UAS Activities at Lamont-Doherty Earth Observatory of Columbia University

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LDEO Team:
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MIZOPEX: Turbulence Mechanisms in Polar Systems

Measurements of Visible and Infrared Imagery from LDEO Payload on Scan Eagle

• Mechanisms for mixing / turbulence that are prevalent in polar environments.
  • Shear at the ice-ocean boundary layer
  • Interaction of ice floes with surface currents and waves
• Infrared imagery show cold wakes mixing near-surface ocean in the lee of ice floes.

Visible (Left): 1.4 km x 1.8 km
Infrared (Right): 0.54 km x 0.41 km

Christopher J. Zappa, Lamont-Doherty Earth Observatory, Columbia University
Moore Foundation: UAS Payload Development
BASE payload allows for quick change between sensor payloads
# UAS Payloads

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Sea Ice Radar Development – Built on experience from IcePOD at LDEO
Bridging the Scientific and Indigenous Communities to Study Sea Ice Change in Arctic Alaska

Christopher Zappa (LDEO), Andy Mahoney (UAF), Alex Whiting (NVK), Sarah Betcher (FNF)
Sea Ice is Thinning

Sea Ice Thickness (m)

Consequences of Sea Ice Change
Project Goals

• Understand sea ice dynamics and how it is changing with a warming climate

• Bridge scientific & indigenous knowledge to study changes in sea ice that will lead to predictive models for:
  • Sea ice loss
  • Impact on ocean life
  • Impact on land mammals
Indigenous knowledge is “a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation” (ICC Alaska 2015).
## Project Objectives

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Bridging the Scientific and Indigenous Communities to Study Sea Ice Change in Arctic Alaska

Christopher J Zappa
Lamont-Doherty Earth Observatory

Andrew R Mahoney
University of Alaska Fairbanks

Ajit Subramaniam
Lamont-Doherty Earth Observatory

Sarah Renee Betcher
Farthest North Films

Donna Hauser
University of Alaska Fairbanks

Alex Whiting
Native Village of Kotzebue

John Goodwin
Community of Kotzebue

Cyrus Harris
Community of Kotzebue

Bobby Schaeffer
Community of Kotzebue

Ross Schaeffer
Community of Kotzebue
Overview

• The Ikaagvik Sikukun project
• Community-based approach to research design
• Value of indigenous partnerships
• Summary and outlook
Study Region

**Kotzebue**
- Iñupiaq community of ~3250
- Situated on Baldwin Peninsula

**Kotzebue Sound**
- Large shallow embayment
- Extensive landfast ice in winter
- Influenced by the Noatak and Kobuk Rivers
- Important habitat for ringed and bearded seal

**Southern Chukchi Sea**
- Important migration corridor for seabirds and marine mammals
- Extensive loss of sea ice coverage in recent years
Community-based research design

- Begins with community engagement
- Before research questions have been defined
- Ensures our observing plan meets our science, community, and legacy goals
Co-production of Research Questions

Q0. What species of marine mammals and birds occupy the lead system west of Kotzebue Sound prior to break-up of sea ice within the Sound?

Q1. What environmental factors control marine mammal use of Kotzebue Sound?

Q2. What environmental factors control the length of the bearded seal hunting season in Kotzebue Sound?

Q3. What determines ice transport processes in Kotzebue Sound?

Q4. What snow and ice surface properties promote ringed seal den integrity and pupping success?

Q5. What role does sea ice play in sediment transport / deposition in Kotzebue Sound?
Q0. What species of marine mammals and birds occupy the lead system west of Kotzebue Sound prior to breakup of sea ice within the Sound?

- Region seldom visited due to inaccessibility by snow machine or boat
- How many species or individuals go past Kotzebue Sound without coming in?
- Local residents wonder if “invasive” species are outside Kotzebue Sound at this time

Requires understanding of the coastal flaw lead system and the means of spotting and identifying wildlife
Q1. What environmental factors control marine mammal use of Kotzebue Sound?

- Bearded seals require opening to form before the enter the Sound
- It’s not clear how much open water they need
- Sequence of events typically leading to break-up of the ice also unclear

Requires understanding of local mechanisms promoting ice fracture and movement as well as sea ice use by different species.

May 15, 2016
Q2. What environmental factors control the length of the bearded seal hunting season in Kotzebue Sound?

