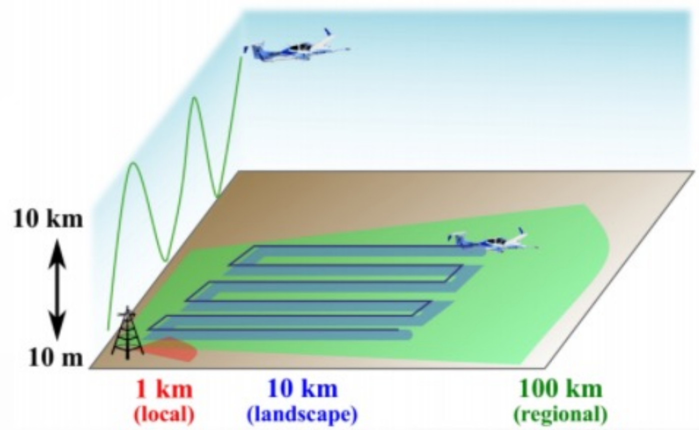
NSF-funded project:

# Bridging the scale gap between local and regional methane and carbon dioxide isotopic fluxes in the Arctic

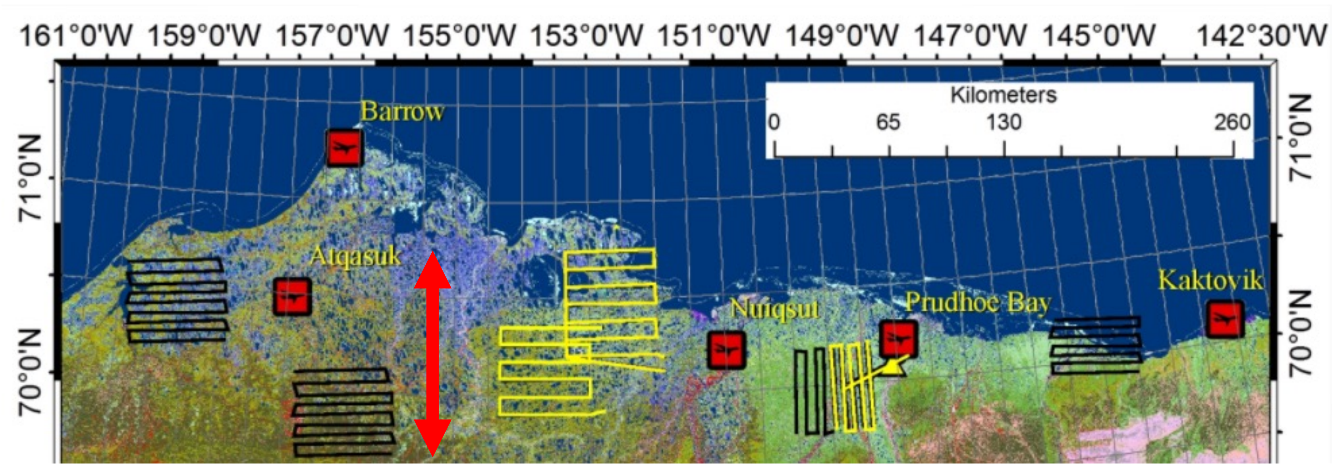
FOCAL 2:
Flux Observations of Carbon from an Airborne Laboratory

Harvard PIs – Jim Anderson and Steve Wofsy
**Columbia PI – Róisín Commane**
**Luke Schiferl and Ludda Ludwig**
ORAU & NOAA/ATDD PI – Praveena Krishnan
Aurora Flight Sciences PI – Gil Crouse
Mission Scientist – David Sayres




Airborne and ground-based eddy flux of $CO_2$ and $CH_4$ and isotopes

# Integrate aircraft carbon flux measurements into modeling/analysis framework




Explore flux differences along wetness gradients

Additional flux and ecosystem behavior data outside of single point site locations

2021-2022:
Instrument development
Refine modeling framework
Test with 2013 data

Spring 2023:
Flight planning
Test flights Wallops, VA

**August-September 2023:**
**Science flights**
**Prudhoe Bay, AK**

# Physical Volcanology from UAS

Einat Lev, Lamont Research Professor, LDEO Columbia University

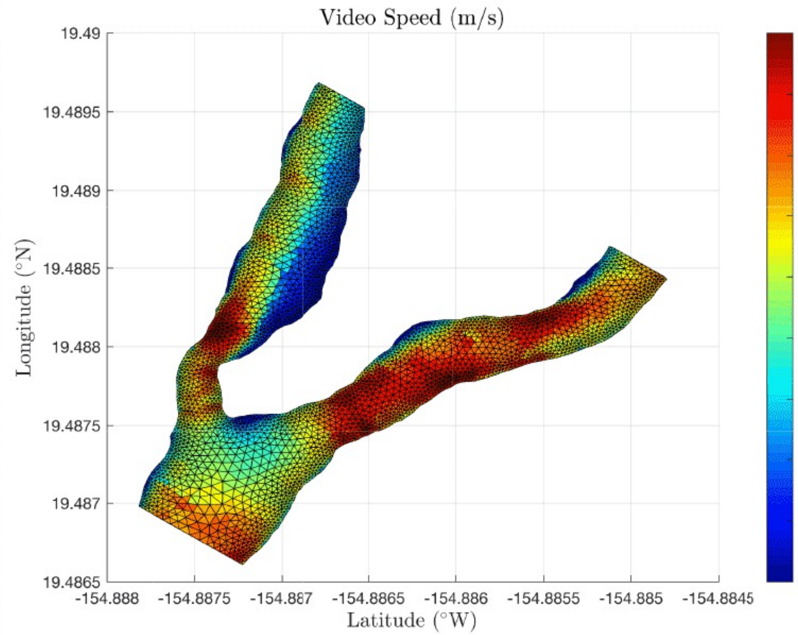
*The physical volcanology group at LDEO uses UAS with visible and thermal cameras, as well as gas sensors, to study volcanic eruptions in real time. They capture images to construct digital elevation models using photogrammetry, and videos of flowing lava to measure effusion rates and infer magma rheology. Gas samples help identify changes in the magma before and during an eruption.*

<u>Anticipating Volcanic Eruptions in Real-Time (AVERT)</u>: The researchers will monitor two volcanoes in Alaska in real-time to identify early warning signals and to develop an array of instruments that could be deployed worldwide for better eruption forecasting.
https://avert.ldeo.columbia.edu/

*Pictures from Iceland and the Galapagos Islands.*

# Physical Volcanology from UAS

Einat Lev, Lamont Research Professor, LDEO Columbia University




*(Left) Zoomed in view of the section of the braided channel system established by Fissure 8 modeled in this work, near UAS site 8 (See Fig. 1). UAS photo by Ryan Perroy, University of Hawai'i-Hilo. (Right) Map view of the lava surface velocity measured using Optical Flow from videos captured by UAS on 22 June 2018. Colors represent magnitude in m/s. Also shown is the finite-element mesh used to evaluate the model.*

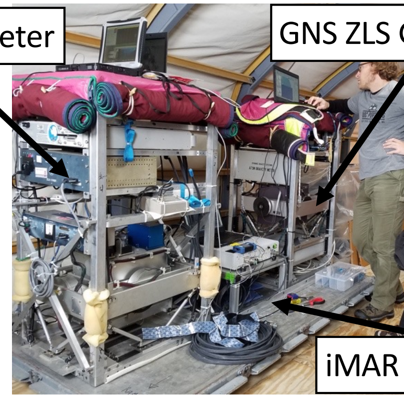
# High-resolution gravity on ever-smaller platforms

**Kirsty Tinto, Lamont Associate Research Professor, LDEO Columbia University**

IcePod and LC130

DgS Gravimeter

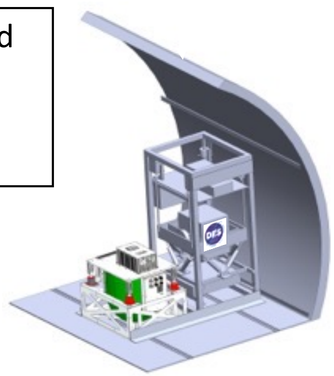
GNS ZLS Gravimeter

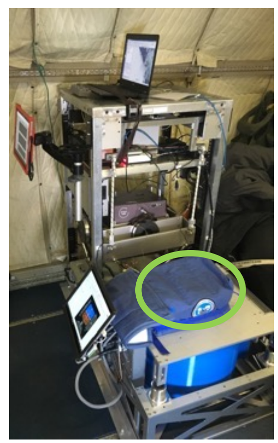


iMAR RQH IMU

Loading gravity pallet

Hybrid stabilized platform (DgS) and strapdown system



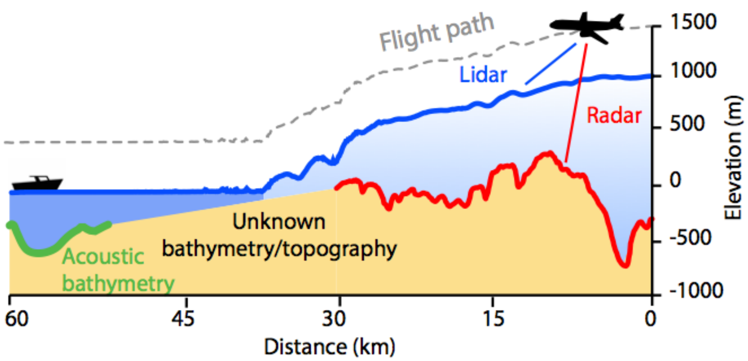


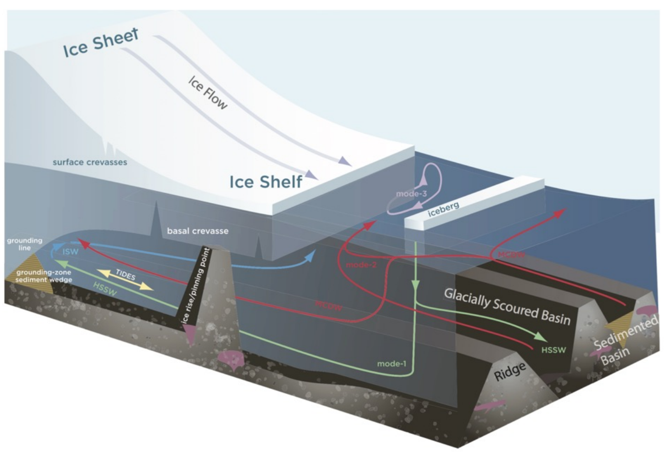
<10 kg standalone strapdown

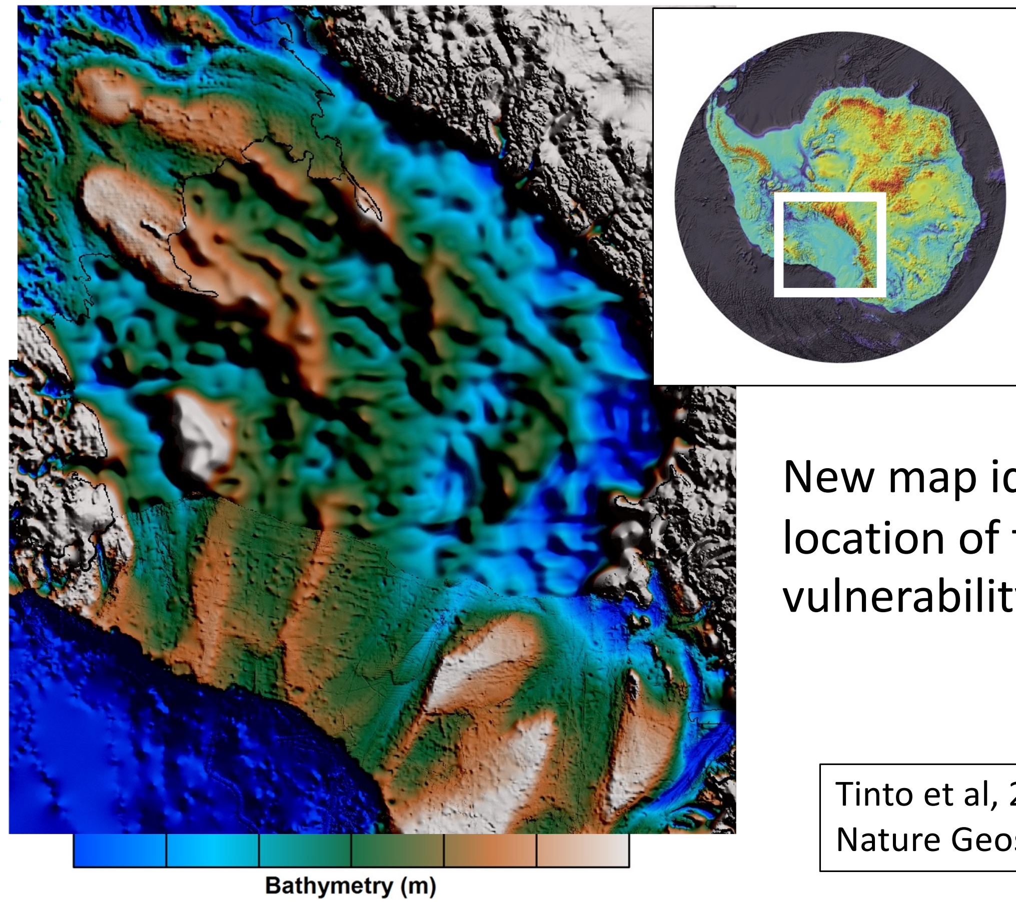
UAV

LDEO has been conducting aero gravity surveys that can fit on smaller and smaller platforms - from a pallet of multiple instruments on the LC130 to just the 10 kg standalone imar that could (but hasn't yet) deploy on a UAV

# New, gravity-based bathymetry of Ross Ice Shelf, Antarctica




New map identifies location of future vulnerability

Tinto et al, 2019, Nature Geoscience

IcePod group used the system to map the Ross Ice Shelf and develop a new, 10 km resolution bathymetry map that allowed ocean simulations that identified vulnerability of ice shelf (Tinto 2019)

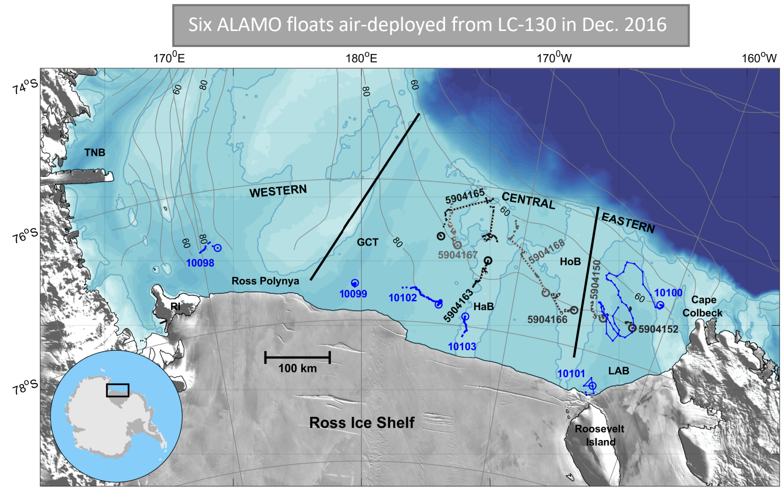
# Autonomous profiling floats in the Ross Sea

