UAS Activities at Lamont-Doherty Earth Observatory of Columbia University

Christopher J. Zappa
Lamont-Doherty Earth Observatory,
Columbia University

LDEO Team:
S. Brown
T. Dhakal
R. Harris
C. Witte

GORDON AND BETTY MOORE FOUNDATION

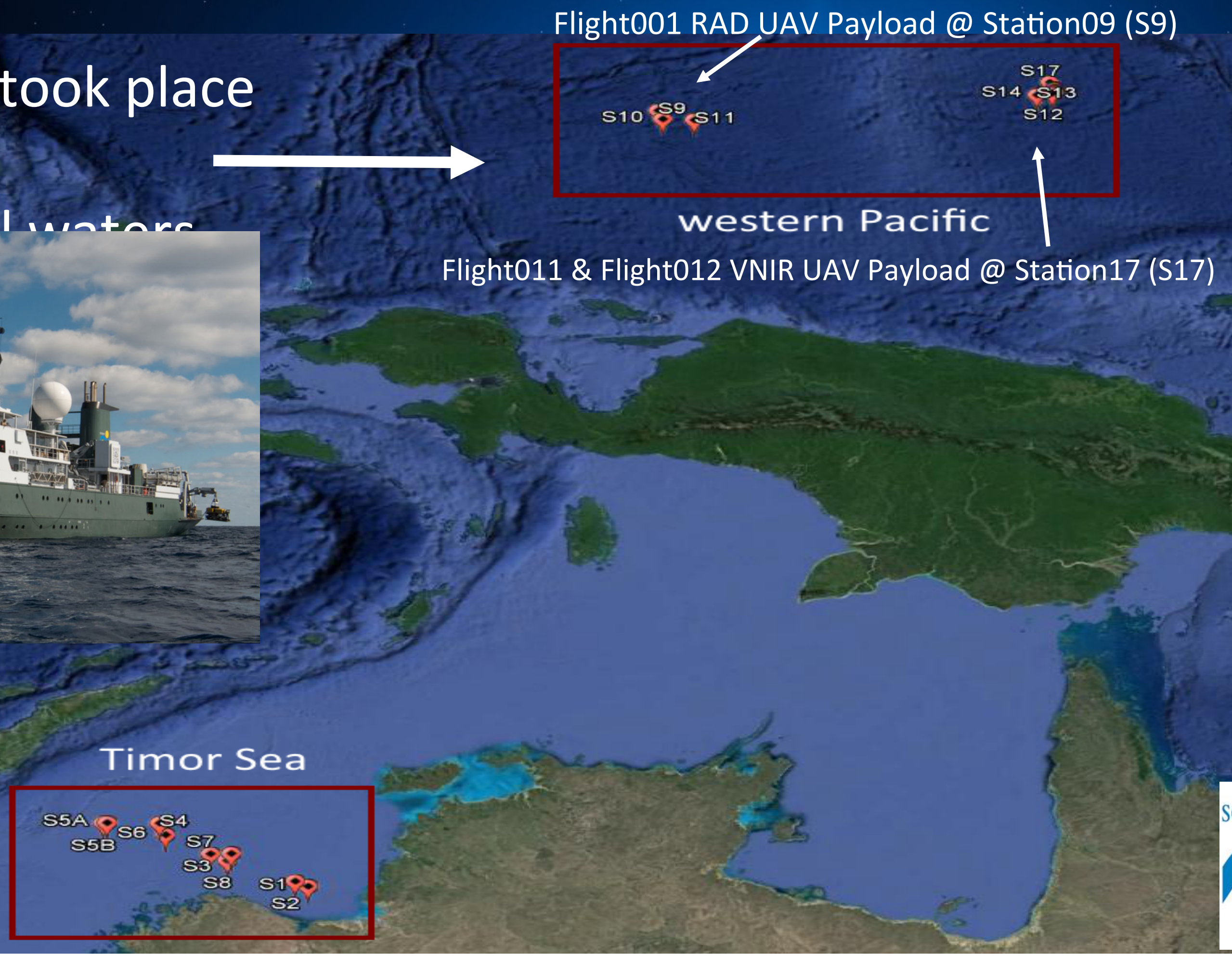
SCHMIDT OCEAN INSTITUTE

R/V Falkor – October/November 2016

SCHMIDT OCEAN INSTITUTE

R/V Falkor – October/November 2016

All UAV flights took place here,
in international waters



SCHMIDT OCEAN INSTITUTE

UAS from Ships (Latitude HQ-60B)

