MIZOPEX and IcePod: Unmanned and Manned Aircraft Systems

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IcePod Team (LDEO): R. Bell, N. Frearson, S. Brown, C. Bertinato, T. Dhakal, L.-L. Dong, K. Tinto.

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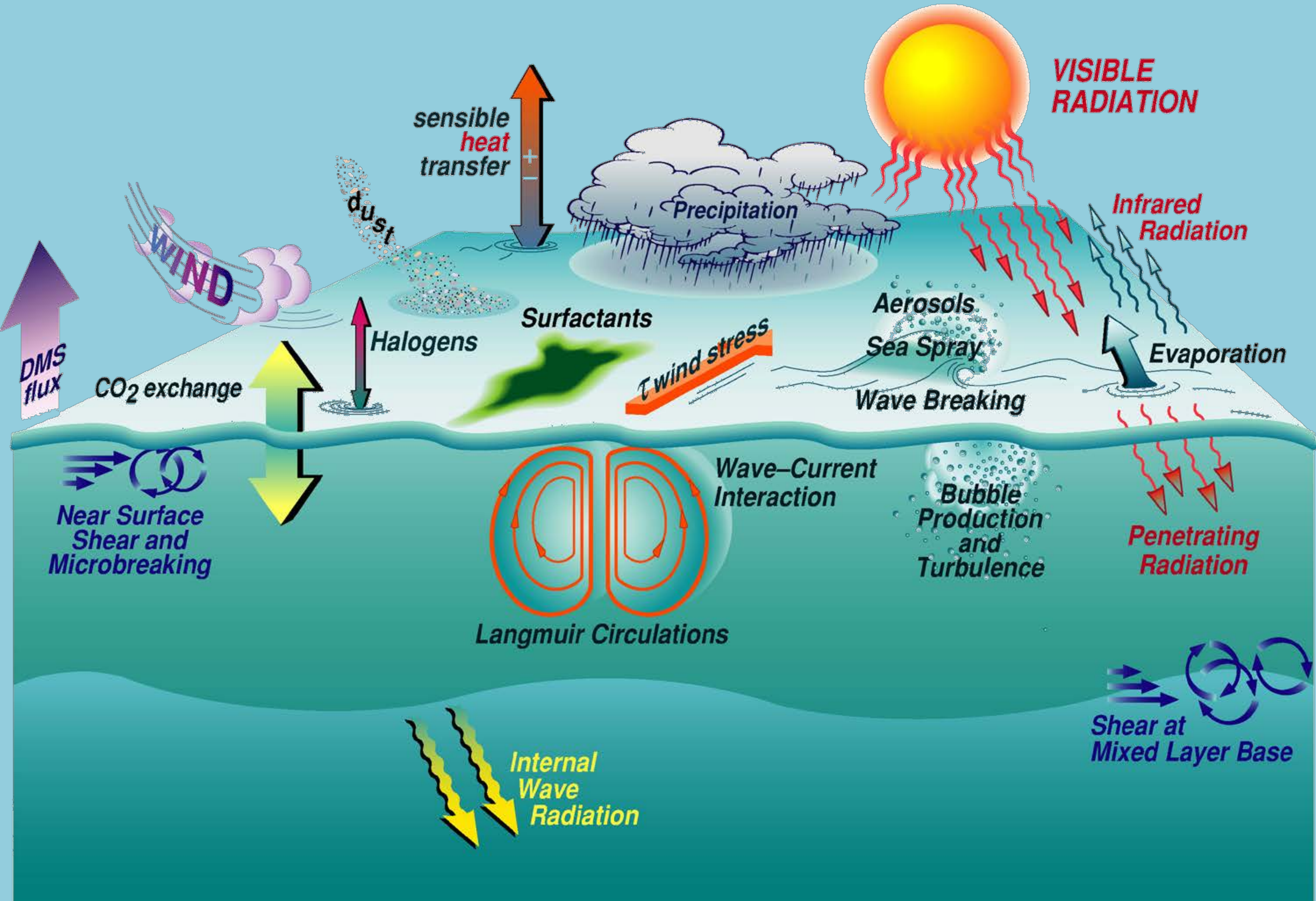
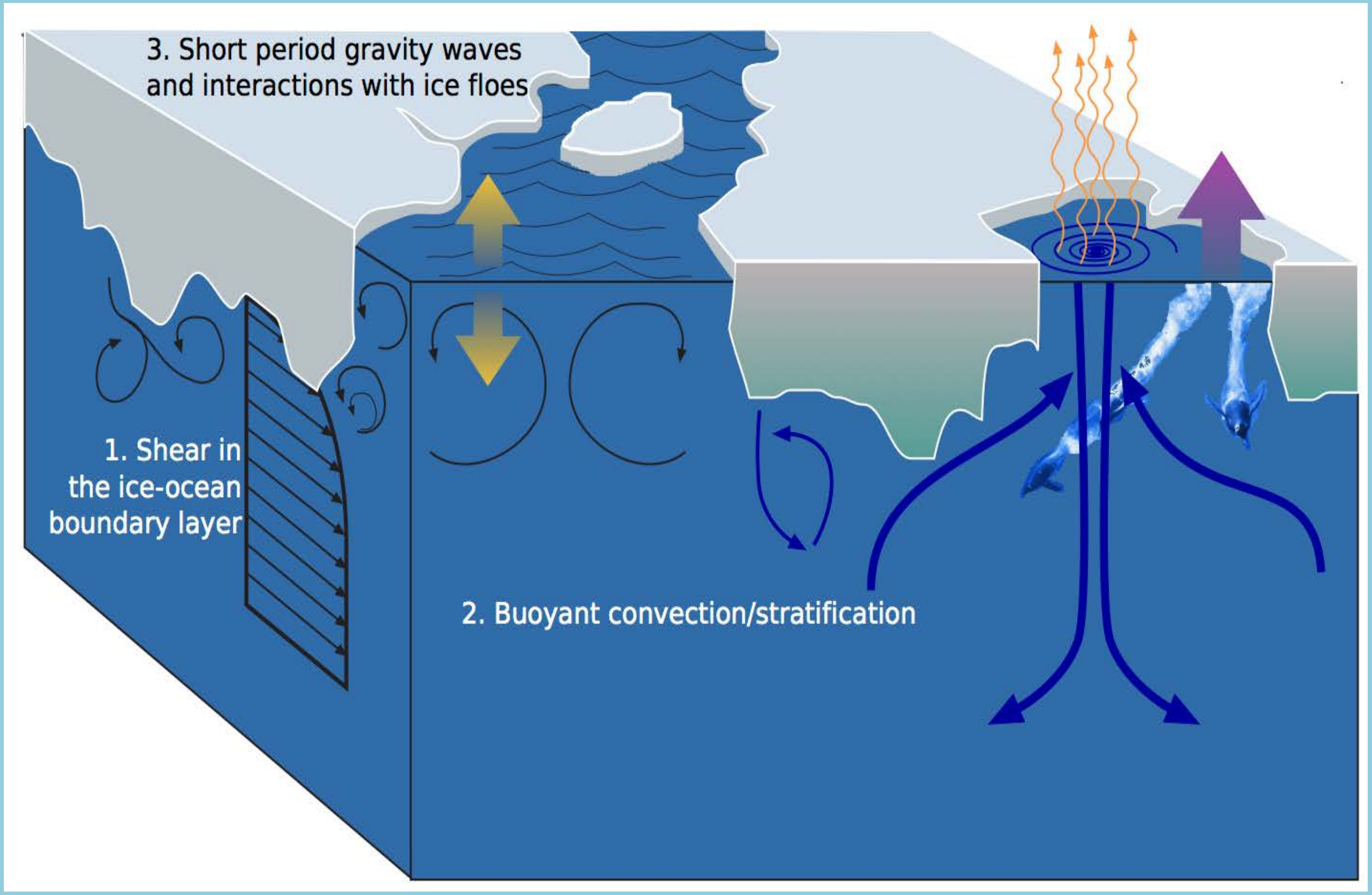
Air-Sea Interaction Processes



Turbulence Mechanisms in Polar Systems

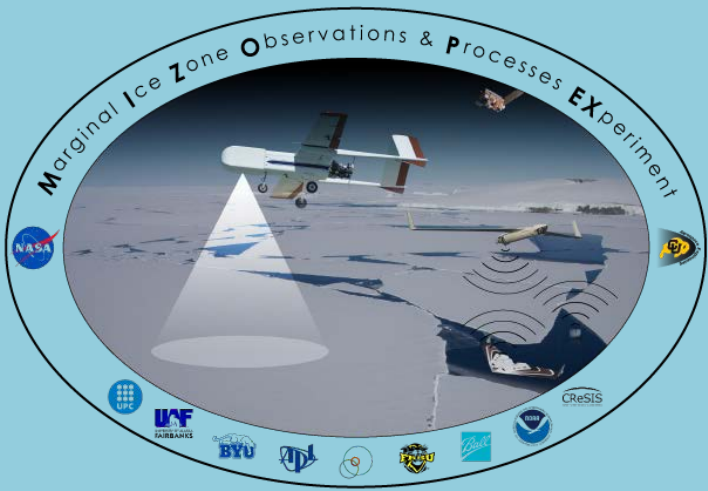


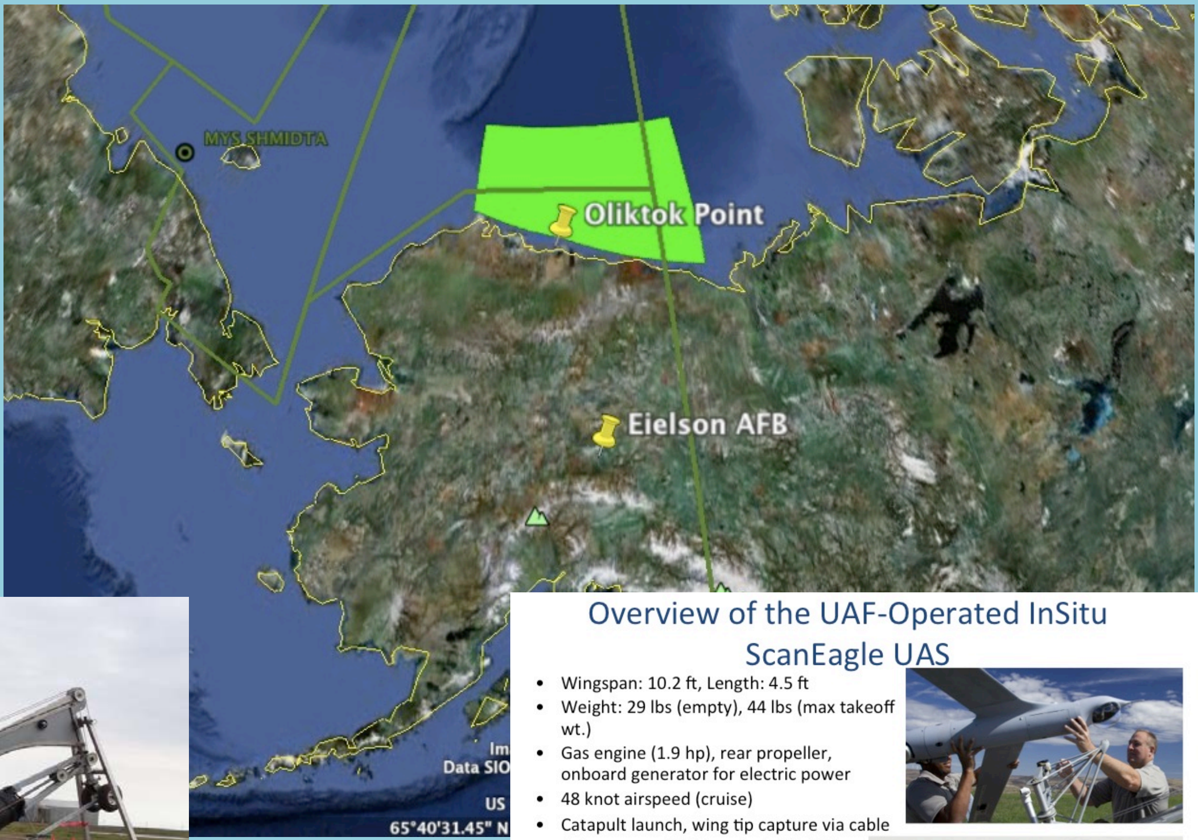
- Three mechanisms for mixing / turbulence that are not prevalent in low-latitude environments.
- Compare the structure of circulation and mixing of the influx of cold skin SST driven by surface currents and wind.

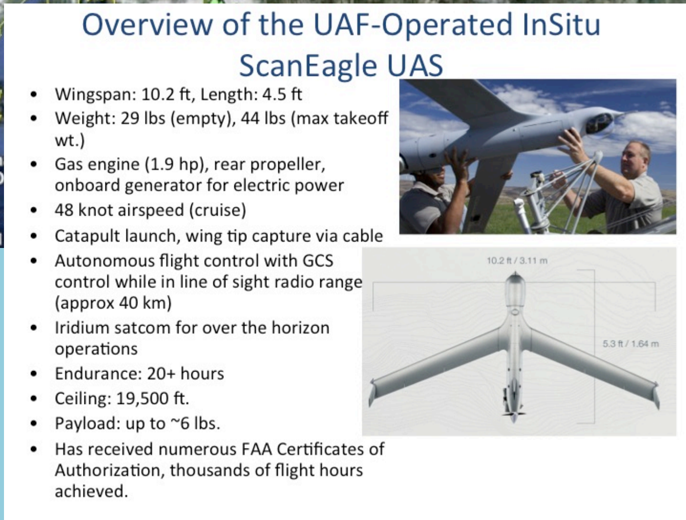
MIZOPEX 2013

Goals:

- Assess ocean and sea ice variability in the Alaskan Arctic Ocean (Beaufort Sea/Prudhoe Bay area).
- Demonstrate potential for research using multiple unmanned aircraft systems (UAS) in polar regions.
- Determine best practices for safe, reliable operations in the National Air Space.







Overview of the UAF-Operated InSitu ScanEagle UAS

- Wingspan: 10.2 ft, Length: 4.5 ft
- Weight: 29 lbs (empty), 44 lbs (max takeoff wt.)
- Gas engine (1.9 hp), rear propeller, onboard generator for electric power
- 48 knot airspeed (cruise)
- Catapult launch, wing tip capture via cable
- Autonomous flight control with GCS control while in line of sight radio range (approx 40 km)
- Iridium satcom for over the horizon operations
- Endurance: 20+ hours
- Ceiling: 19,500 ft.
- Payload: up to ~6 lbs.
- Has received numerous FAA Certificates of Authorization, thousands of flight hours achieved.