On the same surveys we air-deployed ocean profiling floats and identified substantial freshwater fluxes from Ross and Amundsen Seas (Porter 2019)

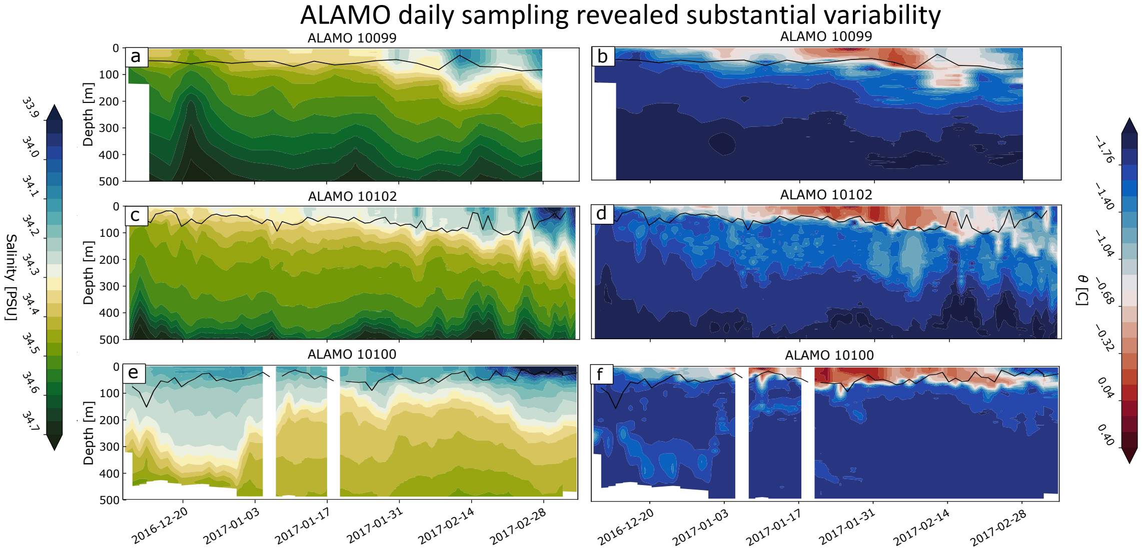
- First aircraft deployments of profiling floats near an ice shelf front document heat and freshwater evolution in spring and summer

- Multi-year time series of Ross Sea upper-ocean hydrography under sea ice reveal annual cycle and interannual variability

- Summer upper-ocean freshwater budgets require substantial lateral fluxes of ice melt from the Amundsen Sea and Ross Ice Shelf



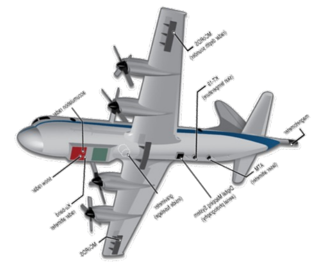

ALAMO daily sampling revealed substantial variability




David F. Porter, Scott R. Springer, Laurie Padman, Helen A. Fricker, Kirsty J. Tinto, Stephen C. Riser, Robin E. Bell, and the ROSETTA-Ice Team, Evolution of the seasonal surface mixed layer of the Ross Sea, Antarctica, observed with autonomous profiling floats, *2019 JGR-Oceans*.

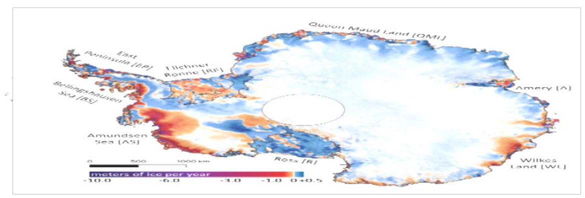
# SCAR (Scientific Committee on Antarctic Research) RINGS action group co-ordinating circumpolar surveys of Antarctic Coast

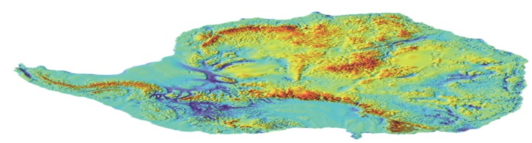
**Kirsty Tinto, Lamont Associate Research Professor, LDEO Columbia University**

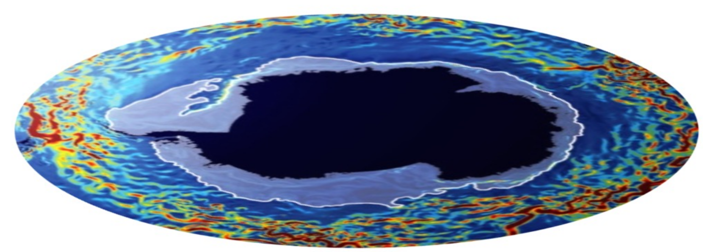


FUTURE PLANS - I'm on the steering committee fo this SCAR effort to coordinate international surveys of coastal Antarctic - needs a lot of coordinated air and ship work.

- Seasonal, annual and long term elevation trends
- Ice sheet stratigraphy for climate history and understanidng ice flow
- Bed topography for numerical models of ice and ocean
- Ocean properties
- Future vulnerabilities and rate of change



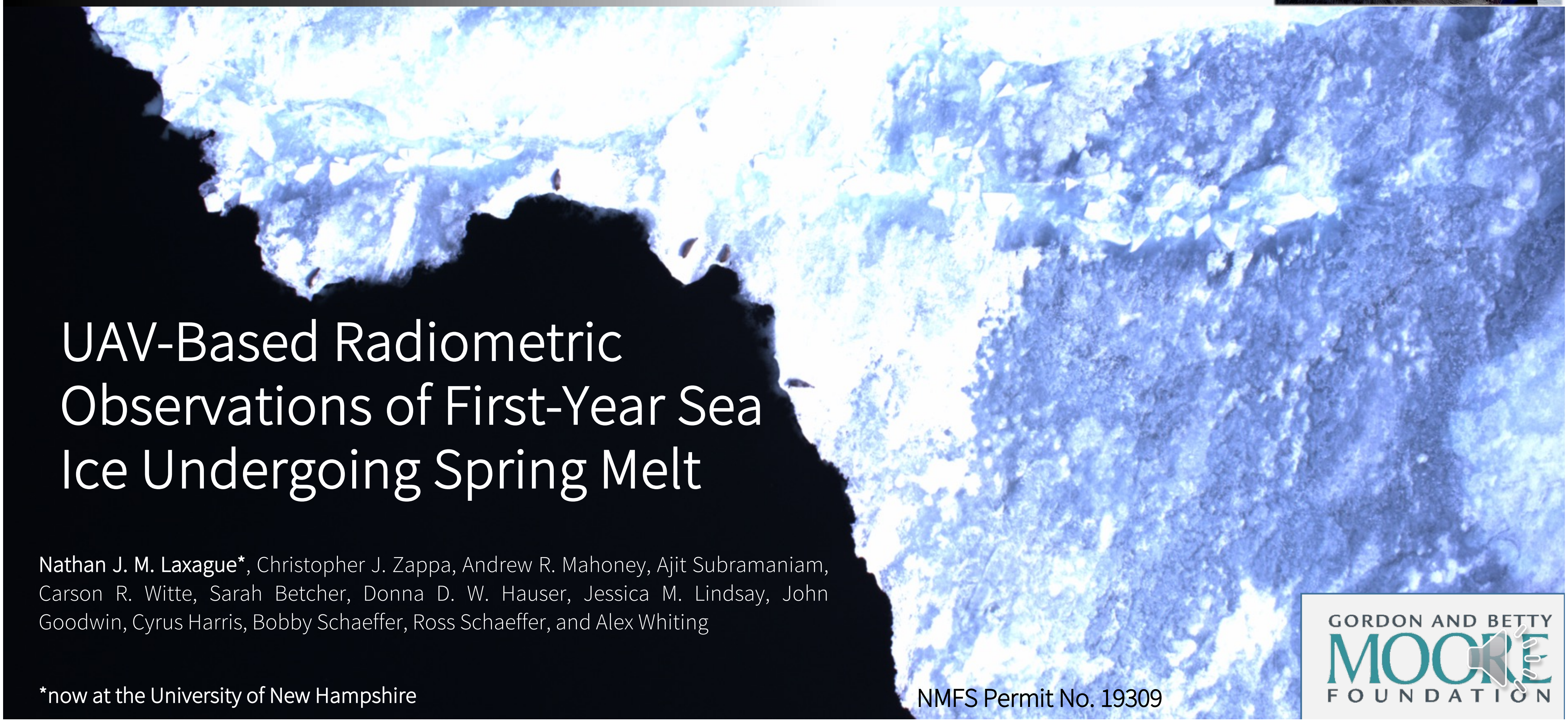




Columbia University
Lamont-Doherty Earth Observatory

UAF University of Alaska Fairbanks

Native Village of Kotzebue
Kotzebue IRA

# UAV-Based Radiometric Observations of First-Year Sea Ice Undergoing Spring Melt

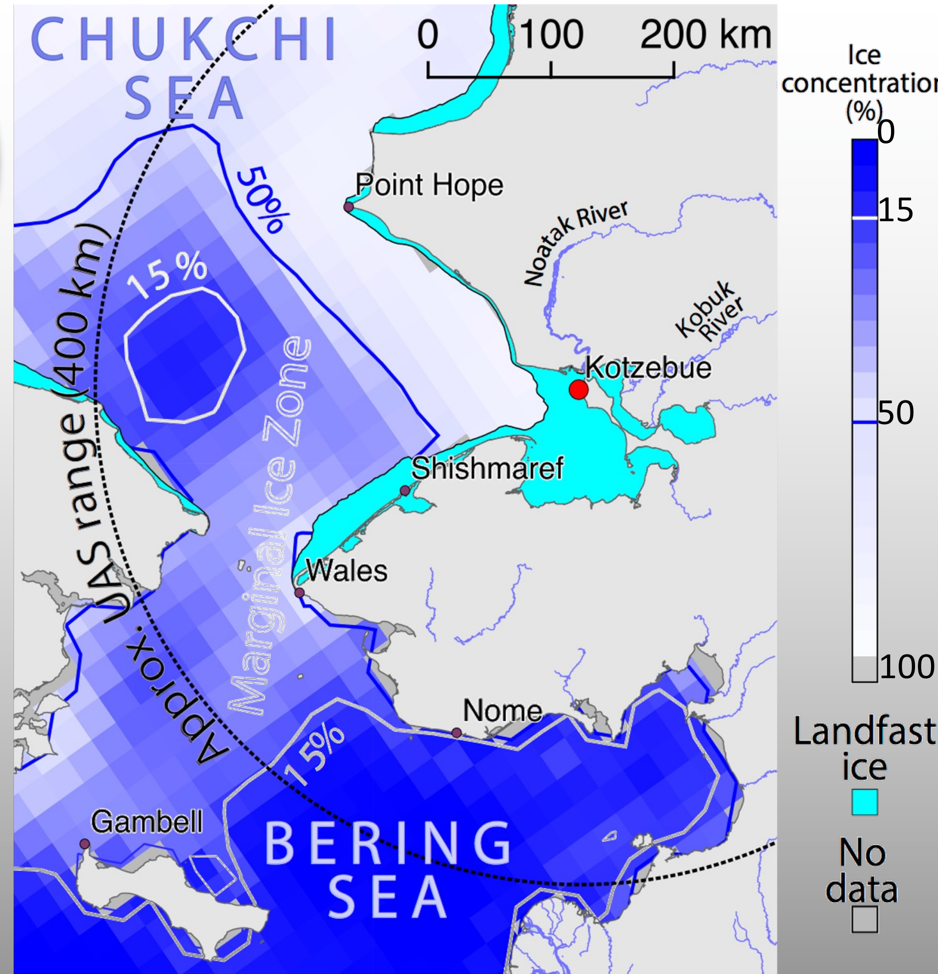
**Nathan J. M. Laxague***, Christopher J. Zappa, Andrew R. Mahoney, Ajit Subramaniam, Carson R. Witte, Sarah Betcher, Donna D. W. Hauser, Jessica M. Lindsay, John Goodwin, Cyrus Harris, Bobby Schaeffer, Ross Schaeffer, and Alex Whiting

*now at the University of New Hampshire

NMFS Permit No. 19309

Gordon and Betty Moore Foundation

# 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

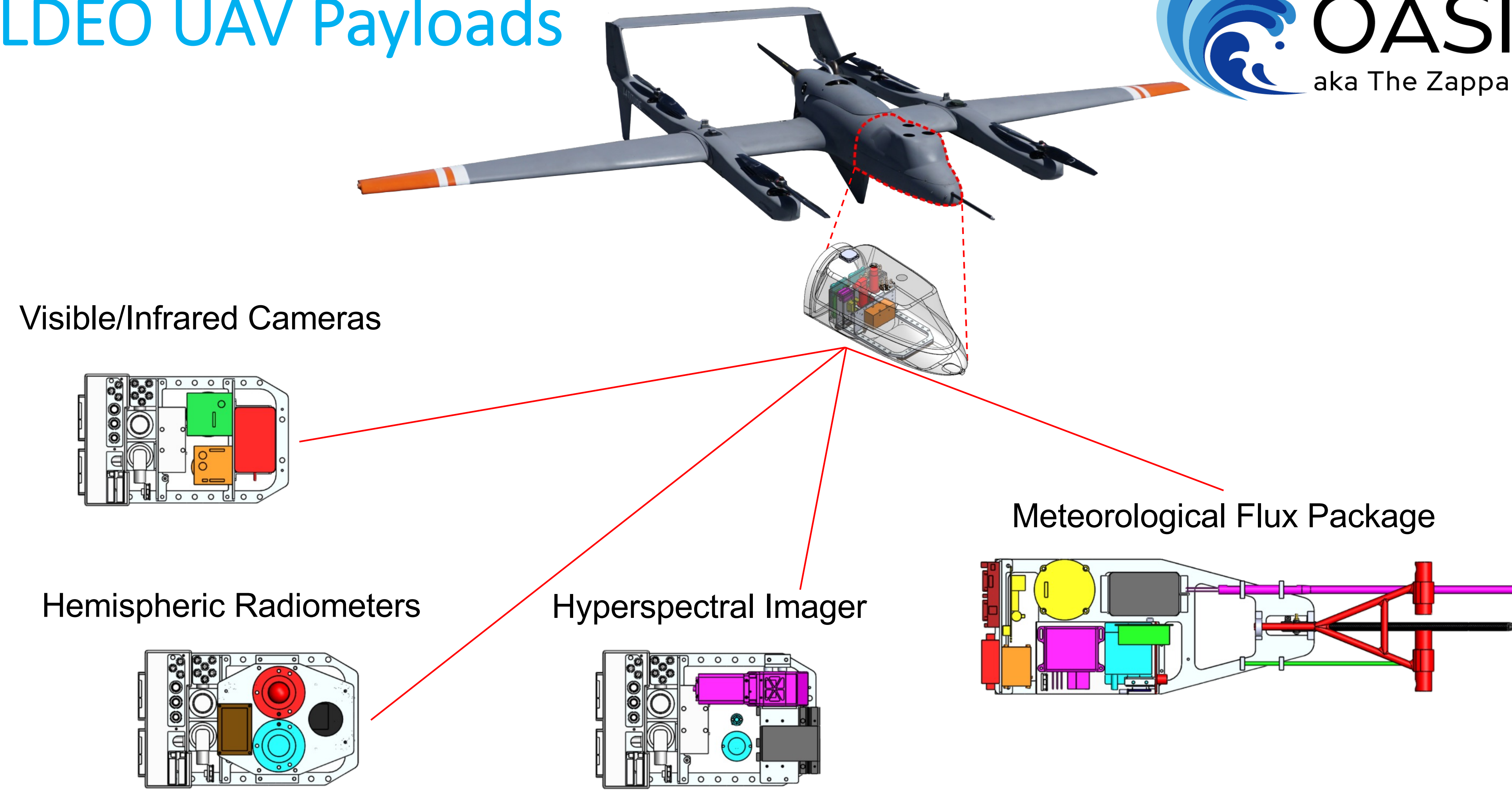
- Important migration corridor for seabirds and marine mammals
- Extensive loss of sea ice coverage in recent years