- Bearded seal hunting requires a channel through the landfast ice to reach loose ice floes by boat.
- Some seasons have been very short due to rapid loss of ice in the Sound.

Requires understanding of the mass and momentum balance of sea ice in the Sound as well as the ecology of sea ice use by bearded seals.
• Highest HQ wind launch to date: 31 knots
• Expected launch/recovery wind limitation: ~30 knots, on the nose.
• No crosswind limitation. HQ automatically negotiates crosswind up to max wind limitation
• Max rain demonstrated to date: 0.25 inch/hour
• Max demonstrated WMO sea state capability: 5
• Flight into known icing (FIKI): Under Development
HQ-90 Airframe Endurance / Payload Tradeoff
Kotzebue Temperatures

UAS: Maximum Temperature 100.4F and Minimum Temperature -4F
Village of Kotzebue
UAS in Kotzebue – Operational Limits

- **Range:** Operations were limited to daytime and line of sight (~2 nm) within the 10 nm LOS COA.

- **Altitude:** Operations range up to 4000 ft. (LOS COA)

- **Wind:** Operations were limited to wind speeds less than 20 knots.

- **Clouds and Visibility:** Operations were limited to visual line of sight and class E airspace weather minimums (3 statute miles flight visibility and 500 ft below any clouds).
UAS in Kotzebue – Takeoff
UAS in Kotzebue – In Flight
UAS in Kotzebue – Flight Summary

- **Tucson Integration:**
  - 7 Total Flights (3 hours)
  - 2 Functional Check Flight (FCF) with Hover Test
  - 5 Flights with Payloads (2 hours)
    - ATOM, RAD, VNIR, DDuD payloads

- **Warm Springs OR Flight Testing:**
  - 5 Total Flights (9 hours)
  - 2 Functional Check Flight (FCF) with Hover Test
  - 3 Flights with Payloads (6.5 hours)
    - ATOM, RAD, VNIR payloads

- **Kotzebue 2018 IOP:**
  - 12 Total Flights (30 hours; 5-hour Max)
  - 9 Flights with Payloads (25 hours)
    - RAD, ATOM, VNIR, MET payloads
  - 3 FCFs

- **Kotzebue 2019 IOP:**
  - 29 Total Flights (40 hours; 5-hour Max)
  - 22 Flights with Payloads (35 hours)
    - RAD, ATOM, VNIR, MET payloads
UAS in Kotzebue – 2018 Accomplishments

- 24 Total Successful Flights (42 hours) with HQ-90B
- 17 Successful Flights with payloads.
- Flights were conducted with takeoff directly into the wind.
- Demonstrated the ability to operate the HQ technology autonomously.
- Demonstrated the ability to operate the HQ technology in cold weather conditions.
Setting The Stage

Apr 04, 2018
Ice Thickness Measurements

Ikaagvik Sikukun Project, Unpublished Data
Sea Ice Concentration

AMSR-2 Passive Microwave Satellite 12.5km Product Processed with ASI Algorithm & 5-day Median Filter (Hamburg ICDC)
Sea Ice Concentration

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Sea Ice Concentration

AMSR-2 Passive Microwave Satellite 12.5km Product Processed with ASI Algorithm & 5-day Median Filter  (Hamburg ICDC)
2019 IOP

Channel Sea Ice Station...

Leading up to the Melt Season
Measuring Speed and Direction of Current Flow

Measuring Water Temperature at each blue box (Also measures Salinity)

Ice reflects energy from the Sun, Ice emits energy (proportional to the ice surface temperature)

Sun emits energy

Clouds & gases reflect some of the energy emitted by the ice

Measuring Wind, Humidity, Temperature, Pressure, Rainfall, and Solar Energy

Sensors Powered by Wind Turbine & Solar Panel

Measuring Net Energy From Sun & Ice

Ice emits energy (proportional to the ice surface temperature)
2019 IOP: A Dynamic Week In Kotzebue Sound

[Images of satellite maps and data points]
Our Driving Questions

• What environmental factors control marine mammal use of Kotzebue Sound?
• What environmental factors control the length of the bearded seal hunting season in Kotzebue Sound?
• What determines ice transport processes in Kotzebue Sound?
• What snow and ice surface properties promote ringed seal den integrity and pupping success?
• What role does sea ice play in sediment transport / deposition in Kotzebue Sound?
Targeting Them Using UAVs

• What environmental factors control marine mammal use of Kotzebue Sound?
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Re-Examining Our Driving Questions

• What environmental factors control marine mammal use of Kotzebue Sound?
  • Re-examination: How did environmental factors (e.g., ice type, nature of ice melt) change over our intensive observational period? Why?