"Marginal Ice Zone Observations and Processes EXperiment" (MIZOPEX)

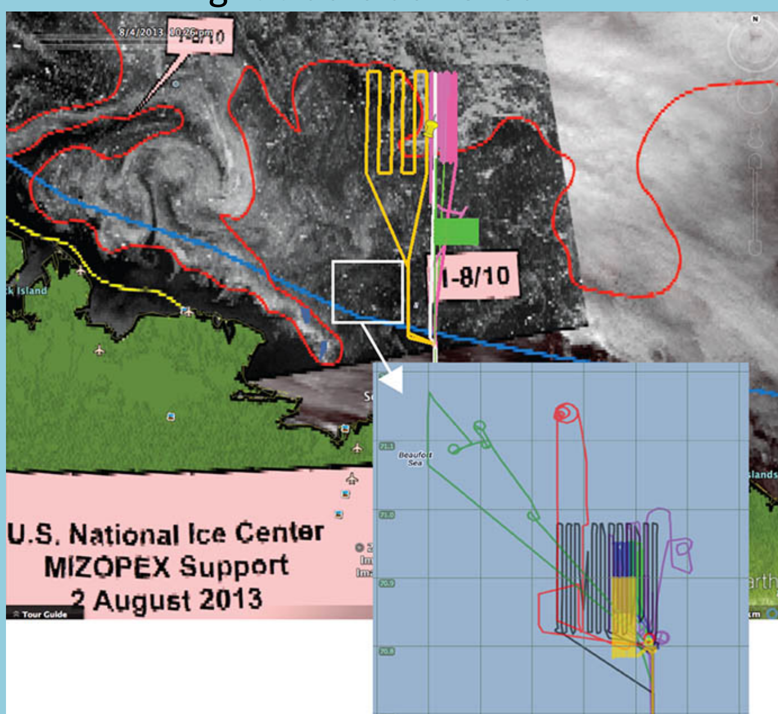
Goals:

- Assess ocean and sea ice variability in the Alaskan Arctic Ocean (Beaufort Sea/Prudhoe Bay area).
- Demonstrate potential for research using multiple unmanned aircraft systems (UAS) in polar regions.
- Determine best practices for safe, reliable operations in the National Air Space.

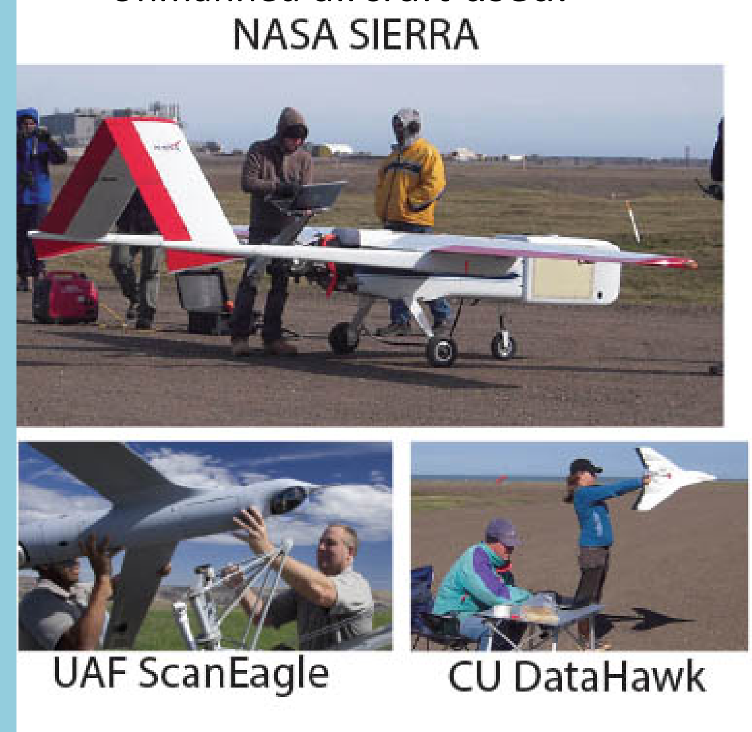
Accomplishments:

- 3 separate UAS deployed at Oliktok Point (USAF/DOE site; Alaskan coast) during 10 July – 9 Aug 2013
- 24 separate UAS flights carried out; 54 flight hours; visible and thermal imaging and microbuoy drops
- First beyond-line-of-sight flights, concurrent UAV ops., coincident remote and in-situ sensing, multi-agency coordination, use of ground-based radar for safety

Flight tracks achieved:

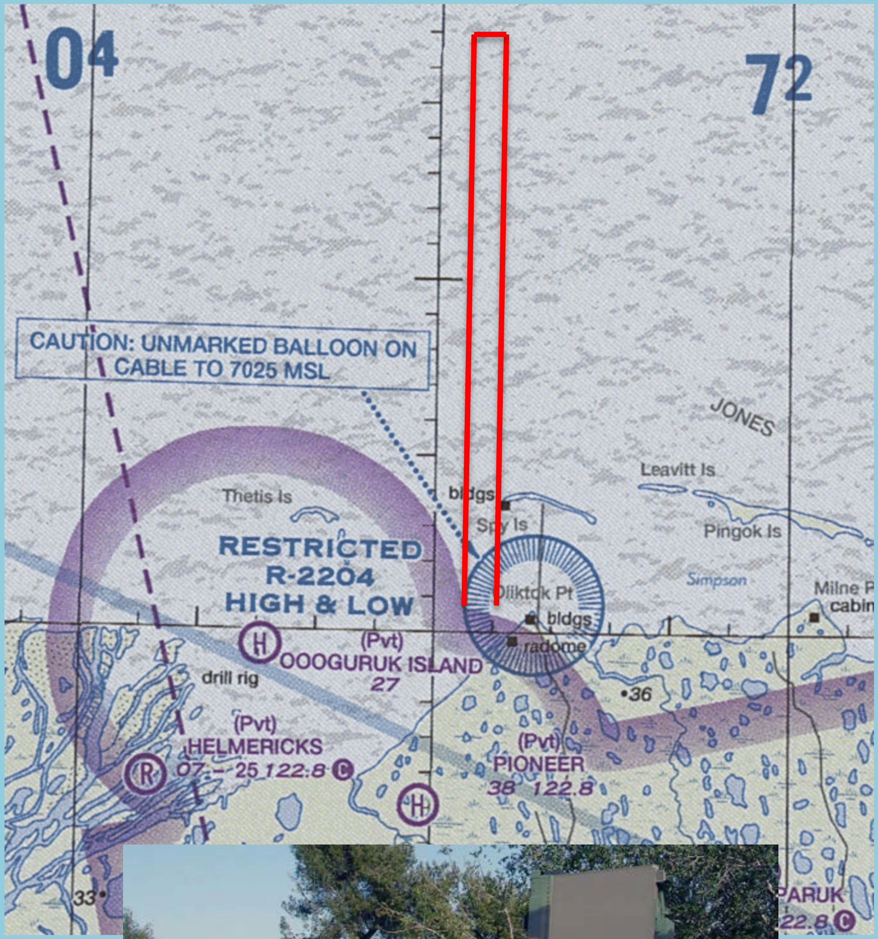


Unmanned aircraft used:



Domestic Airspace Operations

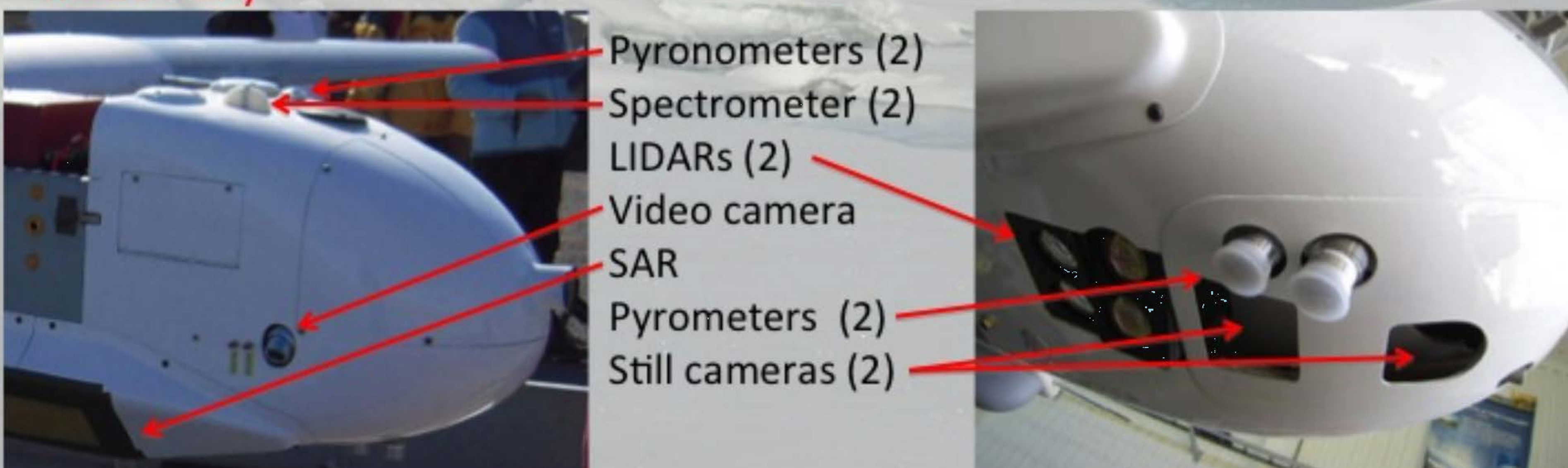
- Operations under FAA COA
- Launch/land from C-130 gravel runway in restricted airspace
- Utilize 1 nm wide x 2000’ high transit corridor to international airspace
- Sense-and-Avoid (SAA) required; ground-based radar in lieu of surface observers or chase
- Loss of radar capability
  - RTB if in transit corridor
  - RTB at end of mission if in international airspace



The NASA SIERRA UAS

Science Instrumentation Environmental Remote Research Aircraft

- 6 m wingspan
- 25 kg payload (15 – 33 kg for MIZOPEX)
- 10 hr, 1000 km range (4 to 7 hours for MIZOPEX)



Instrumentation integrated into SIERRA payload bays for MIZOPEX use.

Sierra Systems

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, Attitude	
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 & 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

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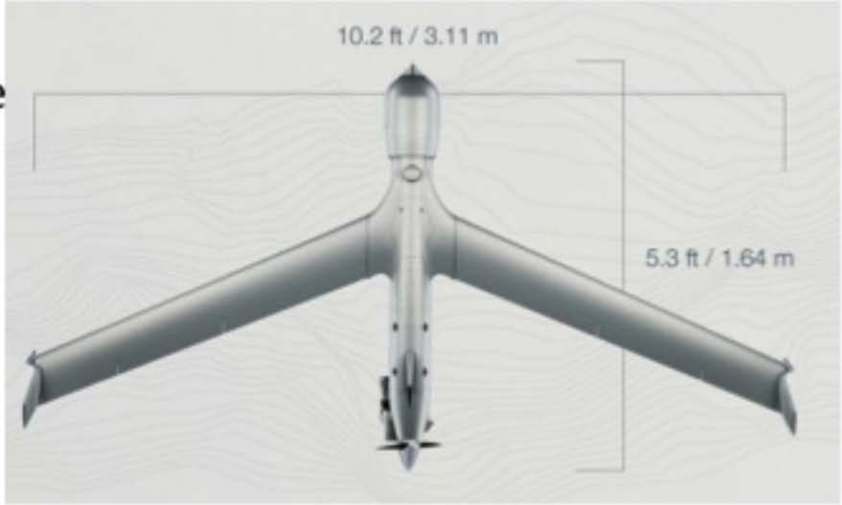


ScanEagle & Buoy Systems

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	
Ariel	Microwave Radiometer	SSS	UPC
BESST	Thermal IR Still Camera	Skin SST, Ice Surface Temperature	Ball

System Name	System Type	Geophysical Measurement	Affiliation
SDSS	SRE UAS & Surface Buoy	Bulk SST	CU
UpTempO	Surface Buoy	Bulk SST	APL-UW

Why??

- Marginal ice zones (MIZ), or areas where the "ice-albedo feedback" driven by solar warming is highest and ice melt is extensive, may provide insights into the extent of changes in the Arctic Ocean.

- MIZ plays a role in setting the air-sea CO_2 balance making them a critical component of the global carbon cycle

- Incomplete understanding of how the sea-ice modulates gas fluxes renders it difficult to estimate the carbon budget in MIZ

- Identify potential turbulent mechanisms that drive mixing and gas exchange in polar regions
  - Leads, Polynyas and in the presence of Ice Floes

- Field - UAV Flights that during MIZOPEX in August 2013
- Laboratory - GAPS in September-November 2012 at CRREL

IR / Visible ScanEagle Payload

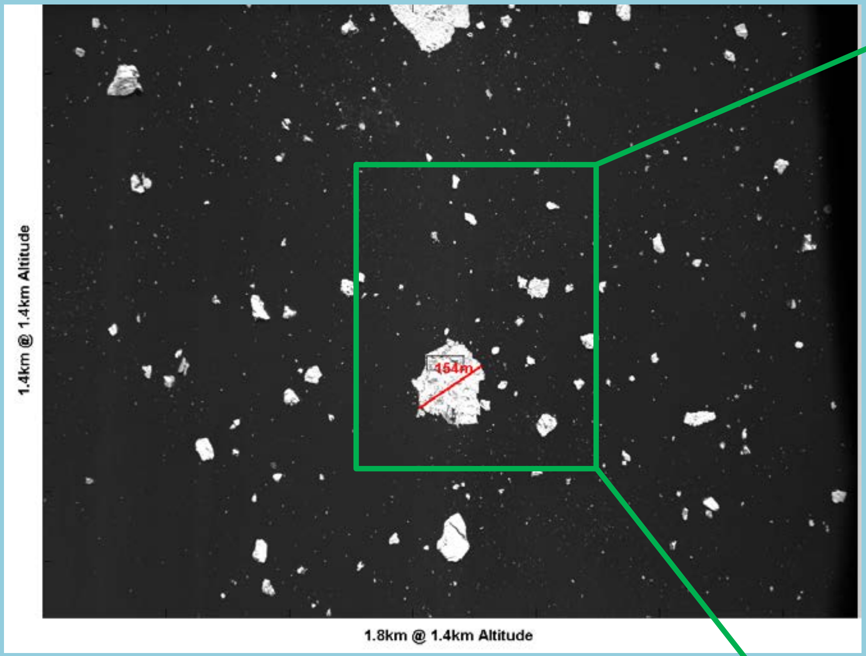
7 flights from 1-9 August, 2013;   10 hours of data

