U.S. DEPARTMENT OF ENERGY | Office of Science

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.

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ARM
CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

AMAP	Arctic Monitoring and Assessment Programme
ARM	Atmospheric Radiation Measurement
ASCOS	Arctic Summer Cloud Ocean Study
ASR	Atmospheric System Research
BER	Biological and Environmental Research
CESD	Climate and Environmental Sciences Division
CESM	Community Earth System Model
COA	Certificate of Authorization
CULPIS	University of Colorado Lidar Profilometer and Imaging System
DOE	Department of Energy
ERASMUS	Evaluation of Routine Atmospheric Sounding Measurements using Unmanned Systems
ESM	Earth System Modeling
FAA	Federal Aviation Administration
IARPC	Interagency Arctic Research Policy Committee
ISDAC	Indirect and Semi-Direct Aerosol Campaign
MIZOPEX	Marginal Ice Zone Observations and Processes Experiment
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
MSL	Mean sea level
RCGM	Regional and Global Climate Modeling
SBIR	Small Business Innovation Research
SHEBA	Surface Heat Budget of the Arctic
SLCF	Short-lived climate forcers
TES	Terrestrial Ecosystem Science
UAS	Unmanned aircraft systems

Executive Summary

The Arctic is experiencing rapid climate change, with nearly double the rate of surface warming observed elsewhere on the planet. While various positive feedback mechanisms have been suggested, the reasons for Arctic amplification are not well understood, nor are the impacts to the global carbon cycle well quantified. Additionally, there are uncertainties associated with the complex interactions between Earth's surface and the atmosphere. Elucidating the causes and consequences of Arctic warming is one of the many goals of the Climate and Environmental Sciences Division (CESD) of the U.S. Department of Energy's (DOE) Biological and Environmental Research (BER) program, and is part of the larger CESD initiative to develop a robust predictive understanding of Earth's climate system.

Through the activities of its Atmospheric Radiation Measurement (ARM) Climate Research Facility, CESD is at the forefront of utilizing unmanned aircraft systems (UAS) as a tool to address science questions relating to Arctic research. Valuable data from remote and logistically difficult locations are needed to build statistical information required to advance climate models. DOE atmospheric researchers use unmanned aircraft to study problems requiring frequent or long-duration observations in locations not easily or safely accessed by manned aircraft.

Presently the ARM site at Oliktok Point on the North Slope of Alaska contains the only restricted airspace (R-2204) in the Arctic, which makes it ideal for conducting UAS operations on a routine basis. In July of 2013, a meeting was held to discuss recent DOE investments in ARM's North Slope infrastructure, with an emphasis on how these and future investments could support ongoing high-priority CESD research on atmospheric and ecological systems in the Arctic. The discussions also included required measurements of sea ice, and how knowledge of these coupled systems could be used to develop accurate input into CESD's Community Earth System Models.

Participating atmospheric scientists agreed that there is a major gap in the understanding of mixed-phase clouds and the thermodynamic structure of the Arctic atmosphere, and that unmanned aircraft could provide much of the data needed. Basic process-oriented research is needed, with an emphasis on obtaining accurate data concerning the thermodynamic and microphysical structures of the lower layers and fluxes through those layers. High temporal and spatial resolution will be required. It was agreed that airborne atmospheric research will benefit enormously from contemporaneous ground-based observations that will be available during the long-term deployment of ARM Mobile Facility 3 (AMF3) at Oliktok Point, Alaska. Meeting participants strongly recommended that atmospheric measurements from UAS and tethered balloons be initiated to address current high-priority science questions.

Ecologists identified soil moisture, surface temperature, and elevation as key variables that could be advantageously measured from UAS. The importance of surface imagery, including observations of inundation, was also emphasized. The group agreed that the needed observations could be implemented using existing sensor technology modified for UAS. Other airborne capabilities developed and tested at Oliktok Point could be applied to CESD's Next-Generation Ecosystem Experiments-Arctic, which includes field sites in Alaska. The meeting also included discussions on the linkage between the Earth's surface and the atmosphere and the role of this relationship in the models. The discussions addressed ice sheets and the interaction between the atmosphere and the ocean.

Participants discussed measurements that could fulfill both near- and long-term objectives for observing the atmosphere and Earth's surface (Table 2). It was agreed that some data, including basic meteorological measurements and surface imaging, could be obtained using currently available miniaturized instrumentation and could be implemented on existing unmanned aircraft in the near-term or intermediate-term. But longer-term measurements are also desired. Some of these would require new sensing technology or aircraft or would involve operating parameters that are currently unallowable or are cost prohibitive. Achieving CESD goals in the Arctic will require spatially and temporally distributed observations of atmospheric state and surface conditions. The necessary spatial resolution can likely be obtained only with navigable aircraft, manned or unmanned, although tethered balloons will remain important for some campaigns, particularly those requiring long-duration measurements.

Broadly, two types of observational data sets are needed:

1. Process-level study data sets with detailed characterization of surface ice state, atmospheric thermodynamic state profiles, cloud properties, and short- and long-wave radiation measurements, and
2. Climate-scale observations for regional evaluation of the mean atmospheric and surface state and their temporal and spatial variability.

The data sets needed for climate model assessment require regular measurements over multiple seasons deep into the Arctic Ocean basin, with flights extending from the coastal plains across the coast and over the marginal ice zone. Such data sets can capture the seasonal, inter-annual and spatial variability (i.e., "large system variability") of atmospheric and surface states. These observations can best be conducted by small, unmanned aircraft.

The proposed activities provide an opportunity for DOE to develop a strategic plan for utilizing UAS platforms in the region, given the remoteness of the region and extreme weather conditions that are dangerous to manned aerial missions. The plan should include leveraging UAS, tethered balloon systems, ground measurement capabilities from the AMF3, and other proposed observations to enhance the understanding of the processes involved in the Earth system relationship in the region.

1.0 Introduction

1.1 Purpose of the Meeting

The Arctic is particularly sensitive to climatic change, with far reaching implications for the rest the planet. A major goal of the U.S. DOE CESD BER program is to understand changes that are taking place in the Arctic, with the aim of improving the predictive capability of regional and global climate models (See Strategic Plan[1]). One way that CESD advances this goal is through support of research programs and a scientific user facility, the ARM Climate Research Facility. ARM has nearly two decades of experience in Arctic atmospheric observations and facility support.

CESD programs are invested in research examining Arctic atmospheric and terrestrial processes, with the goal of bettering the representation of these processes in climate models. The Atmospheric System Research (ASR) Program focuses on Arctic clouds and aerosols and their influence on the radiation budget. The Terrestrial Ecosystem Science (TES) Program, as one of its foci the Next-Generations Ecosystems Experiment Arctic (NGEE-Arctic) project, is addressing terrestrial impacts of climate change and feedbacks to the carbon cycle. CESD also supports the Earth System Modeling (ESM) Program, which incorporates data and process-level models from ARM, ASR and TES.

The following are CESD research priorities:

- Developing Earth system models and strengthening the predictive understanding of climate
- Advancing studies to enhance the understanding of atmospheric and terrestrial system processes
- Understanding and predicting biogeochemical processes in subsurface environments
- Utilizing CESD’s user facilities for experimental studies designed to achieve unprecedented understanding of Earth’s dynamic processes.

The ARM Climate Research Facility provides the climate science community with strategically located *in situ* and remote sensing observatories designed to improve the understanding and representation in climate and Earth system models of clouds and aerosols as well as their interactions and coupling with the Earth’s surface. ARM operates these remote sensing observatories in climatically distinct locations to sample continental and marine conditions in tropical, mid-latitude, and Arctic environments (Figure 1). There are four fixed sites (U.S. Southern Great Plains, Tropical Western Pacific, North Slope of Alaska, and the Azores) and three mobile facilities that are used in experiments across the globe in under-observed regions critical for model improvement. ARM also has an aerial measurement capability to complement the ground measurements.