• What environmental factors control the length of the bearded seal hunting season in Kotzebue Sound?
  • Re-examination: Which physical processes most strongly impacted the timing and pace (i.e., rapidity) of the Kotzebue Sound breakup? We understand that the channel melt is key here - which other factors must coincide to accelerate the whole breakup?

• What determines ice transport processes in Kotzebue Sound?
  • Re-examination: Once the landfast ice has broken up, is it primarily moved by ocean currents or wind forcing?
Changes In Ice Color Along Channel
Ice Color/Type Changing Near Edge
Changes In Ice Color Along Channel
Driving Questions, Sensor Payloads

- Changes in sea ice color/type due to melting
  - How does the melt process change absorption broadband (white) visible solar radiation? How does it change the way heat is radiated? (RAD)
  - Given high spatial resolution of the way melt features absorb or reflect different wavelengths of visible light, how does the color of sections of ice relate to the way they take up solar energy? (VNIR)

- Changes to wind forcing and air-ice heat exchange as the melt/breakup progresses (MET)
  - How strongly does the wind force the sea ice before the melt accelerates? Does this change as the melt progresses?
  - During the melt, does the way that heat is exchanged between the ice and the atmosphere change?
  - What are the particular physical processes in the atmosphere which most strongly determine the sea ice melt rate and breakup timing?
In-Situ Observational Surveys of Seal Habitat

Jessica Lindsay, UW Grad Student
Thermal camera
All UAV flights took place here, in international waters.
Combines vertical takeoff and landing (VTOL) capabilities of a quadrotor and the speed and range of a fixed-wing (FW) aircraft
UAS from Ships – Launch
UAS from Ships – Return Transition and Landing
UAS from Ships – Flight Summary

- **Tucson Integration:**
  - 2 Total Flights (3 hours)
  - 1 Functional Check Flight (FCF)
  - 1 with Radiation Payload

- **Falkor Cruise:**
  - 17 Total Flights (30 hours)
  - 11 Flights with Payloads (23 hours)
    - RAD, ATOM, VNIR payloads
    - Nominally < 3 hours
  - 3 Hover Tests
  - 3 FCFs
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## UAS Payloads

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Sea Ice Radar Development – Built on experience from IcePOD at LDEO
Dense internal wave field

- Effects of biogenic slicks on albedo, near-surface heat flux, diurnal warm-layer processes and mixing.

(Top) True color image captured by the Landsat satellite on November 17, 2014, of the coast of Northwestern Australia, east of Point Samson. (Bottom Left) 30 m resolution chlorophyll map obtained from the Landsat data. The high albedo from the dense surface slicks trigger the cloud mask (white). (Bottom Right) MODIS Aqua map of chlorophyll for the same day.
Current Directions – R/V Falkor

Trichodesmium
a) *Trichodesmium* sp. abundance as the number of normalized bacterial 16S rRNA genes (Normalized Reads) in manual samples taken at 04:15 UTC (15 Oct 2016) from 1m below the surface, the surface skin and surface slick. Note that the skin sample was collected between the surrounding banded slicks, and cannot be considered as a “clean” skin layer. b) Micrograph of sampled colonies of *Trichodesmium* sp. Scale bar represents 50µm.
Enhancements to HQ-90B for Ship Deployment

1. **Complete autonomous takeoff and landing from ships.** This project provides a considerably safer and more reliable VTOL operation. Integration of Novatel ALIGN dGPS system for automated VTOL takeoff and landing. Dual dGPS system determines aircraft heading. Additionally, the ground station on the ship uses the ALIGN system to send the vehicle data including the ship’s heading and heave. The precise relative position data achieved with a dGPS solution allows the vehicle to autonomously land on a moving platform at sea.
2. **Dual- (Multi-) UAV aircraft flight operations.** For most scientific applications, multiple aircraft are required for both varied payload deployment as well as variable temporal spatial scales to be observed. The primary required element is the integration of long-range mesh network radios and antennas.

