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Investigations of Spatial and Temporal Variability of Ocean and Ice Conditions in and Near the Marginal Ice Zone: The "Marginal Ice Zone Observations and Processes Experiment" (MIZOPEX) Final Campaign Summary

JA Maslanik

February 2016

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JA Maslanik, University of Colorado Boulder
Principal Investigator

JJ Adler, University of Colorado Boulder
BM Argrow, University of Colorado Boulder
GL Bland, National Aeronautics and Space Administration's Goddard Space Flight Center
SL Castro, University of Colorado Boulder
WJ Emery, University of Colorado Boulder
EW Frew, University of Colorado Boulder
JF Heinrichs, Fort Hays State University
D Lawrence, University of Colorado Boulder
C Leuschen, Center for Remote Sensing of Ice Sheets, University of Kansas
DG Long, Brigham Young University
A Mahoney, Geophysical Institute, University of Alaska Fairbanks
SE Palo, University of Colorado Boulder
M Steele, Applied Physics Laboratory, University of Washington
MA Tschudi, University of Colorado Boulder
G Walker, Geophysical Institute, University of Alaska Fairbanks
B Weatherhead, National Oceanic and Atmospheric Administration's Earth System Research Laboratory
GA Wick, National Oceanic and Atmospheric Administration's Earth System Research Laboratory
C Zappa, Lamont-Doherty Earth Observatory
Team Members

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Executive Summary

Despite the significance of the marginal ice zones of the Arctic Ocean, basic parameters such as sea surface temperature (SST) and a range of sea-ice characteristics are still insufficiently understood in these areas, and especially so during the summer melt period. The field campaigns summarized here, identified collectively as the "Marginal Ice Zone Ocean and Ice Observations and Processes Experiment" (MIZOPEX), were funded by U.S. National Aeronautic and Space Administration (NASA) with the intent of helping to address these information gaps through a targeted, intensive observation field campaign that tested and exploited unique capabilities of multiple classes of unmanned aerial systems (UASs). MIZOPEX was conceived and carried out in response to NASA's request for research efforts that would address a key area of science while also helping to advance the application of UASs in a manner useful to NASA for assessing the relative merits of different UASs. To further exercise the potential of unmanned systems and to expand the science value of the effort, the field campaign added further challenges such as air deployment of miniaturized buoys and coordinating missions involving multiple aircraft. Specific research areas that MIZOPEX data were designed to address include relationships between ocean skin temperatures and subsurface temperatures and how these evolve over time in an Arctic environment during summer; variability in sea-ice conditions such as thickness, age, and albedo within the marginal ice zone (MIZ); interactions of SST, salinity, and ice conditions during the melt cycle; and validation of satellite-derived SST and ice concentration fields provided by satellite imagery and models.

The measurement strategy consisted of three basic aspects: (1) airborne surface mapping repeated frequently over sufficiently large areas to accommodate comparisons with satellite-derived SST and sea-ice data sets; (2) sustained, continuous observations of ocean surface, subsurface, and atmospheric conditions over tens of hours, sufficient to investigate ocean-ice-atmosphere interactions and obtained at spatial scales orders of magnitude finer than those provided by satellites; and (3) repeated visitation to locations within the drifting ice pack, allowing Lagrangian tracking and observations over a period of weeks to assess how specific portions of the ice pack evolve over the summer. Key data sets planned for collection included ocean surface skin temperature, subsurface ocean temperatures, surface roughness, sea-ice thickness, surface drift trajectories, and ice floe shape and characteristics. Primary sensor packages consisted of thermal imaging systems, standard video and photography, synthetic aperture radar, ice-penetrating radar, profiling and scanning lidar, and custom-designed air-deployed microbuoys and (ADMBs) self-deploying surface sensors (SDSS) equipped with thermistor chains. The base of operations was the U.S. Air Force Distant Early Warning Line site at Oliktok Point, Alaska, west of Prudhoe Bay. UASs deployed included the NASA SIERRA, Insitu ScanEagles, and small DataHawk aircraft.

The first UAS flights for MIZOPEX were carried out by a DataHawk on 21 July, with the first SIERRA flight on 26 July, and the first ScanEagle flight on 28 July. A total of 24 UAS flights were performed prior to the last field day on 9 August: 2 SIERRA flights, 16 ScanEagle flights, and 4 DataHawk flights, for a total of 54 flight hours. One DataHawk flight included testing the aircraft in its SDSS configuration, which included a water landing, deployment of a 10-m thermistor string, and data recording and transmission. Seven ADMBs were deployed from ScanEagles within the MIZ, with four additional ADMBs deployed by hand by M. Steele (University of Washington [UW]), in conjunction with an UpTempO buoy. While the focus of the field campaign was on the UAS data collection and performance

assessment phases, preliminary science results revealed previously undetected details of ocean temperature interactions of melting ice floes with open water, along with unique information on skin temperature and upper-layer subsurface temperatures along monitored drift tracks. Because of the early loss of the SIERRA UAS, measurements were not acquired using the planned radar and lidar systems.

Acronyms and Abbreviations

ADMB	air-deployed microbuoy
ARC	Ames Research Center
ARM	Atmospheric Radiation Measurement
BESST	Ball Experimental Sea Surface Temperature Radiometer
BLOS	beyond-line-of-sight
CASIE	Characterization of Arctic Sea Ice Experiment
CCAR	Colorado Center for Astrodynamics Research
COA	certificate of authorization
CReSIS	Center for Remote Sensing of Ice Sheets
CTD	conductivity, temperature, depth sensor
CU	University of Colorado, Boulder
CULPIS	CU LIDAR Profiler and Imaging System
DEW	distant early warning
DOE	U.S. Department of Energy
EMI	electromagnetic interference
EO	electro-optical
FAA	Federal Aviation Administration
FHSU	Fort Hays State University
GPS	global positioning system
IMU	inertial measurement unit
ITAR	International Traffic in Arms Regulations
KU	University of Kansas
LDEO	Lamont-Doherty Environmental Observatory
LIDAR	light detection and ranging
MIZ	marginal ice zone
MIZOPEX	Marginal Ice Zone Observations and Processes Experiment
NAS	National Airspace System
NASA	U.S. National Aeronautics and Space Administration
NMML	National Marine Mammal Lab
NOAA	U.S. National Oceanic and Atmospheric Administration
NOTAM	notice to airmen
NSIDC	National Snow and Ice Data Center
R-2204	DOE-overseen restricted airspace zone centered over Oliktok Point
SAR	synthetic aperture radar
SDSS	self-deploying surface sensor

SST	sea surface temperature
UAF	University of Alaska, Fairbanks
UAS	unmanned aerial systems
UAV	unmanned aerial vehicle
USAF	U.S. Air Force
UW	University of Washington

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1.0 Background

The field campaign described here, identified collectively as the "Marginal Ice Zone Observations and Processes Experiment" (MIZOPEX), consists of a two-year effort and a one-year no-cost extension (see http://ccar.colorado.edu/mizopex/ for further information). Quarterly reports were provided to the U.S. National Aeronautic and Space Administration's (NASA's)' Cryospheric Sciences and Airborne Sciences programs throughout the two years.

Key goals for the campaign are as follows:

- Assessing ocean and sea ice variability in the Alaskan Arctic Ocean (Beaufort Sea/Prudhoe Bay area)
- Demonstrating potential for research using multiple unmanned aerial systems (UASs) in polar regions
- Determining best practices for safe, reliable operations in the National Air Space

The field campaign's deployment and operations lasted from July 21 to August 9, 2013, and took place in Alaska at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Olitok Point site. Other collaborators included the National Aeronautics and Space Administration (NASA), the U.S. Department of Energy (DOE), the U.S. Air Force, the National Oceanic and Atmospheric Administration (NOAA), and the Federal Aviation Administration (FAA). Individual collaborators are listed as follows:

Doug Wiebel	University of Colorado Boulder
Jack Elston	University of Colorado Boulder
Gabriel LoDolce	University of Colorado Boulder
Darren Jackson	NOAA Earth System Research Laboratory
William Good	Ball Aerospace
Albert Aguasca	Universitat Politècnica de Catalunya, Spain
Scott Brown	Lamont-Doherty Earth Observatory
Jinlun Zhang	Applied Physics Laboratory, University of Washington
John Paden	Center for Remote Sensing of Ice Sheets, University of Kansas
Fernando Rodriguez	Center for Remote Sensing of Ice Sheets, University of Kansas
Judith Riley	Center for Remote Sensing of Ice Sheets, University of Kansas

1.1 Rationale

MIZOPEX was conceived and carried out in response to NASA's request for research efforts that would address a key area of science while also helping to advance application of UASs in a manner useful to NASA for assessing the relative merits of different UASs. The specific proposal call was NASA ROSES 2010 Solicitation, entitled "UAS Enabled Earth Science" (NNH10ZDA001N-UAS); the funding originated from a congressional earmark to facilitate research on UASs. As specified in the announcement, campaigns needed to include at least two classes of UAS, either the NASA Ikhana or SIERRA and another UAS. Based on our previous experiences with different UASs applied to geophysical research (polar and otherwise), the MIZOPEX team targeted a science problem—interactions within the marginal ice zone (MIZ)—that, rather than simply being a mechanism to justify using different types of UASs, actually lends itself very well to a coordinated deployment of multiple classes of aircraft. In addition, to further exercise the potential of unmanned systems, the campaign added further challenges such as air deployment of miniaturized buoys and coordinating missions involving multiple aircraft.

1.2 The Science Problem

Despite the significance of the MIZs of the Arctic Ocean, basic parameters such as sea surface temperature (SST) and a range of sea ice characteristics are still insufficiently understood in these areas, and especially so during the summer melt period. MIZOPEX was conceived to address directly these information gaps through a targeted, intensive observational campaign that would take advantage of the capabilities of multiple classes of UASs combined with in situ sensing and satellite observations. Specific research areas that were proposed to address using MIZOPEX data include:

- Relationships between ocean skin temperatures and subsurface temperatures and how these evolve over time in an Arctic environment during summer
- Variability in sea ice conditions such as thickness, age, and albedo within the MIZ
- Interactions of SST, salinity, and ice conditions during the melt cycle
- Validation of satellite- and model-derived SST and satellite-derived ice concentration.

1.3 Approach

The measurement strategy consisted of three basic aspects:

- Extensive airborne surface mapping repeated frequently over sufficiently large areas to accommodate comparisons with satellite-derived SST and sea ice data sets
- Sustained, continuous observations of ocean surface, subsurface, and atmospheric conditions over tens of hours, sufficient to investigate ocean-ice-atmosphere interactions and obtained at spatial scales orders of magnitude finer than those satellites can provide
- Repeated visitation to locations within the drifting ice pack, allowing Lagrangian tracking and observations over a period of weeks to assess how specific portions of the ice pack evolve over the summer.

Figure 1 shows the MIZOPEX study area, covering portions of the Alaskan Beaufort Sea. As the spring and summer ice conditions evolved, the actual flight areas were narrowed down to a smaller region, both to maximize useful data collection and to help minimize impacts on manned aircraft operations. The desire to capture the summer transition from predominantly sea-ice-covered to open water (i.e., the evolution of the MIZ as it has developed in recent years) set a relatively strict date limit on when the UAS flights would need to take place (Figure 2). We concluded that mid-July was the latest that flights could begin if we were to observe this full transition.

Figure 1. MIZOPEX operations area.

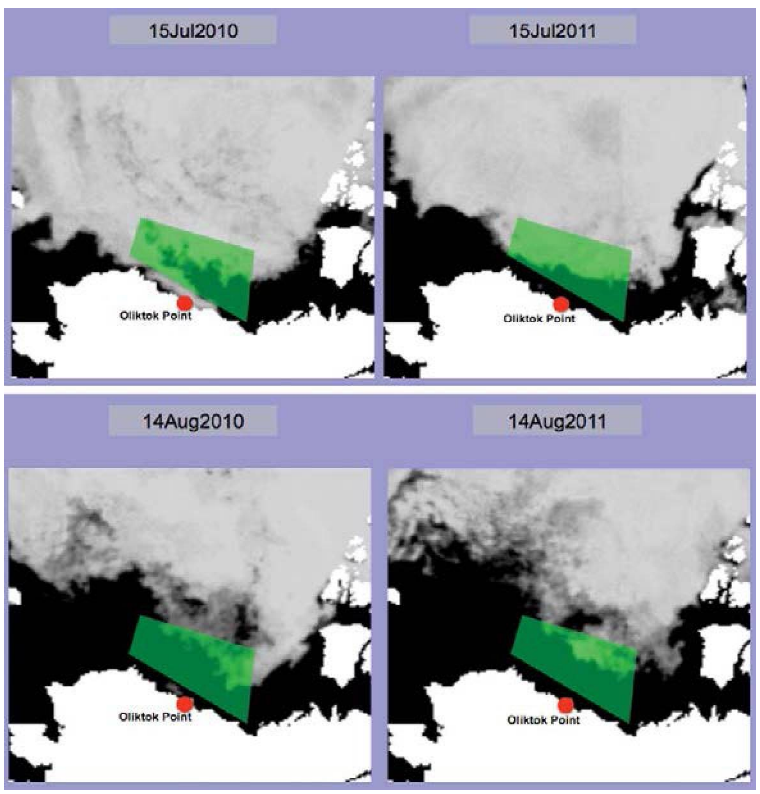


Figure 2. Progression of MIZ conditions in mid-summer.

1.4 The UAS

Each of the three measurement strategy elements listed above requires unique capabilities that are either impossible to attain or are too dangerous or impractical to be performed using manned aircraft or satellites. They therefore provide the rationale for UAS use and set the baselines for assessing how effective the UASs were in meeting these demands. Specifically, from the UAS perspective, MIZOPEX was designed to do the following:

- demonstrate the operational capabilities of UASs when deployed in a difficult environment and tasked with challenging mission profiles, and
- act as a "pathfinder" type campaign to identify and take the steps necessary to operate multiple UASs, including multiple classes of UASs and multiple UASs of the same class, in and near the U.S. National Airspace System (NAS) and under beyond-line-of-sight (BLOS) conditions.

This second goal warrants particular emphasis. Readers of this report should be aware that use of unmanned aircraft within the NAS requires approval by the U.S. Federal Aviation Administration (FAA) of Certificates of Authorization (COAs). These COAs impose a variety of requirements on UAS operators, such as operation of one aircraft at a time, flown within (un-aided) visual line of sight. MIZOPEX was designed specifically to provide legitimate science reasons to go beyond these restrictions. There was never any guarantee, even up until the last week prior to deployment to the Arctic, that MIZOPEX, working with FAA, NASA, DOE, and other players, would be able to achieve any of these flight permission-related goals. As this report shows, however, nearly all of these goals were achieved.

The UASs used for MIZOPEX were the NASA SIERRA operated by NASA Ames Research Center (ARC), the smaller Insitu, Inc. ScanEagles operated by the University of Alaska, Fairbanks (UAF) in original and UAF-modified forms, and the micro DataHawk UAS developed and operated by the University of Colorado (UC). The general concept of the roles of the different UASs and how they would be used in a coordinated way is given in Figure 3, with their specific roles summarized in Figure 4.

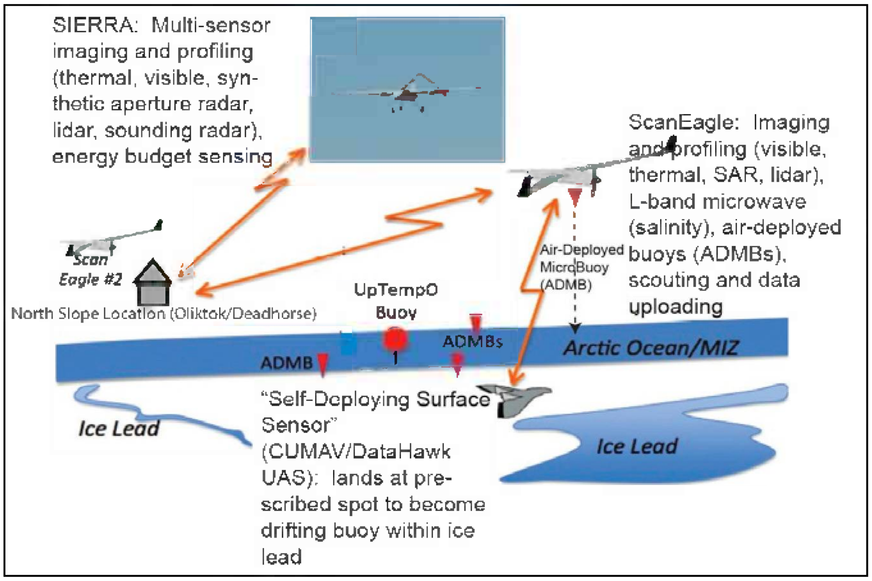


Figure 3. Concept of operations for MIZOPEX, showing the roles of the three different UASs, along with the air-deployed microbuoy (ADMB) and self-deploying surface sensor (SDSS).

Roles of the three UAS within MIZOPEX

The three UAS complement each other by providing a mix of payload capacity, electrical power for sensors, flight duration and range that are not available from any single UAS.

SIERRA: Deployment of relatively heavy payloads that require considerable electrical power, including coincidently-operating skin temperature sensors for sensor intercomparison, IceBridge-analog and IceBridge-relevant sensors such as the KU CReSIS Snow Radar, Riegl LIDAR scanner, and Artemis synthetic aperture radar. SIERRA offers demonstrated capability and familiarity for the Science Team through previous use during the NASA Characterization of Arctic Sea Ice Experiment (CASIE) operating from Ny-Alesund, Svalbard.

ScanEagle: Collection of skin temperature data over longer durations and with longer flight range than SIERRA. Placement of Air Deployed Microbuoys (ADMBs) and data uploading from ADMBs and the Self-Deploying Surface Sensors (SDSS). Proven operation in polar environments, with ability to fly at lower altitudes than SIERRA to help assure operations below cloud cover.

DataHawk/SDSS: The DataHawk provides the means to target an in-situ ocean subsurface temperature sensor package at desired locations by flying to a designated location and landing on the ocean surface.

Figure 4. Summary of the specific roles allocated to each of the UASs.

The individual UASs and the payloads used for MIZOPEX are described in Figures 5, 6, 7, 8, 9, and 10. The air-deployed microbuoy (ADMB) and SDSS systems were another component of MIZOPEX and are summarized in Figure 11 and in subsequent sections. The UpTempO buoy operated by Michael Steele (University of Washington [UW]) provided additional surface data, and is described in the Results section.

Because MIZOPEX is a NASA-sponsored campaign, all the UASs had to go through NASA's flight readiness review process while the deployment underwent a simultaneous mission readiness review. These reviews were completed successfully. Also, because it was a NASA campaign, overall supervision of safety and operations—including the review and approval of individual UAS operations and the certification of command pilots—was conducted by NASA (ARC personnel, led by Mark Sumich in particular).

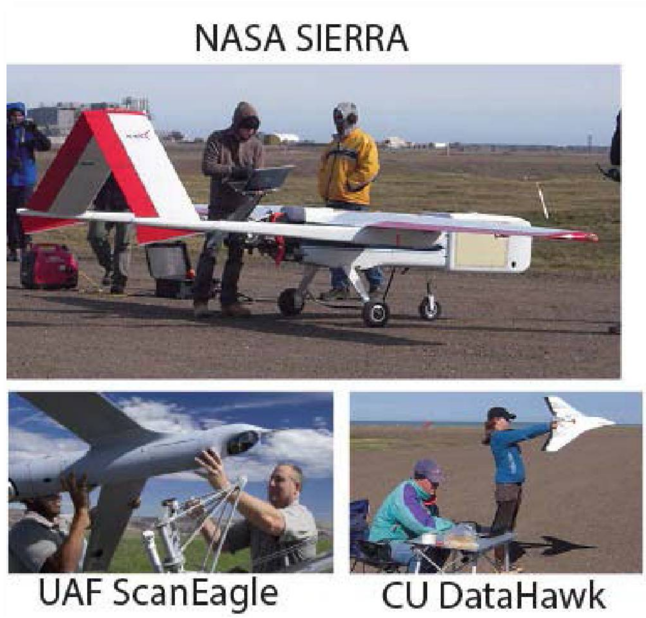


Figure 5. Three types of UAS shown deployed during MIZOPEX.