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[1] http://science.energy.gov/~/media/ber/pdf/CESD-StratPlan-2012.pdf

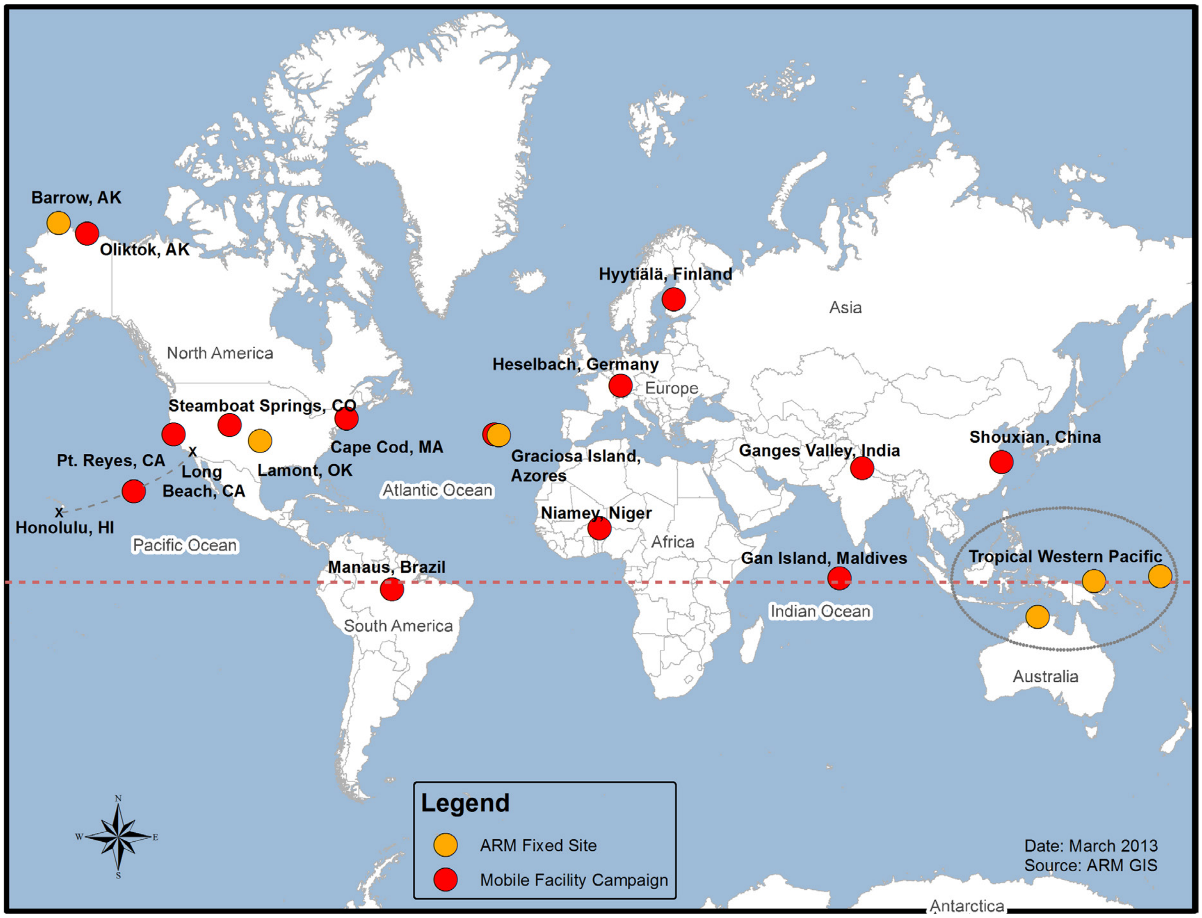

Figure 1. Global distribution of ARM facilities and deployments.

As a DOE user facility, ARM serves the broad climate research community and with CESD has close working relationships with ASR and TES.

The extreme environmental conditions of the Arctic present significant challenges to the use of aircraft for scientific research. The prevalence of inclement weather, including extreme cold, low clouds, strong and gusty winds, and severe icing conditions, along with the difficulty of performing rescue operations, can make manned aviation activities particularly risky. To mitigate risks to personnel, there is a need for UAS, which in this report includes fixed-wing platforms, rotorcraft (e.g., multicopters) and tethered balloons.

Because of its focus on clouds, and the inherent danger of flying into clouds containing ice, ARM will utilize *in situ* measurements from UAS and tethered balloon systems and ground measurements from its Third Mobile Facility (AMF3) to understand cloud processes in the region. ARM has used UAS platforms in the past[2] to address anomalous radiation absorption at its Southern Great Plains site (Stephens et al., 2000). ARM has conducted campaigns with balloons on the North Slope of Alaska, beginning with the Mixed-Phase Arctic Cloud Experiment (M-PACE) in 2004, and Indirect and Semi-Direct Aerosol Campaign (ISDAC) in 2008.

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[2] http://www.arm.gov/sites/aaf/uavcampaigns

To better define the scope of research that might involve UAS on the North Slope of Alaska over the next several years, Sandia National Laboratories recently hosted a meeting of approximately thirty science experts. This meeting, titled "Planning and Operational Meeting on Polar Atmospheric Measurements Related to the DOE ARM Program Using Small Unmanned Aerial Systems and Tethered Balloons," was held July 24 to 26, 2013, at the American Association for the Advancement of Science facilities, 1200 New York Avenue NW, Washington D.C. (see Appendix A for the original Meeting Agenda). Participants represented ARM, ASR, Climate and ESM, and TES programs within CESD as well as 16 additional institutions, including other U.S. federal agencies and programs, national laboratories, research universities and private manufacturers of meteorological sensors (see Appendix B for full list of participants).

The objective of this meeting was to develop recommendations for ARM priorities for the utilizing of UAS, including tethered balloons, in the Arctic. This meeting built on progress made in the broader 2004 interagency workshop "Utilization of UAVs for Global Climate Change Research" sponsored by NOAA, NASA, and DOE.

Meeting presentations and discussions at this meeting focused on the following topics:

- Atmospheric modeling gaps. What measurements are needed in order to improve the representation of clouds in models used by DOE researchers?
- Ecological experiments. How can unmanned aircraft serve the observational needs of Arctic ecologists, particularly DOE's NGEE-Arctic?
- Recent technological advances. How can improved sensor technologies and UAS capabilities be used to meet these observational needs?

This document summarizes the key recommendations from the meeting and also provides information on current facilities and capabilities in the Arctic. Presentations from the meeting are available on the web[3] to meeting participants and ARM collaborators. (For access to this wiki site, contact Tonya Martin at Pacific Northwest National Laboratory, tonya.martin@pnnl.gov.)

1.2 Perspective: Data Needs for Arctic Models

Surface temperatures in the Arctic have risen at almost twice the rate compared of rest of the world for the last few decades, resulting in broad-ranging changes on land, at sea, and in the atmosphere. Recent observations reveal multi-year reductions in perennial sea ice and summer sea-ice extent, increased permafrost melt, and shifts in ecosystems—all indicators of regional climate change—with likely global repercussions. As a result, there has been a sustained interest in studying processes that might contribute to the accelerated changes seen in the Arctic, and on understanding and predicting the nature of future impacts.

The workshop focused on those measurements that would improve the understanding of processes and their representation in models, including atmospheric processes, sea-ice impacts, and terrestrial ecological systems.

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[3] https://wiki.arm.gov/bin/view/PolarUAS/WebHome

1.2.1 Observing the Arctic Atmosphere

Arctic amplification, or greater change in the climate near the poles compared to the rest of the planet, is a poorly understood characteristic of Earth's climate system (Serreze et al. 2009). Of particular concern is the decline in perennial sea ice and summer sea-ice extent (Markus et al. 2009). Various factors contributing to this decline have been identified, including the ice-albedo feedback, decreasing concentrations of sulfate aerosols, increasing concentrations of black carbon, inherent climate variability coupled with long-term ice loss, ongoing increases in greenhouse gas concentrations, changes in Arctic cloudiness and specific humidity, and the inflow of warmer ocean water (IPCC 2007). It seems likely that each of these contributes in a complicated, nonlinear way to changes in perennial and summer sea ice (Roberts et al. 2010). As a consequence, the variability in the prediction of climate trends is much greater in the Arctic than anywhere else on Earth. This uncertainty derives from the contribution of ice and snow in higher latitudes to climate trends through the ice-albedo feedback. The magnitude of this feedback remains uncertain because it is coupled to cloud processes and ocean heat transport (Inoue et al. 2006; Tjernstrom et al. 2008; Kay and Gettelman 2009).

Recent studies suggest that sea-ice retreat, as depicted by the summer ice edge, is correlated closely to an upward trend in the downwelling, long-wave radiative flux in the Arctic springtime. Increasing downwelling long-wave flux is driven mostly by increases in atmospheric water vapor and low-level clouds, the properties of which depend on the aerosol layers the cloud can access. The water vapor and aerosols necessary for cloud formation may originate locally from open ocean water or may be advected into the local area from distant sources. This coupling between the underlying ocean/ice surface and the critical atmospheric layers is poorly understood. For example, an assessment of the Community Climate System Model 4 (CCSM4), one of the contributing models to the Community Earth System Model (CESM), reveals large biases in the strength of the lower troposphere inversion, resulting in significant biases in clouds and their radiative impacts (de Boer et al. 2012).

Analyses of data from intensive observation periods with manned aircraft revealed clouds embedded in complex thermal and vapor fields with large spatial and temporal variability. Most studies thus far have focused on a few days when conditions were ideal for flying close to land. The conclusions of these studies have yet to converge to accepted interpretations for relatively simple atmospheric structures (single layer decoupled from surface) (e.g., Avramov et al. 2011; Solomon et al. 2011). Our limited knowledge of the structure and processes of the atmosphere in the deep Arctic during winter comes primarily from a single experiment, the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment, conducted from September of 1997 through October of 1998.