# UAS in Kotzebue

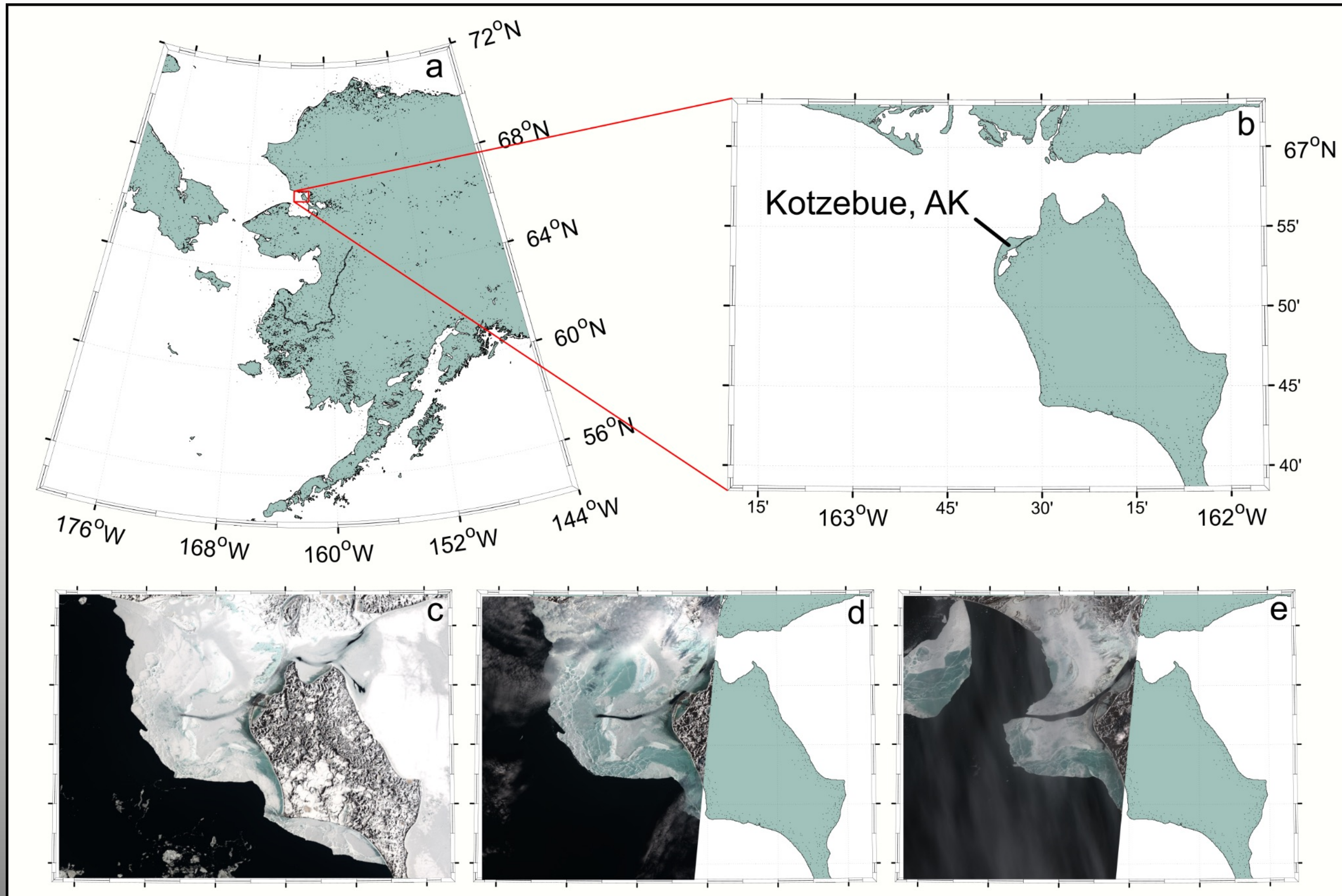

GORDON AND BETTY MOORE FOUNDATION

# LDEO UAV Payloads

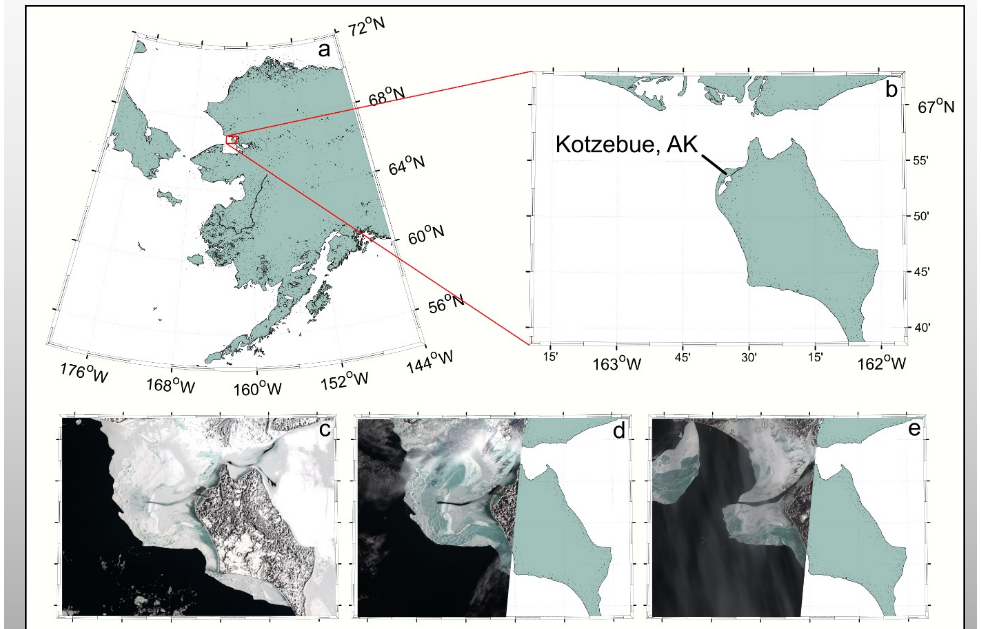
OASIS
aka The Zappa Lab

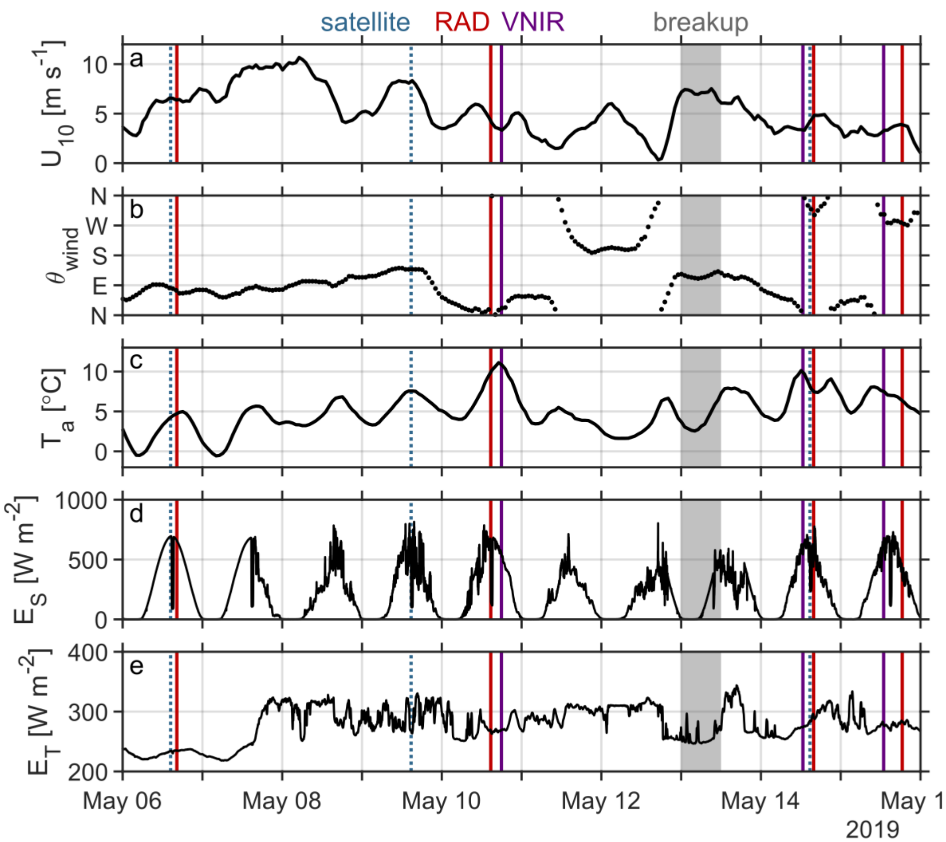


# Spring Melt Season Event

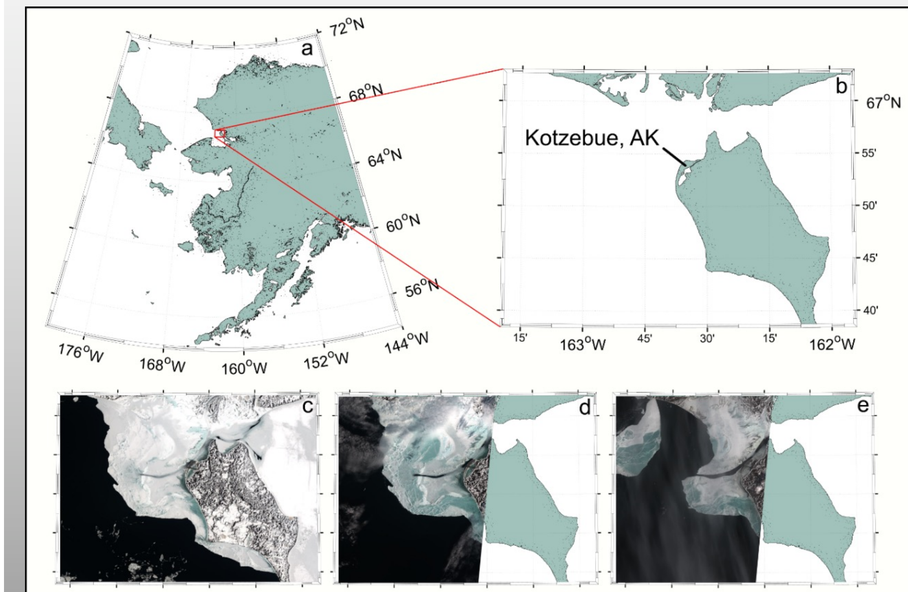


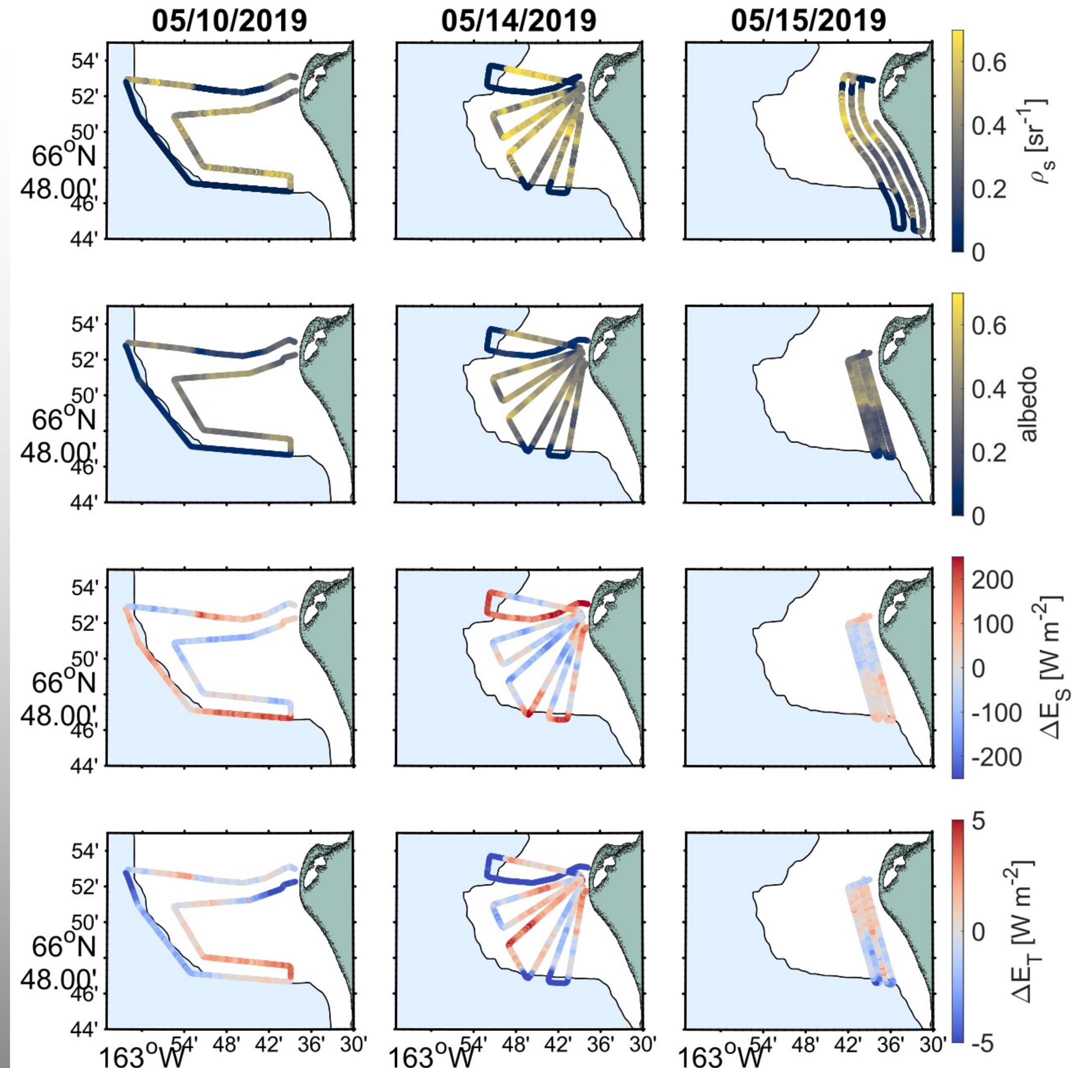
# Spring Melt Season Event



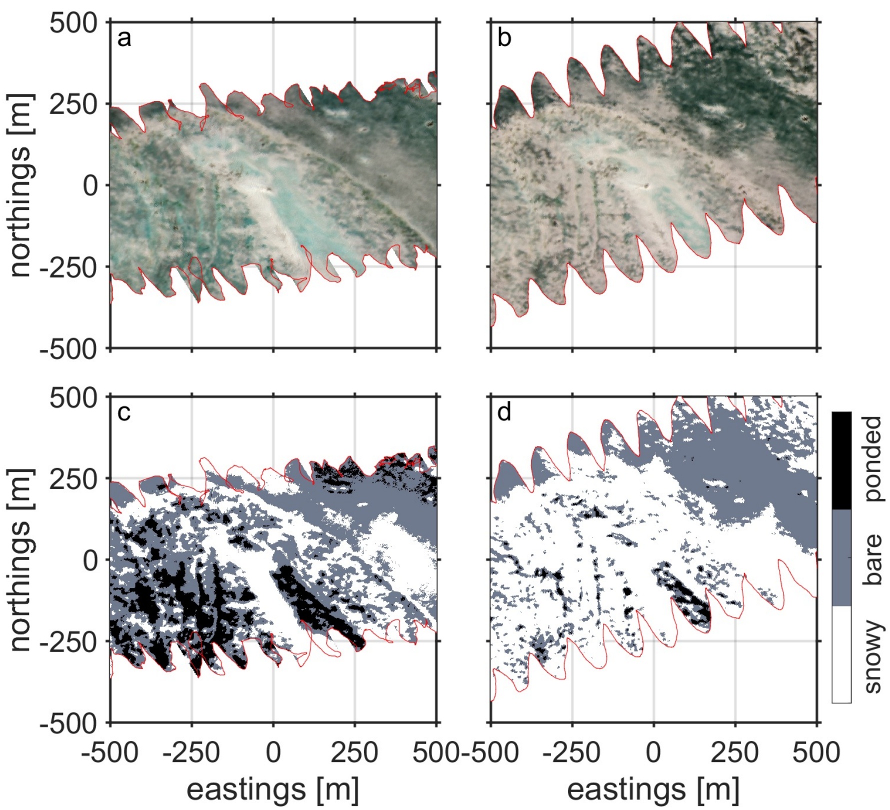



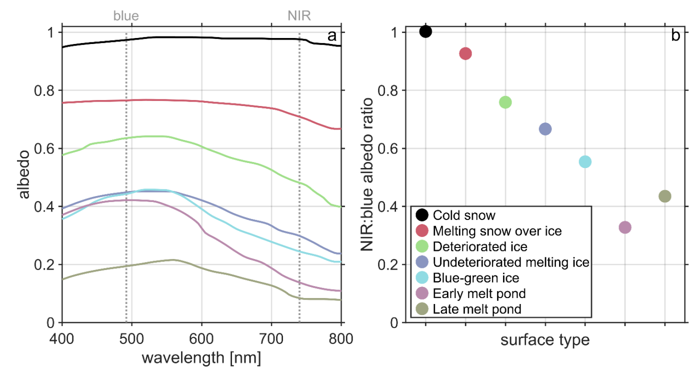
# Spring Melt Season Event

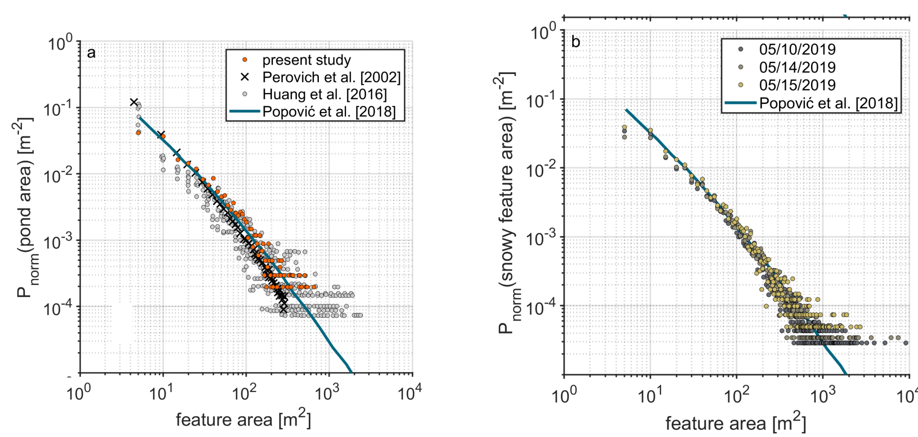