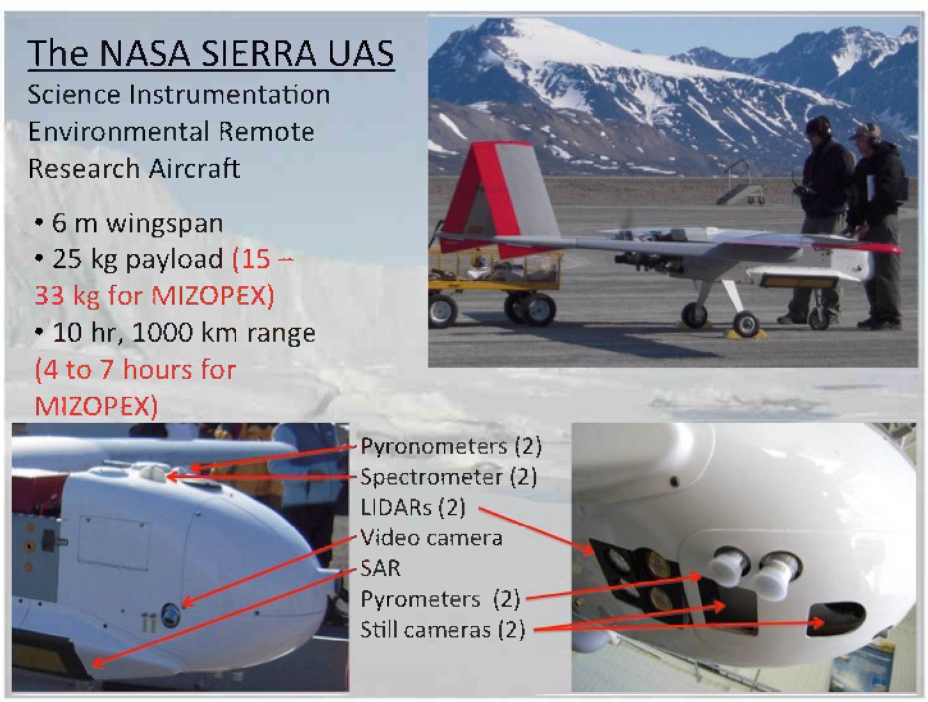


Figure 6. Overview of the NASA SIERRA UAS as configured for Svalbard operations during the Characterization of Arctic Sea Ice Experiment (CASIE).

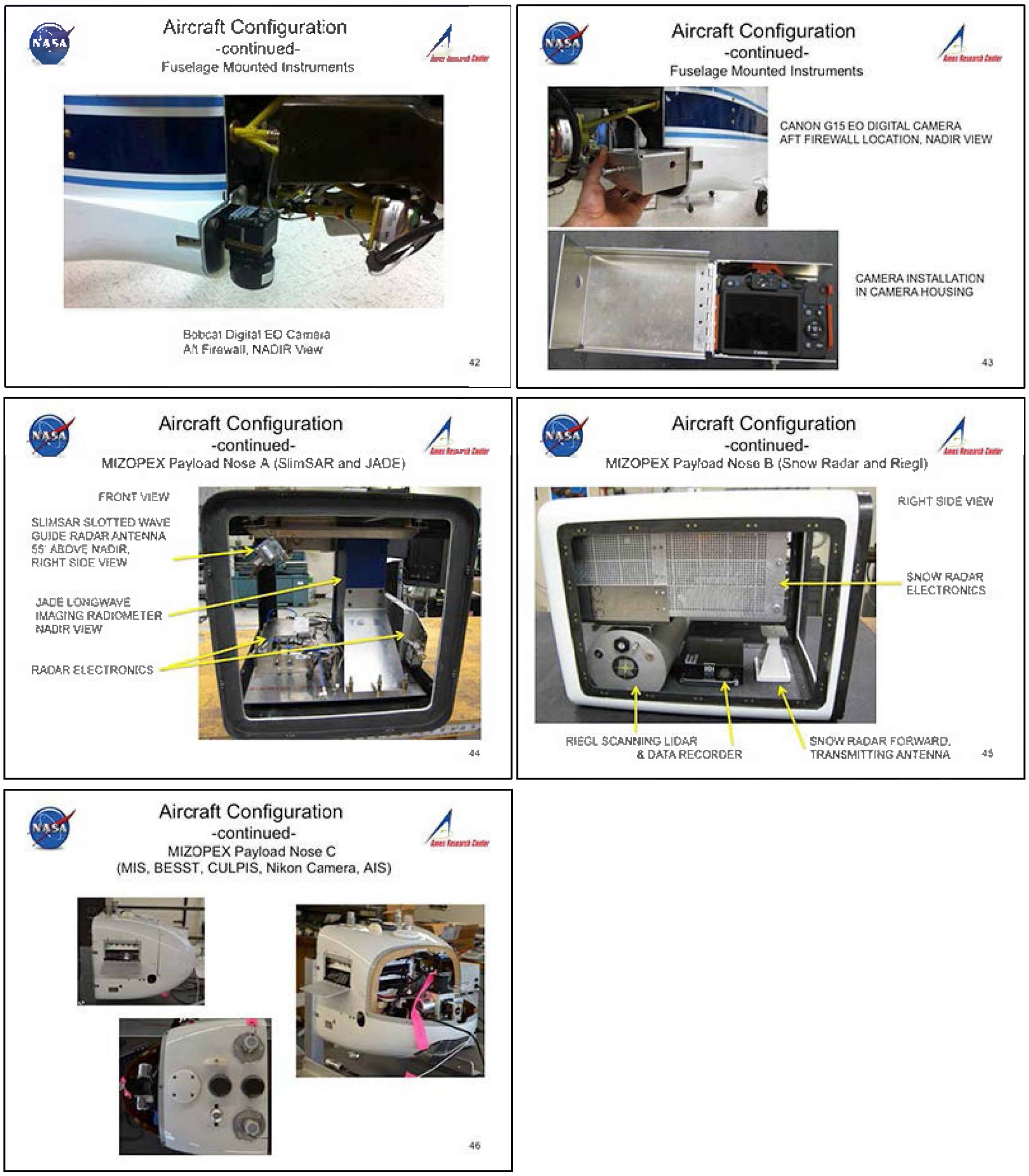


Figure 7. Payloads shown installed in the SIERRA fuselage and in payload Noses A, B and C, as configured for MIZOPEX.

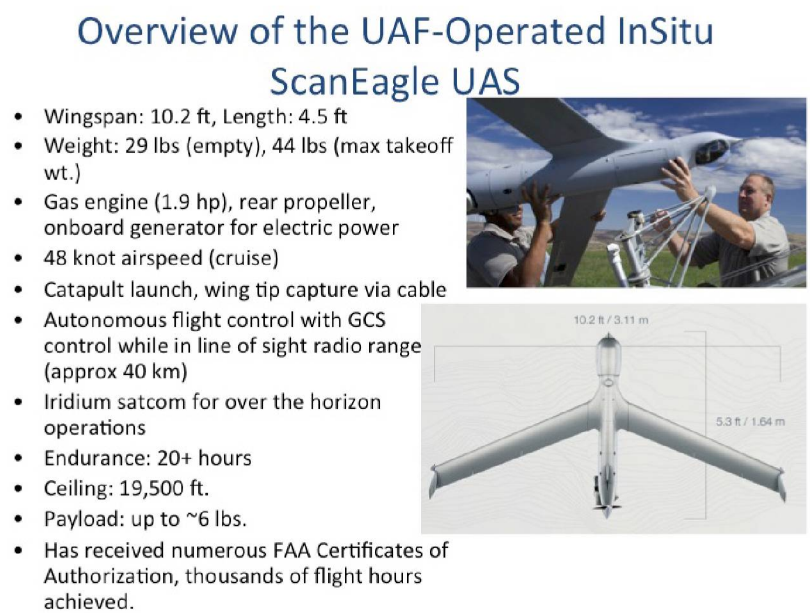


Figure 8. Overview of the UAF-operated Insitu ScanEagle UAS, including modifications for Piccolo autopilot use.

Figure 9. Payloads installed in ScanEagle payload bays, as configured for MIZOPEX.

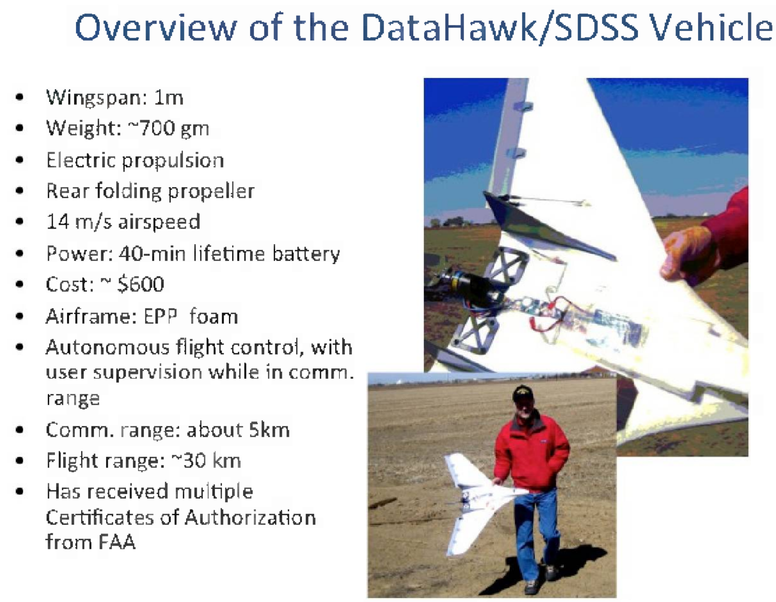


Figure 10. Overview of the UC-developed and operated DataHawk UAS, with SDSS system included.

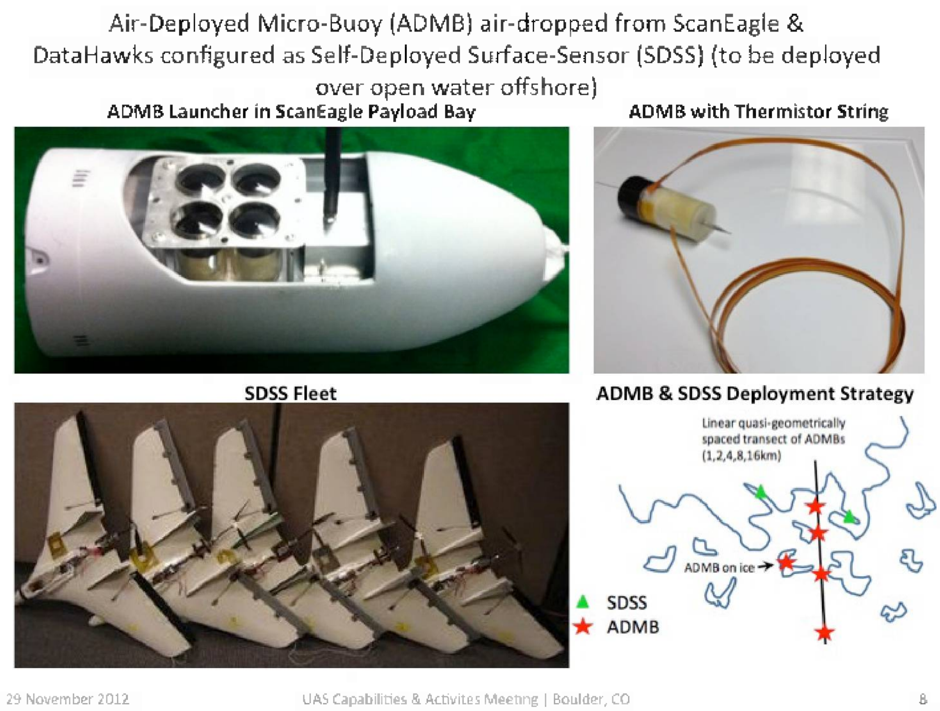


Figure 11. ADMB and SDSS systems installed in a ScanEagle bay and in DataHawks.

As originally proposed, MIZOPEX consisted of a data collection phase in Year 1 (summer 2012) with a data analysis and archiving phase in Year 2. The NASA UAS we proposed to use for this effort was the SIERRA, outfitted with basically the same instrumentation our group had used during a previous SIERRA campaign that collected Arctic Ocean and ice data with flights from Ny-Alesund, Svalbard (the NASA/CU CASIE in 2009). However, at NASA's request, MIZOPEX switched to the NASA Ikhana

UAS, with the campaign now to consist of intensive UAS field operations in summer 2013, with combined small UAS and Ikhana deployments in Year 2 at Oliktok Point and Fairbanks, Alaska, respectively. Work progressed on multiple fronts to employ Ikhana, including identifying additional remote sensing instruments and learning the capabilities of aircraft and flight systems. However, by January 2013, NASA decided that due to lack of resources, Ikhana could not be made available for a summer 2013 deployment. Because programmatic factors meant that a delay to a 2014 field season was not possible, the decision was made in late January to switch to SIERRA, including the decision to integrate several of the sensors that the MIZOPEX team had added for use on Ikhana. These decisions carried with them considerable risk regarding SIERRA and SIERRA payload readiness. Implications of this are discussed further in Section 3.2.2.

1.5 UAS Instrumentation and Data Management

The suites of sensor instruments as deployed during MIZOPEX are listed in Table 1 and Table 2. Please see the quarterly reports for additional details regarding the sensors.

Table 1. Instrumentation integrated into SIERRA payload bays for MIZOPEX use.

System Name	System Type	Geophysical Measurement	Affiliation
DMS	Visible still camera	Ice concentration, topography, melt	NASA WFF
MIS	Pyrometers	Skin SST, ice surface temperature	
	Spectrometers	Spectral radiance, albedo	
	Pyranometers	Solar irradiance, albedo	
Applanix	GPS, IMU	Aircraft position, altitude	
Bobcat	Visible still camera	Ice concentration, topography, melt	LDEO
Jade	Thermal IR still camera	Skin SST, ice surface temperature	
Shallow Ice Radar	L-band radar	Snow and ice thickness	
Snow Radar	Ultra-wideband radar	Snow thickness	CReSIS
BESST	Thermal IR still camera	Skin SST, ice surface temperature	Ball
SlimSAR	Imaging SAR	Ice concentration, roughness	Artemis
CULPIS	Profiling laser altimeter	Ice thickness, topography	CU
AIS	VHF communications	Ship identification and tracking	NOAA

Table 2. Instrumentation integrated into ScanEagle payload bays for MIZOPEX use, as well as the SDSS (DataHawk UAS with ADMB system) and the UW hand-deployed UpTempO buoy.

System Name	System Type	Geophysical Measurement	Affiliation
NanoSAR	Imaging SAR	Ice concentration, roughness	UAF
Gimbal	Visible video camera	Ice concentration, melt	
Bobcat	Visible still camera	Ice concentration, topography, melt	LDEO
ATOM	Thermal IR still camera	Skin SST, ice surface temperature	
ADMB	Surface buoy	Bulk SST	CU

CULPIS	Profiling laser altimeter	Ice thickness, topography	
SDSS	SRE UAS & surface buoy	Bulk SST	
Ariel	Microwave radiometer	SSS	UPC
BESST	Thermal IR still camera	Skin SST, ice surface temperature	Ball
UpTempO	Surface buoy	Bulk SST	APL-UW

For ScanEagle, Bobcat and ATOM were combined into one payload bay, while CULPIS, Ariel, and BESST each occupied an individual bay. A small video camera was added to ScanEagle to provide real-time video when in radio range. Multiple ScanEagles were fitted with ADMB/SDSS data receiver boards so that those aircraft could be used for ADMB data uploads while also carrying other payloads. During ground testing, it was found that electromagnetic interference (EMI) from the ScanEagle avionics was too great to allow for useful data collection with Ariel. The Ariel payload was therefore dropped from the available payload list, as was the NanoSAR, which proved to be unavailable for deployment because of sensor problems. Additional work was done on the ATOM/Bobcat payload by Scott Brown (Lamont-Doherty Environmental Observatory [LDEO]) while at Oliktok.

For SIERRA, the sensors were partitioned as follows among the three separate payload bays and the fuselage:

- **Payload Nose (large) #A:** Artemis X-band synthetic aperture radar (SAR) (SlimSAR), Jade longwave imaging radiometer, APTEK high-resolution electro-optical (EO) video camera
- **Payload Nose (large) #B:** University of Kansas CReSIS ultra-wideband (2 to 8 GHz) Snow Radar, Riegl Q-240i scanning LIDAR
- **Payload Nose (standard) #C:** WFF Micro Spectrometer Instrument Suite, BESST radiometer, CULPIS LIDAR, Nikon D7000 EO digital camera, L3 Protec-MRX Airborne Automatic Identification System (AIS)
- **Airframe (fuselage) Instruments:** Novatel interial measurement unit (IMU) and global positioning system (GPS) (replaced by a Blackswift, Inc. autopilot with onboard recording), Snow Radar receiving antenna (nadir), Bobcat high frame-rate (EO) digital camera, LDEO data system for sensor operation and data logging, Canon G15 EO digital camera

Sensor integration on Noses A and B was performed by ARC, with additional integration work done on Nose B by Fernando Rodriguez-Morales (U. of Kansas; CReSIS) while at Oliktok. Integration of the multiple sensors into payload Nose C was performed by NASA Wallops Flight Facility's Matt Linkswiler and others under the supervision of Geoff Bland. Payload Nose A and the airframe-installed instruments were installed for SIERRA's test flight and its aborted science flight. Portions of SIERRA were recovered later in the season.

1.6 Field Deployment, the Oliktok Site, and Flight Operations Domain

The field deployment planning, site selection, rationale, etc. are presented in earlier reports. Additional details on the mission planning, safety aspects, organization, etc. can also be found in the NASA Ames Mission and Flight Readiness Review documents available online at the MIZOPEX website or from NASA by request. A brief review is given here. Overall, a total of 32 different individuals participated in the field, either at Deadhorse or Oliktok Point. This consisted of the operations crews for the three UASs, instrument support personnel, campaign management staff, and data management staff.

Flight operations for all three UASs were based from the active United States Air Force (USAF) Distant Early Warning (DEW) Line station and runway at Oliktok Point, Alaska (Figure 12). Oliktok Point is located on the coast, about 50 miles to the northwest of Deadhorse, Alaska, accessible by a private Prudhoe oil-field service road. Oliktok provided a relatively remote location from frequent air traffic (although as discussed below, air traffic was still significant) and was ideally suited for the MIZOPEX science goals (direct access to an active MIZ). All UASs and supporting equipment were shipped by truck and, in a few instances, aircraft to Deadhorse, then transported to Oliktok Point by truck. Various other sites were considered, including operating from Deadhorse Airport, but were excluded mainly for air traffic reasons.