As with the UAS campaigns proposed for Olitkok Point, SHEBA was motivated by discrepancies in climate models representing the Arctic and by uncertainty of the role of the Arctic on global climate change. With core funding from the National Science Foundation, SHEBA included significant investments and participation by DOE, NOAA and academia (University of Washington, University Corporation for Atmospheric Research, and others). Data sets collected during SHEBA include atmospheric measurements from manned aircraft and tethered and free-flight balloons. These data sets have proven to be unique and essential for the understanding of atmospheric processes and ice-albedo feedbacks in the Arctic. The shelters and instruments used at SHEBA were supplied by ARM and installed on the Canadian icebreaker Des Grosseilleirs (Figure 2). These shelters and many of the associated instruments were later deployed to the ARM ground facility in Atqasuk, Alaska[4].

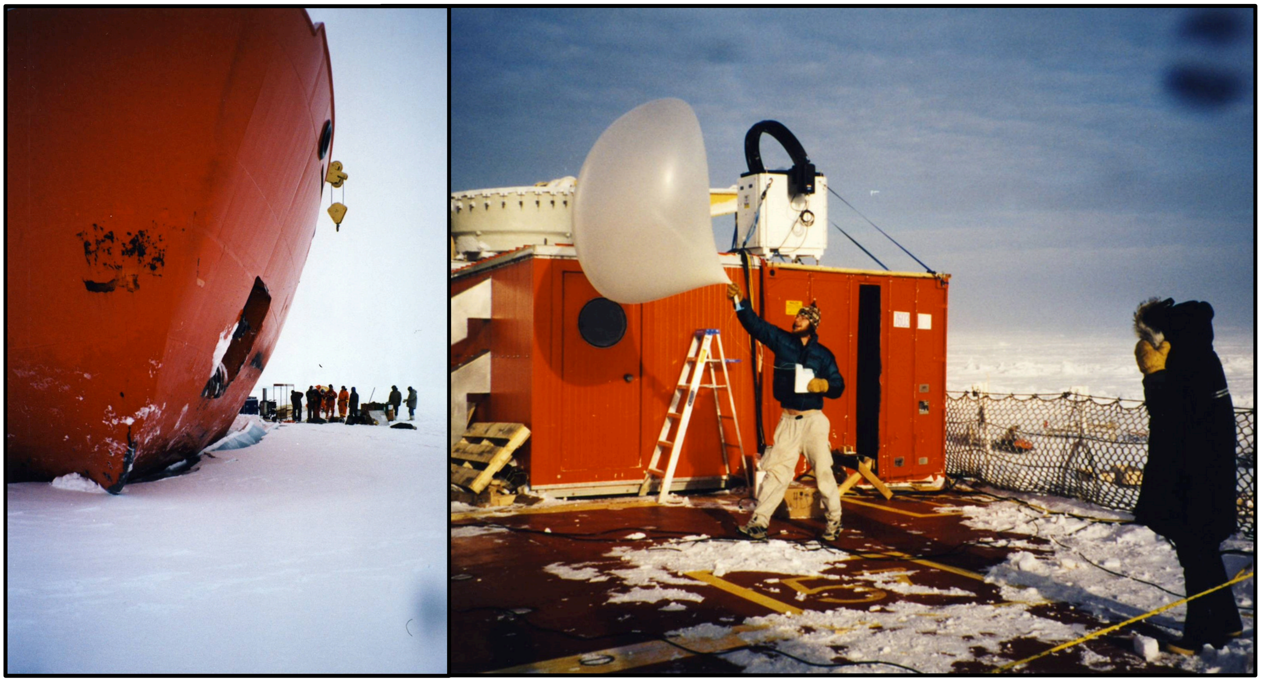

Figure 2. The Canadian icebreaker Des Grosseilleirs and SHEBA Operations.

Atmosphere modelers (cloud resolving, regional and global climate) face a zeroth-order problem, namely the lack of routine, long-term, distributed measurements of the atmospheric thermodynamic structure. Discussions and apparent consensus from this meeting arrived at a key conclusion: ***A high-priority need is for atmospheric observations in the Arctic basin in order to evaluate model processes and inform decisions for focused, short-term field campaigns to address understanding of specific processes.***

1.2.2 Observing Arctic Terrestrial Ecology

Permafrost is an important part of the Arctic landscape. Observations suggest that permafrost degradation is now common in high-latitude ecosystems and is expected to drive changes in climate forcing through biogeochemical and biophysical feedbacks (Rowland et al. 2010; Jorgenson et al. 2006). Biogeochemical feedbacks have the potential to release large amounts of currently stored carbon into the atmosphere as carbon dioxide and methane, whereas biophysical feedbacks can directly influence the terrestrial energy budget. Changes in landscape features associated with permafrost thawing, including thermal erosion, gully formation, and drainage network expansion, are dramatically changing the topography, surface hydrology, and vegetation structure of the Arctic on a time scale of years to decades (Chapin et al. 2005).

The multiple carbon, water, and energy feedbacks that occur in response to permafrost degradation must be adequately represented in models if we are to accurately predict climate change (Schneider von Deimling et al., 2012). Permafrost soils store nearly as much organic carbon as all of the world's remaining soils combined. Thawing could make much of this carbon vulnerable to rapid mineralization

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[4] http://data.eol.ucar.edu/codiac/projs?SHEBA

(Schuur et al., 2008; Zimov et al., 2006). Surprisingly little is known about the vulnerability of permafrost and how the landscape would evolve in the future. The extent to which permafrost carbon is stabilized by processes other than cold temperatures is not known, nor is the extent to which the active layer becomes saturated and anaerobic. These changes largely depend on how the landscape will evolve over time in response to surface-subsurface interactions and changes in local and regional hydrology.

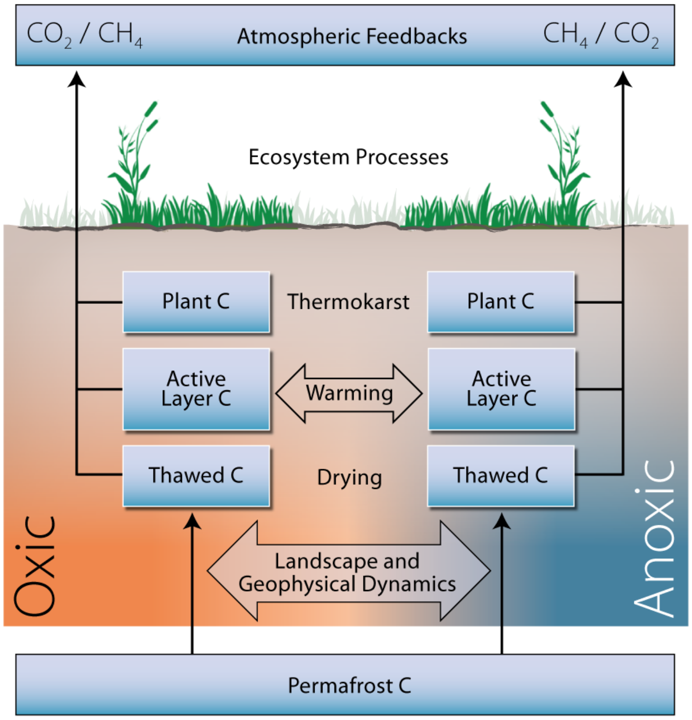

Figure 3. Conceptual diagram showing the effect of permafrost thawing on climate. Adapted from Schuur et al. (2008).

While existing representations of land-surface processes in Earth system models serve an important role in describing interrelationships that exist among vegetation, biogeochemistry, and climate, many of the Arctic system properties and processes related to permafrost degradation are not explicitly represented in climate models. The presence of ice wedges, for example, and their influence on surface topography appear to be critical drivers of plot-scale processes but cannot be resolved at even the highest resolutions presently conceived for global-scale climate models. Similarly, the formation, erosion, and drainage of thermokarst lakes (Walter et al. 2007) may provide important feedbacks to climate in high-latitude systems, because of their role in the surface-energy balance and carbon dioxide and methane emissions. Accurately representing these dynamics in Earth system models is difficult, although progress has recently been made to introduce these processes into the Community Land Model (Subin et al. 2012). There is a need for improved high-resolution Arctic terrestrial simulation capabilities that allow explicit representation of properties and processes at the spatial and temporal scales where they occur. ***Such high-resolution modeling requires the synthesis of new data and knowledge from ground- and air-based field campaigns in the Arctic, including those involving the use of UAS.***

1.2.3 Modeling the Arctic System

Data collection by CESD programs is conducted largely within the framework of addressing the gaps and deficiencies in Earth system models. CESD plays a leading role in developing and testing models, evaluating modeling uncertainties, and developing diagnostic methods and tools. Observational programs including ARM and TES provide the data required to develop and evaluate Earth system models. The Arctic is currently a major focus of CESD’s ESM program, which together with the Regional and Global Climate Modeling (RCGM) program conducts research utilizing CESM. The goals of these efforts include improvement of models used for climate research that accurately predict rapid changes. One of the major challenges faced by ESM in these efforts is to simulate features that are too small to be resolved with current global climate models, but are nonetheless climatically important. This will require improved representations of physical processes (models) as well as improved model parameterizations. ESM and RCGM work together on model development, and coordinate with the Integrated Assessment Research program to evaluate impacts, adaptations, and vulnerabilities, particularly with regard to the energy system. In the years to come, observational programs involving UAS will continue to be driven by the needs of Earth system models, and thus will entail coordination with ESM and RCGM programs as well as TES programs.