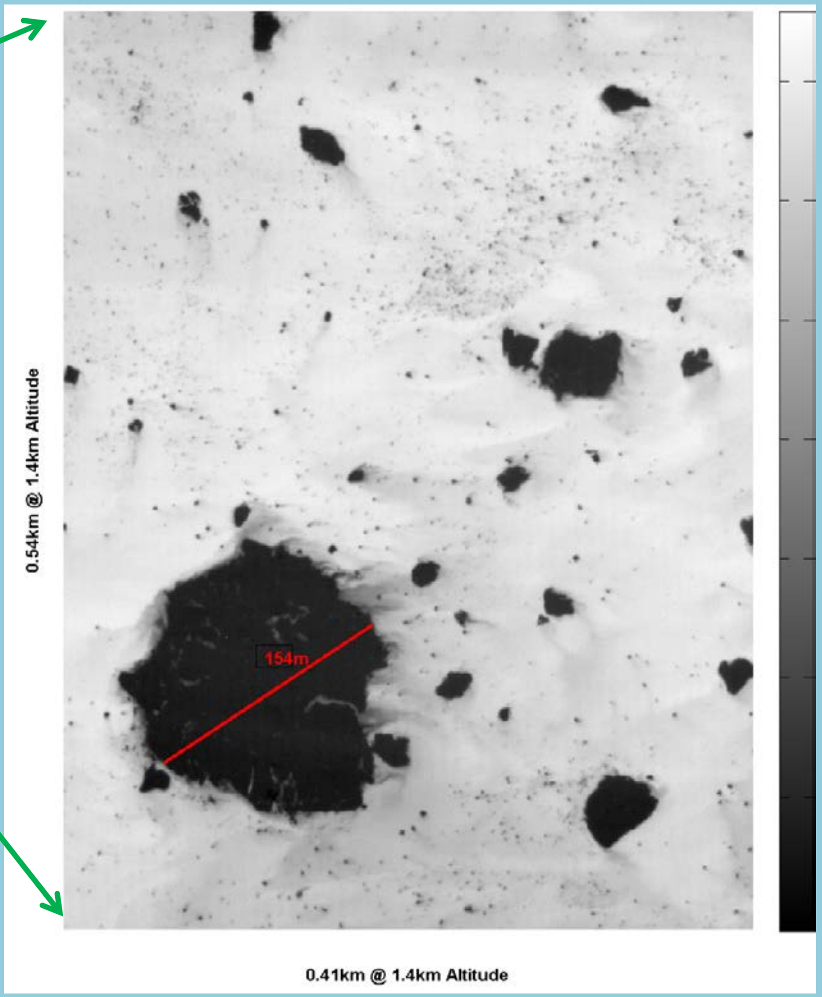
ATOM Camera (50 Hz)

Bobcat Camera (20 Hz)

MIZOPEX: Turbulence Mechanisms in Polar Systems

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





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

- 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.

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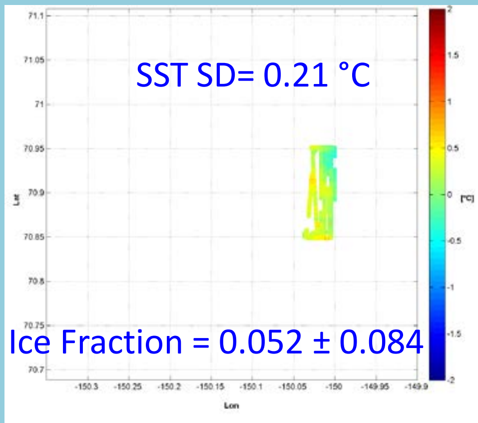
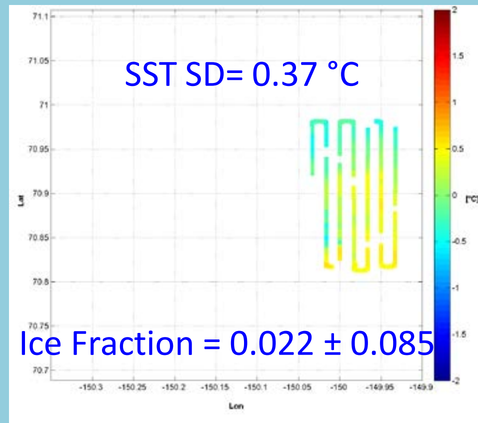
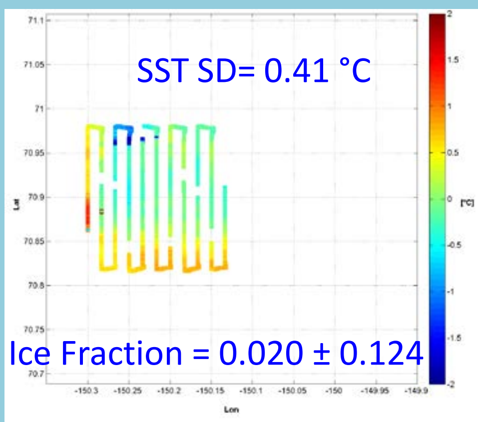
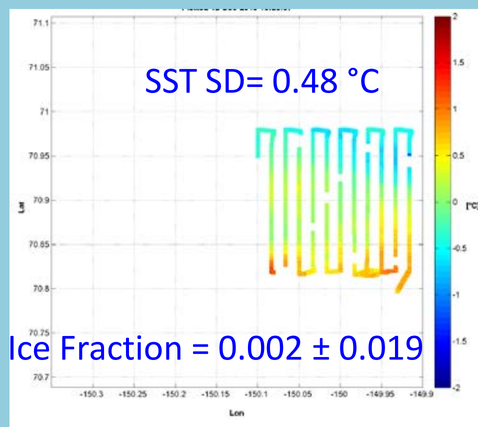
MIZOPEX: Transition Over Beaufort Sea

Measurements of Infrared Imagery from LDEO Payload on Scan Eagle





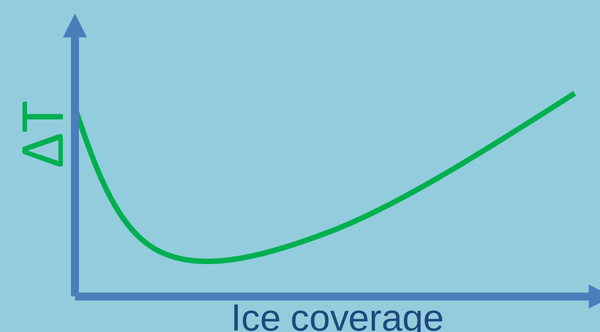




Presence of Sea Ice increases mixing that affects Skin Temperature Variability

- Skin SST variability increases (from 0.21 to 0.48 C) with decreasing ice fraction (from 5.0% to 0.2%)
- Skin SST variability increases due to enhanced melt and decreased mixing over 4-day period

- Data suggests turbulence due to increased floe concentration enhances the mixing of skin SST variability
- We hypothesize that ΔT first decreases with floe concentration up to a certain point where concentration starts inhibiting turbulence and melt processes dominate.
  - Skin SST variability results during MIZOPEX are supported by measurements during experiments at CRREL.



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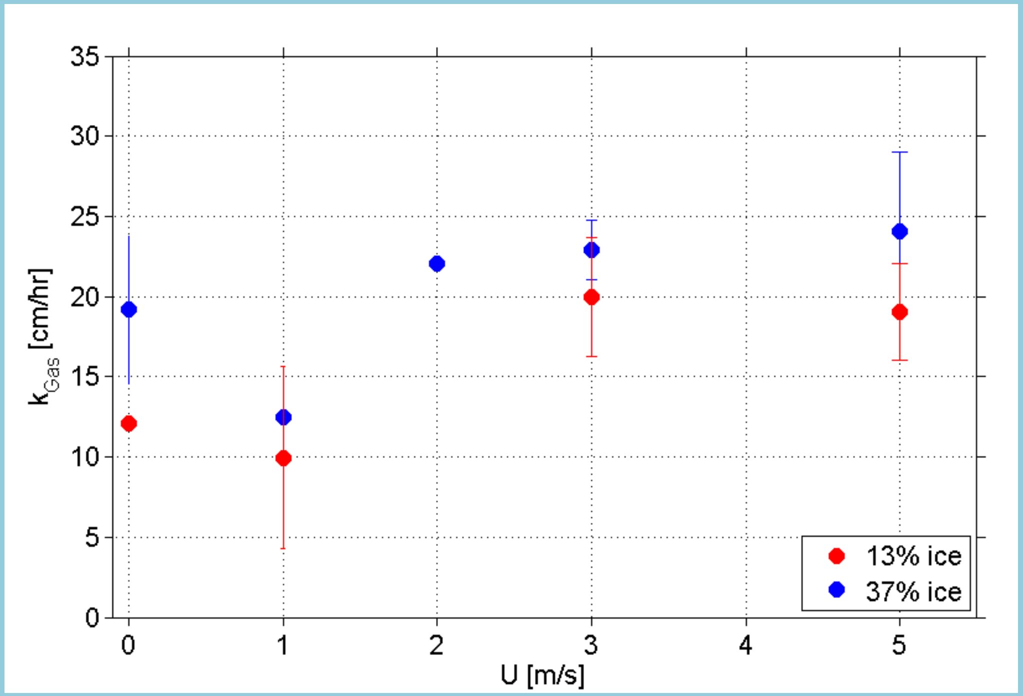
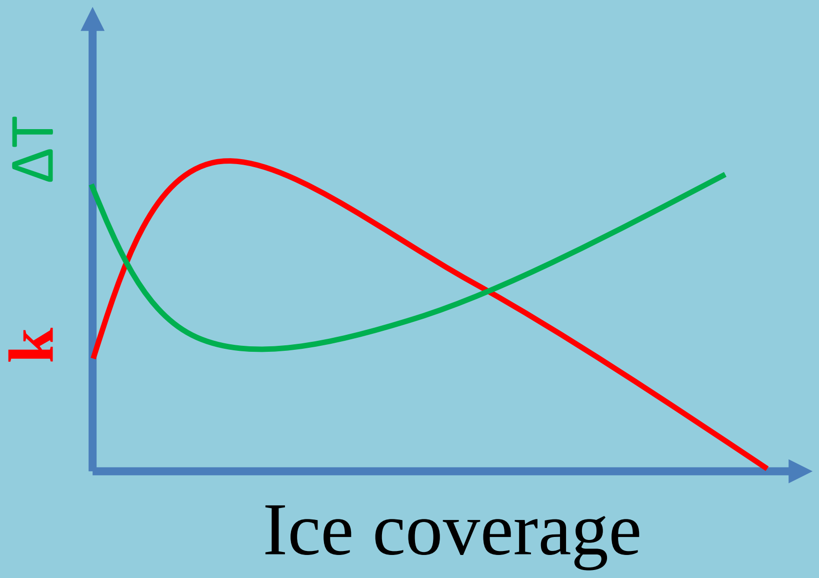
Gas Transfer Variation with Ice Floe Coverage



- k increases with wind
- Error bars account for pump speed variations that show slight increase in k with pump speed
- k increases when ice floe concentrations increases from 13% to 37%

- Data suggests additional turbulence due to increased floe concentration enhances gas transfer
- We hypothesize that k first increases with floe concentration up to a certain point where concentration starts inhibiting turbulence and transfer.

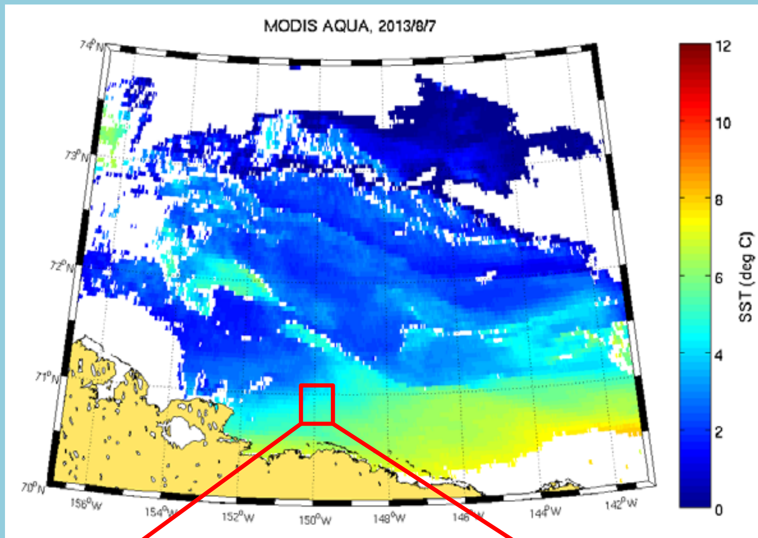


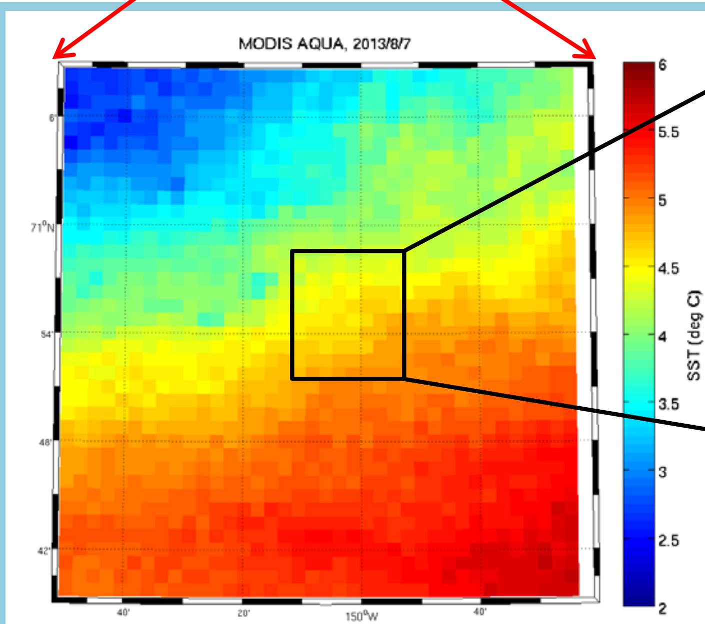
Satellite View of MIZOPEX Transition

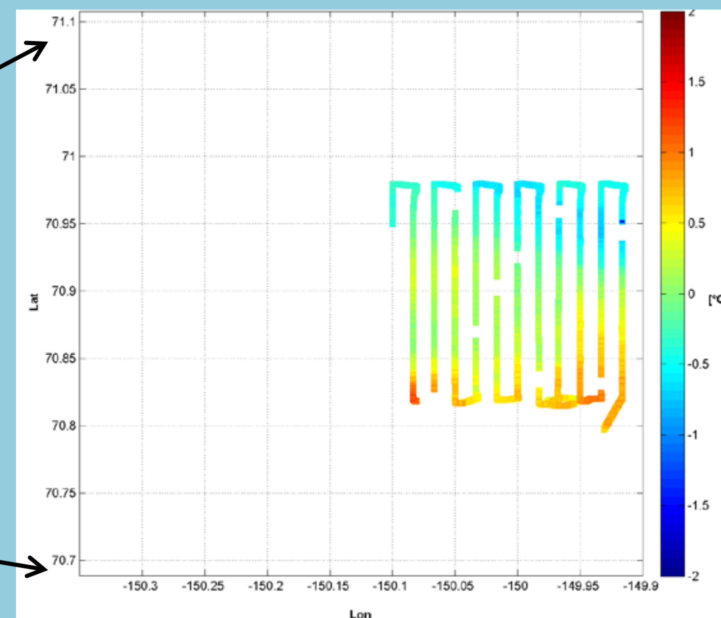
Measurements of Infrared Imagery from LDEO Payload on Scan Eagle

- Objective here to see if variability in the satellite SST fields is consistent with that observed in the airborne data as ice melts away (or if the satellite data is just too coarse to say anything).