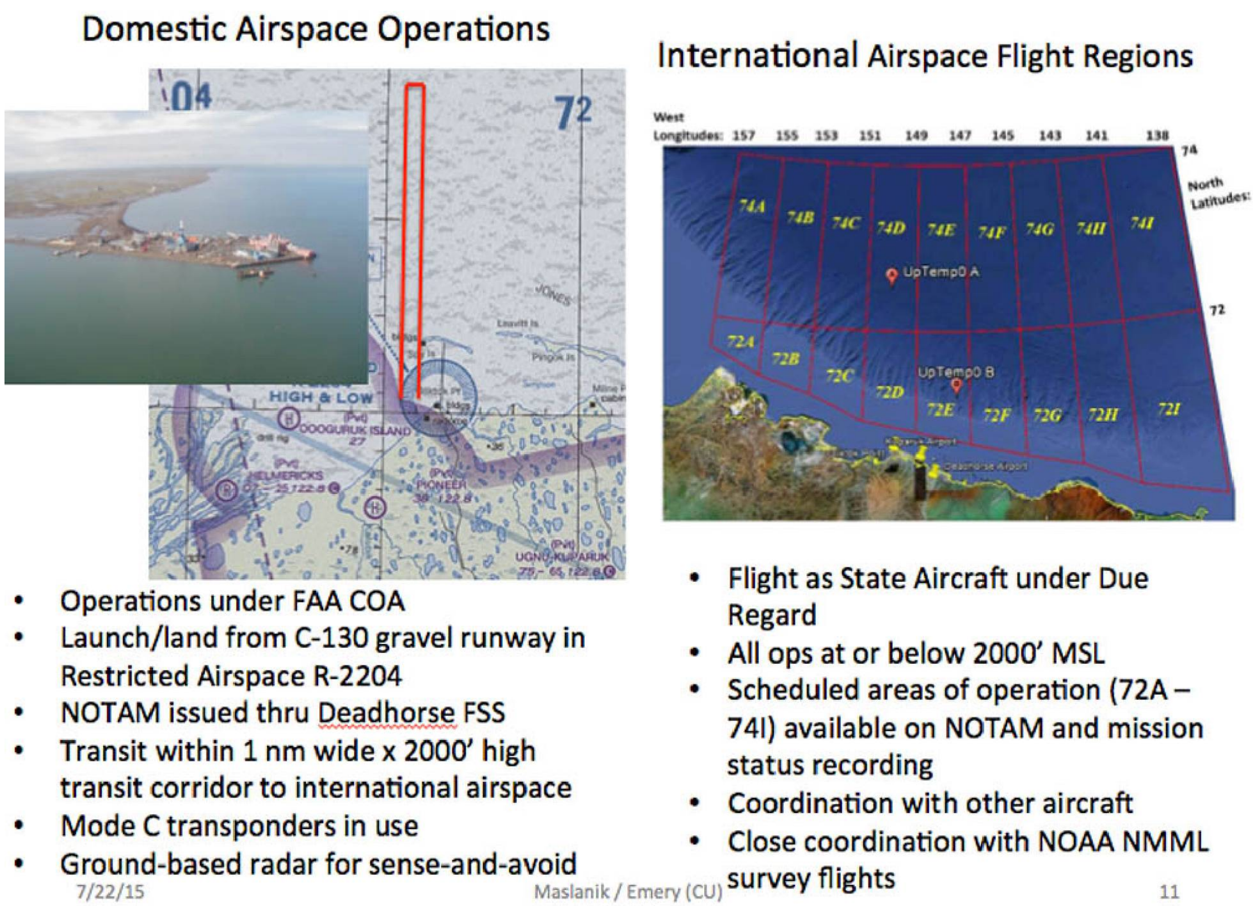


Figure 12. Flight operations designation and coordination.

The DEW Line facility is operated by the USAF. The Oliktok site itself includes the DEW Line building for lodging for a small number of personnel, an unused gravel runway, and an abandoned and partially useable large hangar. Access and use require prior approval. Operation of the site for research purposes is under the supervision of the DOE's Sandia Laboratories. A large ENI Corporation oil production facility is located on Oliktok Point itself. Access to the DEW Line station requires driving through the ENI site.

DOE also oversees a restricted airspace zone (R-2204) centered over Oliktok Point proper (Figure 13). Availability of R-2204 and provision for its use by DOE and FAA were important aspects for ultimate approval of the flight permissions granted to MIZOPEX by FAA (including BLOS and multiple UAS use). The framework ultimately agreed upon for flight operations consisted of use of R-2204, designation of a flight corridor from R-2204 to international airspace, and then operation within international airspace under NASA Due Regard provisions. The international airspace area was divided into multiple regions defined by latitude/longitude coordinates. We then used these individual sub-regions to help coordinate flight operations with others, and particularly with National Marine Mammal Laboratory (NMML). The coverage also extended into Canadian-supervised international airspace. While we obtained approval for a flight into that airspace, the operational situation (loss of SIERRA and delay in start-up of ScanEagle flights) led us to restrict our flights to the locations north of Oliktok (Figure 14).

Figure 13. Operations location at Oliktok Point, Alaska.

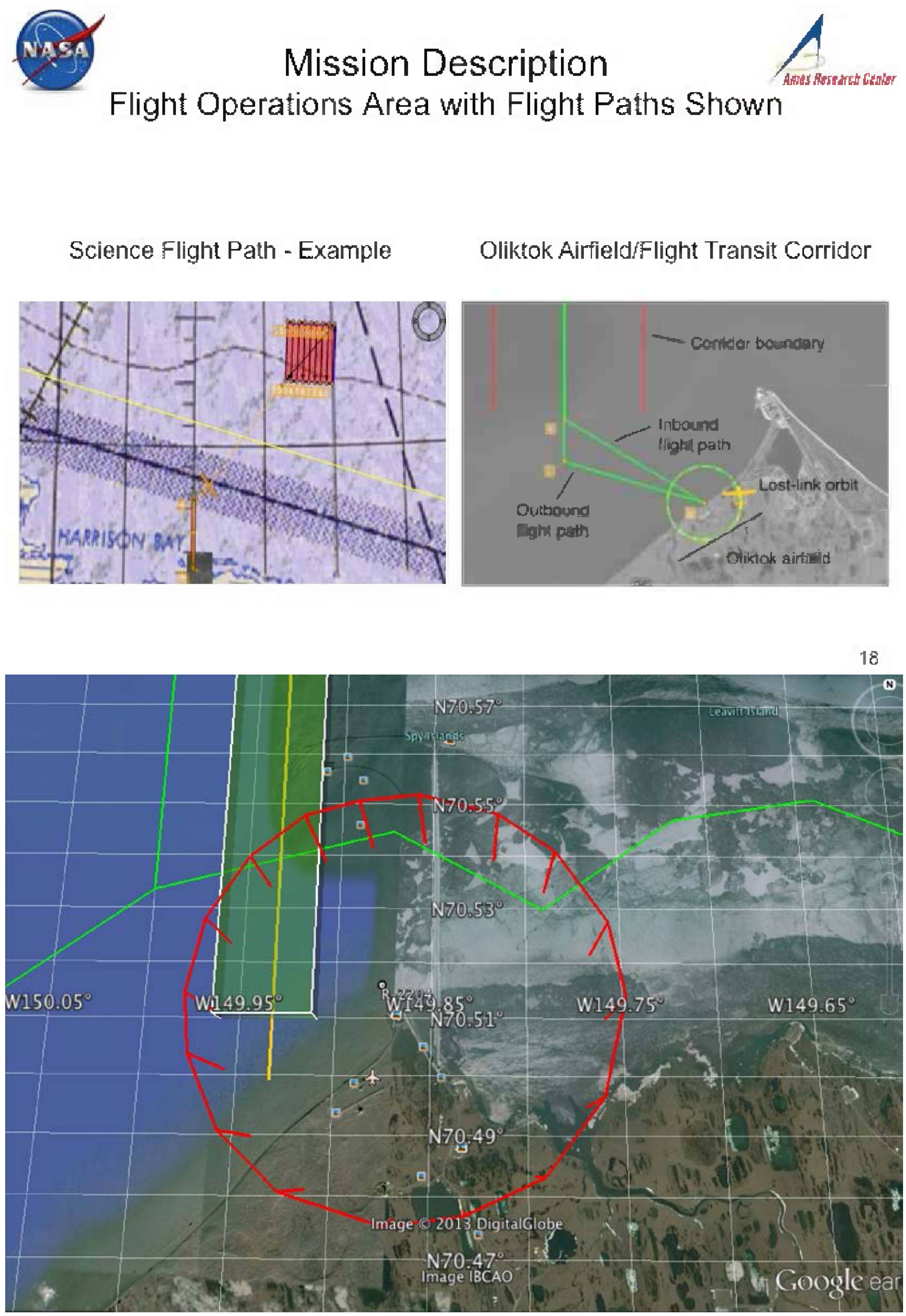


Figure 14. Illustrations of the corridor established for transit from R-2204 to international airspace. The actual domain of the R-2204 is in red shown in the bottom panel, with the transit corridor in green.

It is important to point out that the cooperation we received from USAF, DOE, and FAA regarding facilities and airspace use was critical to the field campaign. Integral to FAA's granting of the COAs to operate in this manner was the inclusion by MIZOPEX of a ground-based radar system to assist with sensing and avoiding local air traffic. This system was leased from and operated by Thales-Raytheon Systems Co. and was deployed on site during MIZOPEX. A test of the radar's performance evaluating its ability to detect air traffic was required by FAA before it could be used as part of the sense and avoid plan. Three days of testing were conducted, during which a chartered, manned aircraft flying a variety of tracks was observed, along with other aircraft, boats, ground vehicles, etc.

As discussed further in Section 3.0, a critical element of flight operations turned out to be planning for coordination with manned aircraft operations in the area, and ultimately the negotiations over and preparation of a comprehensive protocol of operations to be used with participants in concurrent NOAA NMML survey flights using manned aircraft. The coordination plan included the following:

- Established at least some form of relationship with all regional stakeholders that we could identify. This was intended to include (at a minimum) all local airspace operators, research organizations, and U.S. agencies operating in the area (U.S. Coast Guard, NOAA, Fish and Wildlife Service, Bureau of Land Management, etc.).
- Obtained schedule of operations from all regional airspace operators.
- Established a call-in number for all stakeholders, providing status on all daily mission activities.
- Issued notices to airmen (NOTAMs) for flight operations.
- Developed daily airspace operators contact list and planned for direct daily alerts.
- Established clear lines of authority within the field campaign.

The more specific operations protocol developed with NMML and approved by NOAA's flight operations board was put into place at the request of NMML. It addressed their concerns regarding possible airspace conflicts, which arose because NMML's operations specifically required transect flights offshore, within the MIZOPEX areas of interest and during the full MIZOPEX deployment period. The protocol that was ultimately agreed upon was quite rigorous, and defined particular steps such as having daily agreement among MIZOPEX and NMML on flight locations, continuous monitoring of NMML aircraft positions by MIZOPEX staff, contact trees (including satellite phone communications) between NMML aircraft and MIZOPEX, etc.

1.7 Operations Timeline at Oliktok

MIZOPEX personnel arrived at Deadhorse on 9 July, along with the SIERRA equipment and the Raytheon radar. These were hauled to Oliktok beginning on 10 July, along with a staging trailer and toilet facilities. Set-up took the next several days. (The entire logistics effort was a big challenge, which included arranging for equipment and deliveries by a local oil-field service company, MagTec, Inc. This was handled ably by Randy Berthold of NASA ARC.) During this time, the bear safety plan was implemented, including installation of a cyclone fence to help block the open entrance to the hanger. Scrap plywood within the hangar was used to create a floor over the bare dirt in the hangar. This served as the set-up and work site for SIERRA, with the hangar also being used for storage of other equipment.

Ground testing of SIERRA as well as the Raytheon radar began on 12 July, with the first SIERRA flight planned for 14 July. (The first flight was originally intended to be 12 July, but extra days were added for the Raytheon radar testing.) Testing of SIERRA identified several separate problems apparently related to a GPS cable and to other avionics components. Diagnosis and repair required several days. Testing of the full UAS package with Nose A sensors operating was carried out and was initially successful, but interference from the LDEO payload, affecting the GPS signal, appeared prior to the first test flight. This required additional modifications, which were ultimately successful. During this time, there were varying indications of possible EMI from local sources (perhaps the DEW Line radar itself, or other facilities such as oil production structures, etc.). A spectrum analyzer was used to trace the EMI, but results were inconclusive. It is worth noting that NASA ARC engineer Ric Kolyer attributes these problems and delays directly to lack of sufficient flight testing prior to shipping of SIERRA.

Arrival of the ScanEagle systems and personnel at Oliktok was delayed for about 10 days to allow time for UAF to address issues that arose from related flight mishaps during earlier testing at their facility at Poker Flat, as well as lack of readiness of the Piccolo-equipped aircraft. The UAF crew trailered their equipment from Fairbanks. Once on site, additional time was required for UAF to develop a specific safety plan acceptable to NASA and to put in place the ability to upload ScanEagle positions to a NASA website to allow real-time tracking. This was an FAA requirement as part of the MIZOPEX COAs.

The first UAS flights for MIZOPEX were carried out by DataHawk on July 21, with the first SIERRA flight on July 26 and first ScanEagle flight on July 28. A total of 24 UAS flights were performed prior to the last field day on August 9; 2 SIERRA flights, 16 ScanEagle flights, and 4 DataHawk flights, for a total of 54 flight hours. The flights are summarized in Table 3. One DataHawk flight tested the aircraft in its full SDSS configuration, which included a water landing, deployment of the thermistor string, and data recording and transmission. Seven ADMBs were deployed from ScanEagles within the MIZ, with four additional ADMBs deployed by hand by M. Steele (UW), along with his UpTempO buoy (see the Results section for more details on the ADMBs and UpTempO buoy). Three others were dropped over the runway (within R-2204; deploying in the NAS would otherwise have been prohibited) in a successful test of the deployment mechanism. This test also showed that the Piccolo-equipped ScanEagle was able to compensate without difficulties for the changes in center of gravity that occurred with each drop. This was a major concern prior to testing. Of particular note is that the UAF crew was able to carry out 16 flights over a period of just 12 days, including having 2 ScanEagles airborne concurrently on several days.

Table 3. Summary of MIZOPEX UAS flights

UAS Platform	Date	Flight Start Time (Z)	Flight End Time	Duration (hrs.)	Sensor(s)	Mission Type
DataHawk	7/21/13	20:12	20:27	0.3	Autopilot/ ADMB	Checkout of MIZOPEX SDSS configured for cloud boundary study
DataHawk	7/22/13	23:51				
	7/23/13		0:06	0.3	Autopilot/ ADMB	Checkout flight for configuration carrying MIZOPEX ADMB with long thermistor string

Table 3. (Cont.)

UAS Platform	Date	Flight Start Time (Z)	Flight End Time	Duration (hrs.)	Sensor(s)	Mission Type
DataHawk	7/30/13			0.3	Autopilot	Verify automatic vector field switching, observe guidance performance and demonstrate landing accuracy
DataHawk				0.3	Autopilot/ ADMB	Water landing/SDSS deployment within R-2204
DataHawk	7/30/13			.03	Autopilot	Verify automatic vector field switching, observe guidance performance and demonstrate landing accuracy
DataHawk	7/30/13			0.5	Autopilot	Cloud-base height detection experiment
SIERRA	7/26/13	17:55	19:08	1.3	Jade, SlimSAR, Aiptek, Canon, Bobcat	Aircraft and payload checkout
SIERRA	7/26/13	21:48			Jade, SlimSAR, Aiptek, Canon, Bobcat	SST and ice mapping within MIZ
	7/27/13		2:15	4.5		
ScanEagle	7/28/13	23:42				
	7/29/13		1:10	1.3	ADMB receiver and gimbal video	ADMB receiver testing, surface imaging
ScanEagle	8/1/13	23:05				
	8/2/13		3:44	4.7	ATOM/Bobcat	Temperature and ice imaging along mapping pattern in southern portion of study area
ScanEagle	8/2/13	19:44	22:2	3	ATOM/Bobcat	Temperature and ice imaging along mapping pattern
ScanEagle	8/3/13	1:12	1:40	0.5	ADMB system	Test dropping of ADMBs over runway, and testing of Piccolo-based ScanEagle
ScanEagle	8/3/13	21:20	22:40	1.3	ADMB system	Drop of 3 ADMBs in international waters
ScanEagle	8/4/13	21:37				
	8/5/13		4:20	6.7	BESST	Temperature mapping in northern portion of study area
ScanEagle	8/4/13	1:45	3;43	2	BESST	Temperature mapping in northern portion of study area
ScanEagle	8/4/13	2:12	5:20	3.1	ADMB system	Drop of 4 ADMBs in international waters

Table 3. (Cont.)

UAS Platform	Date	Flight Start Time (Z)	Flight End Time	Duration (hrs.)	Sensor(s)	Mission Type
ScanEagle	8/5/13	0:26	3:34	3.1	ATOM/Bobcat	Temperature and ice imaging along mapping pattern in southern portion of study area
ScanEagle	8/5/13	2:28	4:23	1.9	BESST	Temperature mapping coordinated with ATOM aircraft
ScanEagle	8/6/13	22:22			ATOM/Bobcat	Temperature and ice imaging along mapping pattern in southern portion of study area
	8/7/13		1:00	2.6		
ScanEagle	8/6/13	17:57	20:52	2.9	ATOM/Bobcat	Temperature and ice imaging along mapping pattern in southern portion of study area
ScanEagle	8/7/13	22:44				
	8/8/13		2:44	4	BESST	Temperature mapping in northern portion of study area
ScanEagle	8/8/13	22:20				
	8/9/13		0:20	2	ATOM/Bobcat	Temperature mapping coordinated with BESST aircraft
ScanEagle	8/8/13	21:36				
	8/9/13		0:44	3.1	BESST	Temperature mapping coordinated with ATOM aircraft
ScanEagle	8/8/13	1:08	4:55	3.8	ATOM/Bobcat	Temperature and ice imaging along mapping pattern in southern portion of study area

As the ice cover evolved over the July–August period, two separate regions of focus were identified for the UAS flights—a southern region that was within the flying range of the non-Iridium[1]-equipped ScanEagles, and a more northern area where ice concentration was greater (Figure 15). Mapping-type missions were carried out over these locations on multiple days, along with ADMB deployment and data uploading. Because swapping payload bays in the ScanEagles required at least one day of down time, and the start of ScanEagle flights had been delayed for about two weeks, and because the ice-over was sparse, the decision was made to maximize the amount of SST data collected by using the BESST and the ATOM/Bobcat payloads for the remaining portion of the deployment rather than to switch to the CULPIS or gimbaled camera payloads. The flight locations selected were sufficient to meet all of the MIZOPEX science goals, and also allowed us to simplify coordination with other air operators by being able to specify specific sub-regions that our UASs would occupy on given days. (Under the operations protocol with NMML, our UAS sub-regions could be changed during the missions only if communicated directly to the NMML aircraft.)

During the deployment, relatively few flying days were lost due to weather (nine days total). Early on, rainfall was the limiting factor, with a total of six days with too much rain for operations. Rain was heavy on three days when a storm was offshore, and light and variable on the other days. Localized fog became more prevalent at the end of the period, with fog precluding or curtailing flights on two days. Fog correlated well with onshore winds, and drier conditions with southerly winds. The fog was quite variable and quick to appear and retreat. Winds were relatively strong on most days, with wind speeds approaching 25 kts. SIERRA operations were postponed on one day due to increasing cross winds. Variable cloud cover was present most days, but later in the period, when localized fog became more common, skies aloft were occasionally clear. For much of the operations period, the flight planning personnel took part in daily phone conversations with U.S. National Weather Service forecasters in Anchorage. Their forecasts were typically fairly accurate in terms of the periods of persistent rainfall but tended to underestimate wind speeds. ("Oliktok" apparently means or implies "windy" in Inupiat, suggesting winds may be generally higher there than elsewhere.) In turn, the forecasters welcomed receiving our reports of local weather.

A subset of the daily "flight log" flight tracks are plotted in Figure 15 (inset).