# Melt Pond Distributions via UAV



# *Natchiq* – Ringed seal

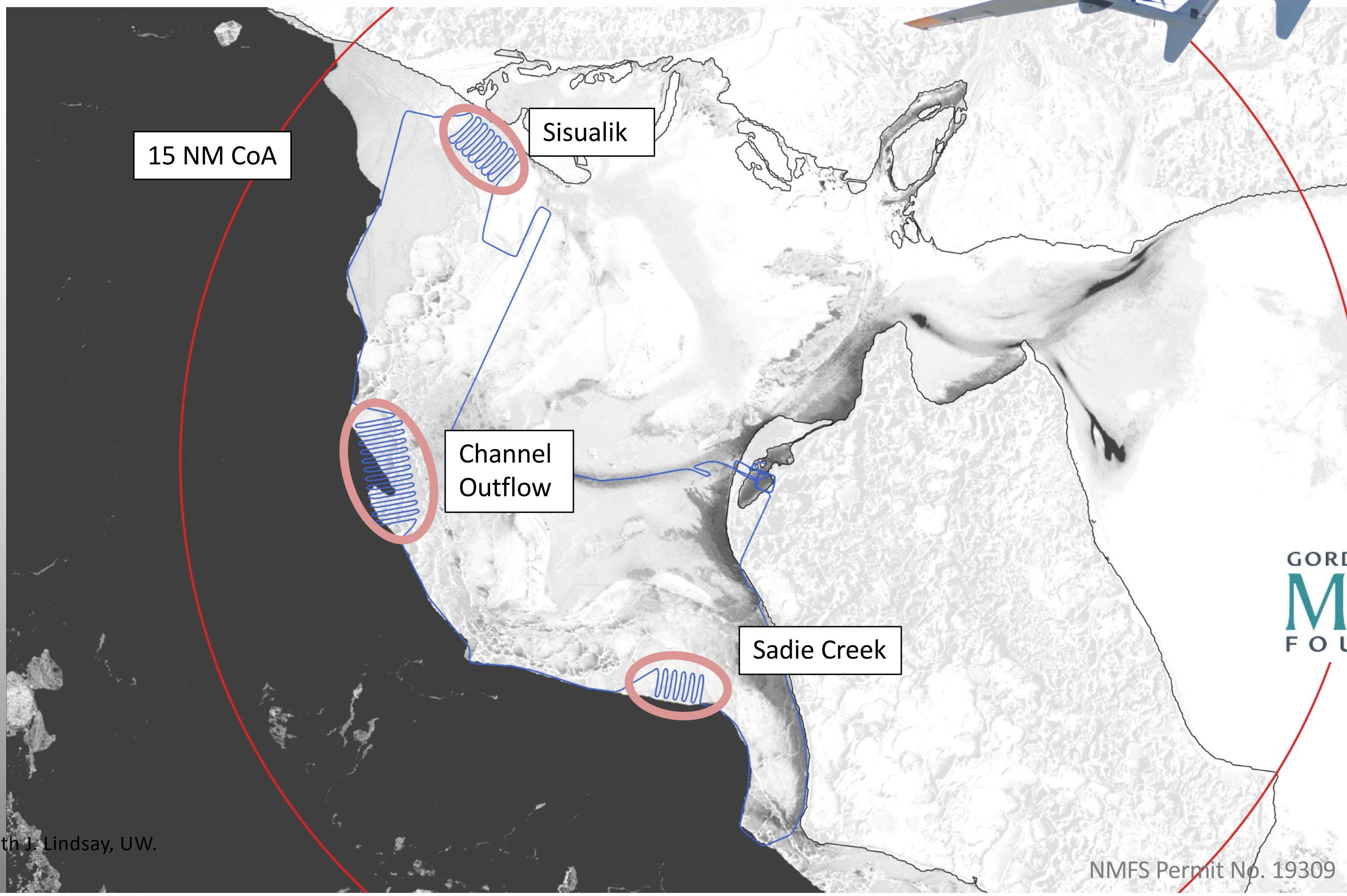
What snow and ice surface properties promote ringed seal denning and pupping?

NMFS Permit No. 19309

Aqqalu Rosing-Asvid, Greenland Institute of Natural Resources

Collaboration with J. Lindsay, UW.

# Aerial surveys with the UA

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Collaboration with J. Lindsay, UW.

# Detecting seals


Collaboration with J. Lindsay, UW.

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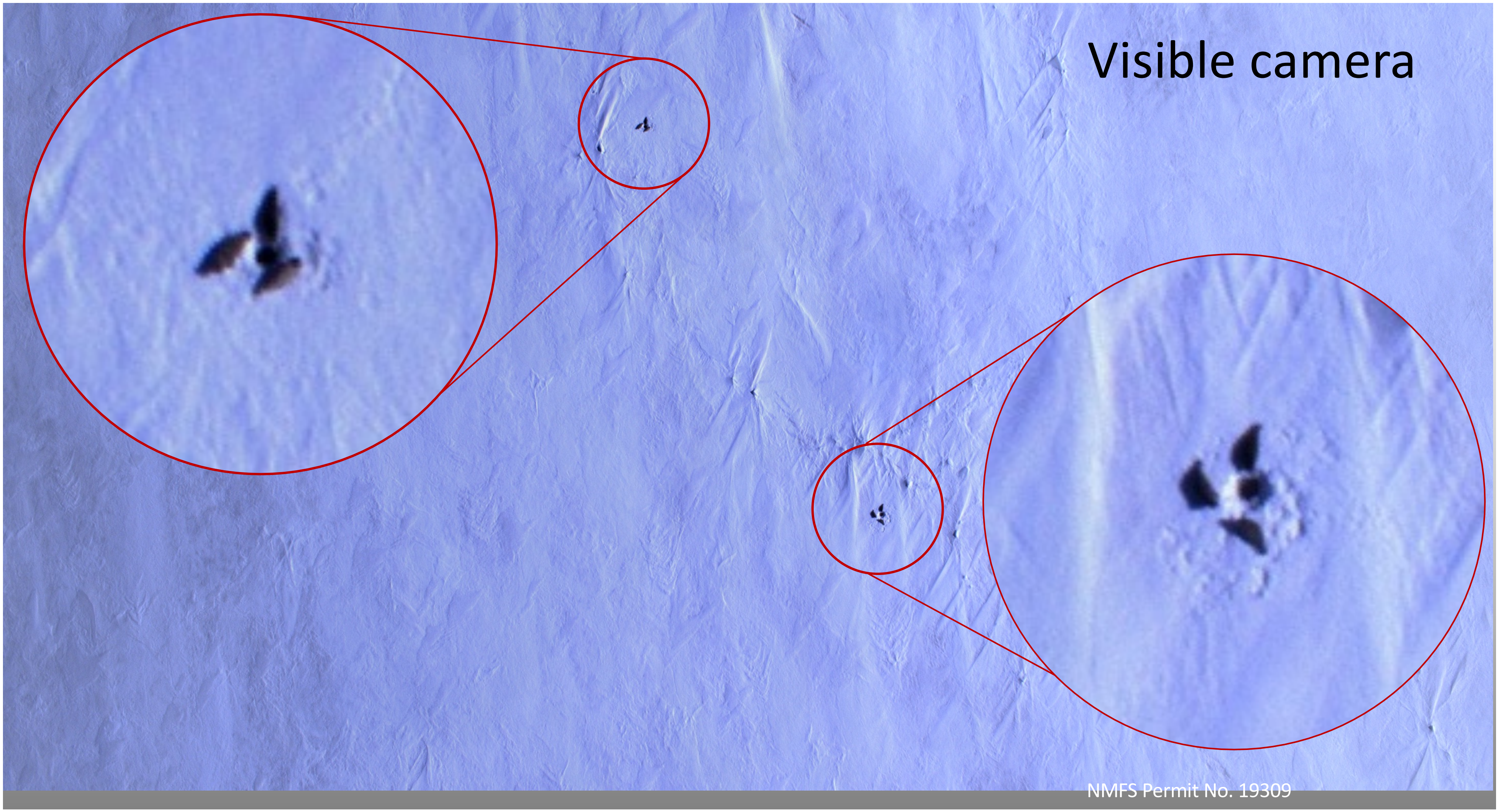
Thermal camera