3. **Long-range capability (50+ nm) with high bandwidth data link** for real-time mission control and tasking. This obfuscates the need for Iridium at distances up to 50 nm. Long-range mesh radios are much faster, more robust, more reliable, and less expensive than total Iridium costs (both modem hardware and data service charges). It further allows for:
   a. Mother aircraft at high altitude to provide relay link to a squadron or fleet of UAVs to fly a greater distance (over 100 nm) from ship.
   b. Mother aircraft at high altitude to provide relay link to a squadron or fleet of UAVs flying at low altitude.
QUESTIONS?
HQ-90B Advantages over HQ-60

• Simpler design for maintenance access:
  • Battery access is now on top, with quick release panels.
  • Each VTOL system is now a field replaceable unit PowerPack system significantly reducing
down time by allowing quick swaps of a whole VTOL corner without significant difficulty.

• Expanded internal comms system for expanded payload capability: To avoid challenges with
running out of serial ports on the autopilot, we have implemented a CAN bus. This has moved
the controls for lighting and power switching of payload off the serial lines. The transponder
and magnetometer are also on the CAN bus. Future iterations will also include the VTOL
motors and potentially all the control surface servos.

• Expanded datalink capabilities: Empty payload volume in the rear landing feet have been
created to house additional radios or other small components. This positions them further
from the payload requiring smaller cable runs to antennas on the tail and also increasing
distance between radios/antennas and sensitive payloads subject to RF interference.
HQ-90B Advantages over HQ-60

• The engine was upgraded from Power4Flight’s B60i to the B100i. This was for two main reasons. The B60i had enough power to fly the HQ-90B, but was at the top of its range, especially with the heavier max take-off weights we were expecting on the HQ-90B. Additionally, after running the B60i on the first two HQ-90B aircraft and other HQ-90A aircraft built prior to the LDEO aircraft, we had a high failure rate. The bearings were not sufficiently strong enough for the engine and were wearing out quickly, causing engine failures. This is not an issue for the B100i, and has gone through rigorous engine run testing to validate. We expect to conservatively get 200-300 hours between overhauls.

• With the larger B100i, the empty weight of the aircraft increased by 2-3 lbs. That, coupled with the increased burn rate of the larger engine reduced the effective range and endurance. To regain the original capabilities of the initial design goals with respect to payload and endurance capabilities, we are increasing the thrust of the VTOL system. With different motors and props, we are expecting to increase the useful load (payload and fuel) by approximately 10 lbs. This translates to 5-6 hours of additional endurance.
• Removable HQ-90 modular nose dramatically simplifies payload integration. With the new HQ-90 design, the noses were shipped to LDEO where we were able to install and test in our own lab. Once complete, one engineer came out for flight testing on the aircraft and after some minor harnessing issues, we had all the payloads tested on the aircraft within a day. This was a significant savings in time/money/resources since we can build payload equipment into the nose without on-site mechanical integration at Latitude.

• 200 W available to payload with a TCP/IP backbone
HQ-60 Advantages over HQ-90B

- The HQ-60 aircraft can handle slightly higher wind limits for launch as the wing area is smaller and won’t try to fly quite as easily on the ground.
- The HQ-60 also has a lower max take off weight, so the heavier payloads become harder to fly.
Flight Provisions for OTZ

• FWS provided Hangar and Tarmac use.

• HQ-90 operators to be manned pilots.

• HQ-90 operators met with local aviators as well as OTZ Flight Services to get familiarized with non standard procedures.
Kotzebue Air Nav

- Owned by AK DOT.
  - Mgr. Alvin Werneke
  - 907-442-3147
- Class E airspace
- No control tower
- Appx 60,000 flights annually
- Multiple instrument approaches
- No radar services (requires verification)

Learned a lot about operating off of a busy airport and how to work around traffic in the area. ADS-B out capability dramatically improved other pilots’ ability to locate and keep visual avoidance of the UAV. Furthermore, it improved the situational awareness of the UAV pilots as they could see at least some of the local traffic operating in the area to aid in deconfliction beyond the visual observers. As we move closer to the 2020 ADS-B mandate by the FAA, the ADS-B advantage will only grow.
HQ-90 Flight Rule Requirements

- HQ-90 falls beyond Part 107 regulations due to weight (>55 lbs).
- COA required.
- Working with ACUASI to support FAA flight approval.
- Submitted both LOS and BVLOS COAs.
- Granted LOS
  - 10 nm
  - 4000 feet
- Awaiting BVLOS COA.
UAS in Kotzebue – Lessons Learned

• On one occasion, the aircraft returned with some light icing on the airframe and some moderate icing on the air intake filter. This was on a clear day flight, so even with no visible moisture, a low temp/dew point spread can certainly result in clear-air icing. Working to use current conditions of the aircraft to help identify potential icing. Also, potentially adding ice detection upgrade.

