data flow from the sites through the DMF to the ARM Data Center.

ARM
CLIMATE RESEARCH FACILITY

www.arm.gov

U.S. DEPARTMENT OF
ENERGY

Office of Science