[1] https://www.iridium.com/default.aspx

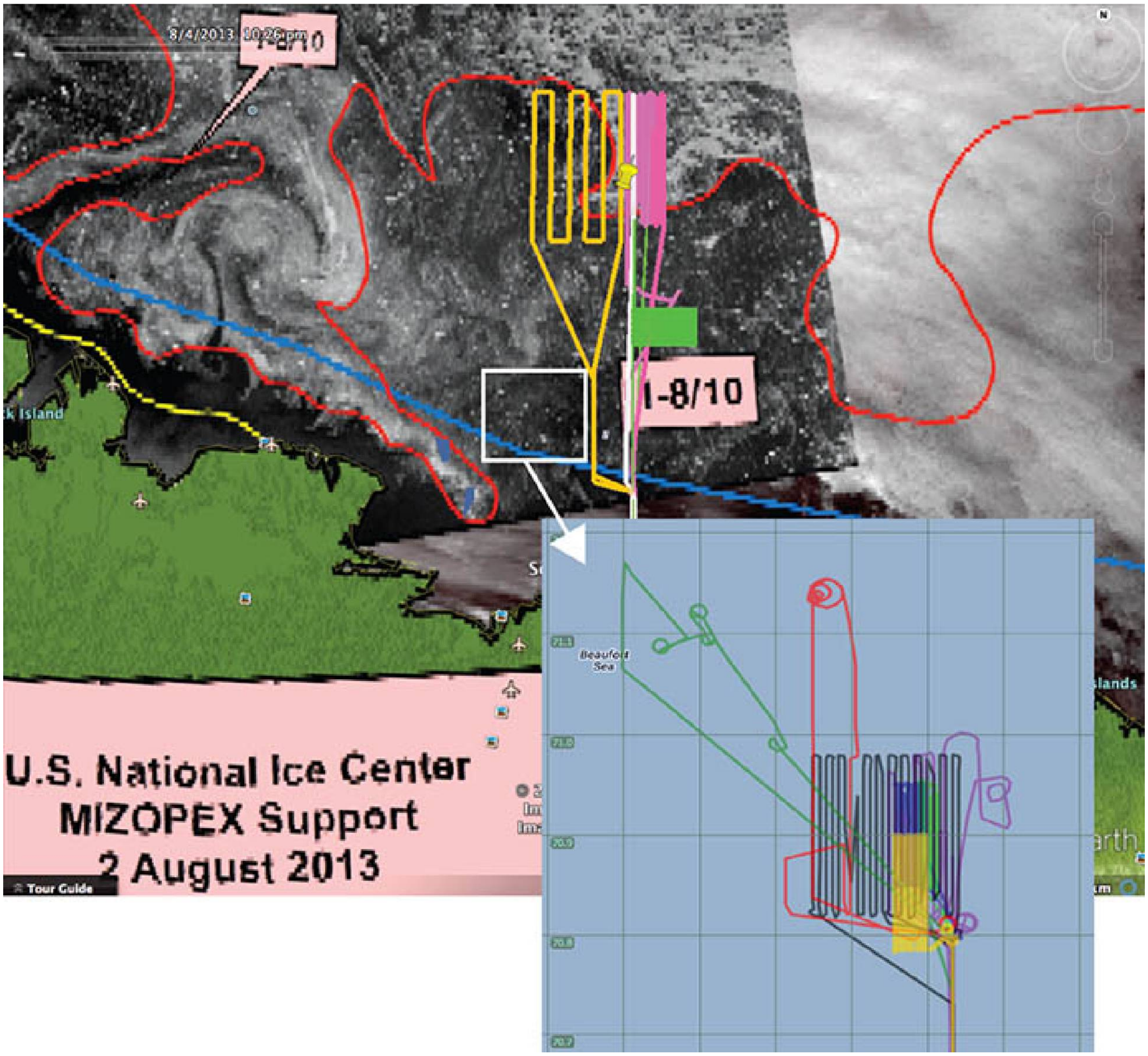


Figure 15. UAS flight tracks displayed on a Google Earth overlay of a sea ice chart prepared for MIZOPEX by the Navy/NOAA National Ice Center. The insert shows more details of flight lines in the southern portion of the study area (as plotted using NASA's Mission Tool Suite).

2.0 Notable Events or Highlights

Some of the most notable outcomes are listed in Figure 16 and the following bullets. Additional lists of successes, failures, findings, and recommendations are provided in the full NASA campaign report, where they are subdivided by different campaign components (overall success criteria, strengths, and weaknesses of the different UAS; science addressed; etc.). A subset of those items are provided below in Section 3.0.

2.1 Achievements

Figure 16. "Summary of Accomplishments" slide.

- Multiple steps to ready and deploy four separate UAS, representing four different classes of UAS (large – NASA Ikhana; medium – NASA SIERRA; small – UAF-operated ScanEagle; micro – University of Colorado, Boulder [CU]-operated DataHawk), with successful concurrent deployment of three of the UAS to an Arctic field location (Oliktok Point, Alaska).
- Extensive knowledge gained regarding positives and negatives of the different UAS, and the organizations and operations associated with each.
- Integration of a wide range of sensors into UAS, with several included as UAS payloads for the first time.
- Engineering of new payload bays for Ikhana and SIERRA, illustrating the potential of these aircraft to carry a wide range of payloads either in a single large pod (Ikhana) or divided among payload bays (SIERRA).
- Identification, enlistment, and engineering of additional sensors to take advantage of payload capabilities of Ikhana.
- Successful deployment of all UAS teams and equipment.

- First approval by FAA of UAS operations BLOS in the National NAS.
- First demonstration of use of ground-based radar as a safety resource.
- Demonstration of the ability to coordinate successfully with other aircraft operators to mutual satisfaction, including development of a detailed operations protocol.
- Approval and demonstration of joint operations of UASs.
- Multiple achievements regarding provision of logistics support for the Arctic location and the development of working relationships with local organizations.
- Development of agreements with USAF and DOE to take advantage of Oliktok Point resources.
- First operational use of UAS-deployed air-dropped sensor packages.
- First demonstration of using a disposable UAS (DataHawk) as a surface sensor platform.
- Demonstration of coordinated collection of remote sensing and in situ sensor data from UAS, with the latter consisting of subsurface ocean temperature measurements. This included coordination of air-dropping of sensors and remote sensing overflights with a large boat-deployed buoy.
- Successful science data collection with two of the UASs (ScanEagle and DataHawk).
- Demonstration of how individual classes of UAS can fill specific niches within a research campaign.
- Illustration of the value of multiple UASs as a risk-reduction factor to avoid complete failure if an aircraft is lost.
- Collection of enough key data sets to exercise the main elements of the field campaign science, including identification of unique and potentially significant interactions of individual ice floes with local ocean temperatures, and documenting changes in skin vs. mixed-layer temperatures.
- Demonstration of the utility of having data management staff on site during the data collection phase.
- Coordination with the National Ice Center for provision of specialized maps for flight planning.
- Coordination with the National Weather Service for daily flight briefings.
- Determination of the approval process for UAS flights in the Canadian flight information region (international airspace under Canadian supervision).
- Exposure of many team members to UAS technology and use, allowing them to gain unique experience useful for future efforts.

2.2 Failures

- Insufficient personnel and funding to make deployment of Ikhana viable, resulting in a switch back to SIERRA very late in the field campaign (SIERRA was originally intended for use), with resulting scheduling problems.
- Insufficient pre-deployment testing of SIERRA and ScanEagle with the integrated instruments, leading to delays in the start of science flights.
- Loss of the SIERRA during its first science flight.

- Intermittent failures of sensor packages, attributable primarily to lack of pre-deployment testing.
- Considerably less data collected than planned, due primarily to the early loss of SIERRA. This resulted in a lack of some key sensor data (the SIERRA loss was the most critical in this respect) and a lack of collection of other data sets over a sufficient time period to enable study of changes in ocean and ice conditions over time—an underlying science goal of MIZOPEX.

In total, we conclude that these achievements result in meeting the overarching goals of the field campaign listed at the start of this section. The successes listed above and later in the report addressed all of the most challenging goals and tasks. We believe we were particularly successful in determining routes and best practices for integrating UASs into routine operations, and in defining and advancing UAS capabilities and operation requirements for an intensive science effort. However, of the three main goals listed above, the science goal will not be met to the degree we had intended. This was due to the abbreviated time period over which science flights were carried out and, more critically, to failure to collect data with the suite of instruments on SIERRA. Overall, though, the problems encountered were not unexpected when carrying out a field campaign with so many challenges and firsts. Any follow-on campaign would likely have much greater success in terms of amount of data collected, aircraft and payload readiness, and payload reliability.

3.0 Lessons Learned

As noted earlier, a basic goal of MIZOPEX was to assess and explore UAS operations in the Arctic using multiple classes of aircraft deployed in a challenging field setting. Therefore, most of the findings and lessons learned pertained to aircraft systems and operations, instrument integration, airspace issues, multi-agency coordination, and field operations. Below, we summarize some of the basic findings that are likely to be most relevant to other UAS operations and to DOE aspects, focusing on the lead-up to the field deployment and the field operation itself. A more extensive list of findings, lessons learned, recommendations, etc. pertaining in particular to UAS and UAS operations under the current regulatory environment can be found in the NASA campaign report, with additional details available in the quarterly reports provided to NASA.

(a) Regulatory and Operations Coordination

- FAA COA process and limitations for a field campaign of this scope are very challenging and time-consuming. Requires extensive interaction, risk mitigation, and lots of lead time. Process and decisions were hard to predict. Success with FAA was only possible due to capabilities and reputation of NASA ("State Aircraft," "Due Regard" operations in international airspace).
- Addressing airspace safety (and perceptions of safety) in a relatively complex airspace environment like Oliktok requires outreach, planning, and methods (protocols, ground-to-air radio, etc.). Lack of information yields unwarranted fear, but outreach can also have unintended consequences.
- Value of web-based flight tracking and reporting tools for coordination.
- Designated "operations zones" such as the one DOE has proposed for Oliktok area would be a great facilitator of UAS-based field campaigns and would reduce concerns about airspace conflicts. (Does not need to be formally restricted airspace, which presents its own types of problems).

- Need realistic regulations for small/micro UASs (5 lbs. or less, for example). This would open up MANY opportunities for science and engineering that the present rules now make too cumbersome or restricted to pursue.
- Interagency cooperation was critical for MIZOPEX and ended up being quite good (but took some last-minute examples of strong leadership at the agencies).

(b) UAS Systems and Preparedness

- Do not try to do too much with a given UAS or field campaign. Creates too much pressure on UAS operators/engineers and can lead to friction and competing interests.
- For polar applications, lower-cost and "acceptable loss" aircraft and payloads are preferable.
- Force the field campaign to allow plenty of time for systems integration and testing at home locations.
- UASs with catapult launch, cable recovery or belly landing, and swappable payload bays offer great advantages for polar deployments.
- UASs that operate with small crews (4 or less) are preferable. Minimizes logistics, safety, and personnel challenges that are typical of remote polar locations.

(c) Data Coordination and Management

- Collecting and organizing data from multiple sensors and multiple flights is very difficult. Effort required is ALWAYS underestimated. Requires strong management. All data sets need to be time- and location-tagged in a consistent manner.

Additional details are provided in the following sections. (As noted above, a full set of these issues/lessons learned is provided in the NASA Year 2 and final reports.)

3.1 Issues Associated with Operating at Oliktok Point

Logistics presented a major challenge for MIZOPEX. Some of this relates to the unique situations associated with the nature of the Prudhoe Bay Oil Field, which is essentially an operation run by private companies (such as the single road between Deadhorse and Oliktok Point). While resources (lodging, meals, fuel, vehicles, structures, etc.) are available at Deadhorse, they are expensive, and subject to the needs of oil-field operators. Lodging is designed for oil-field company use with expectations that lodgers will book a block of rooms for a set period of time. This means that there is little flexibility to change schedules and add or subtract people from the UAS field teams. Some potential exists for arranging lodging/meals nearer to Oliktok Point (such as Sackett Camp near Oliktok), but it is difficult to predict whether these facilities will be available.

Based on our experience, due to the time, delays, and potential difficulties involved in the Deadhorse-to-Oliktok drive, staging out of Deadhorse while conducting flight operations at Oliktok should be a last resort. Daily travel of key personnel to Oliktok to carry out flight operations should be avoided if at all possible for a field campaign as long as MIZOPEX. The single road between the locations is not a public road—it is the property of oil companies, and its use is subject to their needs, limitations, and restrictions. The drive from Deadhorse to Oliktok typically averages about 2 hours, but can be considerably longer depending on other activities on the road. The drive itself can be hazardous and is often challenging even in good situations, and drivers are expected to know and abide by numerous and sometimes unique driving regulations. All who access the road must have prior approval to do so from the oil companies' security offices, and should not assume that they can negotiate this approval after arriving at Deadhorse. Security has the right to deny or cancel approval at any time, which is a significant risk factor for field campaigns.

Despite its remote location, there was a fair amount of air traffic in the Oliktok Point area associated with science and research flights such as wildlife surveys, archaeological sites, etc. The nature of these flights—relatively low altitude along transects with varying schedules and mission requirements—present potential challenges for coordination with UAS.

During MIZOPEX, some strange behavior was observed in UAS electronics and sensors, including servo jitters, unexplained failures of data system software, etc. One possible explanation put forward was possible effects of radio interference in the area. Potential sources of emissions nearby included the DEW Line radar itself, the nearby ENI facility, supply boats, etc. This should be investigated and quantified in terms of characterizing the overall environment for future UAS field campaigns. Some initial work was done toward this end during MIZOPEX using a handheld spectrum analyzer. Results were inconclusive.

Instrumental assistance was provided by DOE/Sandia Laboratories personnel (Mark Ivey, Jerry Peace, Darin Deslits) and administrators within DOE for the Oliktok field campaign and was indispensable in gaining us use of the R-2204 restricted airspace. The lodging, meals, and support provided by the USAF at the DEW Line Station were excellent, and the DEW Line staff was helpful in all respects. Since the existing facility cannot support more than about 6 to 8 non-staff lodgers though, some additional lodging with meals—either at Oliktok station or off site but nearby—would be very valuable. Users contemplating a campaign at Oliktok should be aware that long campaigns with many participants could over-tax the DEW Line building infrastructure and cause disruptions to the site's normal schedules and operations, so any plans for use should be discussed with DOE and USAF early in the planning process.

The runway at Oliktok is not maintained as an active runway (or was not as of summer 2013). It has areas that are soft and/or rutted. The roads from the DEW Line building to the runway also have soft areas that require maintenance by USAF staff if there is much vehicle traffic.

The old hangar at Oliktok proved to be useful as a shelter. Heating and/or lighting within the hangar were not available and had to be provided separately.

Additional infrastructure that would be valuable at Oliktok airfield itself include:

- Trailer(s) or structures with power, heat, and toilet facilities.
- Relatively large fuel and water tanks to avoid the need to haul fuel in 55-gallon drums and to have frequent water deliveries (trips from Deadhorse are expensive).
- On-site electric generator.
- High-speed internet link (the existing temporary link provided by NASA was only minimally adequate).
- One or two vehicles for travel between the airfield and the DEW Line buildings (to avoid having people walking, given bear risk). These could be snowmobiles and ATVs.

The ENI oil production facility on Oliktok Point proper is a large complex that handles oil and natural gas. While it is far enough from the airfield to allow safe operations, the potential ramifications of any incidents related to UAS operations could be very great. UAS operators should be sure to establish flight operations that keep aircraft well away from the Point, including as part of lost-link procedures. The same applies to the offshore oil operations (drill-pad islands) nearby. UAS operators working at Oliktok should keep in mind the frequent boat traffic from the ENI facility to the drill-pad islands, which was encountered during MIZOPEX (July–August).

Recommendations:

- Anyone operating at Oliktok Point needs to be aware of and understand the restrictions imposed by the nature of the Prudhoe Oil Field operations (road access, security, costs, driving time, logistics costs, etc.). Iron-clad arrangements need to be made with the Prudhoe Field security operators to assure that all personnel have permission to access Prudhoe facilities.
- All field campaign personnel need to understand that they are present on the Prudhoe facilities as guests, and they need to be made aware of, and follow, the Prudhoe site rules, including rules for driving. The rules and restrictions are detailed, arcane, and strictly enforced.
- If possible, anyone involved in UAS operations should plan on lodging at or near Oliktok Point, rather than making daily commutes from Deadhorse.
- Investigate the electromagnetic environment at Oliktok to determine possible risks and mitigations.
- Provide additional infrastructure at Oliktok, which would save money and time for UAS operations and reduce the burden on the USAF facility and staff.
- Improve the Oliktok runway and access roads to make the surfaces firmer. Improvement would not need to be up to manned aircraft standards.
- Define a "keep-out zone" for airspace around the ENI facility, and perhaps a minimum altitude near shore (to avoid supply boats). This would help avoid potential conflicts, would probably improve and simplify coordination with ENI and others, and would help alleviate possible concerns watercraft operators may have.
- At least one person from the team should take the Prudhoe Bay oil company driver's training course so that someone in the team is aware of the large number of arcane driving rules and can then instruct other drivers in the group.
- Prepare a field campaign "user's guide" to working in the Prudhoe Bay area. This would highlight issues such as road access, complications regarding lodging, the need for pre-clearance to pass through security gates, etc. DOE might be the logical provider for such a guide.
- International Traffic in Arms Regulations (ITAR) considerations led to a great deal more time being required for shipping, which in turn resulted in loss of systems testing time at ARC. ITAR came into play because shipping to Alaska can involve transiting through Canadian territory. Such ITAR issues are a problem for nearly all UASs. Arranging for some UASs (SIERRA's replacement, UAF ScanEagles, etc.) to have a pre-approved ITAR agreement with the U.S. State Department would facilitate their use and reduce delays.

3.2 Issues Related to FAA and Air Operator Interactions

To meet the objectives of the NASA Research Announcement, the MIZOPEX field campaign was specifically designed to help break new ground in applications of UASs in the Alaskan NAS and over Arctic international waters. This included a requirement for BLOS operations, deployment of different classes of UAS operated by separate organizations, simultaneous flights of aircraft, long-duration flights, and several other challenges. This complexity led to a variety of complications regarding COAs and other flight-related activities. The key ones are noted below, along with recommendations.

3.2.1 Obtaining COAs

The outcomes of this aspect of MIZOPEX need to be considered in several ways. First, the overall goal of advancing the use of civilian UAS within the NAS was a definite success. Achievements include the first approval of operations BLOS, first demonstration of use of ground-based radar as a safety tool, and approvals and demonstration of joint operations of UASs.

Use of three types of UAS for a single campaign, with UASs owned and operated by three different organizations (NASA, UAF, CU), led to some unique complications that are not faced if just a single UAS operation is involved. Individual UAS groups have their own styles for carrying out operations, as well as individuals and teams with different levels of experience. At times, this led to challenges regarding coordination and procedures. Another complication arose from initial confusion during discussions among FAA and UAS providers. Mainly, this can be attributed to (a) it not being clear at first to the FAA that all three UASs were part of a single campaign; (b) multiple lines of communication between the different UAS groups and different FAA personnel; and (c) uncertainty as to whether each of the UAS operating groups should pursue separate, independent COAs versus a single, campaign-encompassing COA. This was ultimately addressed by (1) having NASA Ames serve as the lead organization for FAA interactions and coordination and oversight of COA submissions; (2) having NASA, UAF, and CU submit the individual COA applications separately; and (3) supplying an overall concept of operations that described how the individual UAS fit within the overall MIZOPEX field campaign approach and with the safety- and air operator coordination plans.

Our attempts at obtaining a COA for BLOS operation of the small CU DataHawk UAS, or alternatively, an exemption under Part 101 rules (i.e., treatment as equivalent in risk to a small balloon payload), were not approved by FAA. The COA was rejected based on the fact that our plans involved operating the aircraft beyond communications range (i.e., in "intentional lost-comm mode"). The reasons for rejecting the Part 101 exemption have not been given formally to CU. Informally, it was suggested that an insufficient safety case was made. A standard within-line-of-sight COA had been granted earlier for DataHawk, but was not needed because we were able to operate within R-2204.

Arrangements had been made for permissions to allow UASs to transit through Canadian international airspace from U.S. international airspace. The procedures for this were determined and established, and permissions were in place for such a flight. However, based on the situation in the field (delays, aircraft readiness and other risk factors, ocean conditions, and science objectives), the campaign decided not to attempt this international transit during MIZOPEX.