Visible camera
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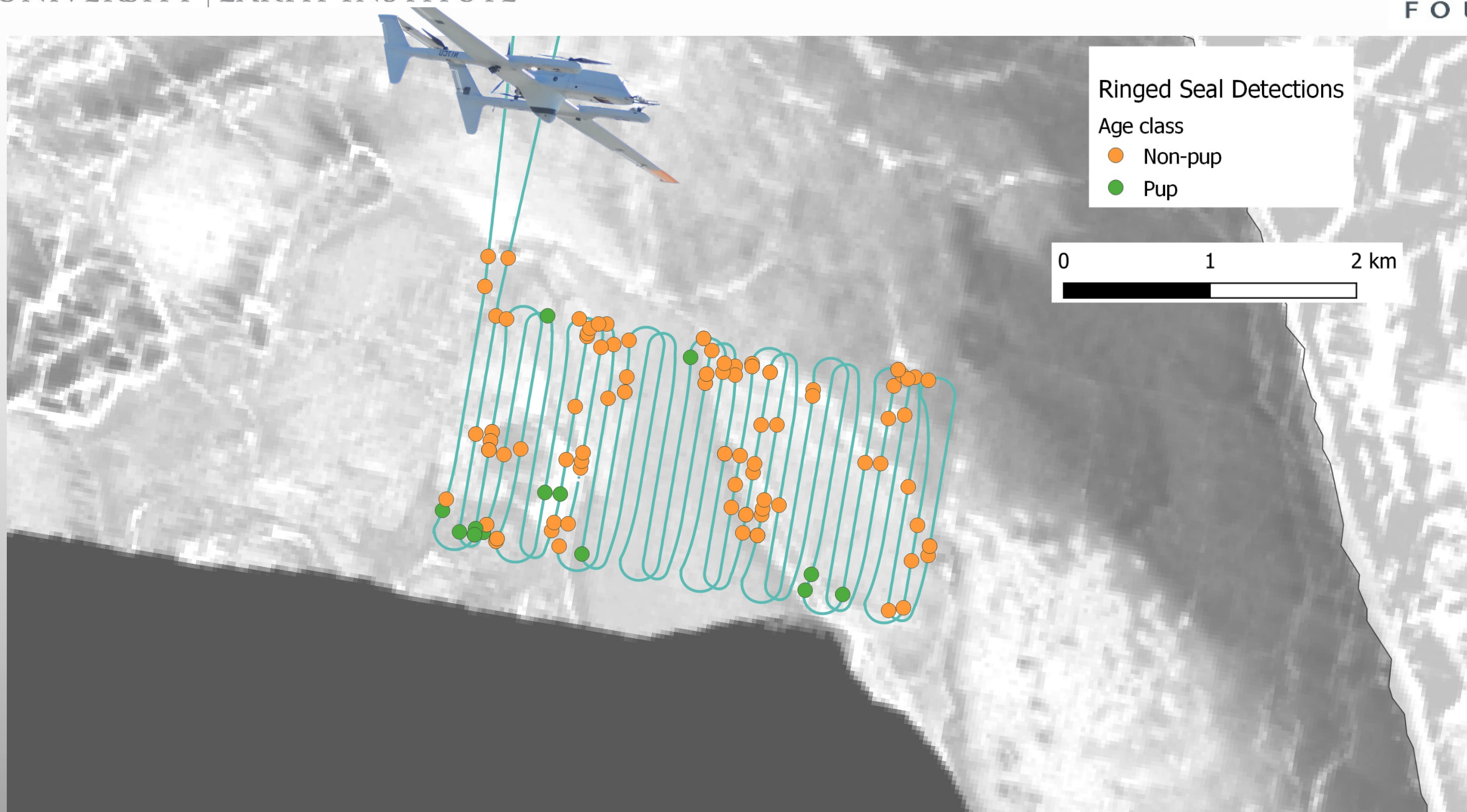
Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

GORDON AND BETTY MOORE FOUNDATION




Collaboration with J. Lindsay, UW.

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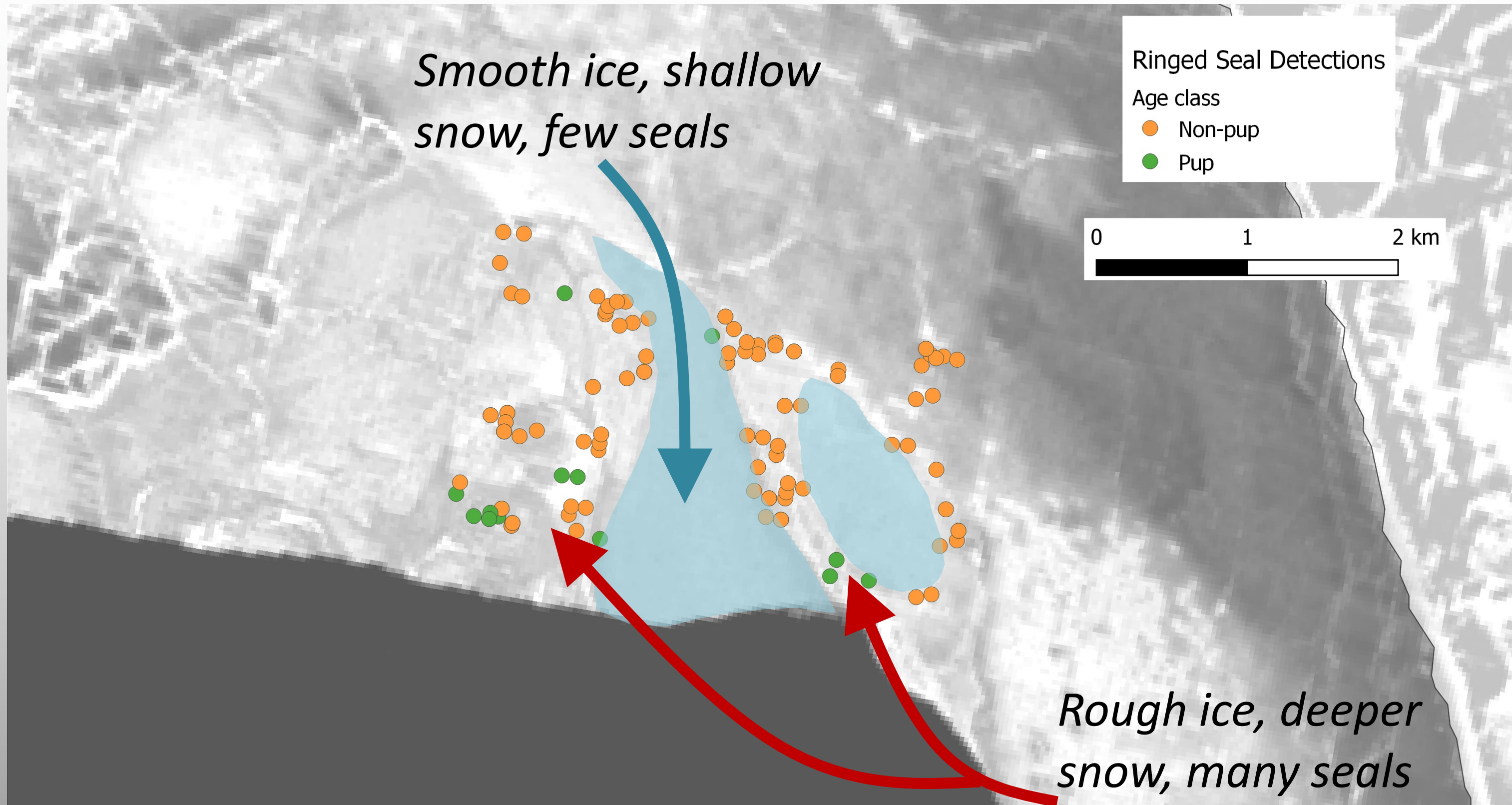


Collaboration with J. Lindsay, UW.

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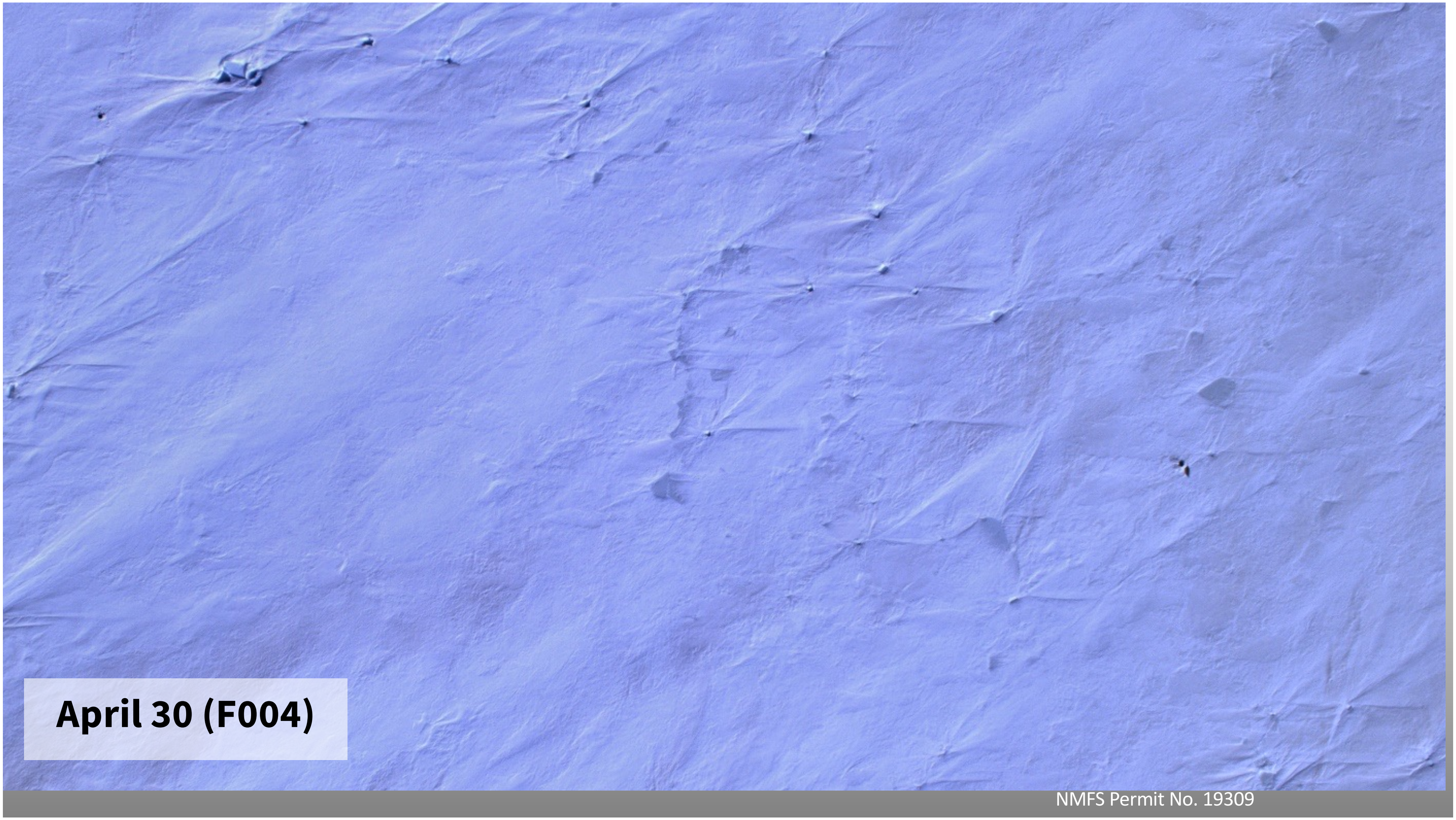
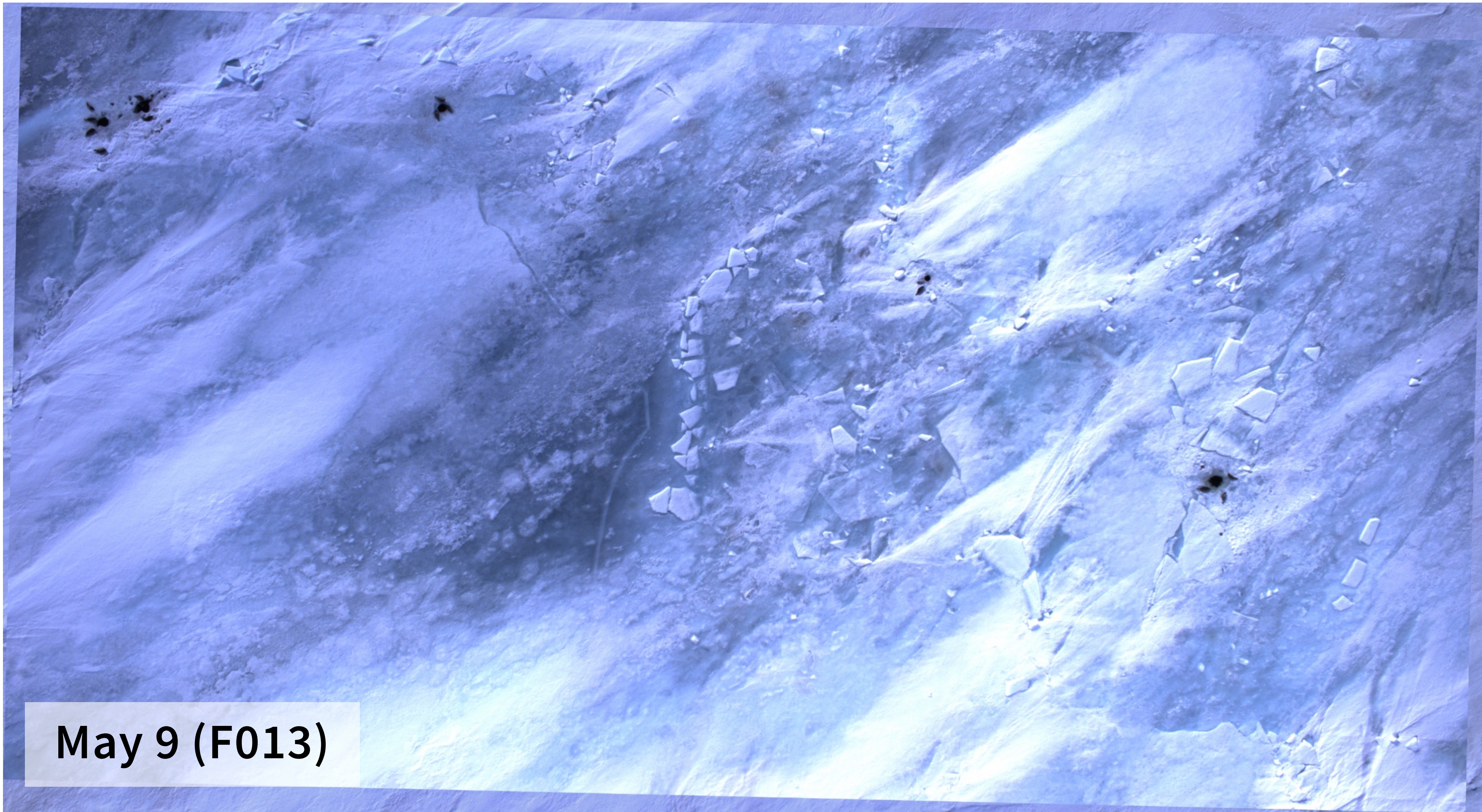
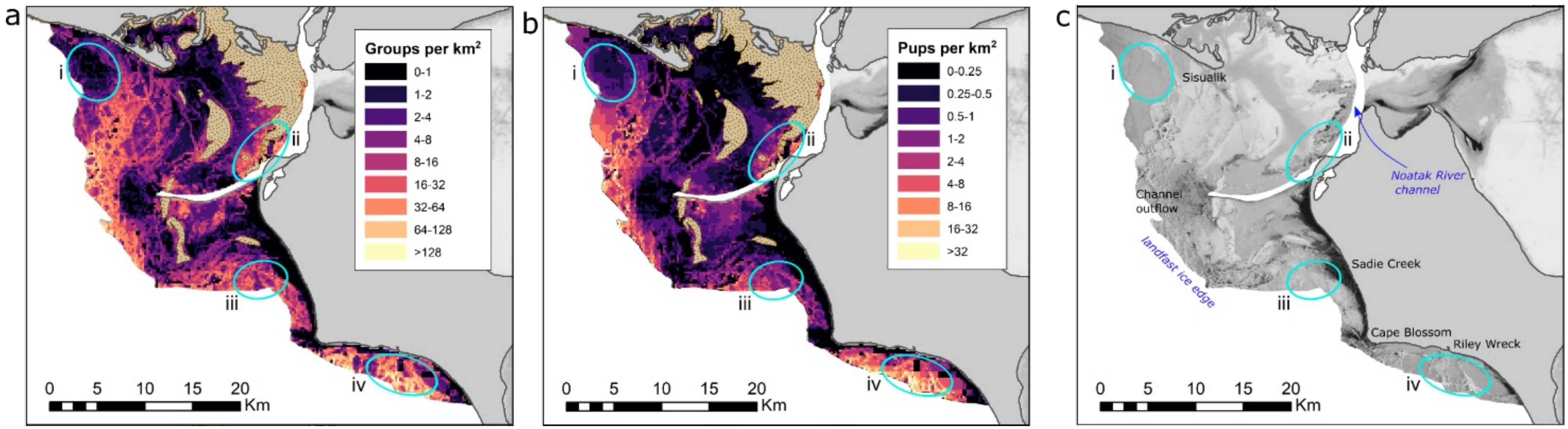