- Image shows the similar N-S gradient observed in UAV data (roughly 1.5 °C).







MODIS Aqua image for 7-August 2013 (Top) and a Zoom in view (Bottom). The image is roughly a 50x50 km square. Unfortunately, we get just this one good satellite look due to cloud cover issues.

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Future Directions

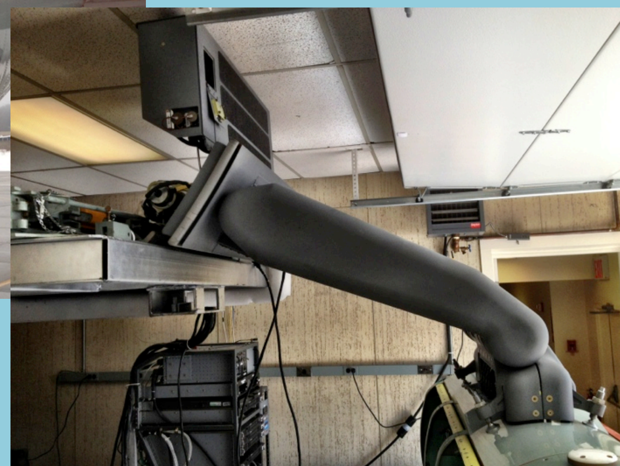
- Developing new payloads for UAVs (e.g., Scan Eagle, Manta, Aerosonde)
- Payloads include: i) VNIR hyperspectral imaging (400-1000 nm), ii) NIR hyperspectral imaging (900-1700 nm), iii) infrared imaging (8-9 microns), iv) Lidar scanner, v) air-sea-ice turbulent fluxes, radiative fluxes, vi) UAV-deployed combination dropsondes (q/T/P) and microbuoys (T/S).
- Airborne surveys over MIZ sea ice from Manta UAVs in Svalbard Norway during experiments March-April 2015 in collaboration with Tim Bates of NOAA PMEL (Seattle).

IcePod

A Modular Approach to Airborne Polar Science.

A Troop Door

An Arm



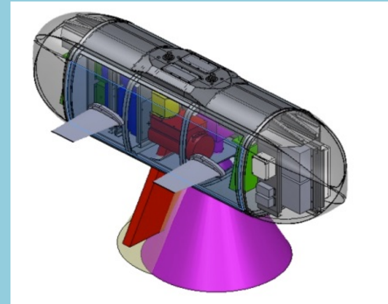
An LC-130

A Sensor Pod

A Data Acquisition Rack

A Skilled Team Including the Guard

IcePod



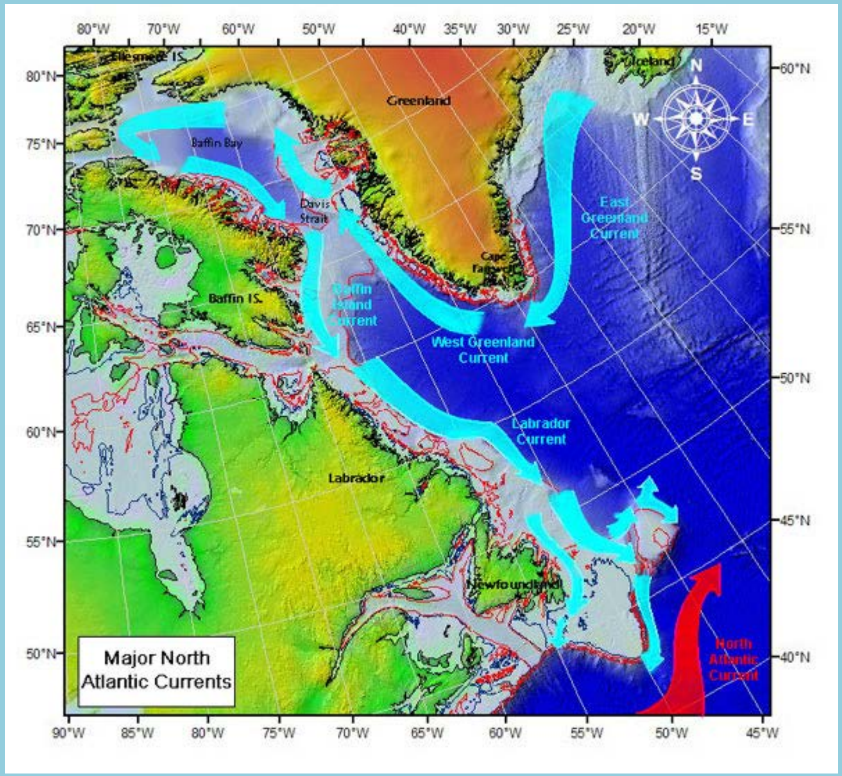
A Modular Approach to Airborne Polar Science.

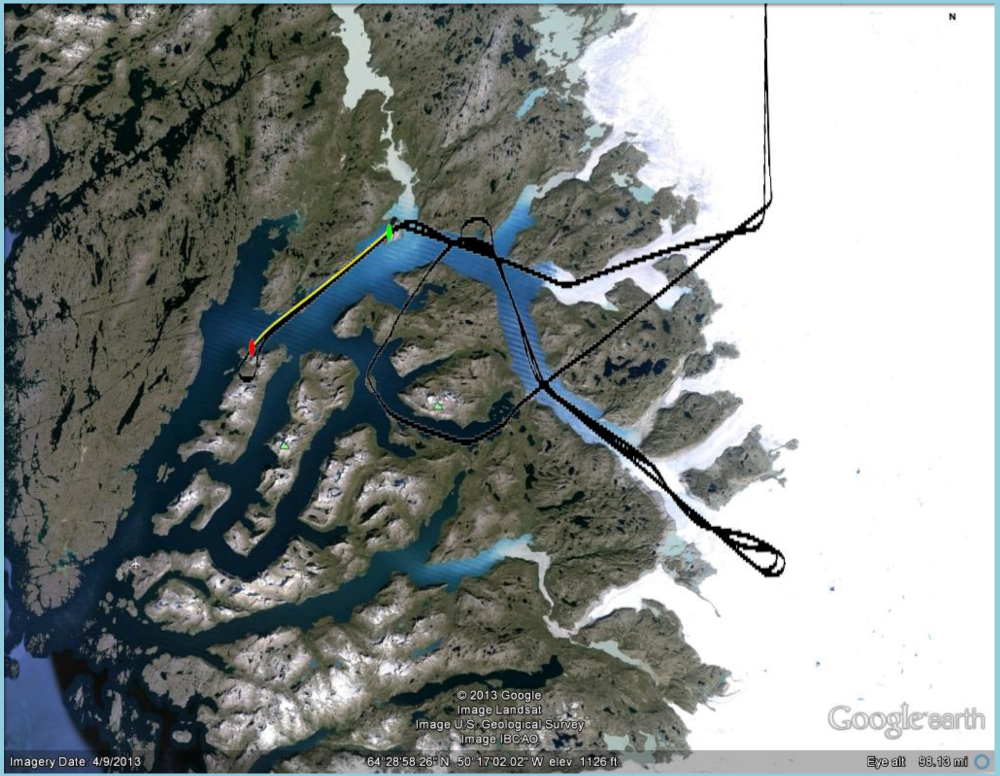
Figure 2 IcePod Components IcePod Common Science Support Pod (CSSP) (far left), SABRE arm (center left), Door plug (center right) and Instrument rack (left)

IcePod Sensor	Data Sets
Airborne laser scanner	Ice surface elevation and roughness
Visible camera	Ice sheet surface elevation and structure
Infrared camera	Ice sheet surface temperature
Deep-ice radar	Ice thickness, basal conditions
Shallow-ice radar	Snow accumulation, snow thickness
Inertial measurement unit/GPS	Geo-referencing

IcePod

A Modular Approach to Airborne Polar Science.



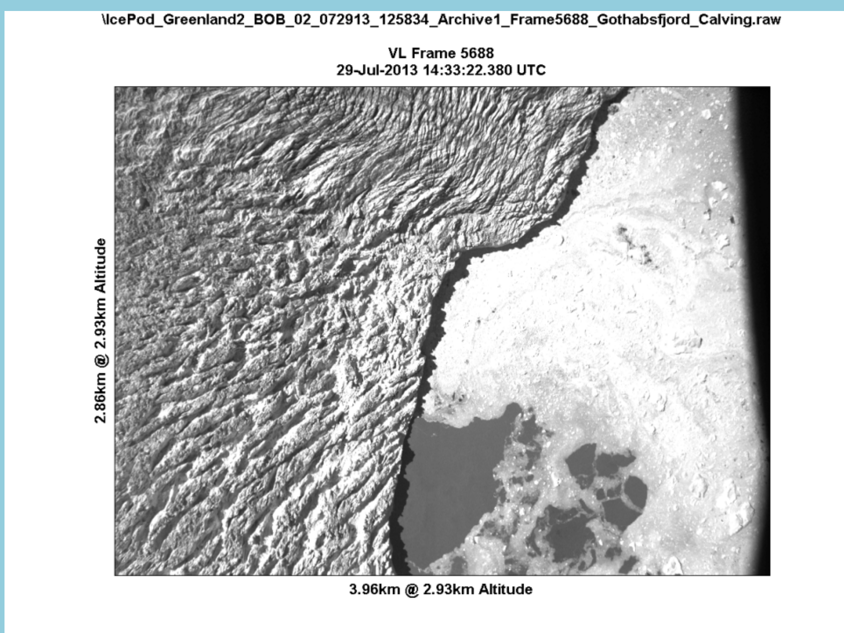


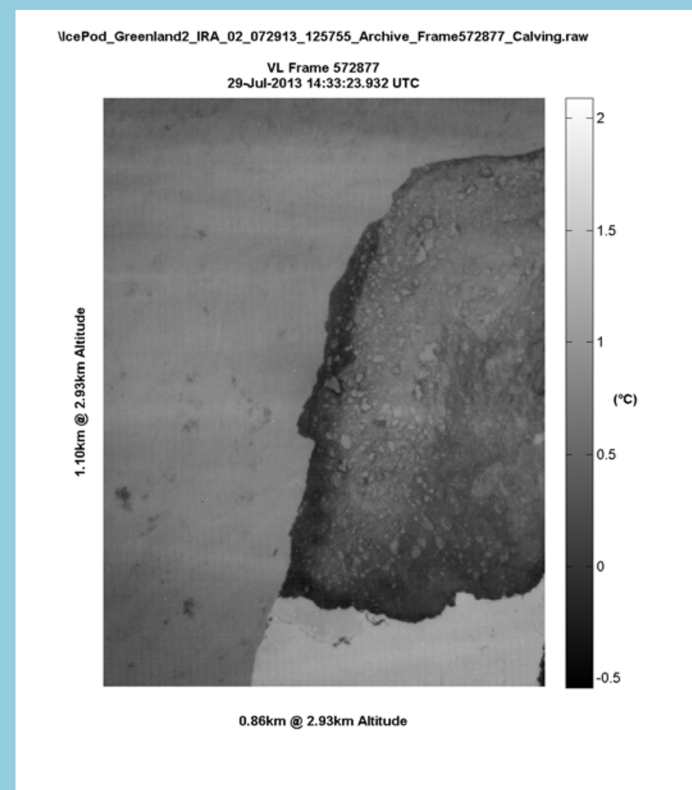
Summer of 2013, multiple passes were made with both visible and infrared cameras of the inner, iceberg-filled region of Godthabsfjord in Greenland

IcePod

A Modular Approach to Airborne Polar Science.

Goal is to investigate how the circulation, transport, and mixing in Godthabsfjord at the calving front of Kangiata Nunata Sermia affect the SST variability and feedbacks on the Greenland ice sheet.

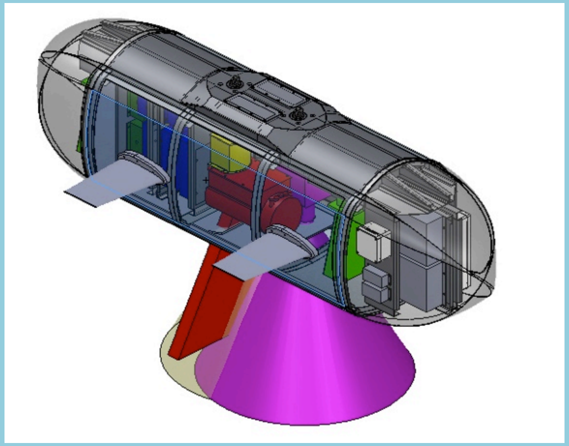


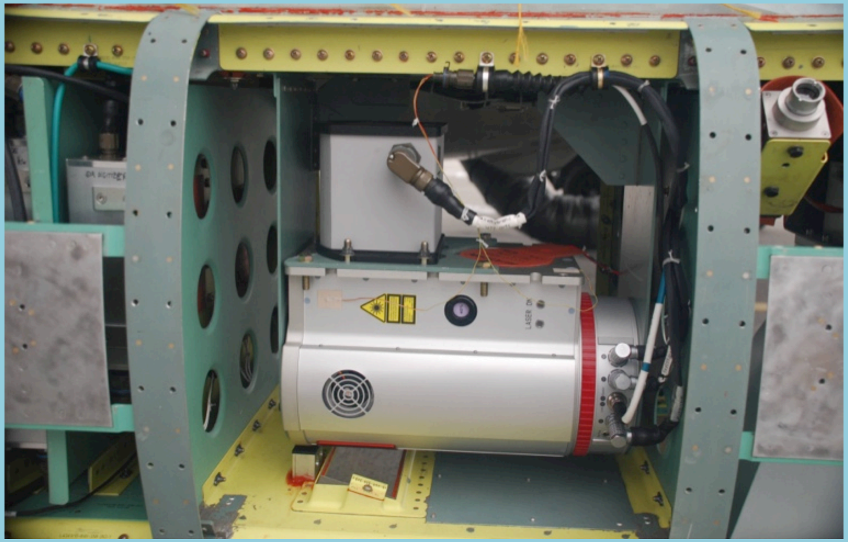



Meltwater Plume

IcePod

LIDAR





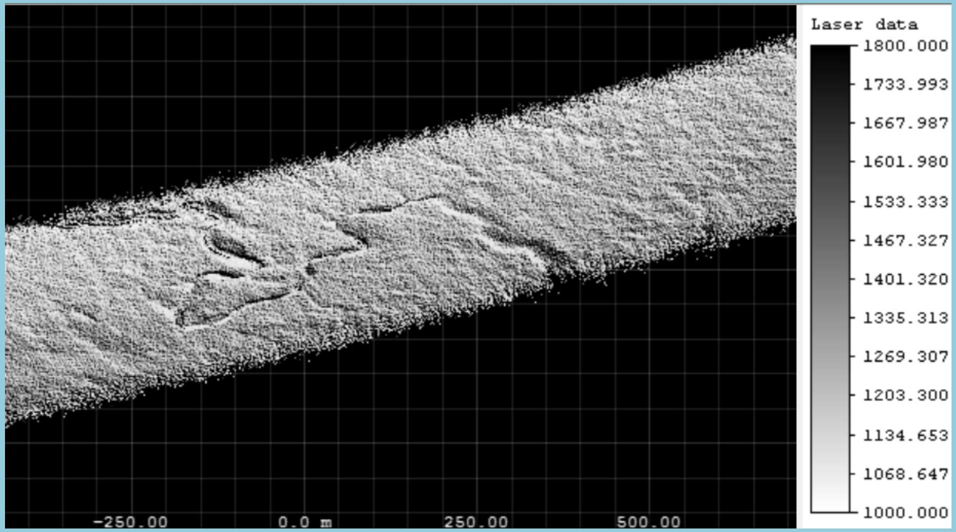
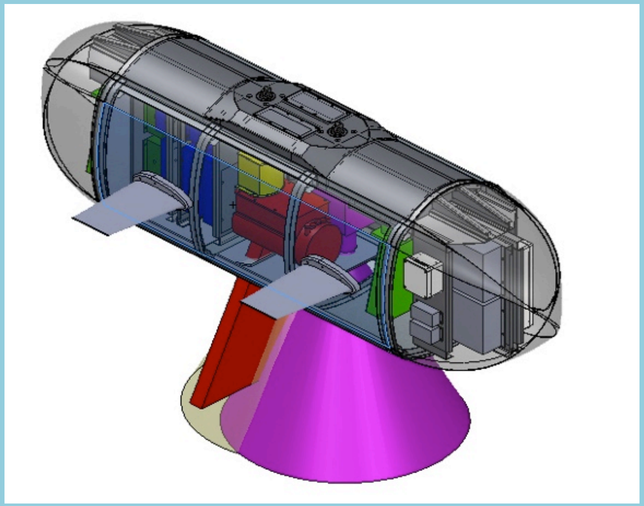