3.2.1.1 Recommendations for Campaigns that have Challenging and/or Unique UAS Aspects

- As early as possible, designate a single field campaign point of contact (POC) to oversee interactions with FAA.
- Request that, if possible, FAA provide a complementary single POC to help assure that consistent information and interpretations are being passed to the campaign's POC. This would be warranted for campaigns with special complications, such as those contained within MIZOPEX.
- Apply for the COA(s) with plenty of lead time, assuming that several iterations and further information will be needed by FAA.
- In the COA application, applicants should consider providing a separate safety assessment for or specific discussion of any particular aspects of the COA application that might raise concern within FAA or potentially with others that FAA might consult. This could avoid misunderstandings or misconceptions about what is being proposed, which can lead to last-minute objections. This is particularly important for any aspect of the proposed operation that appears to be within the COA guidelines, but which might still raise a red flag during FAA's considerations.
- The COA application should include an overall concept of operations to provide FAA a big-picture view of the field campaign. This would help FAA staff understand how different elements of the COA relate to different aspects of the field campaign and provide a route for alerting FAA to the various different groups that are involved. In the case of multiple aircraft elements being employed (multiple UASs, coordination with other operations, etc.) and/or where different resources shared among different COAs (for example, the use of a single designated transit corridor, restricted airspace, and ground-based radar, as was the case during MIZOPEX).
- The iterative nature of the COA application process, in which the COA requester prepares and submits the application, then waits for FAA reactions regarding problems or issues, creates problems for challenging field campaigns such as MIZOPEX. Researchers hoping to propose non-standard UAS field campaigns have no way of gauging ahead of time whether FAA will accept certain approaches, and the tell-us-what-you-want-to-do-and-we-will-respond process leads to delays and some confusion. One approach might be for UAS users to be able to provide a field campaign outline to an FAA contact, and then have FAA provide an initial review of the outline wherein show-stoppers or areas needing major clarification are identified. This would be done prior to COA application preparation. The researchers could then decide whether to go forward with a campaign and a COA request. We recognize that this would place considerable burden and responsibility on FAA staff, but it would greatly facilitate UAS-based research field campaigns.
- Having an FAA staff person on site to observe and learn about operations proved to be valuable for the UAS teams as a way of demonstrating safety practices and helping to reduce some confusion regarding MIZOPEX plans.
- Provision of exemptions for very low-risk UASs such as DataHawk under Part 101 (i.e., treating the aircraft as posing risk comparable to a weather balloon) would open up considerable capabilities for sensing using UASs. An alternative would be to allow such aircraft to operate under a COA in fully autonomous mode outside communications range (i.e., in a planned lost-link mode.)

- When employing multiple UAS groups, establish the required practices, procedures, and expectations early in the planning process.

3.2.2 Interactions with Other Air Operators and Ground Facilities

Despite Oliktok Point's remote location, interaction between MIZOPEX personnel and other agencies' air operators and ground facilities proved to be among the greatest challenges of the field campaign and required considerable effort. Some of this can be attributed to the not-unexpected concerns by pilots about UAS operations in general, but some was also due to the nature of the air traffic present. This air traffic, consisting of biological research flights, supply flights to field camps, and oil-company service flights, proved to be less predictable, and/or tended to fly in locations and altitudes that presented more potential problems than would be expected from scheduled airline flights along fixed routes. For example, these non-MIZOPEX flights were often near shore and at low altitude, and their agencies desired flexibility to change locations and altitudes with little or no notice.

Overall, the interactions between MIZOPEX and manned aircraft operators and ground facilities (e.g., the DEW Line station, DOE Sandia Laboratories personnel, and the ENI oil production facility) went well, but only after some major, relatively last-minute efforts were carried out to obtain permission from DOE to use R-2204, and to develop the joint operations protocol with NMML discussed earlier. Several levels of administration in DOE, along with Sandia staff, helped to get permissions in place. (The USAF was also very responsive in providing access to the DEW Line lodging on short notice.)

A bit of additional explanation regarding the NMML interactions is useful, because similar situations might arise for other large-scale UAS field campaigns. Essentially, NMML staff felt that our earlier efforts at flight coordination were insufficient to alleviate their safety concerns. They were therefore prepared to stop their own operations unless an acceptable protocol could be developed. An important practical point ultimately arose from this: even though UAS operations may possess approved COAs and the UAS operators are within their rights to proceed, other groups have unofficial means of influencing the operations—for example, by threatening to cancel their own field campaigns or by taking other actions that would generate adverse reactions and publicity to a degree that might warrant curtailing or outright cancelling the UAS field campaign. It can require considerable effort (as was the case for MIZOPEX) to alleviate their concerns and to work out mutually acceptable operating procedures.

We also found that our outreach information was not necessarily passed along within organizations. For example, alerting a company's chief pilot about our field campaign did not necessarily mean that other pilots in that company would receive the information as well. There is a limit to how much of this outreach effort can be accomplished by a UAS field campaign, but the reasonable expectation of that limit remains unclear and will likely vary from campaign to campaign, depending on the location, nature of the campaign, and the individuals involved. While a lack of outreach might simplify the UAS operations by raising fewer unwarranted concerns among others, contacting as wide a range of operators as possible can be important. For example, one pilot who was conducting bird surveys heard about our operation from one of our other contacts. He was then able to reach us to coordinate his flights with ours, and was appreciative of being able to do so. Informing as many groups as possible about the planned activities helps in substantial, critical, and sometimes unforeseen ways to aid coordination efforts and reduce concerns.

The limited, well-defined transit corridor from Oliktok Point NAS to international airspace worked quite well, both in terms of interactions with other operators and with the ability of the UASs to respect the corridor restrictions. The nature of the corridor (clearly defined in terms of width, distance, and altitudes) could be easily explained to other operators, and appeared to provide a sufficient comfort level for them. Depending on specific UAS capabilities, establishing this narrow corridor to extend further offshore than just to international waters—far enough to exceed the typical distance from shore of nearly all manned aircraft flights—would likely further alleviate concerns. In general, the more certainty and assurances we could provide other air operators as to where, when, and at what altitudes our UASs would be operating, the better. In this regard, one issue that seemed to raise particular concerns was what the aircraft would do in lost-comm situations. We also encountered some basic misunderstandings in how UASs operate, leading to mostly unwarranted concerns about safety.

Based on general impressions while on site, it appeared that the Raytheon ground-based radar worked essentially as desired, in terms of providing a tool to detect aircraft within the area. Boat traffic offshore apparently was one source of potential confusion. NASA is preparing a report on the radar operation, which presumably will provide details about performance, limitations, and possible improvements.

While other operators have the responsibility to respect restricted airspace and be aware of NOTAMs, it cannot be assumed that they will do so. This may be particularly true in a case where a restricted airspace zone is seldom active. While we do not have definitive proof that this might be more prevalent in a location such as Alaska, where air traffic is less routine and fewer operators are in place, but some reasons exist for our thinking so.

3.2.2.1 Recommendations

- UAS groups need to do background work to find out what local operations are planned. To some degree, this can only be learned through experience, but an agency such as FAA or DOE (for Oliktok) maintaining a list of operators could help. If nothing else, this would effectively alert those proposing UAS operations to the extent of the coordination that might be required. Rather than expecting each field campaign to learn this separately at the considerable expense of its own time, staff, and funding (with the knowledge perhaps lost when that field campaign ends), having an individual whose role within an agency (FAA, DOE) includes maintaining this knowledge as a resource would be very valuable.
- Guidelines that outline some minimal experience that UAS operators should be expected to have with manned aircraft operations in terms of information and outreach would be valuable. Though such guidelines would need to vary so much from operation to operation that it is hard to envision a reasonable general list, the MIZOPEX experience could serve as a useful template.
- During MIZOPEX, there was no aircraft radio communications capability between DOE's Range Control Facility and manned aircraft. This led to questions about whether the Range was "hot" or "cold," especially important on the North Slope where communications between entities are already challenging. The Range Control Facility should have an established aircraft VHF radio frequency published, and the hardware installed, to enable two-way cockpit-to-controller communication.
- Other reliable means of communicating with aircraft operators—prior to and during flight—would be beneficial. The coordination protocol developed for MIZOPEX involved use of multiple means of

contacting other operators (email, phone, satphone). A sufficiently powerful ground-to-air radio would be valuable.

- Activate the Oliktok R-2204 restricted airspace frequently enough so that other agencies' pilots factor it into their thinking.
- Even when operating in restricted airspace, maintaining a visual lookout for other aircraft is recommended.
- Establish a fixed, "permanent" transit corridor from Oliktok Point to international airspace, with perhaps a second segment that extends from the international airspace boundary to approximately 60 NM from shore. This would allow other air operators to become familiar with its existence.
- While lost-comm procedures are clearly spelled out in COAs, these procedures should also be documented and described in a way that helps alleviate potential concerns of other aircraft operators.
- Although the nature of Deadhorse as a community does not lend itself to holding "open house" events to inform the public, the individual companies operating in the area appear to welcome such outreach (for example, a session with held with ENI personnel at Oliktok).
- A "How UASs Work" page on an FAA or NASA website, describing the basic nature of UASs, autopilot functions, typical fail-safe methods, etc., might be a valuable resource to which UAS operators could point others.

3.3 Aspects Related to the Individual UAS

(See the campaign reports submitted to NASA for additional findings and lessons learned.)

3.3.1 NASA SIERRA (ARC)

MIZOPEX investigators had used the NASA SIERRA successfully as part of an earlier NASA-funded campaign (CASIE), so incorporating SIERRA into the MIZOPEX proposal presented minimal risk and no particular challenges. As written, the proposal would have used essentially the same sensor packages (with some upgrades in data systems) and the single SIERRA payload bay (standard Nose C) employed during CASIE. The exception to this was the need to add the Ball Aerospace BESST system. Thus, the sensor integration and performance aspects for SIERRA originally posed relatively little uncertainty. The experience gained during CASIE also allowed us to reliably estimate what the flight duration would be for SIERRA, how well it would perform in Arctic conditions, and what the logistics and crew requirements would be. We were thus confident in the role outlined for SIERRA as part of MIZOPEX.

Once the decision was made to switch back to SIERRA after Ikhana was ruled out for use, the situation changed considerably. The first step was for NASA and the MIZOPEX team to determine jointly whether switching back to SIERRA was feasible. Key decisions then had to be made about whether to try to incorporate the additional sensors that had been identified for Ikhana use, along with the additional investigators supporting these instruments. Given that considerable time, effort, and money had by then already been spent toward use of these instruments (including development of modified versions of the Artemis SlimSAR and the UK snow radar), the decision was made to investigate options for carrying these on SIERRA by packaging sets of instruments into separate payload bays that could be swapped out in the field. This also meant finding lodging at Oliktok or as nearby as possible for the additional staff.

Initially, it was thought that, by adding extensions to the SIERRA wing booms, in combination with the original nosecone bay and adding instruments into the fuselage itself, most of the key sensors could be carried on every flight. Other instruments would be carried in a separate, larger nosecone used for a subset of the flights. Also at this time, a few instruments that were of lower scientific value and/or too large to reasonably accommodate were dropped from the payload list. By mid-spring, however, engineering assessments determined that the wing boom option could not be implemented in time (along with a finding that the boom extensions would weigh more than originally thought). The alternative chosen was to build two new large nosecones. These, along with the original small nosecone, could accommodate all of the remaining sensors. This would lead to fewer flight hours for some instruments, but still would meet the field campaign success criteria.

The result of these decisions was that, while we had arrived at a plan that would have demonstrated the ability of SIERRA to deploy a wide range of instruments (albeit not all at the same time), we had complicated the payload integration and testing process considerably, had introduced instruments that existed in different levels of readiness and prior testing, and added to the logistics challenges. This was in addition to the fact that the integration process was late in starting because of the changeover from Ikhana. Ultimately, this turned out to leave insufficient time for testing of the payloads at ARC before deployment to Oliktok. The net result was that testing had to take place on site, which delayed the start of science flights. Problems were identified that could have been dealt with more easily while still at ARC.

In hindsight, if we had done a strict triage of the Ikhana-intended instruments in early spring 2013 and limited the SIERRA integration to only the originally-planned instruments, the integration effort would have proceeded more quickly, presumably allowing time for more testing at ARC. As a result, we would have been more likely to succeed in collecting a basic set of key data types over a 4-week period. While there was significant enthusiasm among the team for the final plan, these decisions were made ultimately by the MIZOPEX principal investigator, who takes full responsibility for them.

From the experiences during MIZOPEX and the earlier CASIE deployment at Svalbard, the following strengths and weaknesses are most notable for SIERRA. (Presumably, many of them will also apply to a SIERRA replacement.)

Strengths:

- Demonstrated capability to operate at low altitudes and in Arctic summer conditions.
- Flight duration of about 10 hours with substantial payload sufficient for many research needs.
- Iridium command and control allows for true global coverage, with no known limitations due to latitude.
- Swappable payload bays add considerable flexibility to SIERRA.
- The bays, along with the additional payload area created within the fuselage, proved to be capable of hosting a wide range of instruments and other hardware.
- Sufficient aircraft-supplied power for numerous or high power-draw instruments.
- SIERRA can be operated from remote locations if a sufficient runway or improved surface is available.
- Relatively quick pre-flight process.

- Logistics needs, although not insignificant for SIERRA, are manageable at a location such as Oliktok Point.
- Strong capabilities of Ames team.

Weaknesses:

- Availability of only a single aircraft, which puts an entire field campaign at risk if loss or damage occurs (as in fact happened). The "one-off" nature of SIERRA also presumably resulted in limited availability of replacement parts, wing sets, engine, etc.
- The SIERRA was fairly sensitive to cross winds for takeoff and landing. This might have proven to be a significant limitation at Oliktok, at least in summer when the prevailing east-west winds are more variable.
- Manually piloted takeoff and landing requires a highly skilled pilot.
- Susceptibility to moisture, which is not a problem for manned aircraft.
- Electromagnetic interference from sensor/data system(s) proved to be a problem.

Suggestions for improving the usefulness of SIERRA's follow-on include:

- Provision of a directional antenna such as that used by UAF (ScanEagles) to provide longer range for the 900-MHz radio communications.
- Given the relatively soft runway at Oliktok, availability of a set of "tundra tires" for use in such conditions is worth considering.
- While EMI is ultimately a responsibility of instrument providers to address, further steps to shield the aircraft's systems may be warranted.
- Steps to improve resistance to moisture infiltration (rain, mist).
- Wheel pants perhaps would be valuable to prevent kick-up of rocks, and to improve wind flow.
- Add one of the inexpensive Iridium locator systems that provide tracking capability independent of aircraft power. This would be useful for locating a downed aircraft as well as perhaps making it easier for external groups to track the aircraft.
- Add, as standard procedure, the ability to port the aircraft's real-time position and altitude to one or more of the flight tracking websites used by other aircraft operators.
- If possible, have spare components available (wing sets, engine, etc.) that could allow a field campaign to continue if the aircraft suffers damage.
- Consider an internal mounting frame for instrument mounting, with a light, easily removable nose fairing for simplified integration and operation.
- Paint some portions of the aircraft orange, for visibility if a search is necessary.
- Implement a centralized data storage system with time and position tagging, to which multiple instruments can feed data.
- Add capability to turn individual sensors on and off at different stages of flight.

- Consider having a separate satcomm system for data/payload monitoring. This could provide "payload status" signals (autopilots are typically not designed with this in mind), and compensate for the standard telemetry stream, which may not allow much flexibility.
- Consider investigating some type of auto-deploying flotation bags or similar item(s) in the event the aircraft goes down over water. The experience during MIZOPEX shows that the SIERRA was apparently able to glide in and mostly survive impact and at least in part, remain somewhat afloat. Such a system, along with a separate position tracker or perhaps a locator beacon, would have made a recovery operation realistic and justifiable.
- UAS providers should be sure that UAS users are aware of the limitations associated with UASs that have duty-cycle rules. This also applies to restrictions such as the number of flight hours allowed before major aircraft inspection is due.

3.3.2 ScanEagle UAS as Operated by UAF

Key features of ScanEagle versus larger UASs such as SIERRA and Ikhana include:

- catapult launch
- boom cable recovery
- fully autonomous launch, flight, and recovery
- ability to provide multiple aircraft for a field deployment
- smaller crew
- considerably lower cost of aircraft
- ability to swap out engines and other parts to keep aircraft operating

All of these features make ScanEagle or UASs like it quite well suited to operations such as MIZOPEX. The launch and recovery system negate the need for a runway. Since the catapult can be oriented into the wind, crosswinds are not a significant concern, and the ScanEagles were flown in wind speeds that likely would have precluded a SIERRA launch. The catapult feature is particularly valuable where weather conditions can change quickly. Their fully autonomous operation allows flights in more marginal conditions, and lessens the need for a highly qualified pilot.

The big limitation of ScanEagle versus an aircraft like SIERRA is the payload capacity (mass, volume and power). However, ScanEagle's capacity is large enough to accommodate sophisticated sensors. Also, as we demonstrated during MIZOPEX, SIERRA's ability to deploy a larger payload can be reproduced to some degree in a ScanEagle by dividing payloads between two aircraft and having them fly in formation. The smaller payload capacity has the indirect and not insignificant benefit of leading to the use of less expensive, one-of-a-kind instrumentation, thus reducing risk if the payload is lost or damaged.

Two versions of ScanEagles were provided by UAF. One used an older autopilot with no satellite communications capability. The other used the more up-to-date Piccolo autopilot with Iridium comms. For MIZOPEX, the latter aircraft was more desirable since it could operate BLOS radio range, and the autopilot was better able to handle shifts in center of gravity associated with the launching of ADMBs. However, the standard ScanEagle proved quite useful as well, primarily because UAF used a directional dish antenna system that provided relatively long radio range, and we were fortunate enough to have MIZ conditions remaining relatively close to shore. This allowed continuous radio contact with science flights in international airspace.

This was the first exposure of the principal investigator to the ScanEagle system. Overall, we were impressed with the aircraft, the launch and recovery methods and procedures, and the ability of the UAF team to accomplish 16 flights within 12 days. As pointed out earlier, there were some delays in the UAF team's arrival and a delay in start of flight operations. Further, some of the aircraft still needed testing and weight-and-balancing on site, requiring more time. It should be noted, though, that UAF performed significant "value-added" engineering to improve the basic ScanEagle system and spent considerable time and effort in integrating the MIZOPEX payloads.

Strengths:

- Flexible, portable launch and recovery system is well suited to field locations with unimproved surfaces.
- Smaller crew size simplifies logistics requirements.
- Fully autonomous operation broadens the operating environment and places less burden on aircrew.
- Iridium command and control allows for true global coverage, with no known limitations due to latitude. (Drop-outs during MIZOPEX were manageable and not a major limitation.)
- Ability to operate in marginal conditions, at low altitude and under cloud cover.
- Real-time video transmission (available when within LOS radio range) is valuable for observing surface and sky conditions.
- Availability of multiple aircraft equipped with different payloads provides flexibility and efficiency for mission planning and operations. This allows planners to adapt to weather conditions and science needs.
- Lower aircraft cost allows for deployment of multiple aircraft, thus lessening overall risk to the field campaign if an aircraft is lost or damaged.
- Swappable parts allow continuation of operations if a single aircraft experiences problems.
- The UAF crew was able to find locations within the fuselage to include additional small instruments such as a video camera or the ADMB receiver.
- ScanEagle UASs thousands of hours of flight history have helped identify and address problems, leading to reliability and efficiency improvements.

Weaknesses:

- Susceptibility to moisture, which is not a problem for manned aircraft.
- Scientific payloads have resulted in heavier aircraft, which has led to overstressing of the recovery boom and resulting damage to aircraft and payload during pre-deployment testing. This boom weakness was also experienced by US Navy ScanEagle operators. A stiffer/stronger boom design may be needed for continued "beyond-OEM configuration" use by the National Science Foundation.

Recommendations:

- Shield all avionics as much as possible to minimize EMI effects from science payloads.
- Seal the aircraft to the degree possible to minimize water infiltration from rain or mist.
- Just as for SIERRA, more pre-deployment testing is critical.
- Further testing to assess the ability of ScanEagle and its launch and recovery systems to handle sustained heavier-than-normal payload operations.
- Document communications reliability of the Iridium system for small UASs operating at low altitudes (for example, failure rate/drop-outs per flight hour). Observed drop-outs were relatively short in duration during MIZOPEX, whereas extended periods of drop-outs were relatively common during some previous field campaigns.

3.3.3 DataHawk UAS (SDSS; UC)

The small, foam DataHawk UAS was operated in its SDSS mode (outfitted with the ADMB electronics and a 10-m thermistor chain) as well as just the aircraft itself, within the R-2204 restricted airspace zone. Four DataHawks were available on site. The SDSS version was tested by carrying out a water landing about 20 m offshore and then testing the recording and transmission of ocean temperature data using a ground-based receiver and a receiver on an overflying ScanEagle. The water landing and the data collection were successful. The SDSS continued to collect data for several days, after which time it washed ashore and was recovered. Unfortunately, FAA did not grant permission to fly DataHawk outside of restricted airspace, so we were limited to demonstrating the system's performance near shore. The COA application for operating DataHawk within the transit corridor to international airspace was rejected on the grounds that the radio range of DataHawk was too short to maintain continuous contact during the entire distance along the corridor. This would have resulted in operation of the UAS in "intentional lost-link" mode, which FAA would not permit. CU also attempted to obtain an exemption for DataHawk on the grounds that the low mass and speed presented comparable or less risk than a small instrumented balloon (e.g., Part 101 exemption). This was also not approved by FAA, although no formal explanation for the rejection has yet been provided.