April 30 (F004)
NMFS Permit No. 19309



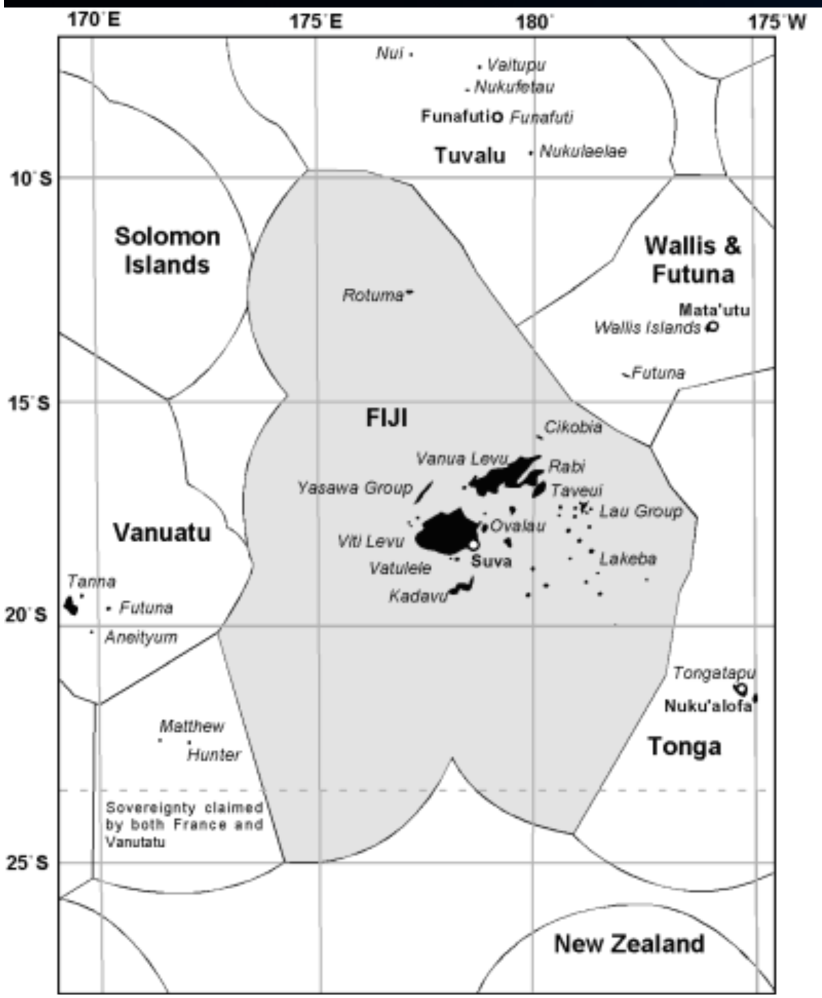

NMFS Permit No. 19309

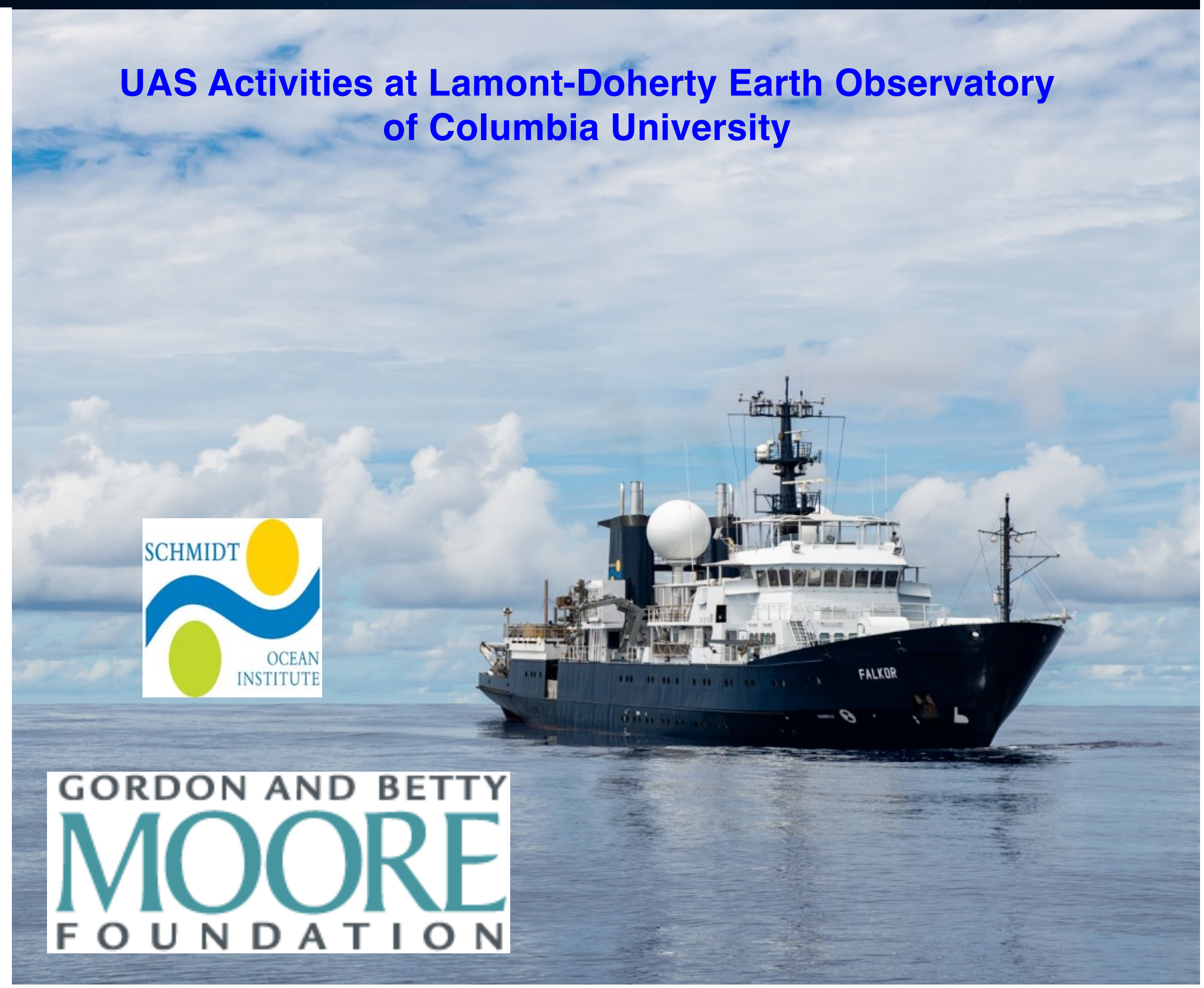
# Predictive Maps of Ringed Seals




- Predicted densities of a) groups of ringed seals and b) ringed seal pups produced by their respective best models. The brown stippled regions indicate sandbars inaccessible to ringed seals. c) Original Landsat 8 image for reference. Circled locations i-iv correspond with areas highlighted by the Elder Advisory Council in the text.
- Submitted to MEPS: Lindsay et al., 2022, Characteristics of ringed seal (*natchiq, Pusa hispida*) denning habitat in Kotzebue Sound during a year of li.mited sea ice and snow

# Investigating Near-Surface Ocean Heating and Mixing Processes in the Presence of Surface Material



# LDEO UAV Capabilities from Ships

OASIS
aka The Zappa Lab

# LDEO Capabilities of UAS from Ships

OASIS
aka The Zappa Lab

- **Complete autonomous takeoff, flight and landing from ships**
- **Dual-UAV aircraft continuous flight operations.**
  - 3 aircraft utilized
- **42 Flights with Payloads (242 hours)**
  - MET, RAD, ATOM, VNIR payloads
- **High endurance flights for > 8-hours.**
- **Long-range capability (50+ nm) with high bandwidth data link** for **real-time mission control and tasking.**
- **Demonstrated 24-hour operations.**
- **Detect/See and Avoid system upgrade**


frontiers in Marine Science
TECHNOLOGY REPORT
published: 21 January 2020
doi: 10.3389/fmars.2019.00777

Check for updates

## Using Ship-Deployed High-Endurance Unmanned Aerial Vehicles for the Study of Ocean Surface and Atmospheric Boundary Layer Processes

*Christopher J. Zappa[1]*, Scott M. Brown[1], Nathan J. M. Laxague[1], Tejendra Dhakal[1], Ryan A. Harris[1], Aaron M. Farber[2] and Ajit Subramaniam[1]*

[1] Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, United States, [2] L3 Latitude, Tucson, AZ, United States