• Currently, the ground wind limitation for launch is 20 kts. This is lower than the HQ-60 flown on Falkor due to the larger wing area and the newness of the HQ-90B design. Based on the experience we gained in Kotzebue and other operations, we plan to bring this up to as high as 25 kts, but any higher will have a high risk of an incident due to the aircraft wanting to fly off the ground in such high winds.
The high winds that were typically seen aloft will dramatically affect the ability of the aircraft to accomplish its mission safely and efficiently. If winds are within 5-10 kts of cruise speed (40 kts), the aircraft cannot make substantial progress into the wind. This needs to be evaluated in flight planning prior to launch. Additionally, the aircraft can “sprint” at a higher airspeed (up to 60 kts) at the cost of endurance/fuel burn, so high wind flights can be accomplished if reduced range/endurance can be tolerated.
UAS in Kotzebue – Lessons Learned

• Lack of visibility is only one reason fog grounds an aircraft. Visible moisture (clouds and fog) in freezing conditions has a high probability of icing conditions within. The aircraft is not rated for flight into known icing, and must be avoided at all costs. Latitude is currently investigating the possibility of wing heaters, icing protection for the intake filter, deicing coatings and other cold weather improvements, but none have been implemented or tested yet.

• In general, cold hinders operations. Cold hands slow work, VOs get cold standing around not moving, etc. Working towards BVLOS operations will dramatically simplify operations and extend capabilities. During Iridium operations, it will be possible to reduce cost of operations by allowing local pilots rest while a single operator controls aircraft remotely from Tucson.
• Everything takes a bit longer to get going. Gas engines struggle in the cold as well as the external starter batteries required to turn the gas engine over.

• Optimizing pre-flight payload checks in conjunction with flight operations should reduce the amount of time the aircraft has to sit outside.

• Keeping the hangar door shut longer will reduce the effects of cold weather.

• Additionally, preheater systems can be investigated to keep the engine at a warmer temperature prior to start.
ADS-B out capability dramatically improved other pilots’ ability to locate and keep visual avoidance of the UAV. Furthermore, it improved the situational awareness of the UAV pilots as they could see at least some of the local traffic operating in the area to aid in de-confliction beyond the visual observers. As we move closer to the 2020 ADS-B mandate by the FAA, the ADS-B advantage will only grow.
UAS in Kotzebue – Lessons Learned

- Operations at an airfield this busy while also requiring VOs would benefit from a team of 3 operators. While only 1 is required to fly the aircraft once it has departed the area, during launch and recovery and in the vicinity of the airport, there needs to be an external pilot as well as an operator on the radios. One person taking both of these responsibilities is approaching task saturation. Latitude is moving toward operations that reduce the workload of the external pilot. We intend to remove the pilot box from the loop and instead include an abort and/or kill button for emergency use only. As we gain comfort with the system, we aim to reduce the human input in favor of allowing the autopilot do what it knows best.
UAS in Kotzebue – Lessons Learned

- With such cold temperatures, typical density altitudes were -2000 ft MSL. The aircraft performed exceptionally well in such thick air, with high climb rates and engine efficiency. In fact, the aircraft reached its max climb rate of ~800 ft/min and still had enough power to fly at max airspeed (60 kts).
- The cowlings to cool the engine were capped to reduce cooling effects in the cold climate, which resulted in engine temperatures exactly where the manufacturer recommends.
- With the high performance during climb, we lowered the max throttle to 90% to ensure the engine did not overheat.
UAS in Kotzebue – Lessons Learned

• We are looking to increase the allowed climb rate to reach altitude faster and leverage the power of the engine more. Part of the great flight performance was also due to the very smooth air, even during strong winds. Lack of gusts or turbulence allowed the aircraft to maintain a highly stable flight condition, requiring minimal throttle inputs which is what has a significant effect on fuel consumption. Additionally, the aircraft performed better than expected in the high winds it encountered (+25 kts winds aloft).