Other experiments carried out with DataHawk within R-2204 included testing of response of the autopilot system in the Oliktok environment and detection of cloud-base height (through flights coordinated with a portable ground-based lidar ceilometer supplied by A. Schweiger [UW] and operated by CU personnel).

Strengths:

- The DataHawk/SDSS demonstrated the ability to land on water, collect subsurface temperature data, and upload those data to overflying aircraft.
- Minimal logistics requirements.
- Low cost allows its use as a disposable sensor platform.
- The effort demonstrated the usefulness of an easily portable, inexpensive UAS, operated by a small crew of two persons, when directed at applications suitable for a small platform.

- At some future point, FAA might grant exemptions to very low-risk platforms of this type, allowing operations outside the current COA limitation. This would greatly expand such UASs' applications.

Weaknesses:

- The short range of communication with the aircraft resulted in curtailed operations due to lack of COA approval.

Recommendations:

- FAA gave some informal indication that, had a stronger safety case been made to justify the "balloon" exemption under Part 101, it might have approved the COA. A recommendation therefore would be to pursue the Part 101 option further as part of a different field campaign.
- Investigate whether a more capable ground radio system and aircraft receiver might allow sufficient range to reach international airspace.

3.4 Issues Related to Sensors and Data Systems

The key aspect of sensors and data systems in the context of UASs essentially relates to the technical readiness level of the various instruments and their data systems. While none of the instruments, in and of themselves, were considered particularly high risk in terms of stage of development, collocating them in UASs as part of a complete system resulted in some problems. Realistically, the only way to address this is to carry out sufficient testing of the installed instruments within the UASs under as typical flight conditions as possible.

The two main issues that arose regarding sensor performance were the interference of payload electronics with aircraft systems, and unreliability of the payloads during flight. The interference manifested itself mainly on the aircraft GPS. This occurred with both SIERRA and ScanEagle. Additional shielding (with metal foil) eventually solved the problem, but considerable time was lost on site in diagnosing and fixing the interference. It is suspected, though not confirmed, that the LDEO data system was the source of the problem on both aircraft. One theory is that the interference resulted from the processor speed of the CPU onboard overlapping with the GPS frequency.

In terms of payload reliability, both the BESST and the ATOM/Bobcat payloads repeatedly stopped working after launch. Testing on the ground was unable to duplicate the problems. For ATOM/Bobcat, one theory is that radio interference, either from the DEW Line radar or some other source near shore, caused an interruption of the operating software post-launch. The system appeared to function better when start-up was delayed until the aircraft was several miles offshore. However, no cause-and-effect has been proven. In any case, BESST needed to be started prior to takeoff.

The BESST package as installed in ScanEagle is being tested further by Ball Aerospace to try to pinpoint why data recording stopped during flights. This package had been damaged in an earlier incident but appeared to have been fully repaired, and operated normally when installed in a ScanEagle for ground testing. However, some damage might have been overlooked. Concerns were also raised about some of the connectors used to interface components with the FitPC computer/logger. Standard office/lab-use connector types were used, so additional reinforcement might have helped.

A general observation is that payload providers should be made well aware of the need to take steps to design their systems with the rigors of UAS use in mind. Designs that are reliable on ships or large aircraft can suffer when wedged into small UAS payload spaces with other instruments and avionics. Builders should take extra steps to shield electronics to avoid interference, and wiring and connectors should be designed more robustly and reinforced. Consideration should also be given to access to memory cards, switches, etc., when the payload is installed. It might be helpful to review the overall payload integration approach in the future—the load-bearing nose cone used on SIERRA made access to components a bit difficult.

As noted earlier, upon being asked what recommendations the UAS engineers would have for a future field campaign, Ric Kolyer (NASA Ames) stated that a UAS should not be shipped to the field site unless it has undergone sufficient testing *with instruments installed*. During the run-up to MIZOPEX deployment, at least some of the time planned for testing was lost due to the extra time that turned out to be required for shipping to Oliktok. However, the basic point remains that allowing time for testing may need to be a hard, non-negotiable element in the schedule. The criticality of doing so rather than planning to fix bugs on site will depend on a variety of factors such as the nature and complexity of the UAS and sensors used, the field campaign's ability to adjust the amount of time on site, the severity of risk associated with different potential problems, etc.

Another consideration that instrument providers as well as UAS operations personnel need to take into account is the time and effort required by sensor systems pre- and post-flight. Practice by the instrument teams is helpful, both for defining the amount of time required and for allowing the UAS operators to learn the steps required. Any steps that delay takeoff once the aircraft has been prepped for flight tend to cause problems, both in terms of aircrew frustration and in terms of trying to capture weather windows or maintain schedules. On the other hand, the UAS operators need to appreciate that some preparation steps may be needed. The main point is that it be well understood ahead of time what will be required, how long the pre- and post-flight processes will take, and the degree to which aircrew assistance is needed (as well as what type of assistance).

One fact that instrument providers should be aware of is that, no matter what aircraft is being used, it is desirable and sometimes required (for efficiency, safety, and other factors) that only aircrew personnel be near the aircraft once it has been readied for flight. For this reason, instrument providers should consider setting up their payloads so that last-minute steps such as switching on power, etc., can be done by the aircrew. Different UAS operators have different tolerances and sensitivities regarding how the science and instrument personnel ought to interact with their crews. To avoid friction, these expectations should be made clear to everyone before deployment.

The need for and importance of time tagging, position, aircraft attitude information, and aircraft telemetry data were well recognized, but remain a difficult challenge for UAS field campaigns. The problem mainly comes about because individual sensor systems used for such campaigns tend to have their own dedicated data systems, sometimes with dedicated GPS and IMU, but not always. Some systems may therefore depend on GPS feeds from other payloads, or they may rely entirely on an internal clock for time stamping, or even something as basic as holding a clock or GPS unit in front of a camera to create a time reference. Lack of accurate time tagging that can allow linking among different data sets creates major problems for data archiving and analysis.

For SIERRA, this tagging need was addressed by using self-contained GPS on some instruments, by providing GPS data feeds to instruments without GPS receivers, by sharing of GPS antenna feeds among sensors with receivers, and by including a separate GPS and inertial navigation system in the fuselage, with the intent being that other data sets could make use of the position and attitude data via the GPS time tags during post-processing. The LDEO Jade and Bobcat sensors shared one data system along with dedicated GPS and IMU systems. A few other instruments relied on an internal clock or external time reference. The ScanEagle sensor packages each had a dedicated GPS receiver (the BESST's GPS receiver had been damaged before deployment and could not be replaced in time). The LDEO ATOM/Bobcat package included an IMU.

One major shortcoming of most existing autopilots, in our view, is their lack of the ability to record autopilot data onboard. Instead, the only access to the wealth of autopilot data is via telemetry during flight. When flying using Iridium communications beyond radio range, this translates to a low data rate and frequent drop-outs. Lack of onboard recording also means that the UAS operators must be relied upon to save and provide the telemetry files, and in some cases run the files through export code. This inevitably seems to lead to some confusion, extra work, and loss of information. For MIZOPEX, we addressed this by including an entirely separate, low-cost autopilot (Blackswift, Inc.) that can record its own data, including GPS and attitude data, during flight. (The new Blackswift system has several novel features and capabilities that would likely be useful for future platforms and missions.)

Successes:

- The ADMBs and SDSSs (configured as the DataHawk UAV), along with air-dropping and data uploading by ScanEagle, were notable successes.
- Considerable success in installing instruments into SIERRA. Of particular note was NASA/GSFC/Wallops' integration of a wide-ranging suite of instruments into the SIERRA's "small nose" payload bay, including the BESST system. It was also a substantial achievement for NASA Ames to have integrated the large, complex Jade and SlimSAR systems. Full integration of the University of Kansas (KU) snow radar and Riegl LIDAR scanner was not achieved prior to SIERRA's loss, although installation into one of the large payload noses was well underway.
- Successful installation and flights of the BESST, and ATOM and Bobcat sensor packages in ScanEagles. CULPIS was installed and available, but was not flown at Oliktok due to lack of time.
- The ability of ScanEagle to transmit real-time video while within radio range (about 20 nm) proved to be quite useful for observing surface conditions and avoiding cloud cover.

Failures:

- Overall, the reliability of the key payload packages on ScanEagles (BESST and ATOM/Bobcat) was less than hoped for.
- No data collection with CULPIS, due to re-prioritization of payloads as time in the field ran out.
- EMI from payload(s) was difficult to diagnose and mitigate in the field, resulting in lost flight time.
- While the ADMB system worked well, better flight planning would have probably resulted in uploading of more data from the InSitu buoys.

Recommendations:

- Require sufficient testing of full systems (aircraft + payloads) prior to deployment. This involves defining what "sufficient" is, which likely will vary depending on the UAS, deployment location, and other variables.
- Payload providers need to be fully aware of the special challenges posed by UAS installations, including the need for EMI protection, reinforced connectors and wires, and providing easy access to memory cards and switches.
- Maintaining good and complete communication between UAS engineers and the instrument providers is critical, and requires particular attention from management.
- Have a well-established and understood plan for pre- and post-flight requirements for payloads, to help minimize delays and frustrations on the ground.
- Configure payloads so that last-minute pre/post-flight steps such as power-on can be carried out by the air crew so that others do not need to approach the aircraft.
- The recording of GPS and IMU data for subsequent sensor data processing and referencing is critical, and can fall through the cracks. A dedicated data system handling multiple sensors is ultimately probably the best solution, but is difficult to achieve in practice.
- Payloads should have the ability to auto-start during flight, and the aircraft should be able to power the payloads on and off during flight.
- Designing the payload to perform auto-starts at fixed intervals during flights (with no overwriting of data) could help reduce the loss of flight hours due to lack of sensor operation.
- While it is more a function of the UAS than the payload itself, the ability to transmit "payload status" information back to the ground would further lessen time lost due to equipment failures.
- Autopilot data always ends up being valuable. Rather than relying on telemetry, at least some of the autopilot information (basic information such as speed, position, and altitude) should be recorded onboard, in real-time, and at the maximum data rates possible.
- Mechanical integration schemes for instruments (for example, mounting and access) could be improved.

3.5 Data Management

The large number of sensors planned for use, allocated among different aircraft and in conjunction with the ADMB, SDSS, and UpTempO in situ measurements, meant that MIZOPEX had the potential to yield a large amount of data of a variety of different types and formats. Previous experience had shown how difficult it can be to gather up and organize large volumes of data from aircraft field campaigns, particularly when the entire responsibility for doing so rested with the instrument investigators in the field and afterwards. To help address this, MIZOPEX included a relatively comprehensive data management approach that included having data management personnel (Fort Hays State University [FHSU] staff) on site. These individuals developed data summary forms, templates, etc., to be used for the various data types as a way of organizing the flood of data that was expected. While on site, they also prepared and maintained various social media outreach tools such as a dedicated Facebook page (https://www.facebook.com/MIZOPEX), and assisted S. Castro (CU) with supporting the MIZOPEX website.

With the loss of SIERRA on its first science flight, the expected data volume and complexity was much reduced. However, the FHSU data management group is continuing its data archiving and documentation tasks with the data acquired by ScanEagles, ADMBs, SDSS and the UpTempO buoy.

A shortcoming of the field campaign was the requirement, due to lodging limitations, that the data management staff be housed at Deadhorse, without immediate and easy access to the instrument personnel and their data, who by this time had mostly moved to the DEW Line station at Oliktok. Even with the reduced data flow following the loss of SIERRA, this separation proved to be a problem and ultimately led to a loss of some effectiveness for our original approach of having the data managers gather flight information and data immediately after flights. These duties were taken up by others who, in the midst of other responsibilities, could not provide the same attention to the data tasks as warranted.

4.0 Results

As pointed out in the introduction, this field campaign (due to the dictates of NASA's funding and schedule) was primarily a data collection and UAS-testing effort focused on science problems. Unlike most other campaigns, it did not include time or funding for a "data analysis" phase. However, sufficient work has been done with the data to demonstrate the value and limitations of many of the data sets collected. These results are illustrated below in summary form. It is also important to note that the data collection was severely limited by the loss of SIERRA and, to a lesser degree, by the delayed start of the ScanEagle flights.

4.1 Relationships Between Ice Floe Characteristics and Surface Temperature

Examination of quick-look data during the deployment suggest that one of the key outcomes of the UAS flights may be the identification of complex relationships between ice floes, meltwater from the floes, and disruption of the mixed layer by the drifting floes. These features appear in preliminary imagery from the LDEO Bobcat and ATOM imagers as variations in SST on floe surfaces and nearby, including apparent wakes (Figure 17). The fact that we were able to carry out the mapping over multiple days should allow study of how the effects vary under different wind and cloud conditions. Whether such effects are significant for redistributing heat during melt remains to be considered, but we suspect that MIZOPEX has captured these effects in ways not previously seen. A subgroup of MIZOPEX investigators is pursuing this line of research using the 9+ hours of Bobcat/ATOM imagery and the BESST thermal imagery collected by ScanEagles. The imagery also suggests that the floes that had survived into early August were heavily deformed. Implications of this in terms of ice mass and possible shipping hazards is being considered by MIZOPEX co-I Andy Mahoney (UAF) and others.

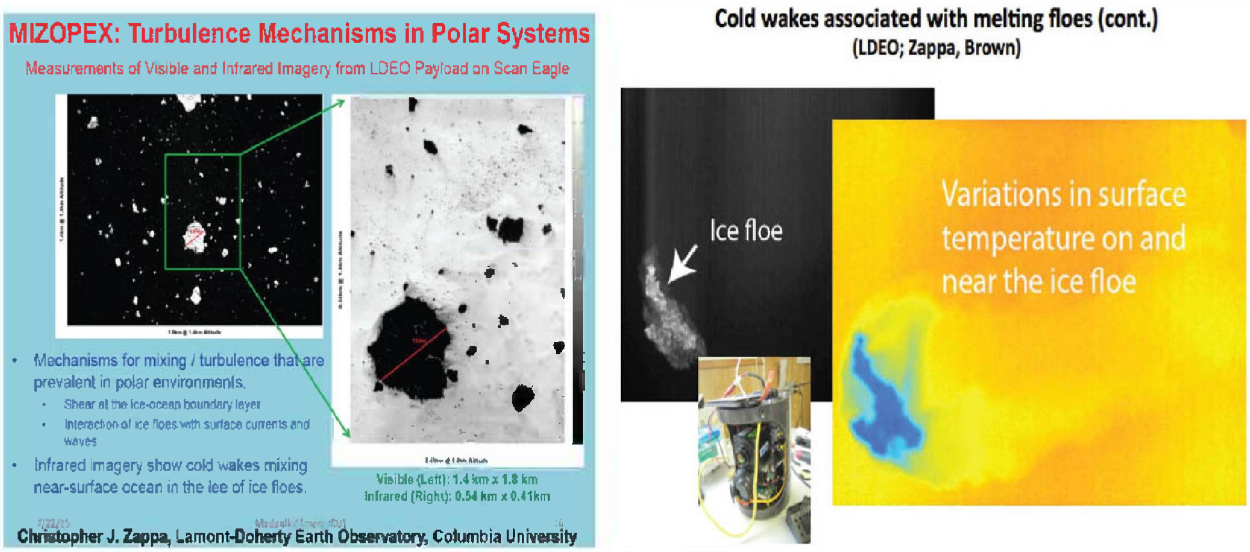


Figure 17. Illustration of one of the many examples of ice floe and surface temperature relationships captured by the LDEO Bobcat EO camera (top) and ATOM thermal imager (bottom) deployed on the ScanEagle. These images were acquired on 4 August from an altitude of 750 ft.

4.2 UpTempO Deployment and Data Comparison with ADMB Data

M. Steele and engineer N. Michel-Hart deployed an UpTempO buoy (manufactured for us by the Pacific Gyre company in Oceanside, CA) north of the Alaskan Beaufort shelf break on Sunday, August 4. It was deployed via the small research vessel Ukpik in the MIZOPEX UAV operational area. Also deployed off the ship were four ADMBs (although only two of these uploaded data to a UAV [see results #2 below]). The UpTempO buoy records ocean temperature at the “surface” (actually, the underside of the floating hull at about 0.12 m depth), and then at 2.5 m, 5, 7.5, 10, 15, 20, 25, 30, 35, 40, 50, and 60 m. There are also three ocean-pressure sensors at 20-m, 40-m, and 60-m nominal depths, and a Seabird CTD at 4-m depth. The buoy also measures sea-level pressure and wind speed and direction. Data were recorded every 10 minutes for much of the first few days of operation, then hourly via Iridium. Deployment occurred in a broken field of ice floes and open water; i.e., within the outer edge of the MIZ. Figure 18 shows a few photographs from the deployment.

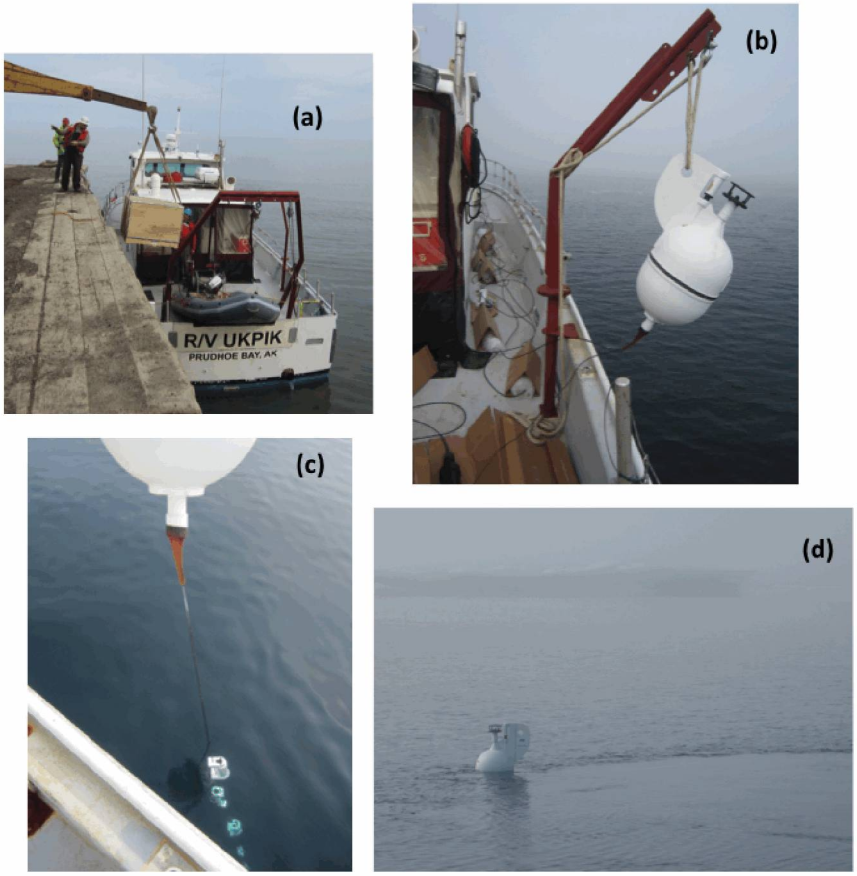


Figure 18. (a) Loading the UpTempO buoy (in box) onto the R/V Ukpik deck in Prudhoe Bay, near Deadhorse, Alaska. (b) Buoy ready for deployment, hanging from a crane by the anemometer vane (which is attached to the hull). The sonic anemometer (black) is visible at the top of the hull, and the cable of ocean sensors is strung out along the deck side (with sensors still in bubble wrap and cardboard). (c) The buoy just after the sensor cable was hand-fed over the deck side into the water, ready for the hull to be lowered down. (d) The buoy drifting away from the Ukpik in light fog, with an ice floe just barely visible in the background.