2.0 BER Investments in the Arctic

The BER ARM program has maintained a presence in the Arctic since 1997, when it established a permanent climate research site in Barrow, Alaska (Figure 4). Observational infrastructure was further expanded by the creation of a secondary site at Atqasuk, 100 km southwest of Barrow, with a reduced instrument set compared to the Barrow facility. Beginning with M-PACE in 2004, airborne operations have been conducted on a campaign basis at Oliktok Point, Alaska. That site has proved particularly useful for hosting aerial campaigns since the same campaigns would not be possible at Barrow due to potential conflicts with air traffic at Barrow’s airport. Recognizing the importance of the Arctic to the planet’s climate, BER deployed an ARM Mobile Facility, AMF3, (see Section 2.2) to Oliktok Point to augment the ground-based remote sensing on the North Slope. Infrastructure resources that are available at Oliktok Point include an airstrip, hangar and dormitory facility that are part of a U.S. Air Force long-range radar station and are available on a non-interference basis for use by ARM climate scientists and their guests.

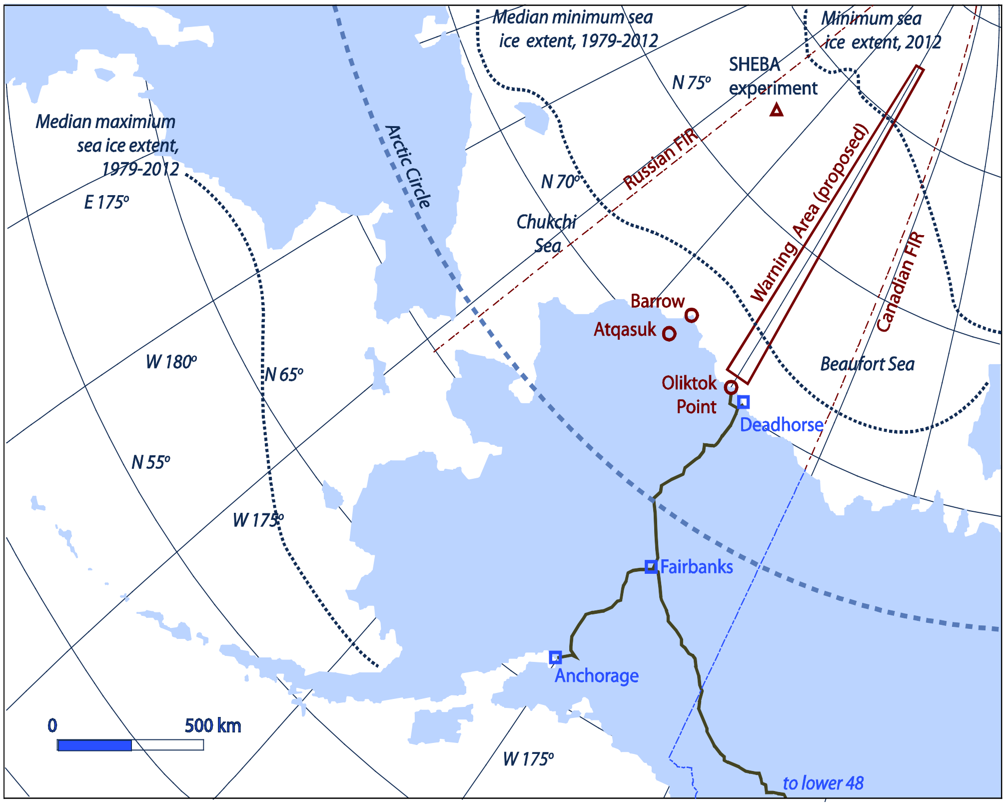

Figure 4. ARM climate research sites (red) on the North Slope of Alaska.

2.1 Restricted Airspace R-2204 at Oliktok Point

An important asset to the ARM Mobile Facility (AMF3) is the restricted area (R-2204) along with its supporting facilities at Oliktok Point (Figure 5). This special-use airspace was designated by the Federal Aviation Administration (FAA) in response to a DOE request, originally to accommodate ARM's M-PACE experiment in 2004. R-2204 encompasses a two nautical mile radius from the surface up to 7,000 ft above mean sea level (MSL) (note that the use of U.S. customary units is commonplace in North American aviation), with its center located approximately at Oliktok Point itself at roughly latitude 70.559° N and longitude 149.865° W. At DOE request, the FAA segmented R-2204 into R-2204 Low (0-1500 ft MSL) and R-2204 High (1500-7000 ft MSL) effective July 31, 2008. It is currently anticipated that the restricted airspace will be renewed every five years for as long as it is needed by DOE. This restricted area will support scientific experiments using tethered balloons and UAS.

DOE is also seeking FAA approval for a warning area (shown in Figure 4) that would cover a swath of international airspace north of Oliktok Point. Its primary purpose would be to accommodate aviation-based and possible ship-based climate research over the Arctic Ocean that poses a hazard to non-participating aircraft. Like the restricted airspace, the proposed warning area would become part of the existing ARM facilities on the North Slope of Alaska, with launch and recovery operations taking place mainly at Oliktok Point. The warning area would facilitate the use of UAS and other platforms that might pose hazards to air navigation (i.e., ice-penetrating dropsondes) by climate researchers across a vastly larger area than is covered by R-2204.