# R/V Falkor – November/December 2019

# R/V Falkor –November/December 2019

# UAS Mission Control on R/V Falkor

SCHMIDT OCEAN INSTITUTE

# UAS from Ships (Latitude HQ-90B)

# Everything Out of the Water


SCHMIDT
OCEAN
INSTITUTE

# Everything Back in the Water


SCHMIDT
OCEAN
INSTITUTE

# UAS from Ships (Latitude HQ-90B)

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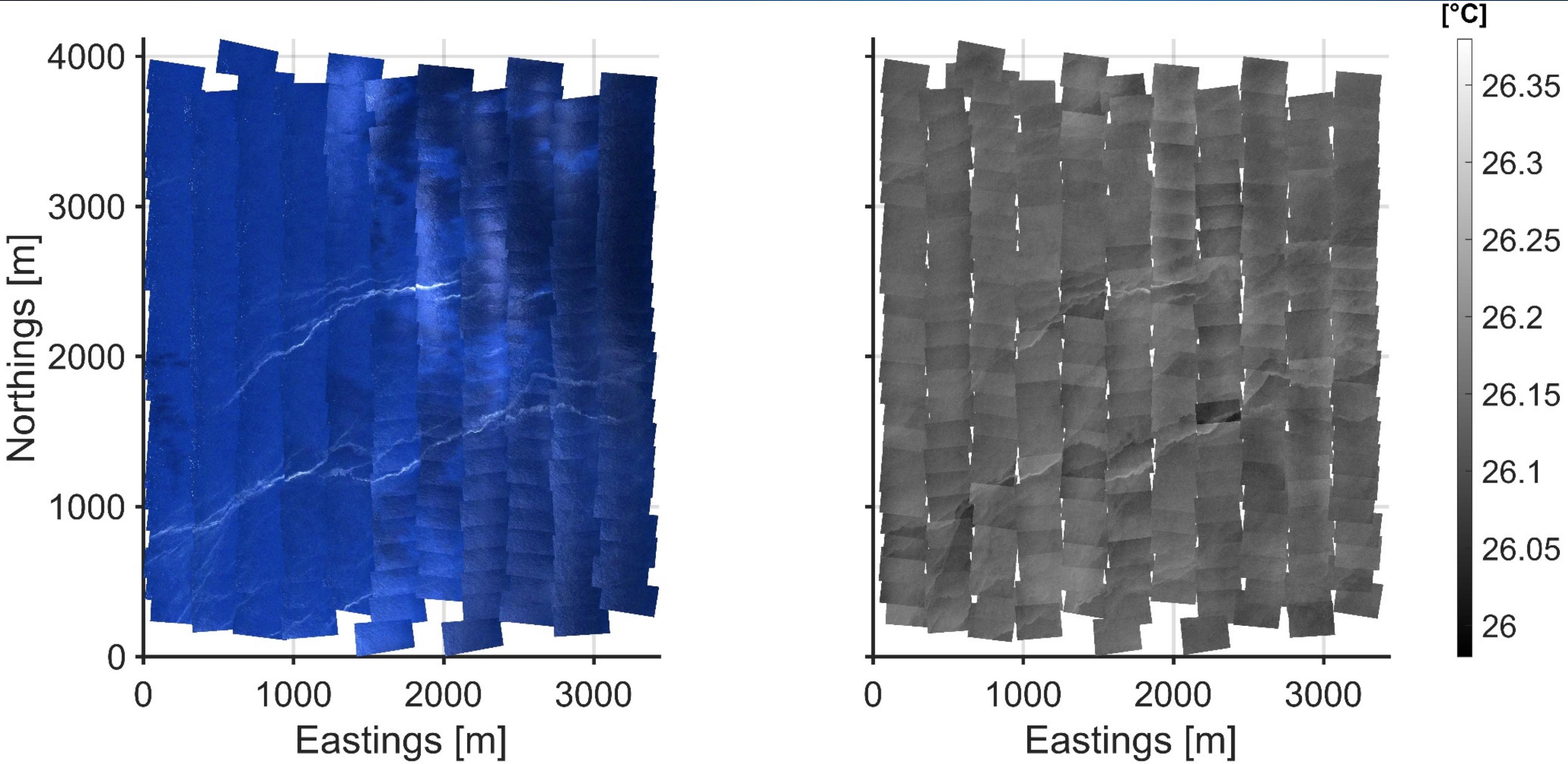
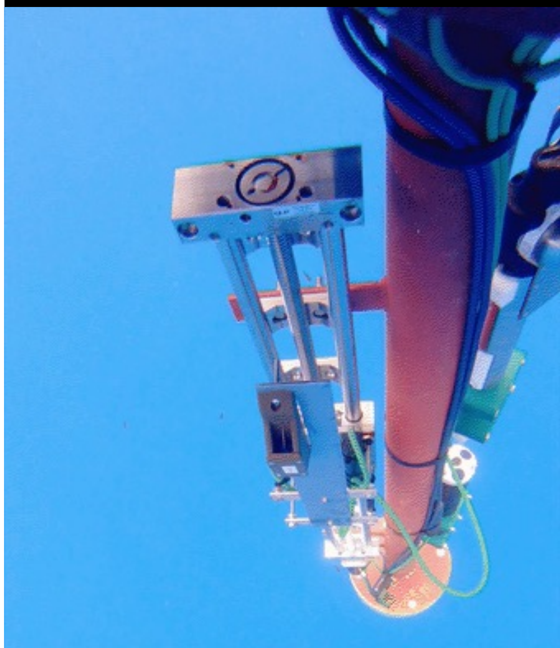
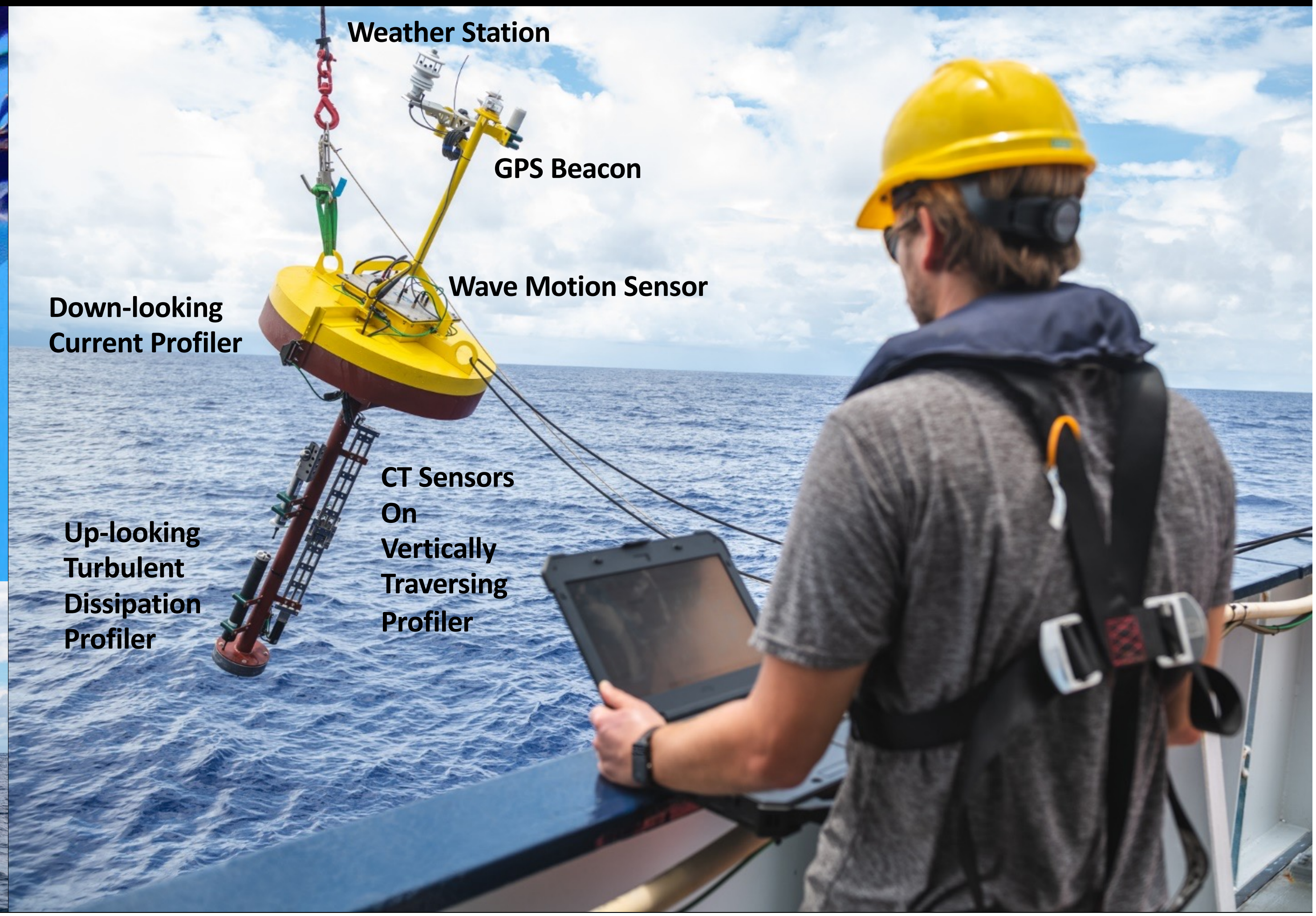
# Observing Cyanobacteria Streaks in Infrared and Visible

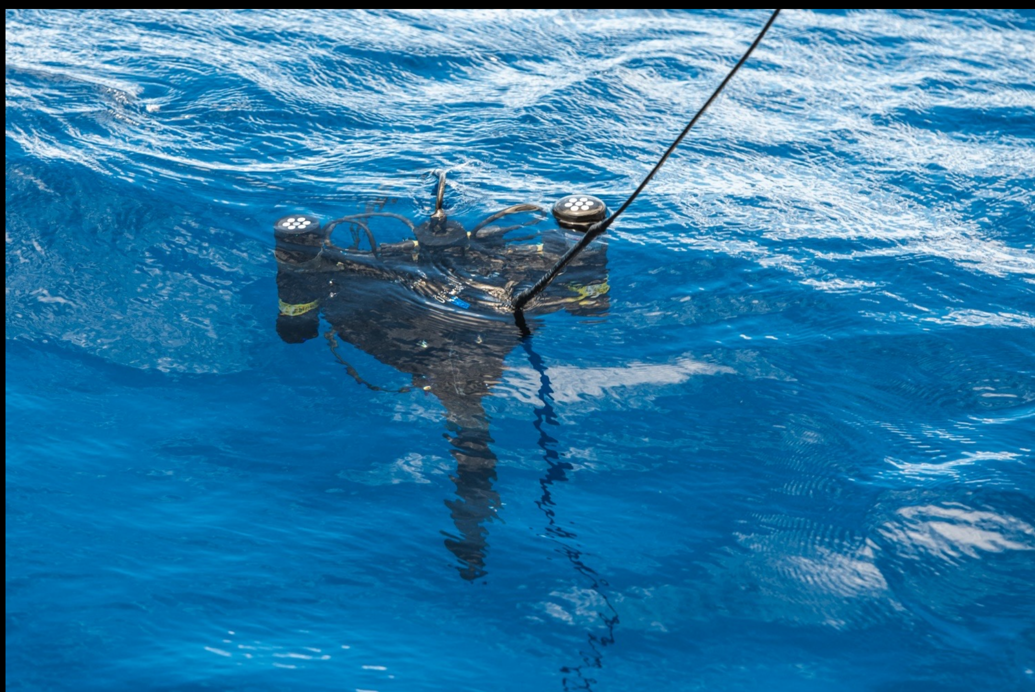


# SPIP-2: Surface Processes Instrument Platform (2nd Gen)

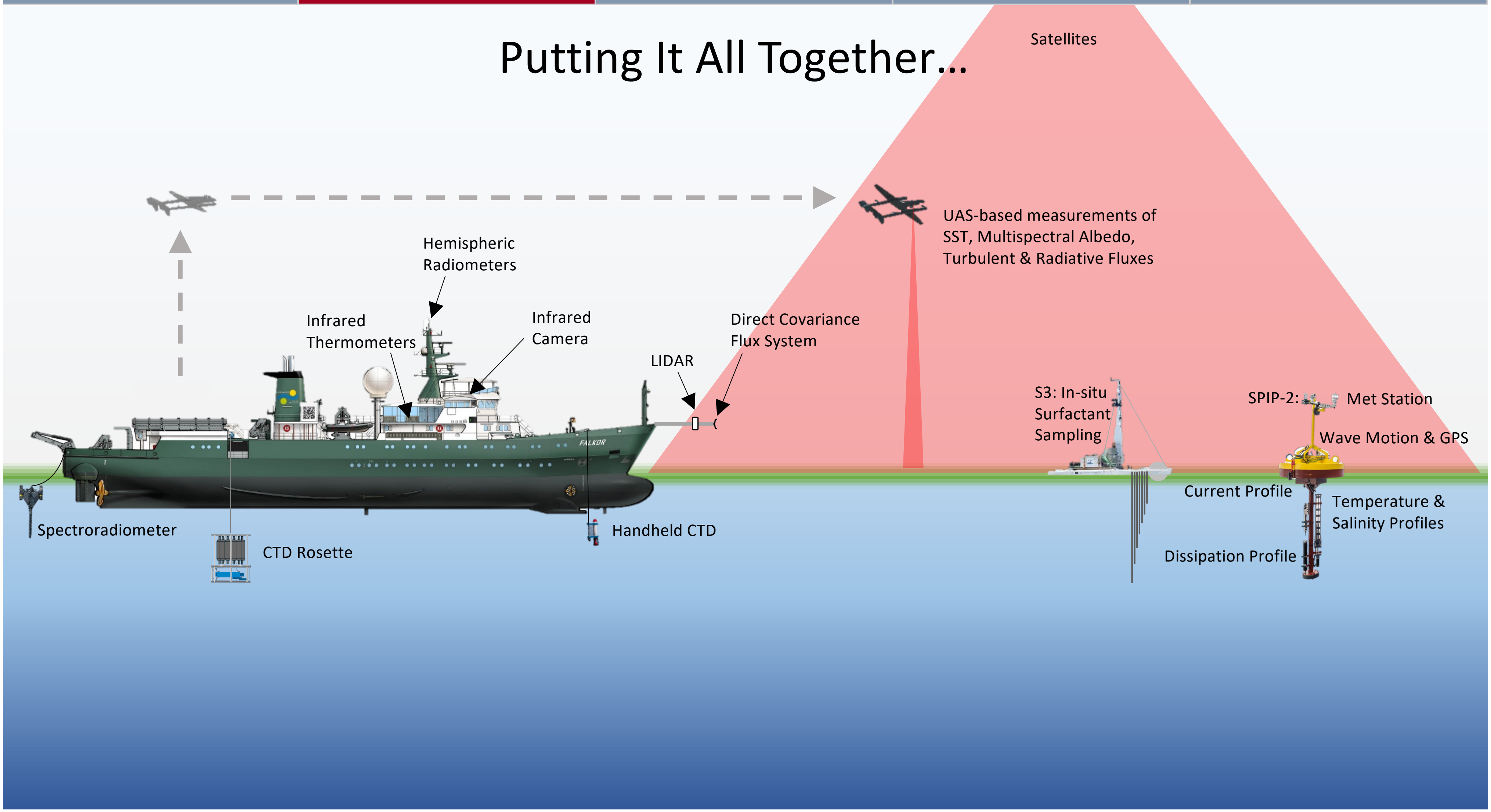




# Profiling Spectroradiometer



# Putting It All Together…



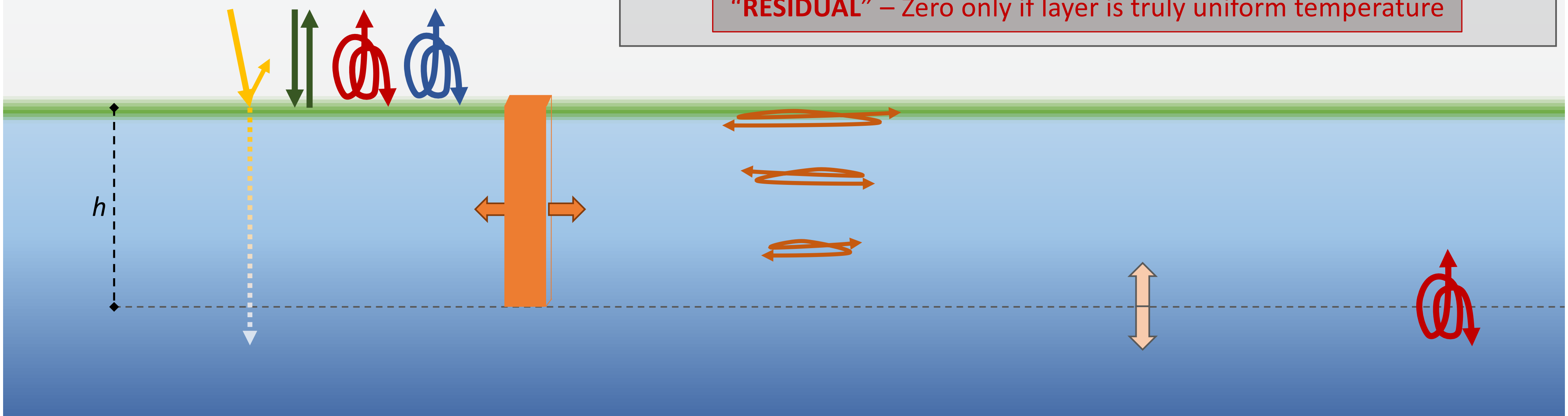
# Quantify the major terms of the upper ocean heat budget in the presence of SAS

*Integrate mass & heat conservation equations from the surface to an arbitrary isotherm $h(x,y,t)$:*

$$\rho c_p\left(h\frac{\partial T_a}{\partial t}\right) = Q_{surf} - \rho c_p\left(h\overrightarrow{v_a}\cdot\vec{\nabla} T_a\right) - \rho c_p\,\vec{\nabla}\cdot\left(\int_{-h}^{0}\vec{v}' T' dz\right) - \rho c_p (T_a - T_{-h})\left(\frac{\partial h}{\partial t} + w_{-h}\right) - Q_{-h}$$

Time-evolution of vertically-averaged temperature in surface layer of arbitrary depth *h* = Surface Fluxes – Horizontal Heat Advection – Horizontal Eddy Heat Transport – Rate of Heat Entrainment Across the Base of the Layer – Turbulent Sensible Flux & SW Penetration Across the Base

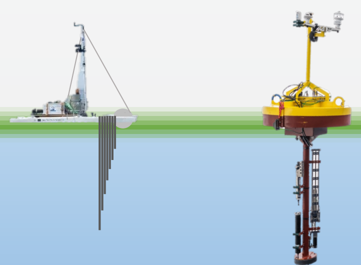
“**RESIDUAL**” – Zero only if layer is truly uniform temperature