Figure 3 Riegl VQ-580 airborne laser scanner and swath elevation over a Greenland melt channel

IcePod

Deep-Ice Radar



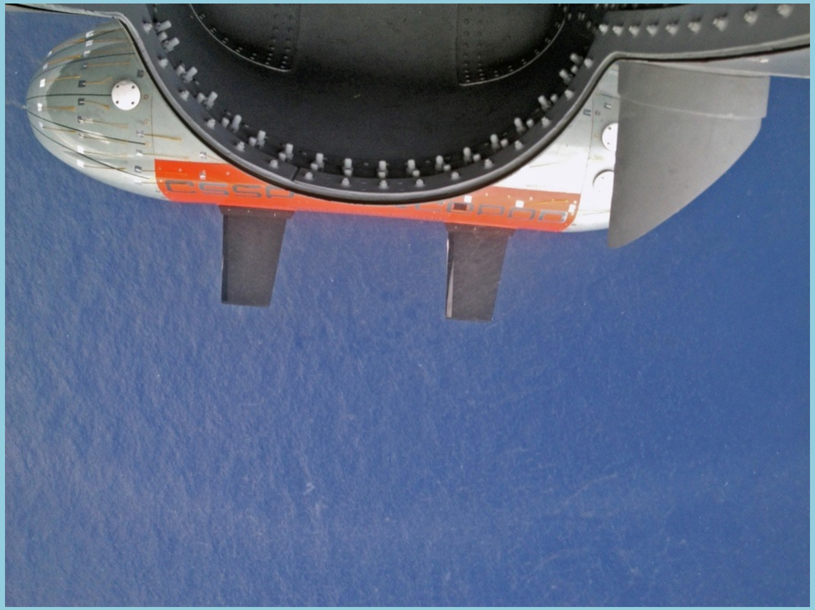
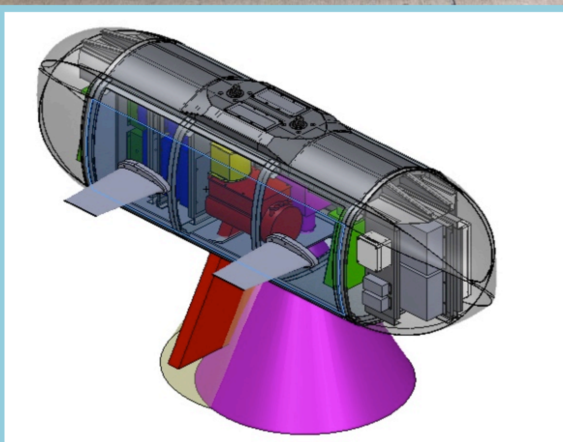


Figure 4 Deep Ice Sounding Radar blade antennae during over ocean calibration and sample radar image of internal layers Russell Glacier, Greenland

IcePod

Visible Photogrammetry



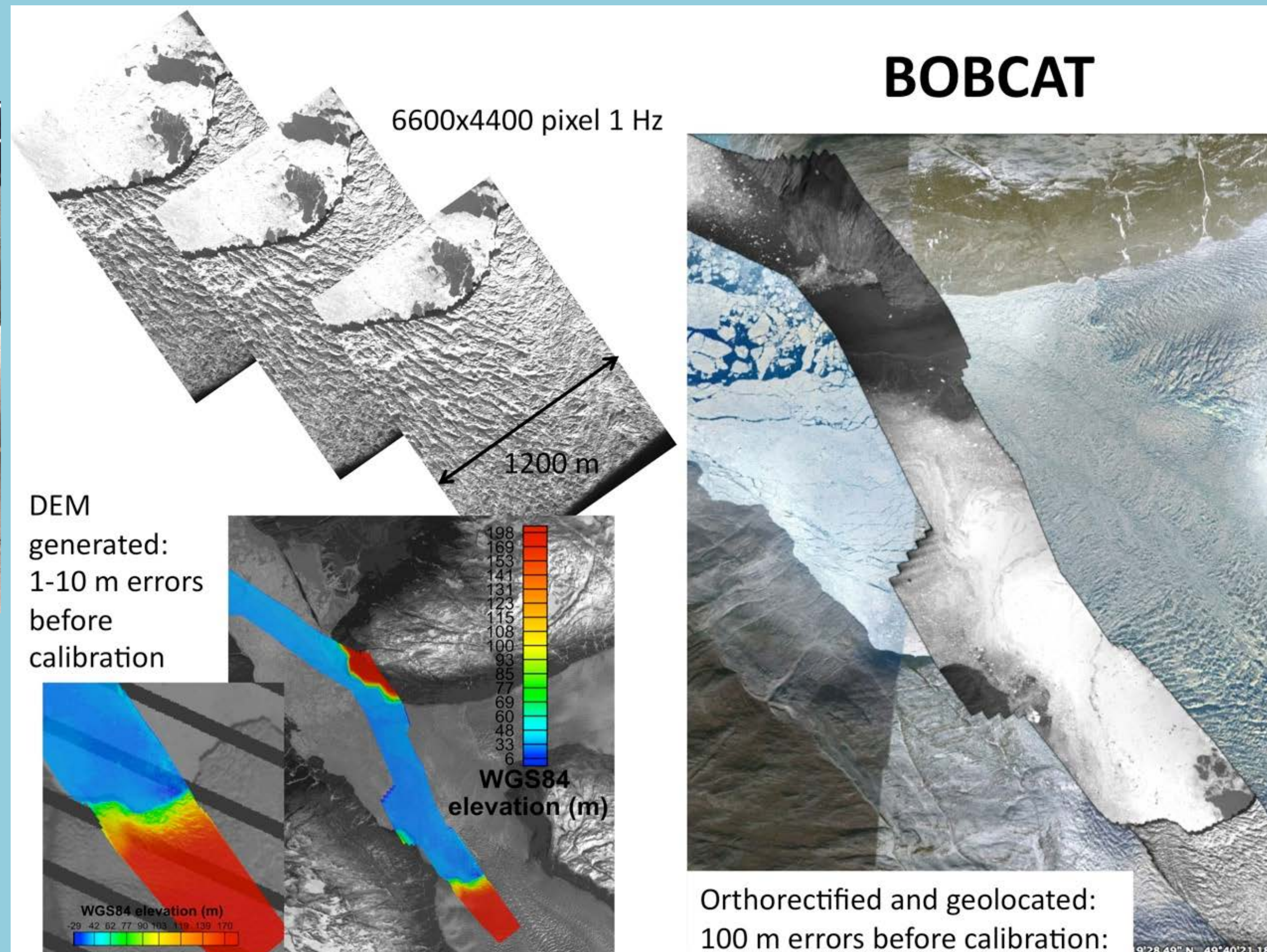
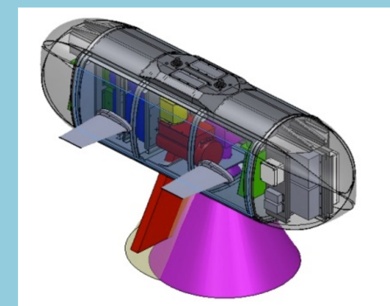


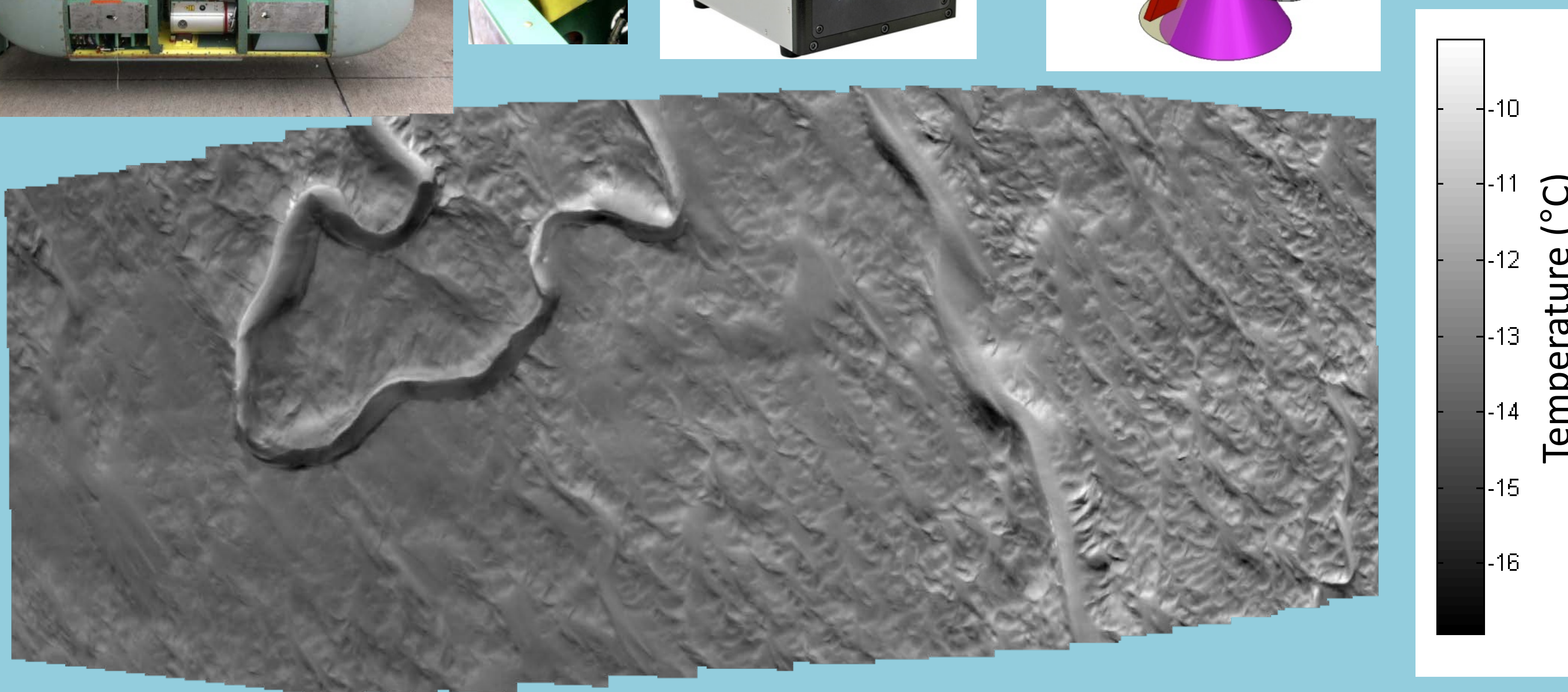
Figure 5 Bobcat Visual Camera(left) Sample Imagery over Godthabsfjord, Greenland and DEM from Images.

IcePod

Infrared Imaging

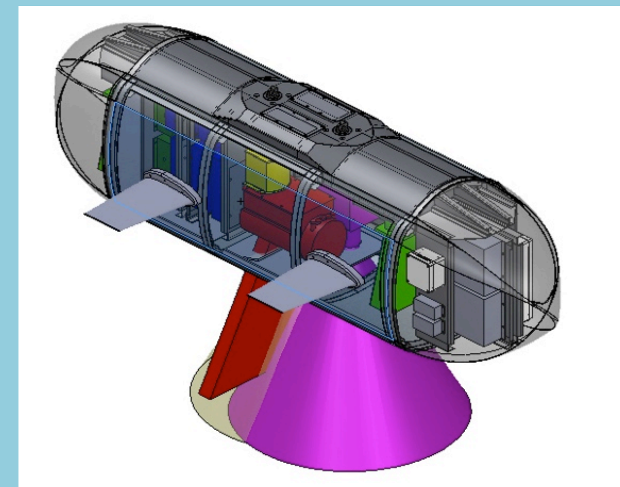
Figure 6 Sofradir IRE640L thermal Infra-Red camera (left). Infra-Red Radiation Heitronics Pyrometer (center) Swath Temperatures over Meltwater channel Russell Glacier, Greenland (right) resolving 1.4°C temperature difference of the ice sheet surface between the south-facing and north-facing channel margins.