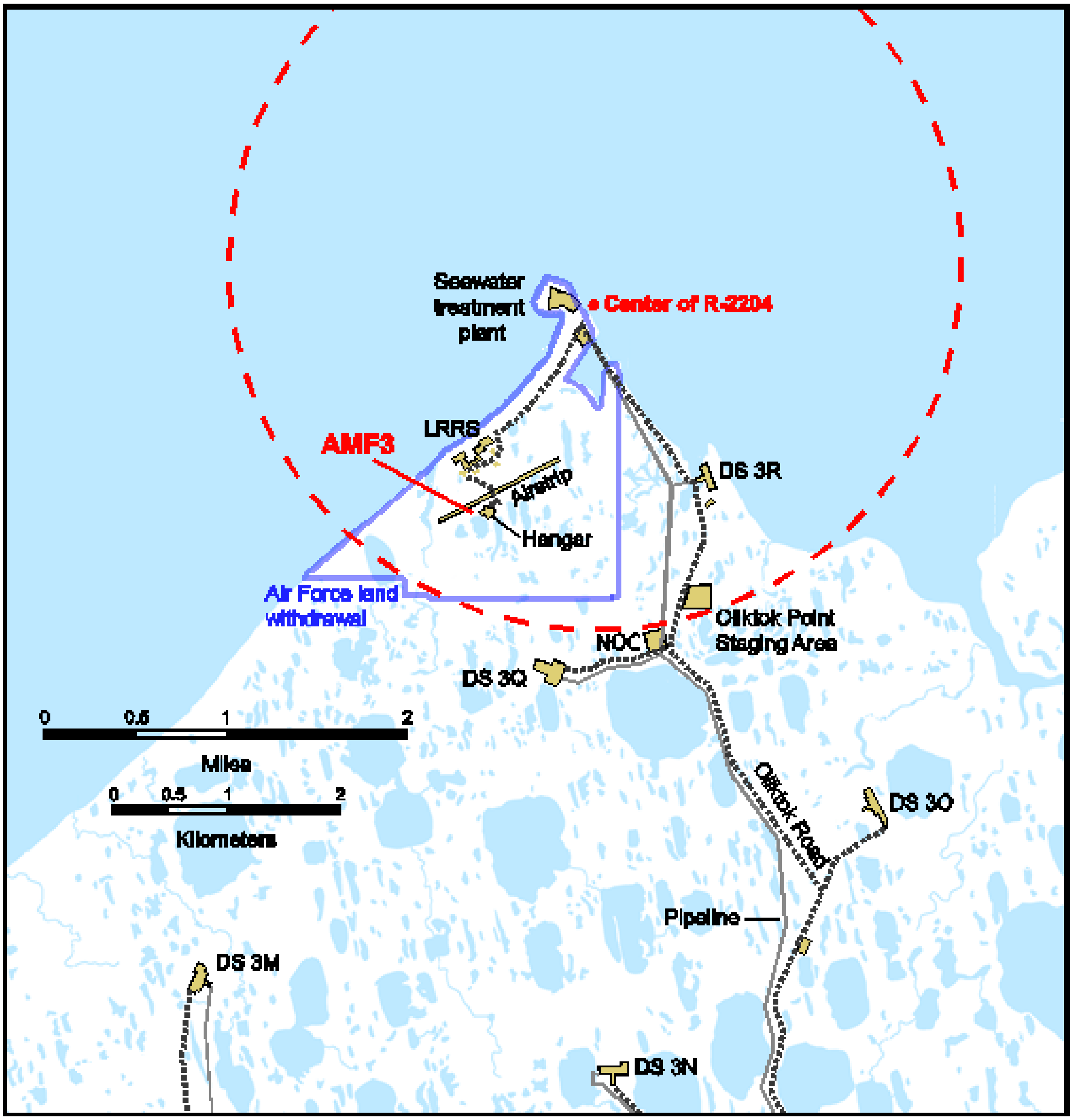

Figure 5. Restricted Area R-2204 (dashed circle) at Oliktok Point, Alaska, with center located 70.5097° N longitude 149.8592° W.

The U.S. Congress recently recognized the need to expand the use of UAS for research in the Arctic, which has positive implications for DOE climate researchers. In a provision of the Modernization and Reform Act of 2012, Congress called for the establishment of "permanent areas" in the Arctic which would enable beyond-line-of-sight, over-water flights from the surface to at least 2,000 ft MSL, with ingress and egress routes from selected coastal launch sites. Oliktok Point and its associated special-use airspace could serve as the center of activity for a hypothetical permanent area over the Beaufort Sea. This designation would facilitate the use of UAS in beyond-line-of-sight applications, such as surveys of marginal sea ice, which currently require a Certificate of Authorization (COA) from the FAA.

At present, international airspace can be reached from Oliktok Point provided that a COA is in place. In general, COAs are approved for a given UAS at a specified location and for a limited duration. Recent experience indicates that it is easier to obtain a COA when launch and recovery operations will take place from within R-2204. Designation as a permanent area would further streamline the process for much-needed beyond-line-of-sight measurements, and thus would enable new BER research in the Arctic.

Figures 6 and 7 below show images of UAS and tethered balloon operations from engineering evaluations performed at Oliktok Point during October of 2012. A fixed-wing UAS (BAT-3 manufactured by MLB Company), a battery-powered rotorcraft, and a tethered balloon were flown in the late fall season of 2012. Additional platforms and sensors will be tested at the site in the near future.

Figure 6. Tethered balloon launch from in front of hangar at Oliktok Point.

Figure 7. BAT-3 unmanned aircraft launched from a truck-mounted catapult located on the deactivated runway at the Oliktok Point Long-Range Radar Station.

2.2 The Third ARM Mobile Facility, AMF3

In early 2012, funding became available to develop and deploy a new ARM Mobile Facility. Designated AMF3, this mobile facility was deployed to Oliktok Point in August of 2013 (Figure 8), and is located within the footprint of restricted airspace R-2204. Previous aerial operations at Oliktok Point used both manned aircraft and tethered balloons and produced important scientific advances. Those campaigns also highlighted gaps in our understanding of Arctic climate processes. The resulting high-priority questions provide the basis for a longer-term Oliktok Point deployment of ground-based instruments as well as complementary aerial measurements.

Figure 8. AMF3 with instruments on the Sky Deck, August 31, 2013.

DOE's focus on developing improved parameterizations for climate models requires both continuous and intensive long-term observations. In addition to complementing aerial campaigns, AMF3 will provide routine measurements that support the ARM goal of obtaining high fidelity climate data from critical sites. Instruments to be included in AMF3 are listed in Table 1.

Table 1. AMF3 instruments.

Phase I (Installed August 2013)	**Phase II**
Radiometers (SKYRAD, GRNDRAD, MFRSR, MFR)	Scanning Cloud Radar (Ka/W)
Meteorology (Surface T, P, RH, Winds)	Zenith Cloud Radar (KAZR)
Boundary Layer Cloud System (VCEIL, CIMEL)	Snowflake Camera
Digicora III, Balloon-borne sounding system	Mobile C-band Precipitation Radar
Micro-Pulse Lidar	Raman Lidar
Data System	915 Wind Profiler
Total Sky Imager	Doppler Lidar
	Eddy Correlation Flux Measurement System
	Total Precipitation Sensor
	Microwave Radiometer, MWR3C
	Extended Range AERI

3.0 Recent Activities at Oliktok Point: MIZOPEX

ARM recently provided logistical support to a major Arctic research effort involving UAS at Oliktok Point, Alaska in July, 2013, concurrently with the meeting in Washington, D.C. This NASA-sponsored mission, named the Marginal Ice Zone Observations and Processes Experiment (MIZOPEX), was part of an ongoing sea-ice observing campaign that seeks to exploit the capabilities of multiple classes of UAS (NASA SIERRA (Figure 9), Insitu ScanEagle, and microUAS), in combination with ground-based sensing and satellite observations. The aim of the project is to examine conditions in the marginal ice zone during the summer melt in an effort to understand the extreme warming, reduced sea-ice extent, and loss of ice in the Arctic Ocean observed in recent years[5].

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[5] http://ccar.colorado.edu/mizopex/

These activities were a timely reminder that Oliktok Point is one of exceedingly few locations in the Arctic that can support launch and recovery of multiple classes of unmanned aircraft. After considering several other options, MIZOPEX investigators chose Oliktok Point because of the availability of restricted airspace, its proximity to the marginal ice zone, and the presence of much-needed infrastructure and logistical support. Olitkok Point is in this respect a figurative "aircraft carrier in the Arctic," providing a useable landing strip and support facilities within a sea of untenable alternate options.

The July mission underscored the benefits and challenges of interagency collaborations and cooperation (see inset box). The core collaborators from NASA, the University of Colorado and the University of Alaska each provided fixed-wing UAS, on-board sensors, pilots and support staff while DOE and Sandia National Laboratories provided logistical and administrative support of activities at Oliktok Point and in R-2204.

MIZOPEX was the largest and most complex collaborative effort yet hosted at Oliktok Point. As such, it both tested the administrative processes of multiple institutions and placed unprecedented logistical demands on project planners. Hence, the project resulted in a number of recommendations which were readily incorporated into meeting discussions (see Section 5).

MIZOPEX Collaboration

Project Sponsor
NASA Ames Research Center

Project Management
NASA Ames Research Center
NOAA Office of Marine and Aviation Operations
University of Colorado

Site and Airspace Management
DOE Office of Science
Sandia National Laboratories

Project Scientists and Collaborators
Ball Aerospace and Technologies Corp.
Brigham Young University
Columbia University
Fort Hays State University
NASA Ames Research Center and Goddard Space Flight Center, respectively
NOAA Earth System Research Laboratory
Universitat Politécnica de Catalunya
University of Alaska
University of Colorado
University of Kansas

Figure 9. ScanEagle (left) and DataHawk (right) UAS, flown successfully at Oliktok during the "MIZOPEX" Campaign, July and August 2013.

4.0 Meeting Summary

4.1 Key Science Questions and Observational Needs

Specific science questions related to CESD goals were described in the session, “Modeling Gaps and Measurements Needed to Advance Arctic Atmospheric Models with a Focus on Manned Aircraft, Unmanned Aircraft, and Tethered Balloons,” which took place on the first day of the meeting. Presentations by Hans Verlinde (Penn State University), David Randall (Colorado State University), and Greg McFarquhar (University of Illinois) focused on atmospheric processes. Elizabeth Hunke (Los Alamos National Laboratory) and John Cassano (University of Colorado) discussed the importance of sea-ice and ocean-atmosphere interactions. Larry Hinzman (University of Alaska) discussed progress with NGEE-Arctic and science questions and observational needs related to that project. The key points from those presentations and the ensuing discussions are summarized here. Full presentations are available on the wiki web site (see Section 1.1).

4.1.1 Atmospheric and Sea-Ice Models

A top priority for BER researchers over the next five years will be to build on progress already made in understanding how mixed-phase clouds affect the radiation budget of the Arctic. Mixed-phase clouds are broadly defined as being a mixture of ice particles and super-cooled water droplets in the same volume. In the Arctic, mixed-phase clouds frequently occur as a single layer with ice mostly concentrated near the base and liquid near the top of the cloud, but deeper precipitating systems tend to consist of multiple shallow layer clouds. Because the formation and stability of Arctic clouds is poorly understood at a fundamental level, there is a consensus that additional process-level data will need to be collected.