4.2.1 Investigation of the Quality of Level 4 SST Products in the Beaufort Sea, Arctic Ocean

This analysis is a collaborative campaign with S. Castro and G. Wick at CU. We seek to characterize the quality of various Level 4 SST products in the Beaufort Sea, using as validation in situ upper ocean temperature data (e.g., UpTempO buoy data including the buoy deployed during the SIZRS field campaign). Our key diagnostic tool is the Taylor diagram, which is a convenient way to compare many SST products with each observational data set (e.g., with a time series from a particular buoy). We are finding significant differences among the data sets, although these are sometimes influenced by small differences in the position of SSTs' fronts. A paper is in preparation on this material (Castro et al. 2013).

4.2.2 The Structure of the Upper Few Meters of the Ocean in the Marginal Ice Zone

The effort to understand the structure of the upper layer of the MIZ was a collaborative task between the ADMB (air-deployable microbuoy) team, Bill Emery's UAV SST team, and the UW UpTempO buoy team. The collaboration compared data collected by two ADMB's hand-deployed from the same small research vessel that deployed the MIZOPEX UpTempO buoy, using SST data obtained via ScanEagle UAV on that same day. A preliminary analysis (Figure 19) indicated good agreement between the two types of buoy at first, but then some differences emerged. These were likely the result of advection into different sea ice melting regimes.

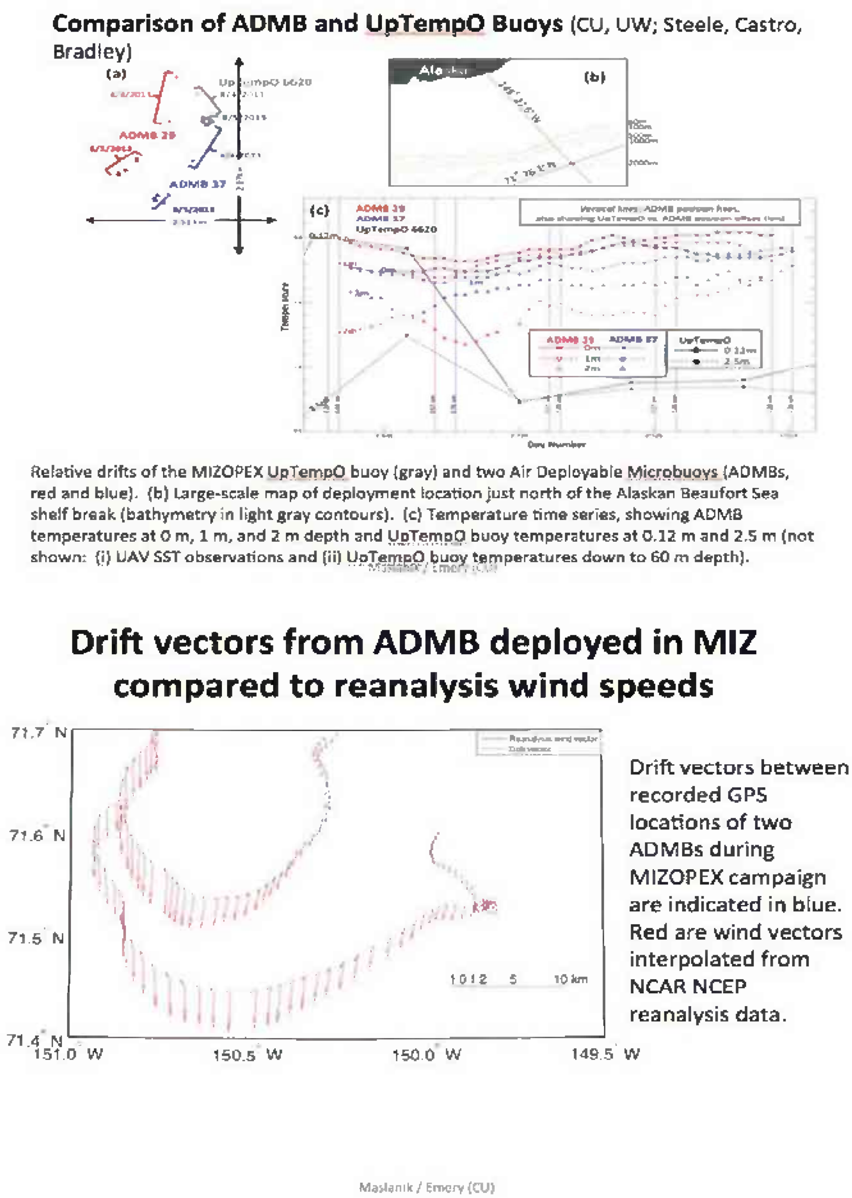


Figure 19. Comparison of UpTempO and ADMB measurements (top). Comparison of ADMB drift with forecast-modeled winds (bottom).

4.2.3 Reasons for Early Melt-back in the Southeastern Beaufort Sea

Investigation of early melt-back in the Beaufort Sea was a project of the UW, with some collaboration from CU's Mark Tschudi and Jim Maslanik. Using satellite data, numerical model output, and ice age maps produced at CU, the team investigated the reason for particularly early sea ice retreat early in late spring/early summer in the southeastern Beaufort Sea. Findings revealed that sea ice in this region was generally thin at the start of the melt season, owing largely to easterly winds in the previous fall which severely limit ice growth until a relatively quiescent period from January through March. Nonetheless, we find that interannual anomalies in ice thickness play no role in the pace of late-spring melt-back. Instead, anomalies in springtime easterly winds drive anomalous ice retreat. Figure 20 illustrates this.

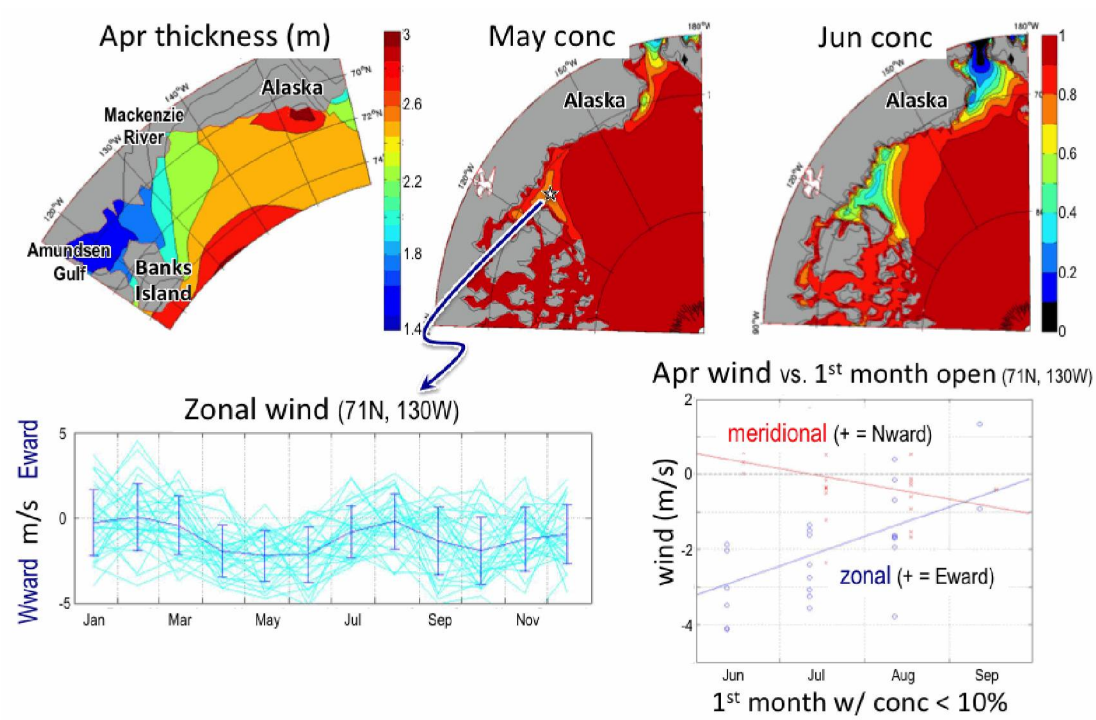


Figure 20. Analysis of early ice retreat in the Southeastern Beaufort Sea. Upper left panel shows climatological April mean ice thickness from PIOMAS, just before the melt season. The next two upper panels show early ice retreat in this area, from NSIDC passive microwave (SSMI) monthly means. The bottom left panel shows zonal wind from NASA's MERRA reanalysis product (positive = eastward) at 71N, 130W (star symbol in May concentration panel above), with each year from 1979-2012 in cyan and the overall mean (plus/minus one standard deviation) in dark blue. The bottom right panel shows how April mean winds predict the first month when ice concentration drops below 10%

4.3 Summary of ADMB Deployment and Results for the 2013 MIZOPEX Field Campaign

One component of the MIZOPEX field campaign was the deployment of ADMBs. These small, disposable instrument packages included a thermistor string to measure water temperature just below the surface and at one and two meters' depth, a GPS to track position, a radio modem to communicate data, processor, memory and battery (Figure 21). A small receiver/logger onboard an aircraft autonomously searches for deployed buoys and uplinks new data. Full details on the ADMB development and system are available in the earlier quarterly reports to NASA.

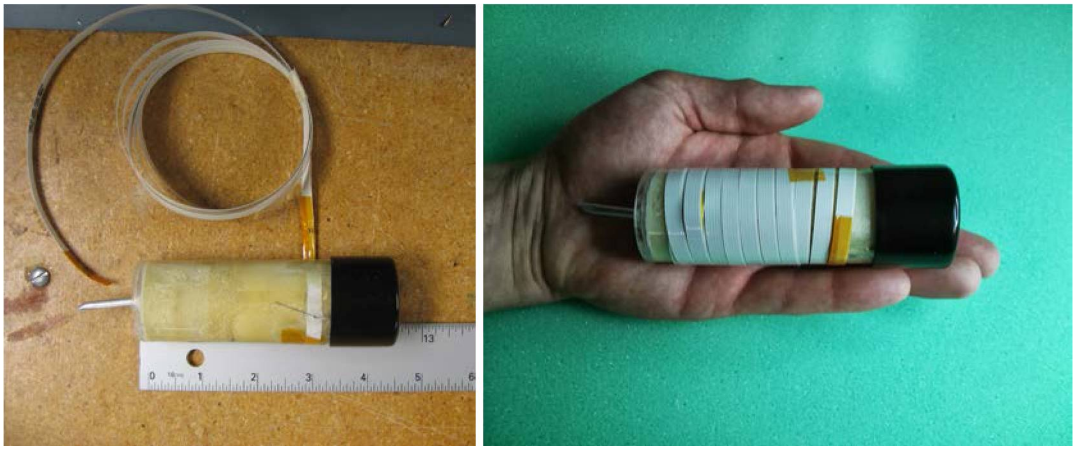


Figure 21. An air-deployed microbuoy.

ADMBs were deployed by dropping from both an unmanned aircraft and a boat. During MIZOPEX, seven ADMBs were deployed over water by UAV and an additional four were placed by hand in conjunction with the deployment by boat of a larger buoy. As shown in the right panel of Figure 21, the thermistor string may be wrapped around the ADMB and secured with a water-soluble tape. Upon deployment, the tape dissolves and a weight at the end of the thermistor string causes it to unwrap and hang vertically. Weighing roughly 90 g, the ADMB has sufficient aerodynamic drag to limit its terminal velocity when dropped from high altitudes so that it survives impact with the sea surface.

The ADMB thermistors are individually calibrated and provide an absolute accuracy of better than 0.1°C over a range of −5°C to 15°C. Temperature measurements are sampled at one-second intervals and stored at six-minute intervals after filtering. GPS location is stored hourly. The ADMB has a demonstrated useful lifespan exceeding 10 days in arctic conditions.

The ADMBs use a custom communications protocol to conserve power. The ADMB radio is powered on with a 3% duty cycle to listen for queries. When queried, data may be uplinked at a rate of approximately one day of saved data per second. The ADMB's communication range exceeds 3 km, but may be reduced by sea state or other conditions.

Figure 22 shows some preliminary results from two ADMBs. Many interesting features are found in these data, such as periods with significant temperature gradients versus periods with no temperature gradient, periods where the surface temperature was depressed, shallow thermoclines, and changes in current direction and velocity. Some evidence of inertial currents also appears.

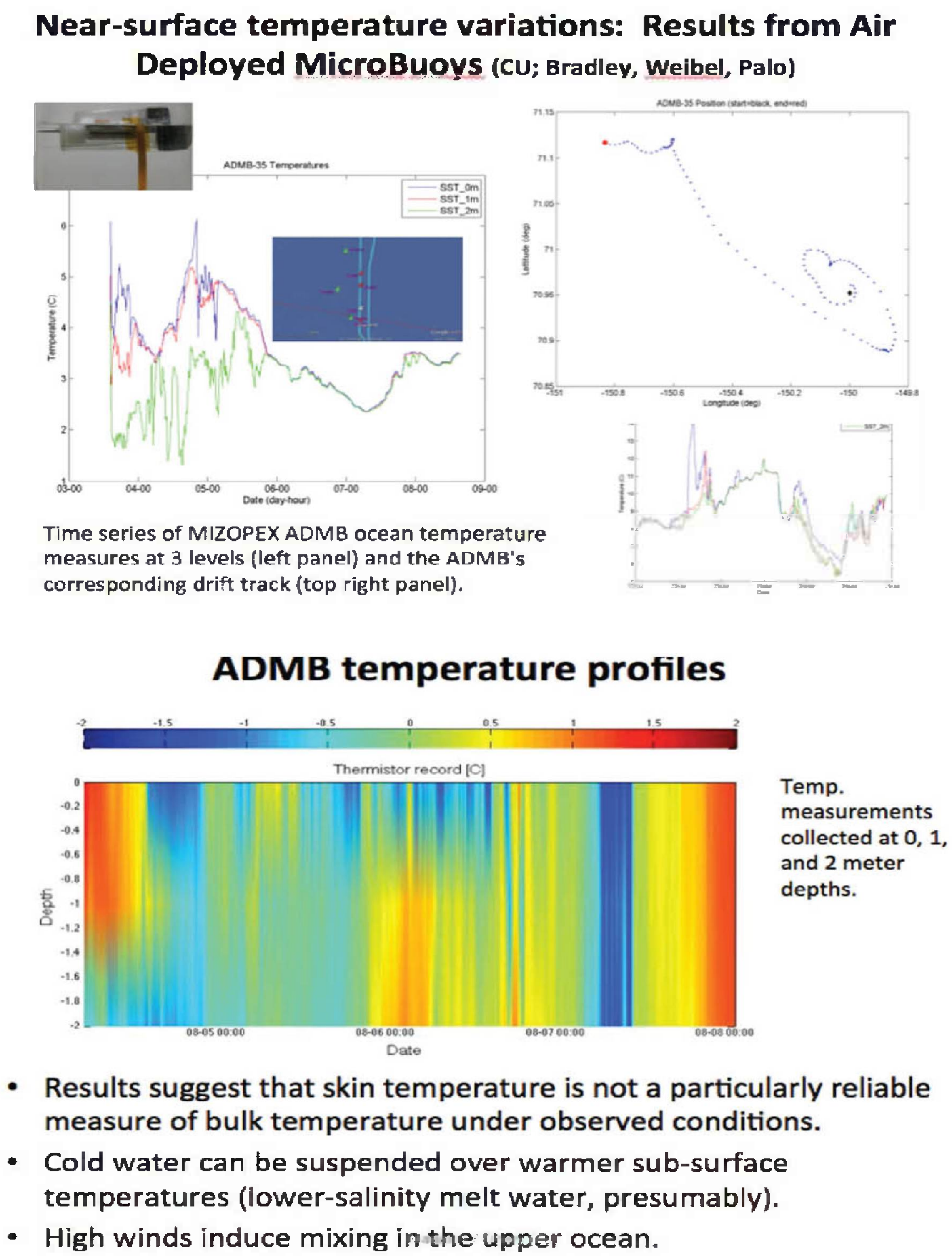


Figure 22. Initial results from ADMB measurements.

Both positive and negative gradients in surface temperatures were observed in the MIZOPEX ADMB data, as well as times with no surface gradient. Data from the nearby UpTempO buoy (see previous section) showed a transition from a positive temperature gradient at the surface to a well-mixed cooler temperature, similar to that observed in the ADMB data. It is hypothesized that the cooler, well-mixed measurements correspond to the presence of moving ice floes that leave cool wakes. Such wakes were observed in the ATOM/Bobcat imagery acquired by ScanEagle, so the hope is that SST data from the BESST and ATOM instruments will be able to confirm this.

Correlation of these data with coincident high-resolution surface temperature measurements collected by UAV during MIZOPEX, along with satellite- and model-derived SST fields and temperature data from other Insitu buoys and with other parameters such as down-welling radiation and winds, may provide valuable insights into physical processes such as the importance of solar heating in producing the extensive losses in sea-ice cover seen in recent years. Applications of MIZOPEX data for validation of satellite- and model-derived SSTs is presented in Figure 23.

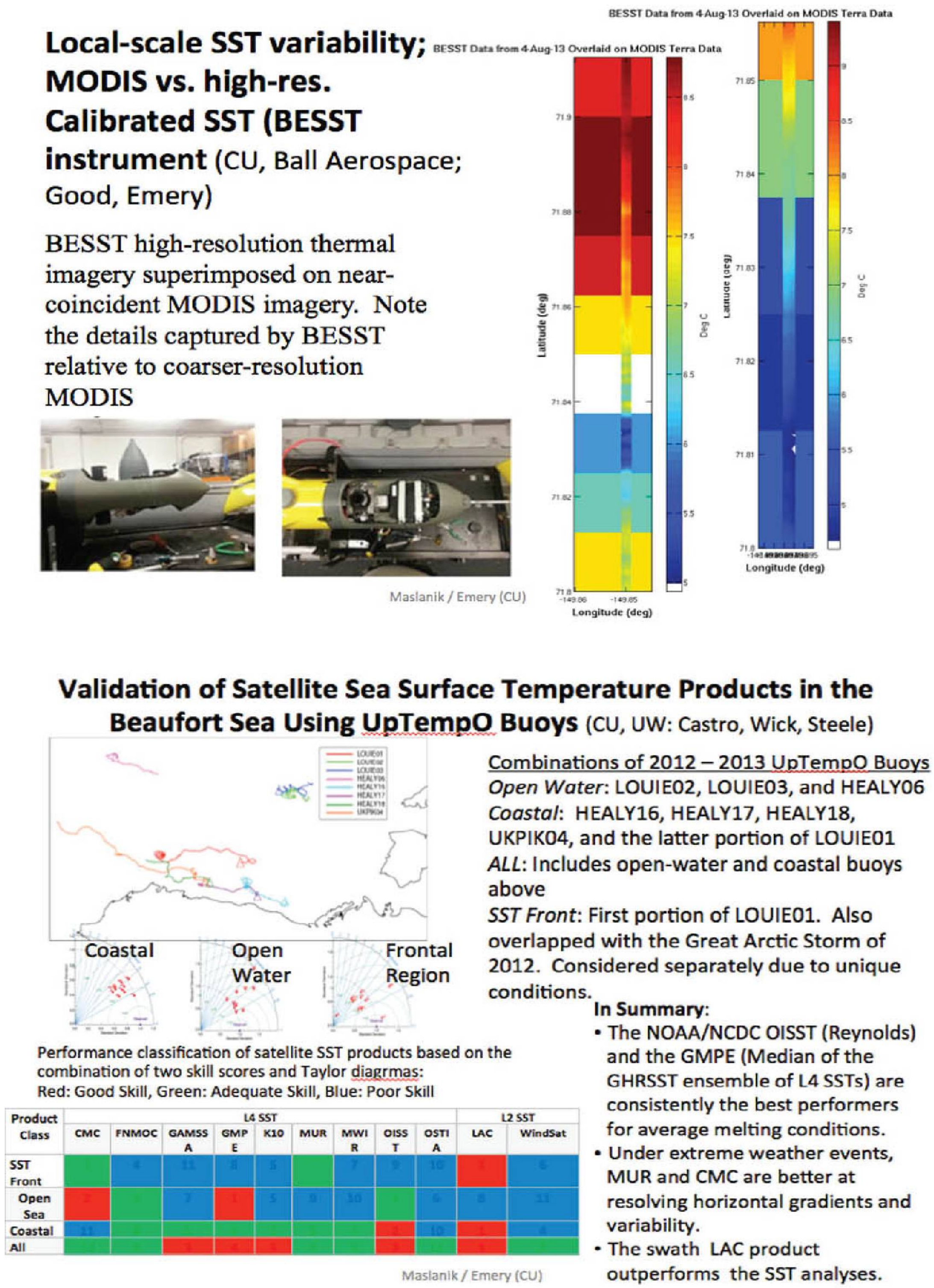


Figure 23. Applications of MIZOPEX data for validation of satellite- and model-derived SSTs.