IcePod

Shallow-Ice Radar



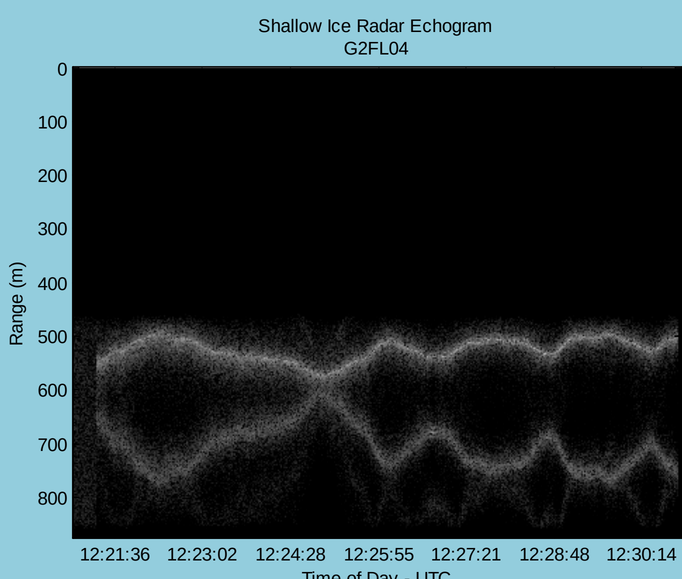
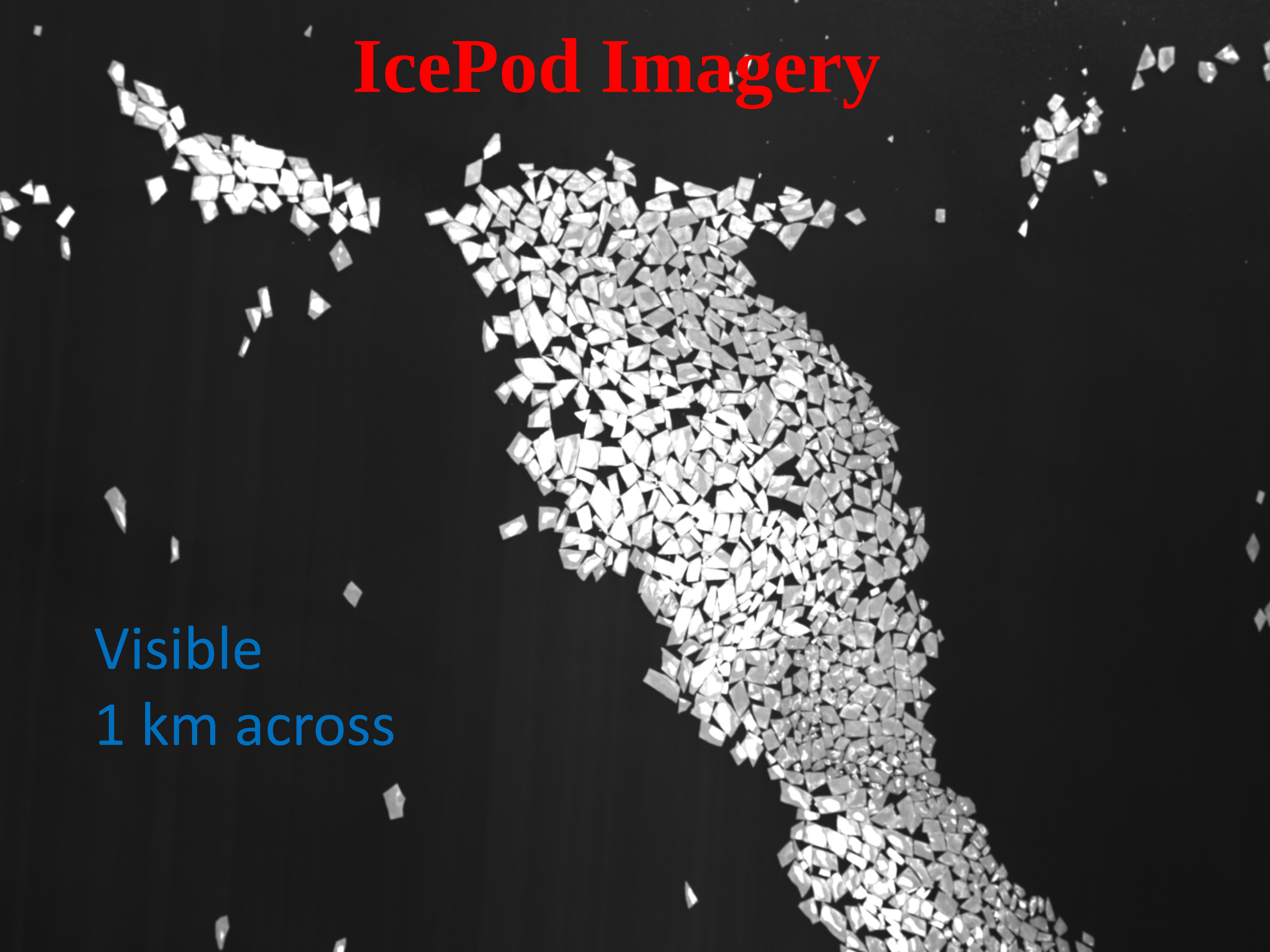


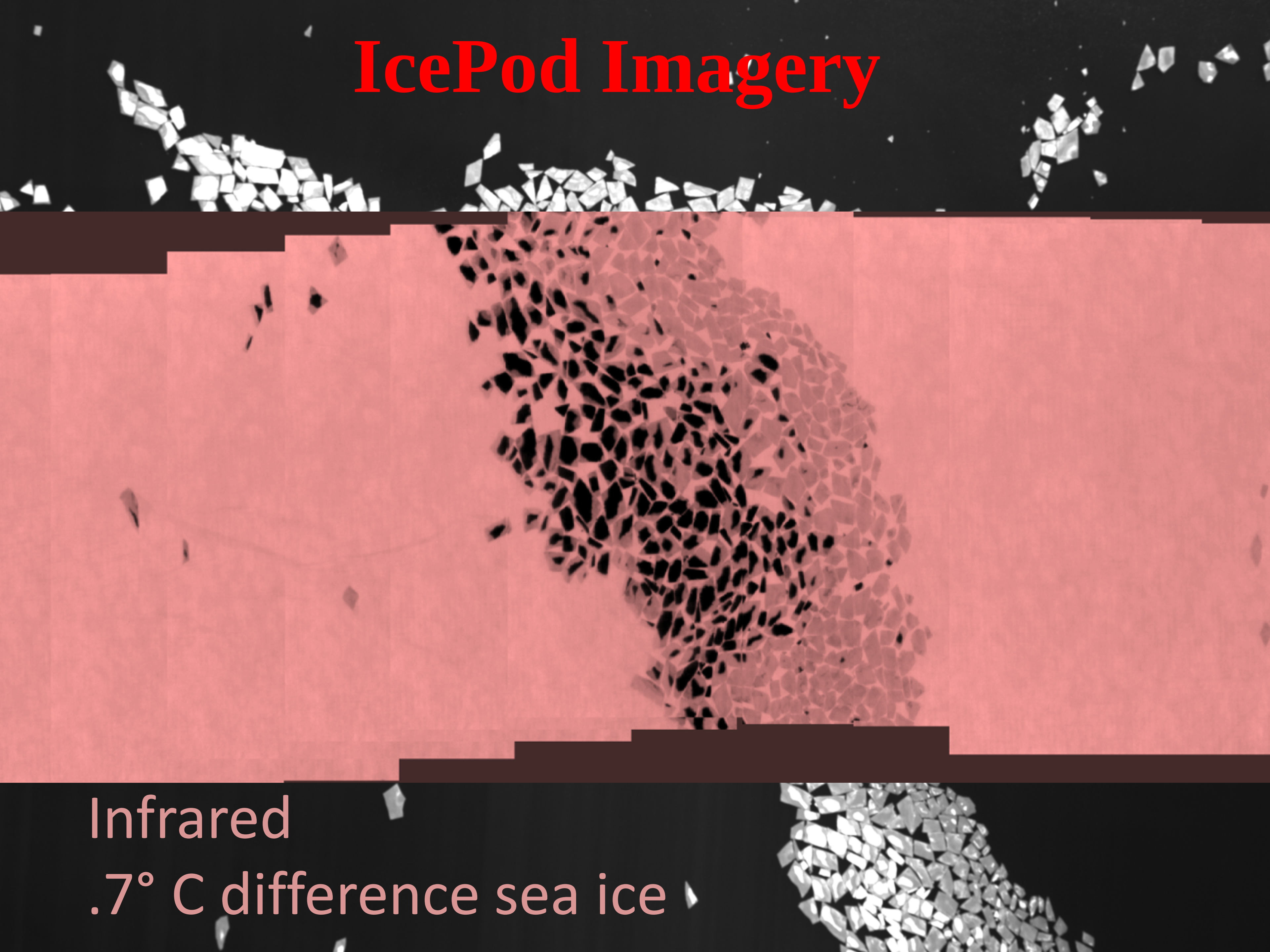
Figure 8 Shallow Ice Radar Horn Antennae (left) and initial waveforms (right). The system resolves near-surface processes, firn depth, snow-pack depth, and sea-ice depth. Data products include geo-referenced compressed radar-grams. The shallow ice sounding radar has the following specifications: power output (< 1 W), center frequency (2 GHz), bandwidth (600 MHz), chirp length (1 ms), depth resolution (0.25 meters), and along-track resolution (nominally 4 m).

IcePod Commissioning Phase Timeline

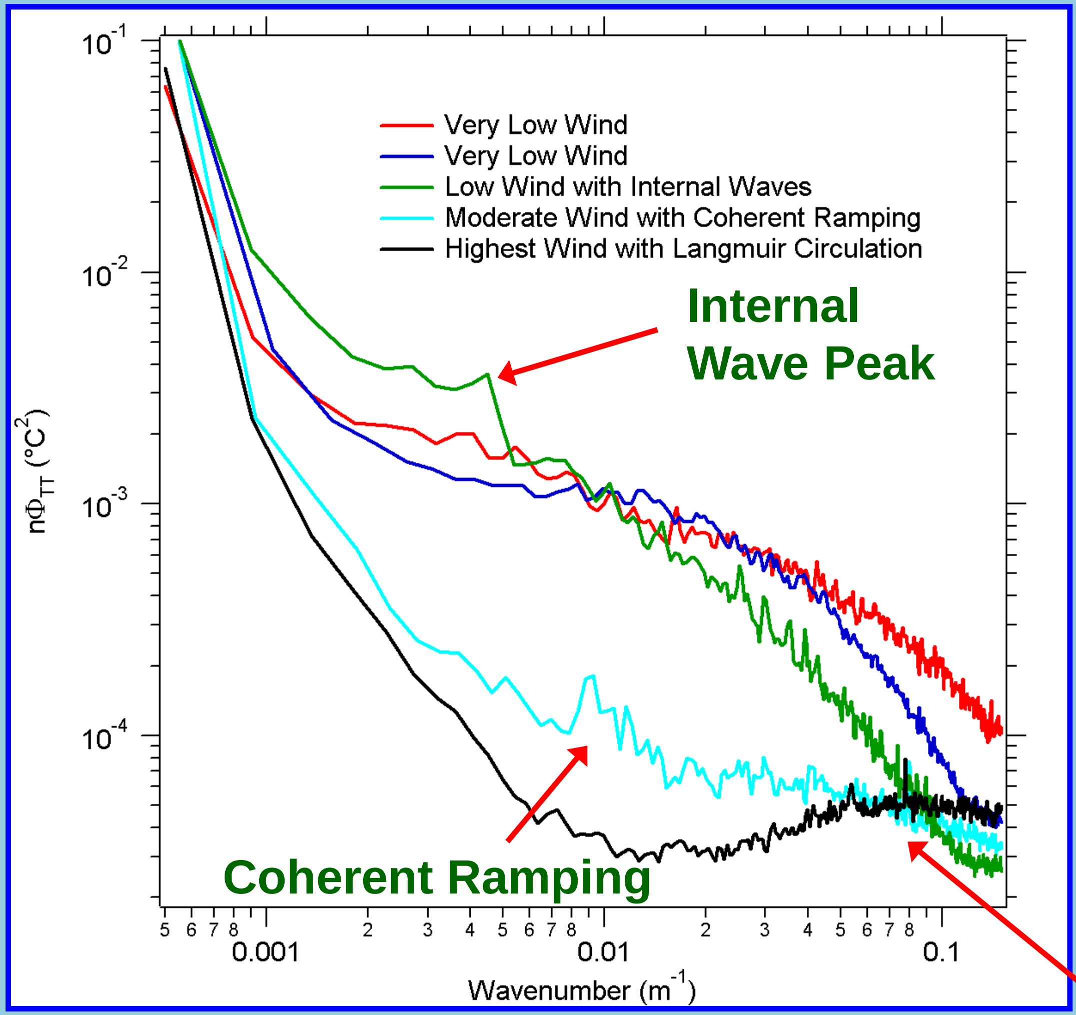
- Summer Greenland Deployment July 2014
  - Deep-Ice Radar
  - Power Conditioner
- Antarctica Deployment November-December 2014
  - Deep-Ice Radar
- Demonstrate Useful Data Products and Data Management Plan for Community
- Facility Goal – 2015… Start Writing Proposals to Use IcePod.

IcePod Imagery




IcePod Imagery
Infrared
.7° C difference sea ice

Spectral Characteristics and Wind



Broad energy distribution that decreases at high wavenumber with increasing wind speed.

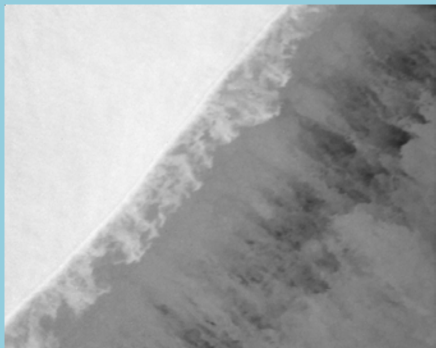
Energy drops significantly at intermediate wavenumber with peak describing coherent ramping scales.

Scales of Langmuir Circulation

Energy dips at intermediate wavenumber but increases at high wavenumber near scales of Langmuir circulation.