David Randall provided a climate modeling perspective of the Arctic, and discussed atmospheric impacts and feedbacks related to greenhouse warming. He described simulations with CESM in which the atmospheric concentration of carbon dioxide was gradually raised to nearly four times the pre-industrial Holocene average. He emphasized the dependence of downwelling long-wave radiation on specific humidity, cloud base height, and cloud amount, and noted that current models do not account for the rapid melt-back of Arctic sea ice. It was clear from the ensuing discussion that the physical characteristics of mixed-phase clouds will play an important role in amplifying or mitigating climate change in the Arctic.

Greg McFarquhar provided an observational perspective and highlighted the following pressing questions regarding the characteristics of mixed-phase clouds:

- What are the spatial scales of mixing between liquid and ice, and how do they vary with height and meteorological conditions?
- What are the relative size distributions of liquid and ice particles?
- How can small particles be distinguished from super-cooled droplets?
- Do frozen drops evolve in shape according to condition?

McFarquhar pointed out that participants in the 2010 Workshop on Airborne, In Situ Instrumentation to Measure Ice Clouds (Seaside, Oregon, USA, June 25-27, 2010) also discussed some of these issues, and have identified a path forward which includes the following objectives:

- Acquiring data over a wider range of conditions
- Carrying larger instrument payload
- Obtaining high temporal and spatial resolution
- Combining in situ and remote measurements.

For ground-based measurements, McFarquhar emphasized the importance of the micro-pulse lidar, ceilometer, millimeter wavelength cloud radar, and microwave radiometer in characterizing clouds. These instruments will be installed in phases as part of the AMF3 deployment.

Future observational needs were put in the context of past DOE-funded cloud studies by Hans Verlinde. Past campaigns include M-PACE, ISDAC and ALTOS. Verlinde emphasized the problems in transferring mid-latitude cloud parameterization schemes to polar regions and also the lack of applicable knowledge of cloud microphysical processes in polar regions. Verlinde pointed out that these model weaknesses were also highlighted in the 2012 NASA Workshop on the Arctic-Boreal Zone, where it was noted that ARM should strive to provide better measurements of cloud ice properties and their effects on radiation.

Improved cloud parameterizations will require measurements of:

- thermodynamic profiles,
- cloud optical properties, together with observations of ice crystal size, number density, and habit,
- short- and long-wave radiation above and below clouds,
- surface meteorological variables, including surface state and radiation and water vapor fluxes, and
- temporal and spatial variability of surface state and the relations to cloud/aerosol layers.

In order to obtain the required data, Verlinde emphasized that different types of aircraft will be necessary depending on the science mission and the type of instrumentation involved (see Section 5). A multi-platform approach was advocated, with reliance on moored balloons, UAS, and manned aircraft as the needs dictate. Measurements will be necessary over both the land and sea and can be accommodated at Oliktok Point.

Elizabeth Hunke (Los Alamos National Laboratory) described the state-of-the-art with sea-ice models. Sea ice represents an important boundary for the atmosphere. Hunke cited a list of observational needs for sea-ice models taken from a short note by F. Massonnet and A. Jahn (http://www.climate-cryosphere.org/media-gallery/709-observational-needs-for-sea-ice-models).

- Polar precipitation and summer temperatures
- Boundary layer structure (including vertical mixing)
- Roughness length and drag

- Full annual cycle of atmospheric column
- Snow depth and density
- Subgrid-scale heterogeneity (e.g., ITD, ponds, floe size)
- Biogeochemistry
- Sea-ice rheology and ridging.

She also listed the following as data needs for modelers of Antarctic sea ice:

- Large-scale observations, including, ice thickness (mean and distribution), drift and biogeochemistry
  - Process-scale observations, including:
    - Redistribution of ice thickness by ridging and rafting
    - Snow (optical properties, redistribution by wind, flooding)
    - Frazil and pancake ice formation processes
    - Sea-ice microstructure
    - Ice deformation
    - Ice-ocean interactions
    - Ice biogeochemistry.

The session concluded with a talk by John Cassano, who discussed observational aspects of ocean-atmosphere interactions. He described ongoing work in Terra Nova Bay, Antarctica, where UAS are used to collect boundary layer temperature profiles and to map windfields at the mesoscale. Cassano highlighted the following unanswered questions regarding the coupling between the polar ocean and atmosphere:

- How does the presence of the polynya modify the katabatic airstream as it passes over the polynya?
- How do changes in the atmospheric state alter the amount of heat and moisture removed from the ocean in the polynya?
- What impact does this have on the development of Antarctic bottom water and on sea ice?

4.1.2 Ecological Models

Larry Hinzman discussed the science objectives of the NGEE-Arctic program, and described work underway at the Barrow Environmental Observatory. NGEE-Arctic scientists are eager to work with ARM to develop airborne measurement capabilities. Hinzman described the overall goal of NGEE-Arctic as delivering a process-rich ecosystem model, extending from bedrock to the top of the vegetation canopy, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the scale of a high-resolution Earth system model grid cell. To this end it will be necessary to develop and test models of Arctic hydrology, geomorphology, vegetation dynamics, soil processes and energy transfer. Currently the mismatch between field measurement scale and numerical model grid size is a limitation in developing and testing models for ecological processes. In Hinzman's view and from discussions following his presentation at the meeting, UAS can help fill the gaps in measurement scale.

4.2 Technical and Operational Discussions

The remaining presentations focused on technical and operational aspects of current and future UAS deployments. Matthew Shupe (University of Colorado) discussed the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC), which is a planned multi-year, comprehensive measurement campaign extending from the atmosphere through sea ice into the ocean. The project will involve the deployment of a heavily instrumented ship-based observatory in addition to a network of spatial measurements including buoys, gliders, UAS and aircraft. Shupe concluded by discussing atmospheric data collected with a tethered balloon during the Arctic Summer Cloud Ocean Study (ASCOS).

Gijs de Boer (University of Colorado) gave a preview of the Evaluation of Routine Atmospheric Sounding Measurements using Unmanned Systems (ERASMUS) project planned for 2015. The project would utilize low-cost UAS to collect observations of atmospheric structure at Oliktok Point. de Boer emphasized measurements of temperature, humidity and aerosol properties. MIZOPEX, conducted by members of the same research group, provided a number of “lessons learned” that can be applied to ERASMUS.

Martin Stueffer (University of Alaska) discussed ice fog and its importance to local climate. Much of what is known about ice fog microphysical properties comes from studies using a “Formvar Replicator,” which collects and preserves ice crystals using a special plastic film. Stueffer has proposed mounting a replicator and a video ice-particle sampler on a small hexacopter or tethersonde.

Jose Fuentes (Penn State University) described experiences going back to the late 1990s with tethered balloons. This included work in the Canadian Arctic and on the North Slope of Alaska. Future work will focus on characterizing turbulent plumes of moist air rising from ice leads and would involve manned aircraft, tethered balloons, and ground-based remote sensing.

Paul Lawson (SPEC Inc.) talked about the SPEC Tethered Balloon System and previous deployments at Oliktok Point, Svalbard, and the South Pole. Lawson emphasized the natural progression of continued miniaturization of balloon sounding systems and the prospects for use with a small unmanned aircraft. Substantial testing has been conducted on the balloon envelope, tether, and winch since an unsuccessful deployment in 2010, resulting in improvements to nearly all aspects of the system. Progress has also been made in developing a particle counter and meteorology package for a small unmanned aircraft.

David Sonnenfroh (Physical Sciences Inc.) and James Smith (AOS Inc.) provided a look at evolving capabilities with miniaturized sensors, emphasizing that these will enable the use of smaller unmanned aircraft for research missions in the near future. Sonnefroh discussed scientific uses of the InSitu ScanEagle, Aerovironment Dragon Eye, NASA Sierra, and University of Colorado Lidar Profilometer and Imaging System (CULPIS).

Doug Davis (New Mexico State University) gave a briefing on the Arctic Monitoring and Assessment Programme (AMAP), an international effort involving eight Arctic nations. AMAP is working with civil aviation authorities to identify options for expanding airspace access for routine environmental observations and to establish “best practices” for science operators.

Mark Ivey (Sandia National Laboratories) gave an overview of the user requirements for the Oliktok Point facility, using the recent MIZOPEX project as an example. Currently several administrative hurdles must be overcome, but these are in the process of being streamlined.

5.0 Recommended Measurements and Platforms

Participants discussed measurements that could fulfill both near- and long-term objectives for observing the atmosphere and Earth's surface (Table 2). It was agreed that some data, including basic meteorological measurements and surface imaging, could be obtained using currently available miniaturized instrumentation and could be implemented on existing unmanned aircraft in the near-term or intermediate-term. For purposes of these discussions, those time periods are defined as:

Near-term:	0 to 18 months.
Intermediate-term:	18 to 36 months.
Long-term:	Greater than 36 months.