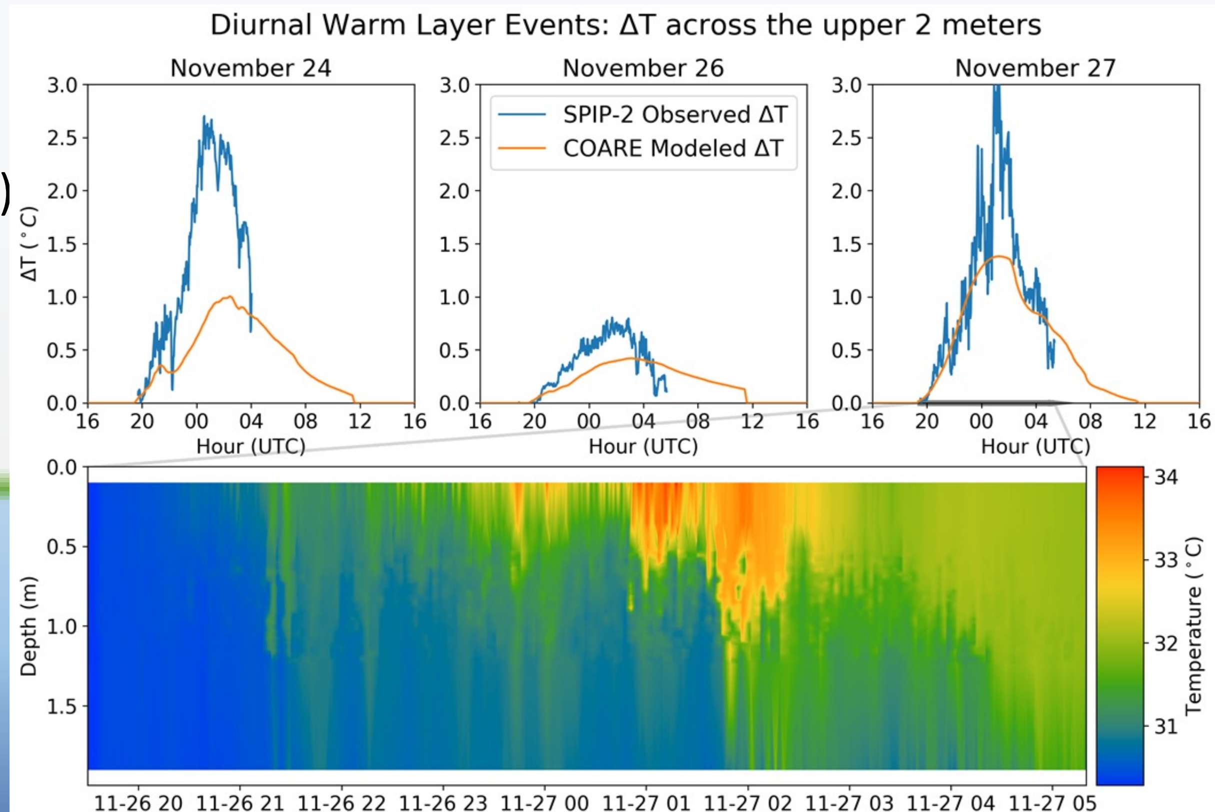



*Stevenson and Niiler (1983)*

Characterize the effect of SAS on diurnal warm layer formation / upper ocean heat content as compared to model predictions

- COARE 3.5 - - - - - ▶
- 1D Mixed-Layer
  (e.g. Price-Weller-Pinkel)
- Turbulence Closure
  (e.g. Kantha-Clayson)



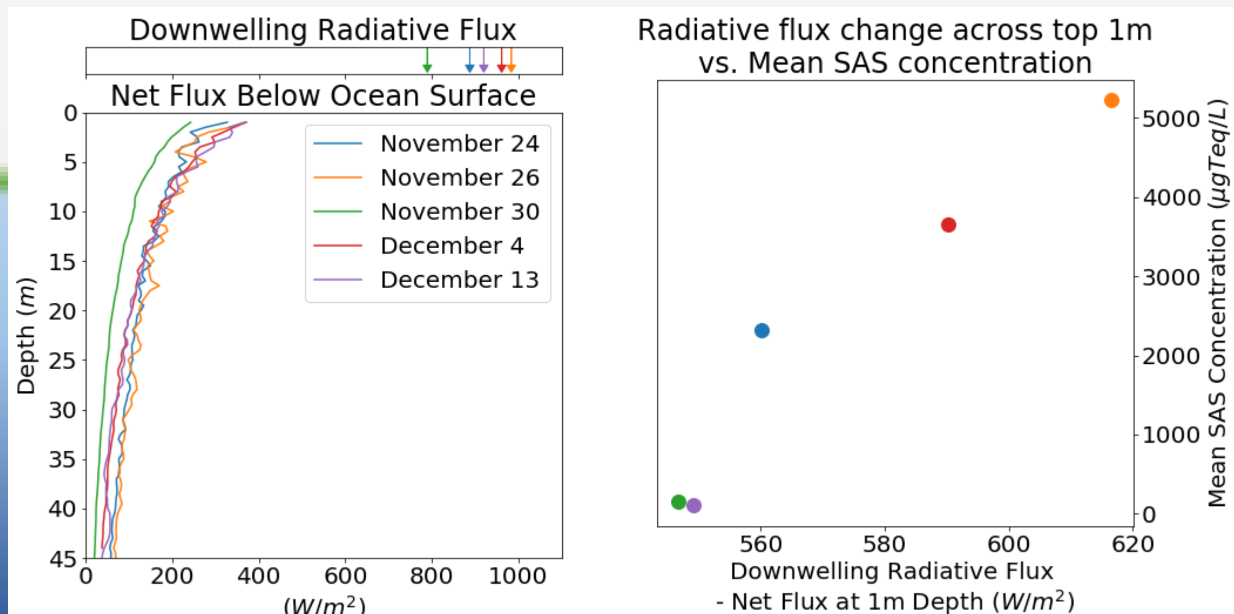


# Chapter 3: Quantify the major terms of the upper ocean heat budget in the presence of SAS

*Integrate mass & heat conservation equations from the surface to an arbitrary isotherm $h(x, y, t)$:*

$$\rho c_p\left(h\frac{\partial T_a}{\partial t}\right) = Q_{surf} - \rho c_p\left(h\overline{\vec{v}_a}\cdot\vec{\nabla}T_a\right) - \rho c_p\,\vec{\nabla}\cdot\left(\int_{-h}^{0}\vec{v}'T'dz\right) - \rho c_p(T_a - T_{-h})\left(\frac{\partial h}{\partial t} + w_{-h}\right) - Q_{-h}$$

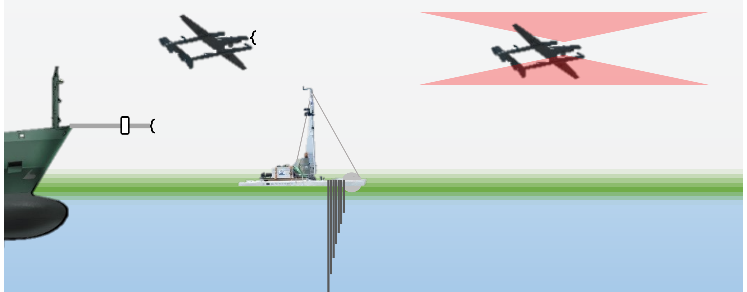
Time-evolution of vertically-averaged temperature in surface layer of arbitrary depth *h* = Surface Fluxes − Horizontal Heat Advection − Horizontal Eddy Heat Transport − Rate of Heat Entrainment Across the Base of the Layer − Turbulent Sensible Flux & SW Penetration Across the Base



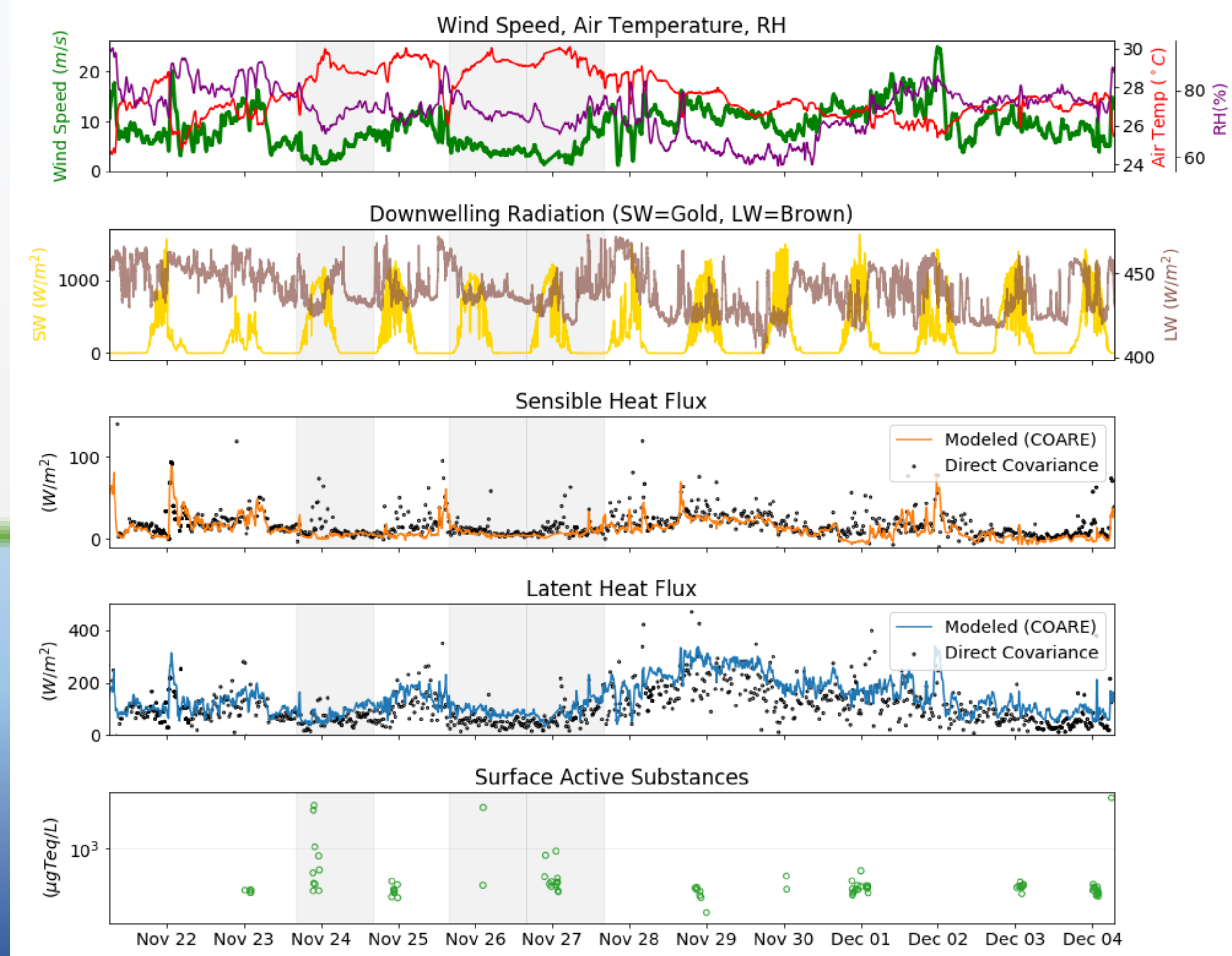

*enson and Niiler (1983)*

# Characterize the effect of SAS on surface fluxes

- Compare turbulent fluxes observed from ship boom & MET Payload to those predicted from bulk measurements by models – where & why do they diverge?



- Quantify the spatial variability of ocean surface albedo & the effect of SAS on albedo using the RAD Payload

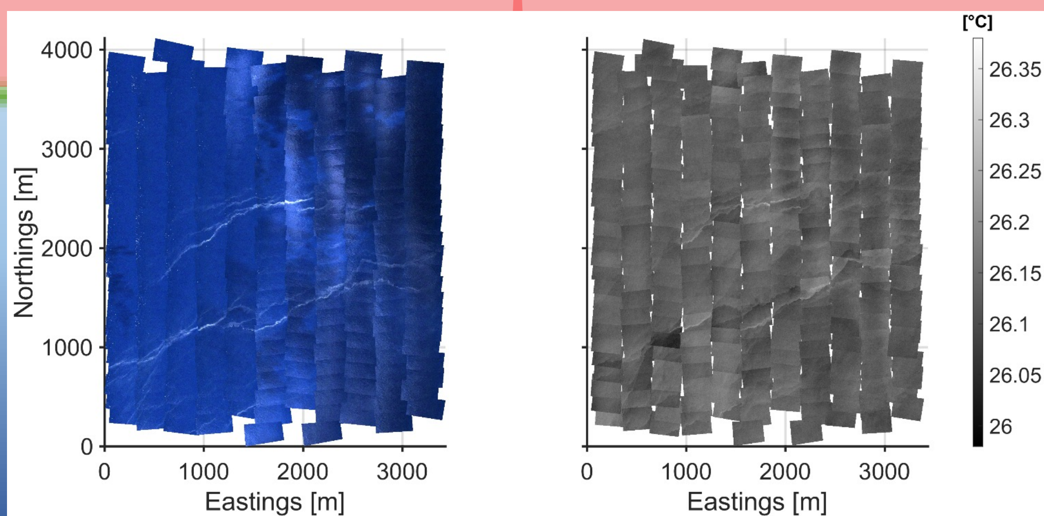


# Chapter 3: Quantify the major terms of the upper ocean heat budget **in the presence of SAS**

*Integrate mass & heat conservation equations from the surface to an arbitrary isotherm* $h(x, y, t)$*:*

$$\rho c_p \left( h \frac{\partial T_a}{\partial t} \right) = Q_{surf} - \rho c_p \left( h \overrightarrow{v_a} \cdot \vec{\nabla} T_a \right) - \rho c_p \, \vec{\nabla} \cdot \left( \int_{-h}^{0} \vec{v}' T' dz \right) - \rho c_p (T_a - T_{-h}) \left( \frac{\partial h}{\partial t} + w_{-h} \right) - Q_{-h}$$

Time-evolution of vertically-averaged temperature in surface layer of arbitrary depth *h* = Surface Fluxes − Horizontal Heat Advection − Horizontal Eddy Heat Transport − Rate of Heat Entrainment Across the Base of the Layer − Turbulent Sensible Flux & SW Penetration Across the Base




*Stevenson and Niiler (1983)*

# Concluding Summary

- **Demonstrated that UAVs provide for “New Transformational Measurement Perspectives”**
  - Real-Time Adaptive Tasking for Enhanced Science from Ships

- **Complex impacts of Cyanobacteria (Tricho) blooms on the upper ocean heat budget:**
  - Blooms cause increased absorption of solar radiation
  - Leads to enhanced near-surface warming that is not predicted by diurnal warm-layer models
  - Air-sea fluxes respond with higher sensible fluxes than predicted by COARE 3.5.

- **Total heat budget will provide insights and lead to improvements for models of air-sea heat fluxes (COARE ?.0) and diurnal near-surface warm-layer models.**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