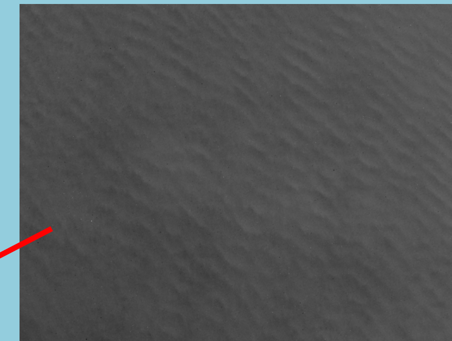
SST Variability Related to Dynamics

Frontal Features



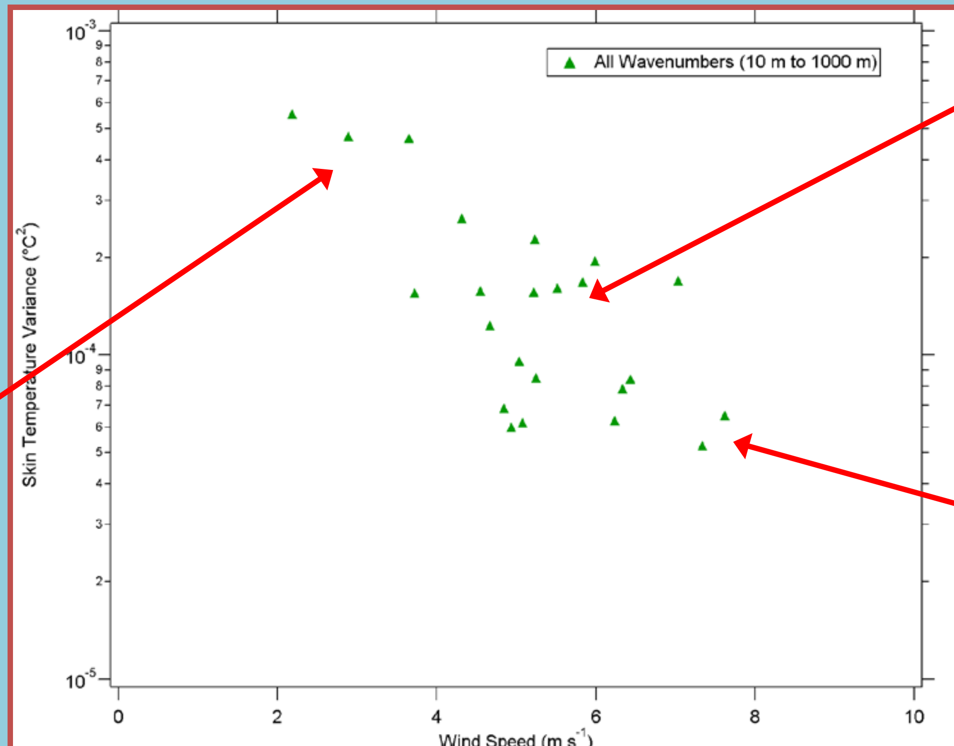
160 m x 200 m

Coherent Structures

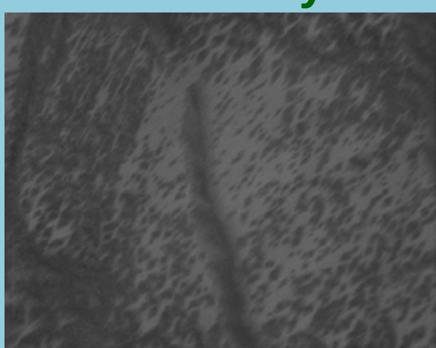


440 m x 555 m

Mean skin temperature variance for each run decreased with increasing wind speed.



Low Wind Variability

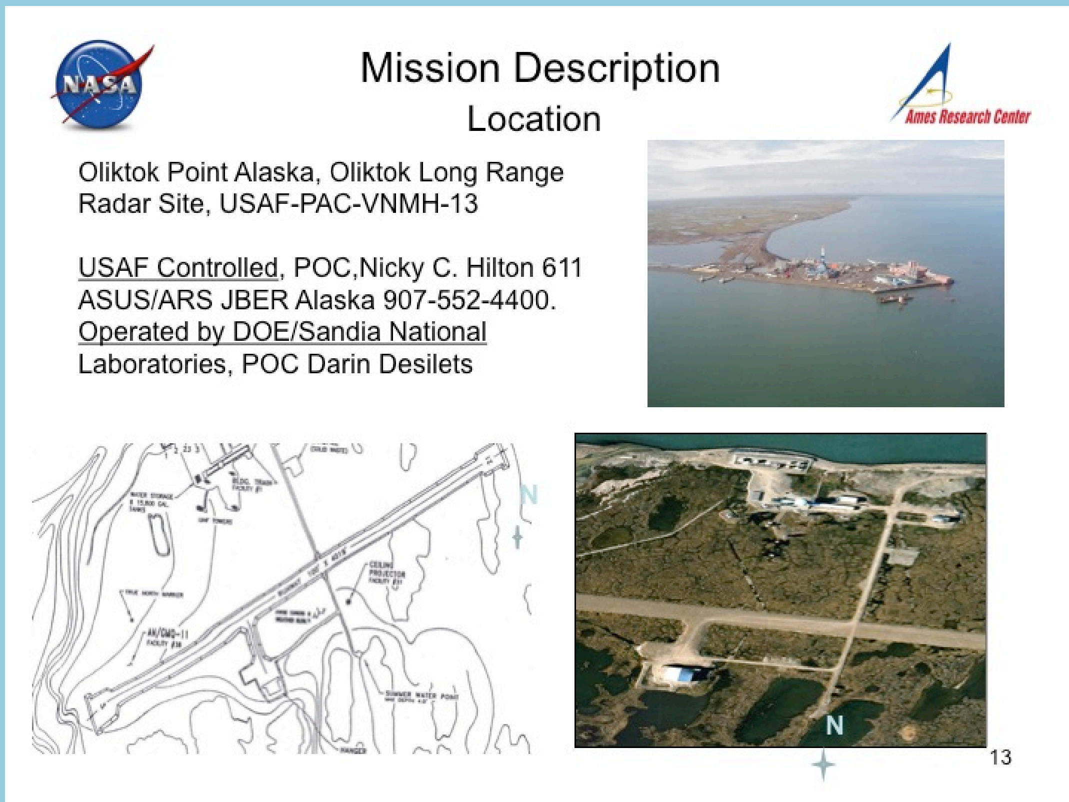


160 m x 200 m

Langmuir Circulation

160 m x 200 m

Operations in Alaska During MIZOPEX



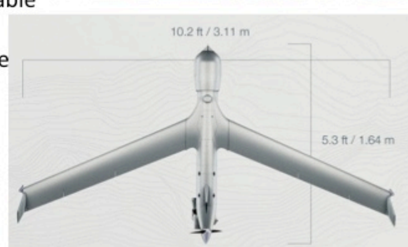
Marginal ice zones (MIZ), or areas where the "ice-albedo feedback" driven by solar warming is highest and ice melt is extensive, may provide insights into the extent of Arctic Ocean changes.

The goal of these and future analyses of the MIZOPEX data set is to elucidate a basic question that is significant for the entire Earth system. Have these regions passed a tipping point, such that they are now essentially acting as sub-Arctic seas where ice disappears in summer, or instead whether the changes are transient, with the potential for the ice pack to recover?

ScanEagle in Alaska During MIZOPEX

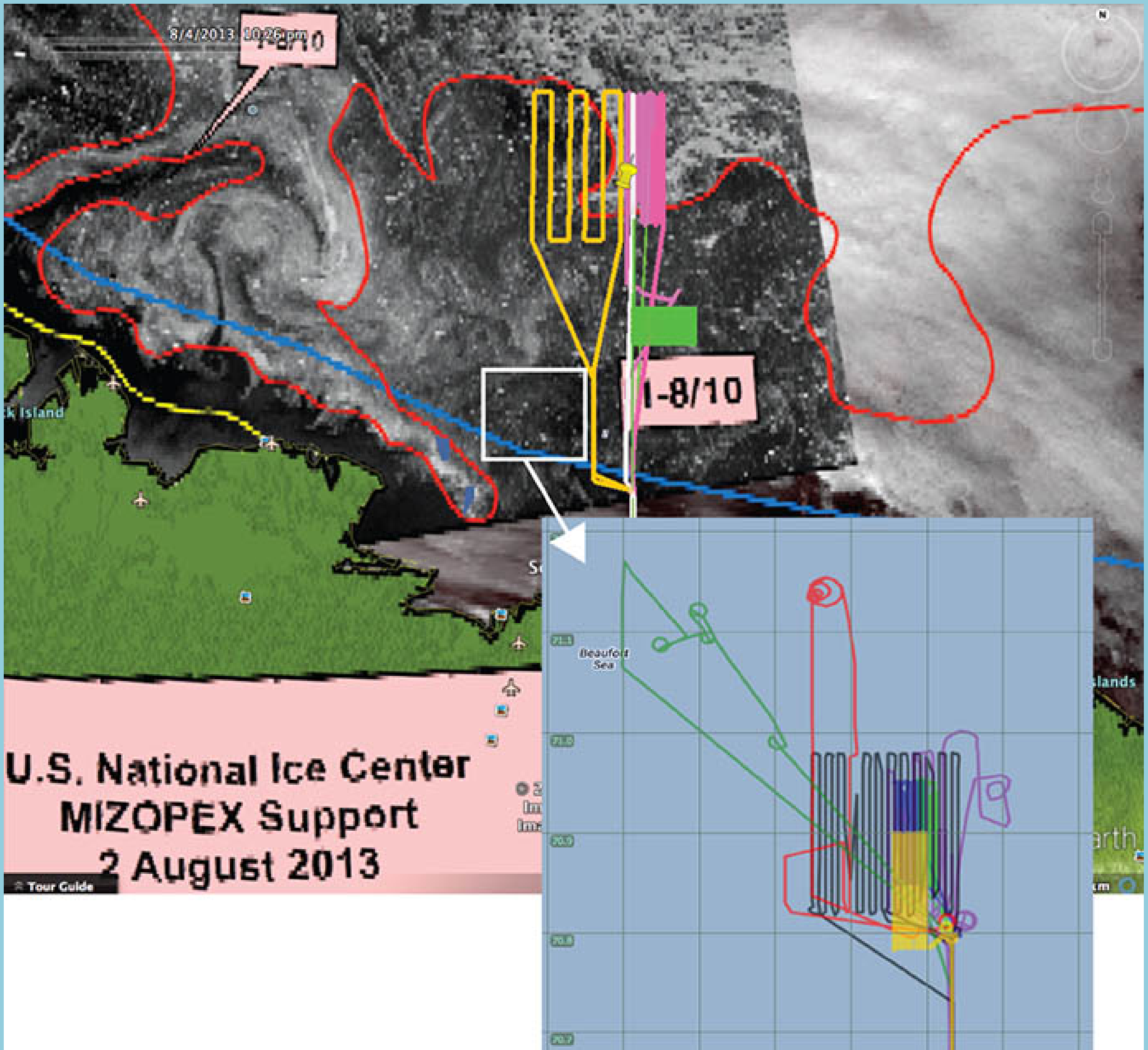
Overview of the UAF-Operated InSitu ScanEagle UAS

- Wingspan: 10.2 ft, Length: 4.5 ft
- Weight: 29 lbs (empty), 44 lbs (max takeoff wt.)
- Gas engine (1.9 hp), rear propeller, onboard generator for electric power
- 48 knot airspeed (cruise)
- Catapult launch, wing tip capture via cable
- Autonomous flight control with GCS control while in line of sight radio range (approx 40 km)
- Iridium satcom for over the horizon operations
- Endurance: 20+ hours
- Ceiling: 19,500 ft.
- Payload: up to ~6 lbs.
- Has received numerous FAA Certificates of Authorization, thousands of flight hours achieved.

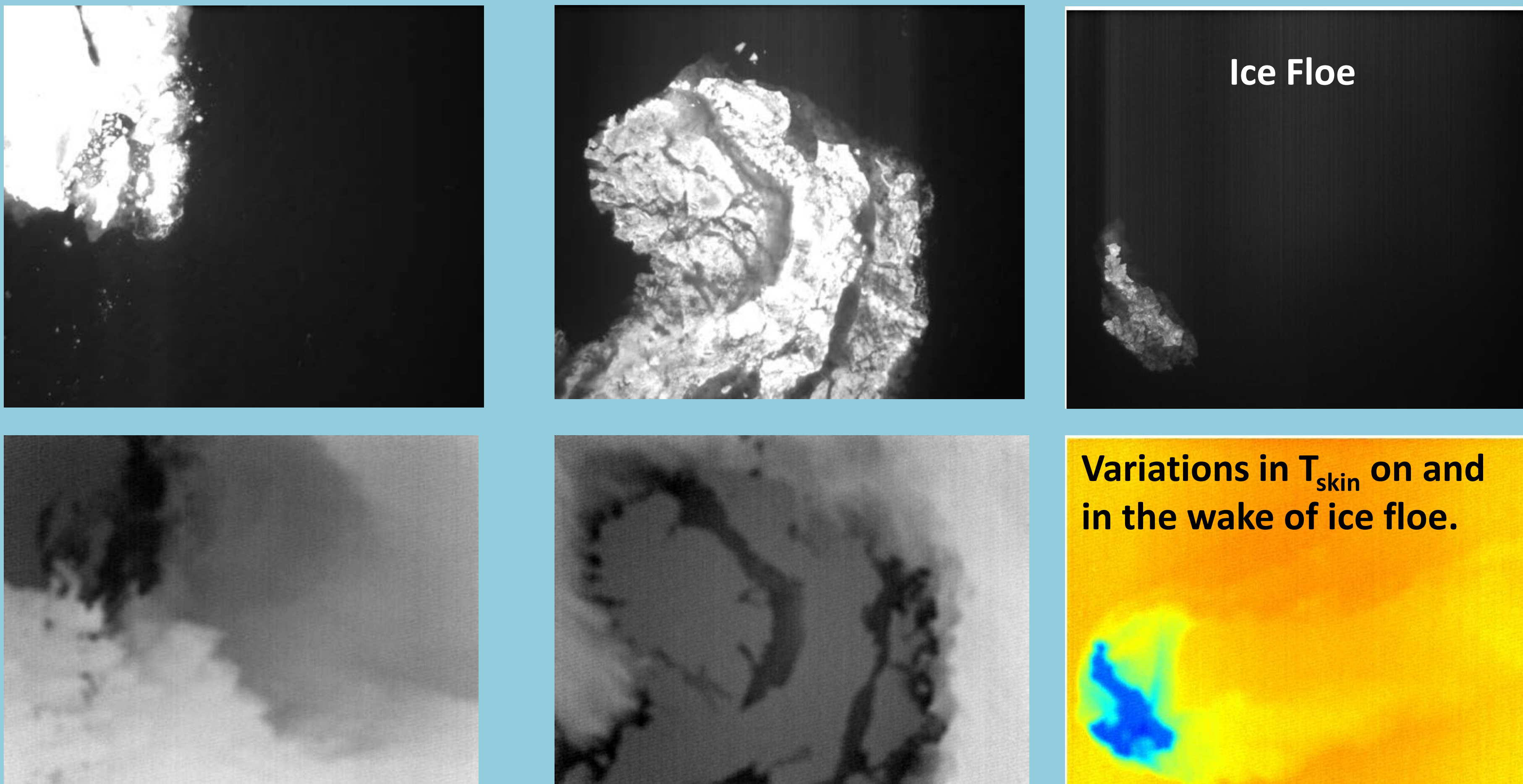


Longer durations and with longer flight range.
Proven operation in polar environments.
Ability to fly at low altitudes.