However, longer-term measurements are also desired. Some of these would require new sensing technology or aircraft or would involve operating parameters that are currently unallowable or are cost prohibitive. The DOE/BER Small Business Innovation Research (SBIR) program is currently funding technology development that will provide needed miniaturized instrumentation for atmospheric science and terrestrial ecology uses in the Arctic. Two presentations on SBIR-related technologies were made on the final day of this meeting addressing this topic. The first presentation described miniaturized instrumentation that was being integrated into the popular ScanEagle UAS platform. The second presentation described an SBIR project focused on carbon dioxide measurements and other airborne data being collected at the Southern Great Plains, as well as a number of instrument miniaturization efforts on small UAS platforms. The utility of tethered balloons as a low-cost "workhorse" for Arctic atmospheric measurements was emphasized in several presentations, and these unmanned platforms received consensus endorsement.

Meeting participants developed a consensus list of measurements (Table 2) that would meet immediate scientific needs and could be implemented in the near-term given the current state of technology development.

As mentioned previously, there were only a few aerosol scientists at the planning meeting, possibly because of limited outreach during the meeting planning process and motivations to keep the meeting relatively small. Input from the aerosol research community will be solicited soon as part of current action plans.

A summary of the five-year research plan recently put forward by the Interagency Arctic Research Policy Committee (IARPC) is given in Appendix C. Recommendations made by IARPC for the next five-year period have direct bearing on the recommendations made by participants at this UAS planning meeting.

Table 2. Recommended measurements for ecology and atmosphere with immediate needs underlined.

Ecology
Surface imagery
Soil temperature
Soil moisture
Inundation
Gas concentrations and fluxes • CO_2 • NH_4 • N_2O
High-resolution digital elevation data (annual)
High-resolution snow surface elevations
Snow water equivalent depth

Atmospheric Science
Air temperature
Humidity
Horizontal wind
Turbulence (i.e., vertical velocity)
Aerosol properties • Number density • Chemistry • Total scatter • Absorption • Morphology
Cloud condensation nuclei number
Cloud liquid water content
Cloud ice content
Cloud droplet number
Cloud droplet size
thickness
Radiation (long-wave and short-wave broadband/spectral)
Lidar (up/down)
Aerosol morphology/ Ice-particle shape
HD Camera

Achieving CESD goals in the Arctic will require spatially and temporally distributed observations of atmospheric state and surface conditions. The necessary spatial resolution can likely be obtained only with navigable aircraft, manned or unmanned. Table 3 matches the essential classes of measurements to key operational characteristics of different motorized aircraft. The primary considerations, in addition to the ability to address science questions, are safety, cost, availability, and maturity of the instrument payload.

Table 3. Suitability of motorized aircraft for high-priority science questions.

▮▮▮▮	Yes/To high degree
▮▮▮▯	Often/Reasonably assured
▮▮▯▯	Possible/To some degree
▮▯▯▯	Marginal
▯▯▯▯	Not practical

Measurement Platform	Arctic Atmosphere - High Priority Science Questions					
	Large System Variability	Off Shore Arctic Clouds and Ice-Albedo Feedback	Atmospheric State	Surface State Coupling to Lower Troposphere	Seasonal/Spatial Variability	Model Process Evaluation
Small UAS	▮▮▮▮	▮▮▯▯	▮▮▮▯	▮▮▮▯	▮▮▮▮	▮▮▮▮
Medium UAS	▮▮▯▯	▮▮▯▯	▮▮▮▯	▮▮▮▯	▮▮▯▯	▮▮▯▯
Small Manned Aircraft	▮▯▯▯	▮▮▮▯	▮▮▮▯	▮▮▯▯	▮▯▯▯	▮▮▮▮
Large Manned Aircraft	▯▯▯▯	▮▮▯▯	▮▮▯▯	▮▮▯▯	▯▯▯▯	▮▮▮▮

	Suitability for Offshore and Near-Shore Operations					
	Meets Safety and Regulatory Requirements	System Costs are Affordable	Good Mission Availability	Instruments are Mature	Operations and Maintenance Costs are Manageable	Satisfies Overall Science Questions
Small UAS	▮▮▮▯	▮▮▮▯	▮▮▮▯	▮▮▮▯	▮▮▮▯	▮▮▮▯
Medium UAS	▮▮▮▯	▮▮▯▯	▮▮▮▯	▮▮▮▯	▮▮▯▯	▮▮▮▯
Small Manned Aircraft	▮▯▯▯	▮▮▮▯	▮▮▯▯	▮▮▮▮	▮▯▯▯	▮▮▯▯
Large Manned Aircraft	▮▮▮▯	▮▯▯▯	▮▯▯▯	▮▮▮▮	▯▯▯▯	▮▮▮▯

Broadly, two types of observational data sets are needed:

1. Process-level study data sets with detailed characterization of surface ice state, atmospheric thermodynamic state profiles, cloud properties, and short- and long-wave radiation measurements, and
2. Climate-scale observations for regional evaluation of the mean atmospheric/surface state and its temporal and spatial variability.

The first type of measurement may best be obtained by short-duration intensive aircraft field campaigns focused on improving parameterizations in climate models. Such campaigns may best be done by large, manned aircraft capable of carrying comprehensive sets of sensors. These campaigns may involve flying over ARM ground instrumentation and can most efficiently be done by manned aircraft for better in-flight decision making. Safety considerations would likely dictate the use of twin-engine aircraft for manned campaigns in the Arctic, particularly where airframe or engine icing conditions might be encountered. These larger aircraft are typically based in Fairbanks because hangar space on the North Slope is not readily available or is extremely expensive, and the resulting long flights between Fairbanks and Barrow or Deadhorse add significantly to total flight hours. The use of UAS can be a safe and effective alternative to manned aircraft for these conditions.

The data sets needed for climate model assessments require regular measurements over multiple seasons deep into the Arctic Ocean basin, with flights extending from the coastal plains across the coast and over the marginal ice zone. Such data sets can capture the seasonal, inter-annual and spatial variability (i.e., “large system variability”) of atmospheric and surface states. These observations can best be conducted by small, unmanned aircraft with measurements of the atmospheric/surface states. Mixed-phase clouds are of particular interest to the climate research community but are notoriously dangerous for manned flight. Again, UAS, including tethered balloons with instrumented payloads, are a safe alternative to the use of twin-engine manned aircraft for flying into icing clouds.

6.0 Operations Plan

Participants at this UAS planning meeting recommended the following:

1. **Scientific Input**. *Continue ongoing means to solicit input from the climate research community on the use of unmanned aircraft and balloons in Arctic research.*

   A focus should be on the development and implementation of platforms, sensors and research. Additional input should be sought on plans for specific operations strategies if routine sampling is to be implemented (e.g., time and height intervals for sampling). Operational strategies will be presented as appropriate to the ARM user communities.

2. **Data management.** *Deliver processed, quality assured data to the ARM archive for distribution.*

   Existing ARM data procedures developed for fixed sites and for Intensive Operating Periods will serve as a template for archiving data from aerial campaigns.

3. **Tethersonde.** *Recommend tethersonde operations as a baseline component of the ARM facility, with emphasis on near-term deployment.*

   The ARM facility will need to procure or develop an operational tethersonde system that can routinely reach altitudes of 1 km above ground level. This system should include an instrument package that measures basic meteorological variables (barometric pressure, air temperature, relative humidity, wind speed and direction). Other measurements of significant value are aerosol number concentration and turbulence. Recent DOE investments in cloud microphysical sensors should be utilized, although the ARM Infrastructure Management Board will be responsible for final decisions on instrument packages for UAS, including tethered balloons.

   As a baseline scenario, it is recommended that the tethersonde operate for two-week periods, approximately once every two months, with 12 hours per day of operations if possible. This operational starting point seems reasonable given resources needed and past experiences with tethersonde operations. As a goal, tethersonde operations may eventually support operations at all times of the day and year to capture diurnal and seasonal processes.

4. **Fixed-wing or multicopter UAS**. *Procure or develop a fleet of small UAS for near-term deployment (e.g., Data Hawk or Dragon Eyes) as a baseline component of the ARM facility, with emphasis on near-term deployment in less than 18 months.*

   As with the tethersonde package, a high priority is placed on basic meteorological measurements. However, given the large variety of commercial UAS now available and the rapid pace of UAS development, more work needs to be done in establishing optimal parameters for the unmanned platform. An optimal balance will also have to be struck between the needs of land surface and atmospheric science.