Potential research using these data include:

- Identification of causes for the different types of surface temperature gradients.
- Comparisons with SST data from BESST, ATOM and satellite-based instruments.
- Evaluation of energy flux terms from other sources (radiation, turbulent fluxes, etc.) and comparison to the surface temperature gradients to determine principle processes.
- Comparison of drift patterns to surface current patterns derived from ATOM data.

4.4 Analyses of Preceding Sea-Ice Conditions

During MIZOPEX, the sea ice in the Southern Beaufort Sea was identified as mostly first-year ice by the UC ice age program (Figure 24; see Maslanik et al. 2007, 2011; Tschudi et al. 2010). Having virtually no multi-year ice advect into the Southern Beaufort was a unique event over the course of the satellite record, and was likely related to winds that opposed the southwesterly movement of the pack from the Canadian Archipelago. This phenomenon enabled MIZOPEX investigators to observe ice properties and ocean temperatures in the vicinity of mostly younger ice.

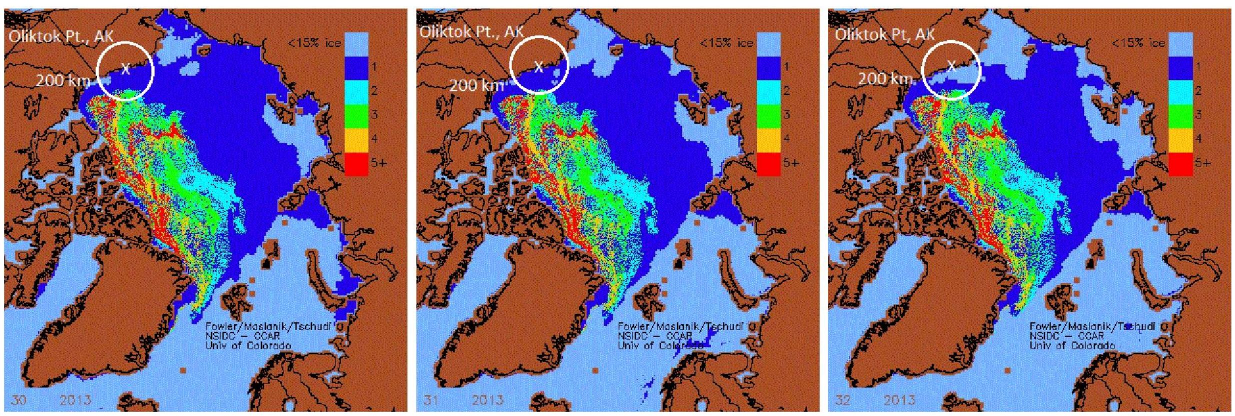
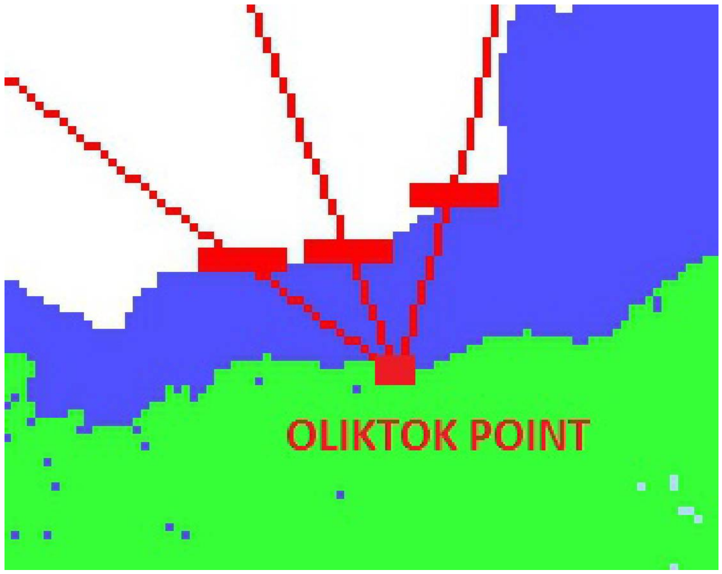


Figure 24. Sea-ice age for Week 30 (July 22–28, 2013, left), Week 31 (July 29–August 4, 2013 center), and Week 32 (August 5–11, 2013, right), covering the MIZOPEX UAS observational period. A 20-km radius around Oliktok Point (white 'X' in upper left of all three panels) is shown.

An algorithm was developed at the National Ice Center in 2008 to utilize sea ice extent from the 4-km Interactive Multisensor Snow and Ice Mapping System data set to estimate distance from Oliktok Point to the ice edge along north, northeast, and northwest directions (Figure 25). Checks were included to ensure the pack was encountered, rather than small ice floes. The motivation for these measurements was initially to examine the history of ice-edge distance for planning MIZOPEX operations. The results for the MIZOPEX UAS operation period can assist investigators in determining the proximity of the ice pack in relation to observed ocean surface and subsurface temperatures and serve as an indicator of the areal extent of the Beaufort Sea in the vicinity of observed ocean surface (UAS, buoy) and subsurface (buoy) temperatures.



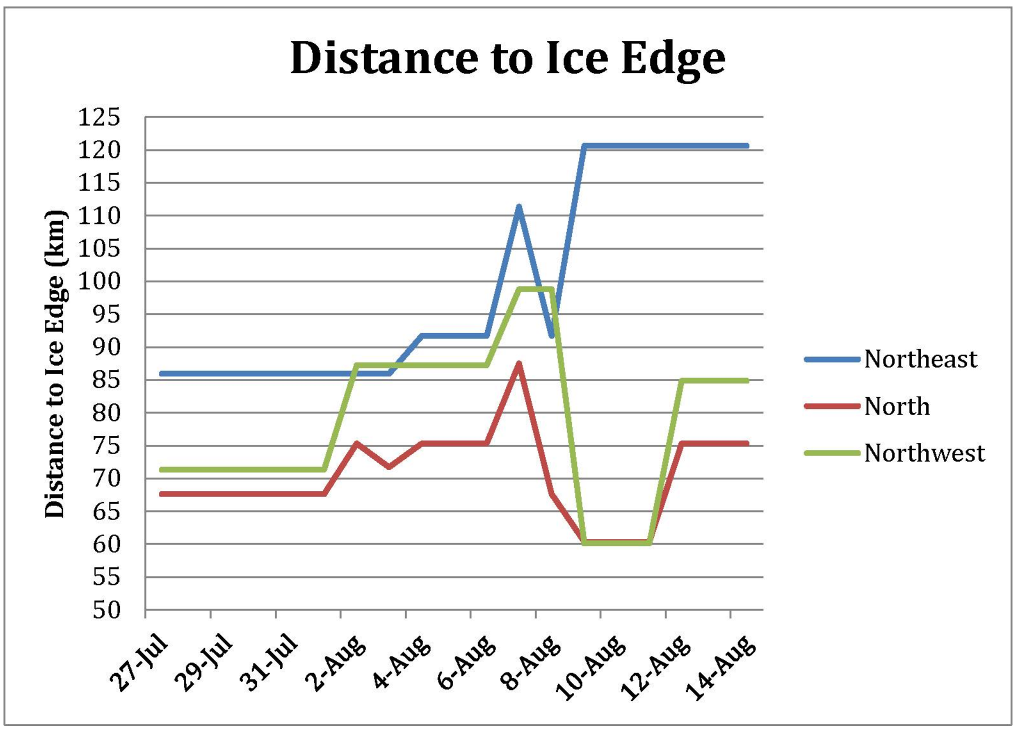


Figure 25. Ice-edge distance from Oliktok Point, Alaska, along Northeast, North, and Northwest-Line measurements. Period of MIZOPEX UAS operations in 2013 is shown.

A MIZOPEX sea-ice subgroup will further examine ice conditions using ScanEagle visible and thermal infrared camera imagery as well as other satellite observations.

4.5 Recovered Data from SIERRA

As noted earlier, the NASA SIERRA was lost during its first MIZOPEX science flight. Fortunately though, a portion of the SIERRA fuselage containing data storage units was later recovered. These contained a small amount of retrievable sensor data that, while limited, is still useful for illustrating the capabilities of two of the SIERRA's imaging systems (camera and SAR) (Figure 26). It was particularly gratifying to recover some imagery from the Artemis, Inc. "SlimSAR" SAR. This was a highly sophisticated instrument developed specifically for MIZOPEX, and in many ways set a new standard for small, high-performance SAR imagers suitable for relatively small UAS and other aircraft.

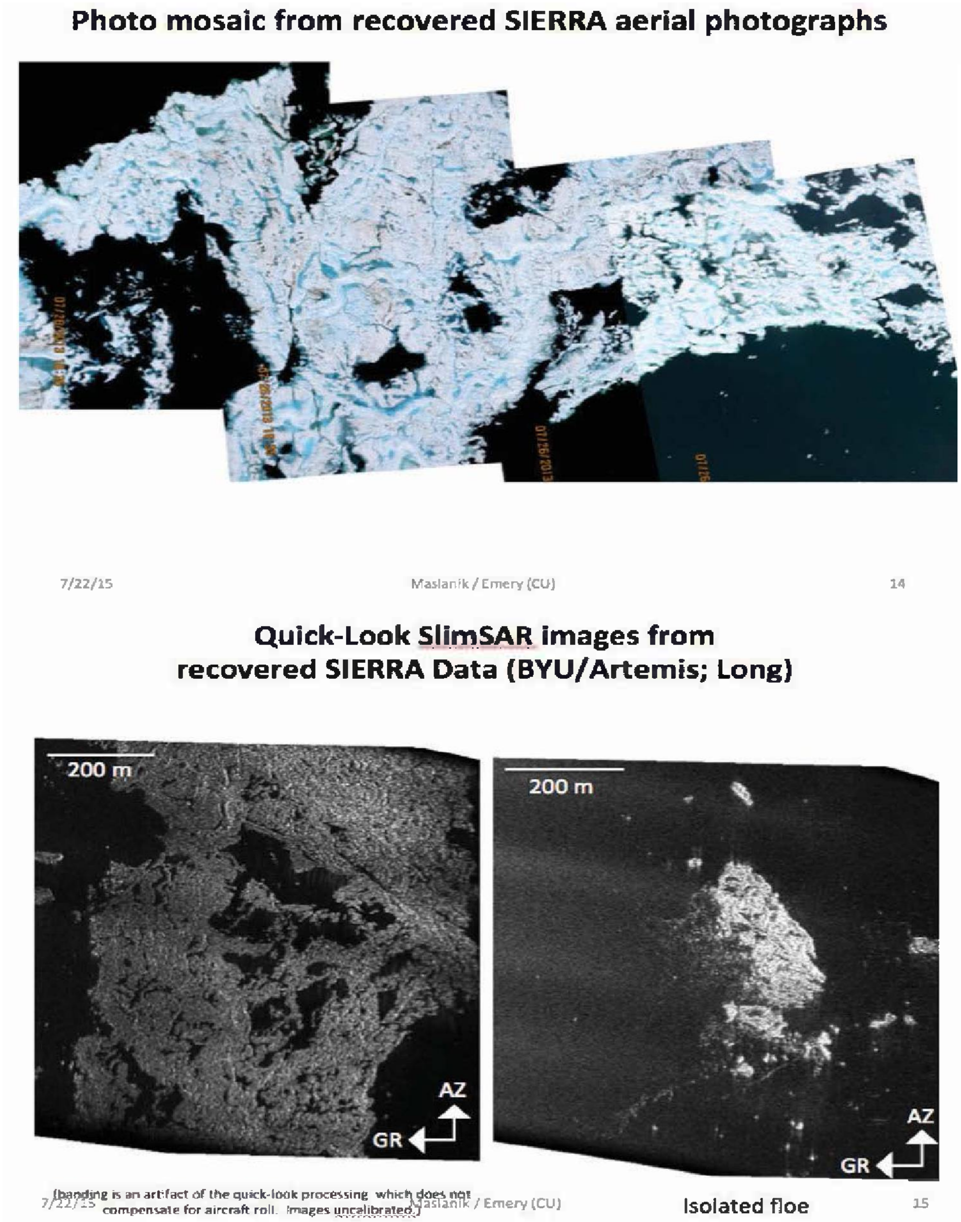


Figure 26. Examples of photographs and radar imagery from SIERRA flight #1.

5.0 Public Outreach

Field campaign website: http://ccar.colorado.edu/mizopex/index.html

Facebook page: https://www.facebook.com/MIZOPEX

News pages and stories:

http://summitcountyvoice.com/2012/01/26/global-warming-is-arctic-ice-at-a-tipping-point/

http://www.uasvision.com/2012/12/03/nasa-ga-asi-agreement-expands-unmanned-aircraft-capabilities/

http://uas.noaa.gov/news/mizopex.html

https://airbornescience.nasa.gov/category/Mission/MIZOPEX

https://www.youtube.com/user/MIZOPEX

https://plus.google.com/100107350731833945073/videos

http://psc.apl.uw.edu/investigations-of-spatial-and-temporal-variability-of-ocean-and-ice-conditions-in-and-near-the-marginal-ice-zone-mizopex/

http://energy.sandia.gov/nasa-award-for-marginal-ice-zone-observations-and-process-experiment-mizopex/

http://energy.sandia.gov/sierra-unmanned-aerial-vehicle-to-begin-flights-over-arctic-sea-ice/

https://www.faa.gov/uas/legislative_programs/arctic/media/Arctic_Lessons_Learned_White_Paper.pdf

Other outreach efforts: A variety of outreach efforts were made to inform and coordination with other aircraft operators in the MIZOPEX study area. To allow others to track the UAS missions, real-time UAS positions were uploaded to a NASA-managed website and to a commercial website.

6.0 MIZOPEX Publications

6.1 Journal Articles/Manuscripts

Bradley, AC, S Palo, G LoDolce, D Weibel, and D Lawrence. 2015. "Air-Deployed Microbuoy Measurement of Temperatures in the Marginal Ice Zone Upper Ocean during the MIZOPEX Campaign." *Journal of Atmospheric and Oceanic Technology* 32:1058–1070, doi:10.1175/JTECH-D-14-00209.1.

Emery, WJ, WS Good, W Tandy, MA Izaguirre, and PJ Minnett. 2014. "A Microbolometer Airborne Calibrated Infrared Radiometer: The Ball Experimental Sea Surface Temperature (BESST) Radiometer." *IEEE Transactions on Geoscience and Remote Sensing* 52(12):7775-81, doi:10.1109/TGRS.2014.2318683.

Howell, KM. 2013. *Ikhana MIZOPEX and Alaska Fire Missions.* Paperback. NASA Technical Reports Server (NTRS), Washington, DC.

Steele, M, S Dickinson, J Zhang, and R Lindsay. 2015. "Seasonal ice loss in the Beaufort Sea: Toward synchrony and prediction," *Journal of Geophysical Research: Oceans* 120:1118–1132, doi:10.1002/2014JC010247.

6.2 Meeting Abstracts/Presentations/Posters

Bradley, AC, S Palo, C Zappa, G LoDolce, D Weibel, and D Lawrence. 2014. "Observations of Wind-Induced Motion in the Arctic Marginal Ice Zone." Presented at American Geophysical Union Fall Meeting, San Francisco, CA, 15–19 December. http://fallmeeting.agu.org/2014/.

Crocker, I, and G Walker. 2012. "Marginal Ice Zone Observations and Processes Experiment Sensors and Measurements." Presented at NOAA - EC Arctic UAS Workshop, Boulder, CO, 25–26 September.

Crocker, I. 2012. "The CU LIDAR Profilometer & Imaging System (CULPIS) High-Resolution Surface Observations from Unmanned Aircraft Systems." Presented at Optimal Unmanned Aircraft Systems River Observing Strategy Workshop, Boulder, CO, 21–23 February. http://uas.noaa.gov/library/workshop/UAS_RFC_Workshop_Summary_final.pdf.

Maslanik, JA. 2014. "MIZOPEX UAS Project." Presented at Sea Ice Collaboration Team Meeting, Online, 27 October. IARPC Collaborations, www.iarpccollaborations.org. http://www.iarpccollaborations.org/events/709.

Palo, SE, D Weibel, D Lawrence, G Lodolce, AC Bradley, J Adler, JA Maslanik, and G Walker. 2013. "First Results from UAS Deployed Ocean Sensor Systems During the 2013 MIZOPEX Campaign." Presented at AGU Fall Meeting 2013, San Francisco, CA, 9–13 December. American Geophysical Union, http://fallmeeting.agu.org/2013/. http://adsabs.harvard.edu/abs/2013AGUFM.C13C0689P.

Tschudi, M., JA Maslanik, WJ Emery, SE Palo, AC Bradley, D Weibel, and others. 2014. "MIZOPEX-A UAS Arctic Campaign During Summer 2013." AGU Fall Meeting Abstracts 1, 07.

Zappa C, S Brown, W Emery, J Adler, G Wick, M Steele, S Palo, G Walker, and J Maslanik. 2013. "Local Effects of Ice Floes on Skin Sea Surface Temperature in the Marginal Ice Zone from UAVs." Presented at AGU Fall General Meeting 2013, San Francisco, CA, 9–13 December. American Geophysical Union, Washington, DC. http://adsabs.harvard.edu/abs/2013AGUFMOS14A..04Z.

Zappa C. 2014. "MIZOPEX and IcePod: Unmanned and Manned Aircraft Systems." Presented at 2014 Scientific Committee for Oceanographic Aircraft Research (SCOAR) Meeting, La Jolla, CA, 4 June. Scripps Institution of Oceanography, San Diego, CA. http://www.unols.org/sites/default/files/201406sco_ap10.pdf.

Zappa, C. 2014. "Local Effects of Ice Floes and Leads on Skin Sea Surface Temperature, Mixing, and Gas Transfer in the Marginal Ice Zone." Presented at 2014 European Space Agency SOLAS Conference, Frascati, Italy, 28–31 October. European Space Agency, Frascati, Italy. http://congrexprojects.com/docs/default-source/14cao_docs/effects-of-ice-floes-and-leads-on-skin-sea-surface-temperature-mixing-and-gas-transfer-in-the-marginal-ice-zone.pdf?sfvrsn=0.

Zaugg, E, M Edwards, J Gomola, and D Long. 2013. "SAR Imaging of Arctic Sea Ice from an Unmanned Aircraft as Part of the MIZOPEX Project." In *Proceedings of 2013 IEEE Radar Conference (RADAR),* 1–5 pp. IEEE, Piscataway, NJ. doi:10.1109/RADAR.2013.6586016.

7.0 References

Maslanik, JA, C Fowler, J Stroeve, S Drobot, J Zwally, D Yi, and W Emery. 2007. "A Younger, Thinner Arctic Ice Cover: Increased Potential for Rapid, Extensive Sea-Ice Loss." *Geophysical Research Letters* 34(24): L24501, doi:10.1029/2007GL032043.

Maslanik, J, J Stroeve, C Fowler, and W Emery. 2011. "Distribution and Trends in Arctic Sea Ice Age through Spring 2011." *Geophysical Research Letters* 38(13): L13502, doi:10.1029/2011GL047735.

Tschudi, M, C Fowler, J Maslanik, and J Stroeve. 2010. "Tracking the Movement and Changing Surface Characteristics of Arctic Sea Ice." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 3(4):536–540, doi:10.1109/JSTARS.2010.2048305.

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