Flights Over Beaufort Sea During MIZOPEX

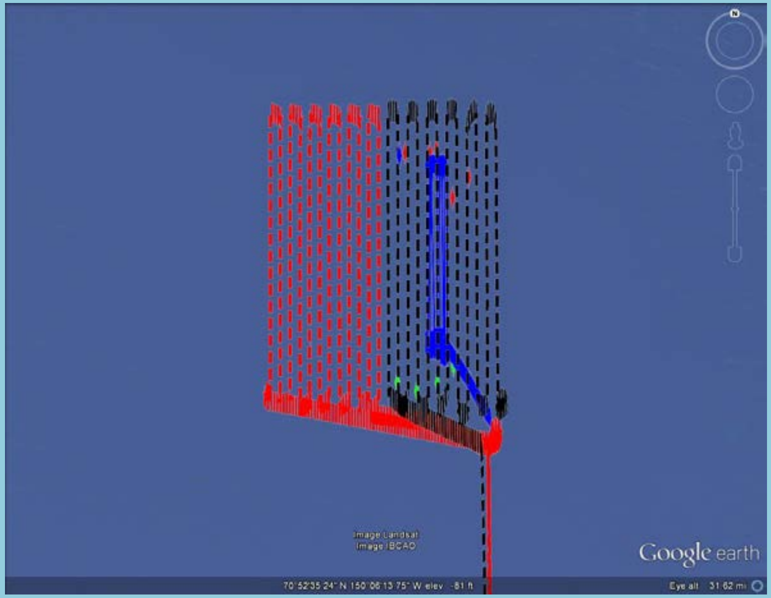


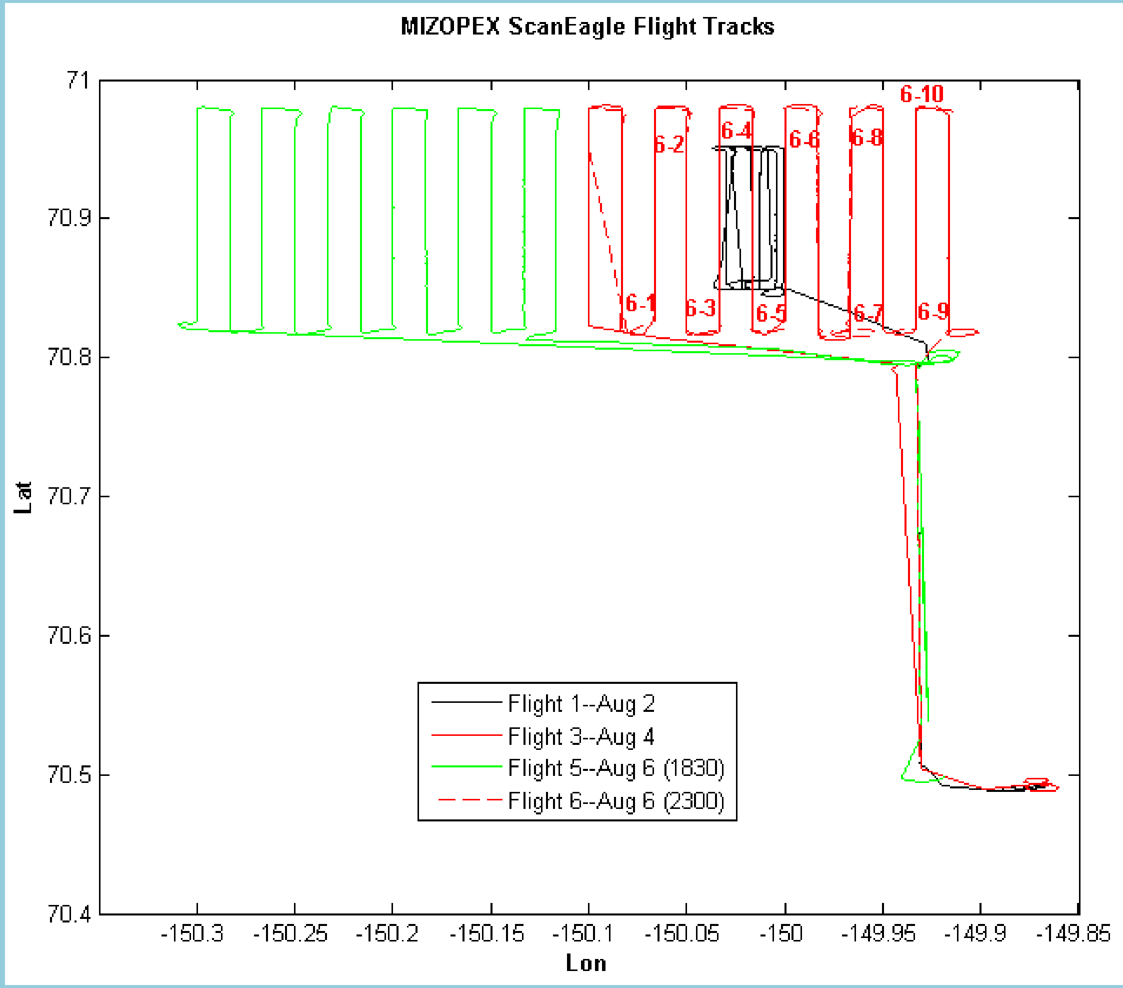
UAV Snapshot of Surface Ice/Ocean Variability



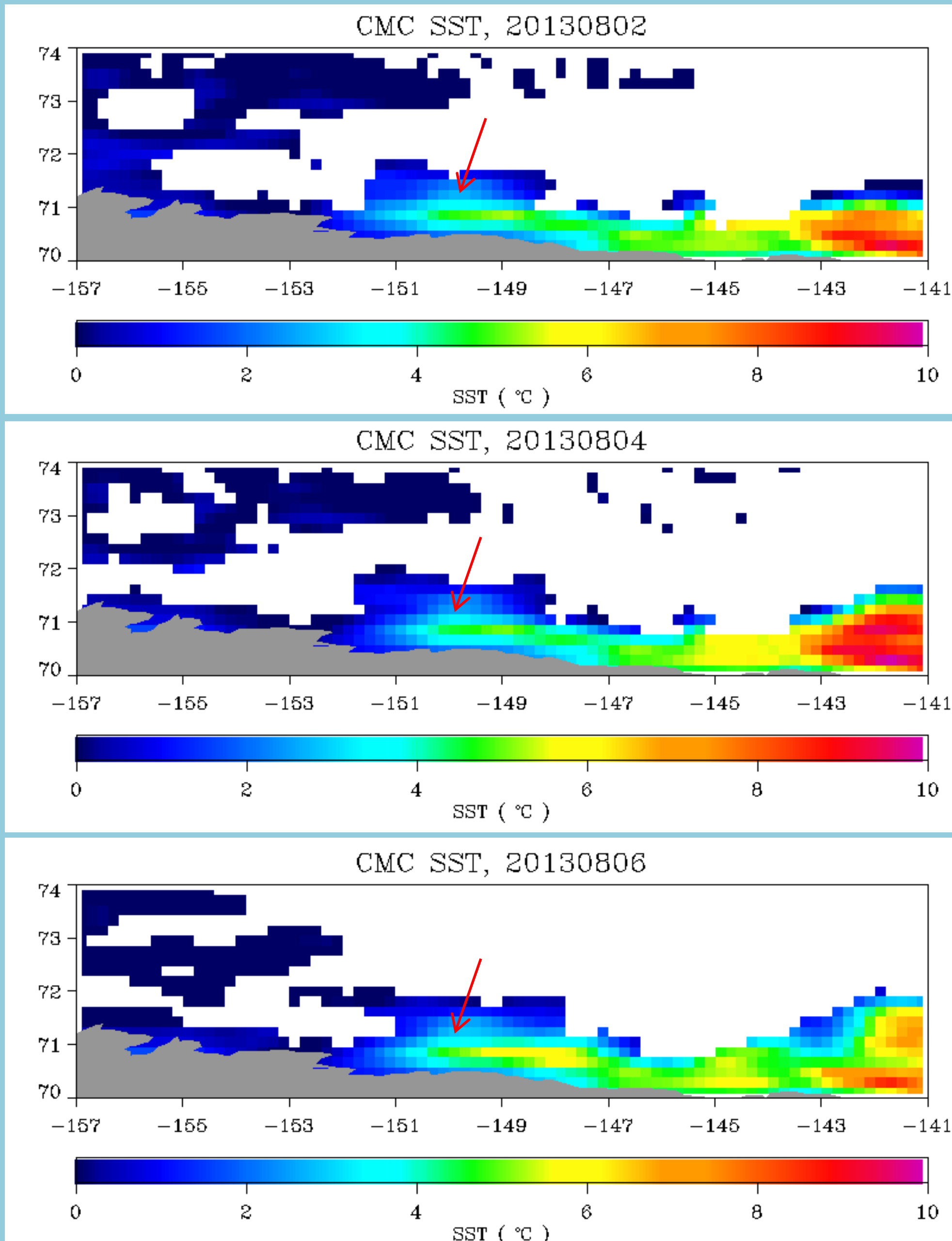
Scale of Visible Imagery (TOP) Sampled from Scan Eagle 130 m x 109 m (7.5 cm)
Scale of Infrared Imagery (BOTTOM) Sampled from Scan Eagle 110 m x 83 m (15 cm)

MIZ Transition Over Beaufort Sea





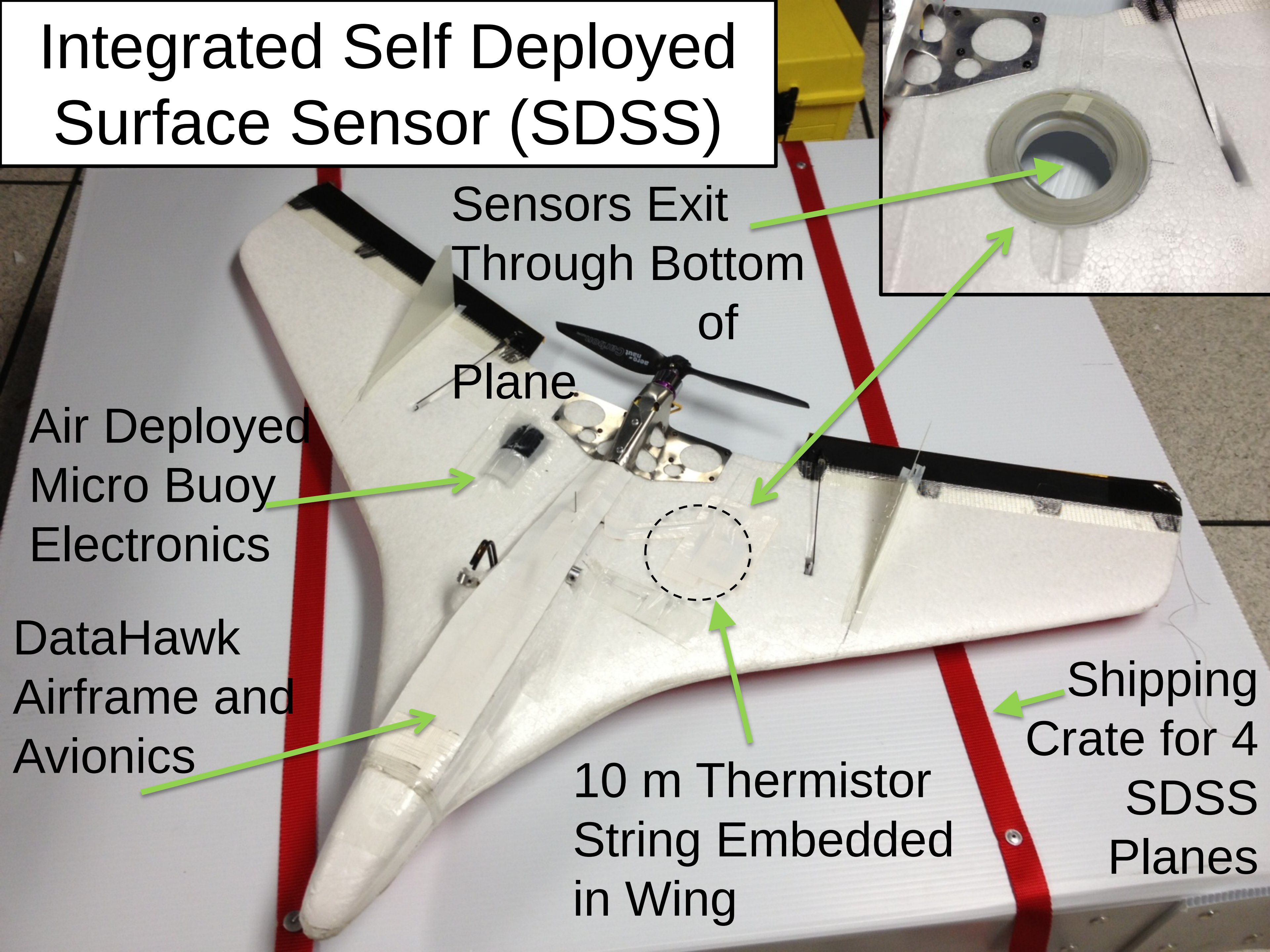
Satellite View of MIZ Transition



- Challenging region for SST satellite retrieval and cloud detection. Are satellite products consistent with the multiple finer scale measurements of MIZOPEX?

- Objective here to see if variability in the satellite SST fields is consistent with that observed in the airborne data as ice melts away (or if the satellite data is just too coarse to say anything).

Canadian Meteorological Center (CMC) SST analysis for the 2nd, 4th, and 6th at a coarse 0.2 deg resolution. The CMC analysis combines data from multiple sensors into a daily product, but at coarser resolution than possible from the highest resolution sensors.


Integrated Self Deployed Surface Sensor (SDSS)
Sensors Exit Through Bottom of Plane
Air Deployed Micro Buoy Electronics
DataHawk Airframe and Avionics
10 m Thermistor String Embedded in Wing
Shipping Crate for 4 SDSS Planes

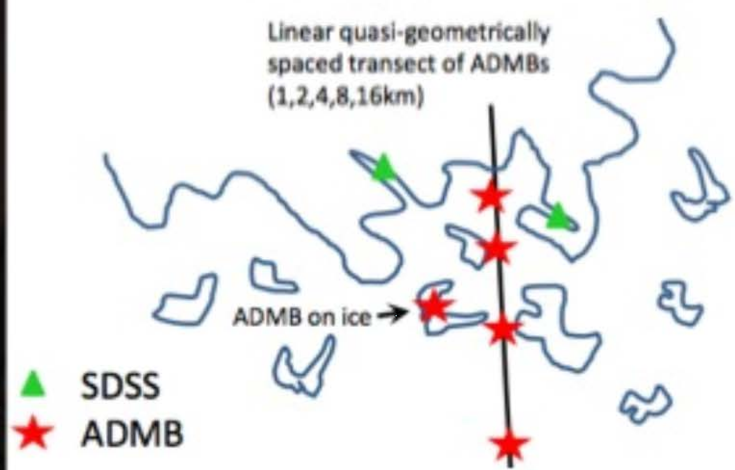
Air-Deployed Micro-Buoy (ADMB) air-dropped from ScanEagle & DataHawks configured as Self-Deployed Surface-Sensor (SDSS) (to be deployed over open water offshore)

ADMB Launcher in ScanEagle Payload Bay

ADMB with Thermistor String

SDSS Fleet

ADMB & SDSS Deployment Strategy



IcePod Instrumentation

- Optical Instruments
  - IR Camera
  - Pyrometer
  - High Res Vis Wave Camera
  - Scanning Laser
- Radar
  - Deep Ice
  - Shallow Ice [100m]
- Georeference
  - GPS
  - IMU