5. **Extended capabilities**. *Pursue longer-term objectives (3+ years) to be driven in part by Principle-Investigator proposals and collaborations with other programs.* Here, the term “extended capabilities” encompasses longer-term objectives that cannot currently be met with existing sensors or platforms. In the longer-term, it will therefore be necessary to develop or repurpose instrumentation for use with balloons and UAS capabilities. Important variables include cloud liquid water properties, cloud ice properties, and vertical velocity. Furthermore, we recognize the value in the capability to fly for extended distances and time periods, enabling observations over the adjacent ocean- and sea-ice environment.

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Appendix A
Meeting Agenda

A Planning and Operational Meeting on Polar Atmospheric Measurements Related to the DOE ARM Program Using Small Unmanned Aerial Systems and Tethered Balloons

AAAS Building - 1200 New York Avenue NW, Washington, D.C. 20005

July 24–26, 2013

Wednesday, July 24, 2013

8:30–9:45am	**Welcome, background, purpose, and perspectives:** **Mark Ivey** - Welcome, agenda updates, meeting logistics **Wanda Ferrell** - "DOE/BER: BER and ARM perspectives." **Rick Petty** - DOE/BER: "ARM's Arctic Climate Observatory." **Bob Ellingson - "**Plans for this meeting and perspectives on past meetings of similar nature that were successful; guidelines for discussion sessions." **Mike Kuperberg -** DOE/BER: "NGEE Overview."
9:45–10:00am	**Break**
10:00–11:30am	**Presentations:** (30 minutes each, including discussion) **Hans Verlinde, Penn State -** "Highlights from a Recent White Paper on Unmanned Aerial Vehicles for Arctic Atmospheric Measurements." **Dave Randall, Colorado State University -** "A Climate Modeling Perspective on the Arctic." **Greg McFarquhar, University Illinois/UC -** "In situ Measurements of Cloud Microphysics from M-PACE and ISDAC: What Additional Observations from UAS Can Provide."
11:30am–1:00pm	**Lunch Break** (on your own at nearby restaurants)
1:00–2:30pm	**Presentations:** (30 minutes each, including discussion) **Elizabeth Hunke, LANL -** "Data Needs for Sea-Ice Models." **Larry Hinzman, UAF - "**Data Needs for the Next-Generation Ecosystem Experiment, Arctic." **John Cassano, University of Colorado -** "Observations of the Antarctic Atmosphere Using Unmanned Aerial Vehicles."
2:30–2:45pm	**Break**
2:45–4:45pm	**Discussion Session 1:** Modeling Gaps and Measurements Needed to Advance Arctic Atmospheric Models with a Focus on Manned Aircraft, Unmanned Aircraft, and Tethered Balloons.
4:45–5:00pm	**Wrap up and review for Thursday**

Thursday, July 25, 2013

8:30–10:00am	**Presentations:** (30 minutes each including discussion) **Matt Shupe, University of Colorado –** “MOSAiC and Recent Arctic Atmospheric Measurement Campaigns” **Gijs de Boer, University of Colorado –** “ERASMUS Campaign Science Goals – Routine Atmospheric Scientific Measurements Using Unmanned Systems in the Arctic” **Martin Stuefer, UAF –** “Arctic Ice Fog Studies and UAS Measurements”
10:00–10:15am	**Break**
10:15– 11:30am	**Presentations:** (30 minutes each including discussion) **Jose Fuentes, Penn State –** “Atmospheric Measurements from Tethered Balloons” **Paul Lawson, SPEC, Inc. –** “Tethered Balloon Systems” **Doug Davis, NMSU –** “Arctic Monitoring and Assessment Program Unmanned Aircraft Systems Expert Group”
11:30am –1:00pm	**Lunch Break**
1:00–2:30pm	**Discussion Session 2:** Modeling Gaps and Measurements Needed to Advance Arctic Atmospheric Models with a Focus on Manned Aircraft, Unmanned Aircraft, and Tethered Balloons, Part 2.
2:30–2:45pm	**Break**
2:45–5:00pm	**Discussion Session 3:** Critical Data from Unmanned Aerial Systems/Platforms That Could Advance Studies of Permafrost of Ecology”

Friday, July 26, 2013

8:30–9:45am	**Presentations:** **Jim Smith, AOS/Boulder –** “Atmospheric Sensing Systems for UAV Applications.” **David Sonnenfroh, Physical Science Inc. –** “A Survey on Instrumentation for Atmospheric Measurements from Small UAVs.” **Mark Ivey, SNL –** Short Update: “What it Takes to Fly a UAS at Oliktok, Alaska – MIZOPEX Summary, Restricted Area, Warning Area, and Safety Reviews.”
9:45–10:00am	**Break**
10:00–11:30am	**Discussion Session 4:** Technology Issues, Next-Generation Technology Needed for UAS and Tethered Balloon Systems Used for Arctic Atmospheric Measurements.
11:30am–12:00pm	**Collect Discussion Session Results and Plan for Report**

Appendix B
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Appendix C
Interagency Arctic Research Policy Committee Five-year Plan

The IARPC is charged with developing five-year plans for federally sponsored research in the region. For 2013 to 2017, The IARPC, which consists of representatives from 13 Federal agencies, departments, and offices, has identified seven research areas that will inform national policy and benefit significantly from close interagency coordination. They are:

1. Sea ice and marine ecosystem studies
2. Terrestrial ice and ecosystem studies
3. Atmospheric studies of surface heat, energy, and mass balances
4. Observing systems
5. Regional climate models
6. Adaptation tools for sustaining communities
7. Human health studies.

The summary recommendations of the five-year IARPC research plan in these areas are:

Terrestrial Ice and Ecosystem Studies

Ongoing changes in the terrestrial Arctic environment that result from climate change are expected to lead to further changes in global climate, or climate “feedbacks,” and affect the ability of local communities to adapt. The IARPC has identified five priority activities to understand such climate feedbacks and terrestrial ecosystem processes. They will be coordinated collaboratively by the DOE, Department of the Interior, National Aeronautics and Space Administration, National Science Foundation, and Smithsonian Institution.

1. Glacial process studies targeting specific dynamic ranges
2. Coordinate and integrate efforts, including information delivery, that contribute to terrestrial ecosystem research
3. Identify and study key sites where climate feedbacks are active, including permafrost, snow, hydrates, glaciers, and ice
4. Investigate the frequency and severity of wild land fires in the Arctic and understand their impacts on vegetation and wildlife
5. Conduct socio-economic research to understand ecosystem services as the Arctic tundra changes with increased warming to inform plans for protecting, managing, and adapting to a fragile and changing Arctic environment.

Atmospheric Studies of Surface Heat, Energy, and Mass Balances

Variability in surface-air temperatures—from year-to-year or longer—tends to be larger in the Arctic than in other parts of the globe. Compared with those at low latitudes, atmospheric processes in the Arctic are influenced by unique features, such as polar night, high reflectivity of the snow and ice cover, and atmospheric stability that influence the degree to which aerosols and clouds warm or cool the region. Scientific uncertainties about these unique features must be clarified in order to more fully understand the Arctic atmosphere and its processes.

Coordinated remote sensing and *in situ* observations, improved representation of atmospheric processes in models, quantification of uncertainty in model outputs, and long-term observational data sets will be critical to addressing these uncertainties. The DOE, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and National Science Foundation will collaborate on three activities to support this research area:

1. Improve understanding of short-lived climate forcers (SLCFs) and their role in Arctic amplification through satellite observations, long-term *in situ* observations, and improved modeling
2. Improve understanding of processes controlling formation, longevity, and physical properties of Arctic clouds, including the effects of—and sensitivities to—aerosols
3. Develop an integrated understanding of Arctic atmospheric processes, their impact on the surface-energy budget, and their linkages with oceanic, terrestrial, and cryospheric systems through improved satellite capabilities, ground-based observations, and representations of Arctic systems in climate and weather-prediction models.

Observing Systems

Arctic change is occurring on multiple spatial and temporal scales. Over the next five years, the DOE, Department of the Interior, Environmental Protection Agency, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, National Science Foundation, Office of Naval Research (Department of Defense), and U.S. Coast Guard (Department of Homeland Security) will focus on nine activities to maintain and strengthen an integrated national and international Arctic observing system to obtain data and information from multiple scales:

1. Facilitate observing system design for the Arctic;
2. Assess local-resident priorities with respect to climate;
3. Combine *in situ* and remotely sensed observation of sea ice with local community and traditional knowledge;
4. Conduct long-term monitoring of key outlet glaciers and tidewater glaciers;
5. Monitor the biological and physical state of the Arctic marine environment;
6. Assess the effects of clouds and atmospheric constituents on surface-radiation balance;
7. Assess the impact of terrestrial warming and permafrost thawing on the carbon cycle;
8. Improve data access; and
9. Engage indigenous observers and communities in monitoring environmental parameters.