Combines vertical takeoff and landing (VTOL) capabilities of a quadrotor and the speed and range of a fixed-wing (FW) aircraft

SCHMIDT OCEAN INSTITUTE

Latitude HQ-60B

HQ-60B
- 103 lbs gross weight
- 12-18 hours endurance
- 8-12 lbs payload

Aircraft built	5
Total flights	130
Total flight time	>80 hrs
Max demonstrated launch weight	105 lbs
Max demonstrated recovery wind	31 kts
Max demonstrated endurance	22.5 hrs

SCHMIDT OCEAN INSTITUTE

UAS from Ships

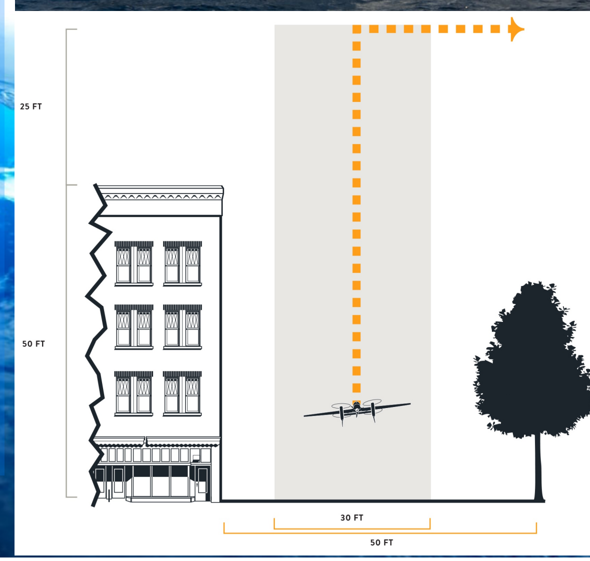
- No runway needed
- Portable
- Shipboard operation demonstrated
- Pusher engine – required for gas and aerosol measurement
- Nose cone payload

SCHMIDT OCEAN INSTITUTE

Shipboard Operation – Confined Area Launch and Recovery

- Standard configuration provides 3 minutes VTOL, at 75ft transition height.
- 30-45 seconds required for each launch and recovery event
- 2 min reserve

- Obstacle height: 50ft
- Landing accuracy: ±15ft
- Lateral launch/recovery area clearance: ±25ft
- Obstacle clearance height can increase with increased VTOL battery mass. 150 ft. transition altitude costs ~2.5 hours fixed wing endurance



UAS from Ships – Operational Limits

- **Range:** Operations were limited to daytime and line of sight (5 nm).
- **Altitude:** Operations range up to 5000 ft. (self-determined)
- **Wind and Sea State:** 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).

SCHMIDT OCEAN INSTITUTE

UAS from Ships – Hover Test

SCHMIDT OCEAN INSTITUTE

UAS from Ships – Launch

SCHMIDT OCEAN INSTITUTE

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

SCHMIDT OCEAN INSTITUTE

UAS from Ships – Accomplishments

- 5 successful hover flights
- 10 successful flights with vertical take off, switch to fixed wing flight, and vertical landing.
- Successful flights were conducted with takeoff 45 off the port into the wind.
- Demonstrated the ability to operate the HQ technology from a ship with limited deck space.
- Demonstrated the ability to operate the HQ technology from a ship under 10 – 18 kt wind speed conditions.

SCHMIDT OCEAN INSTITUTE

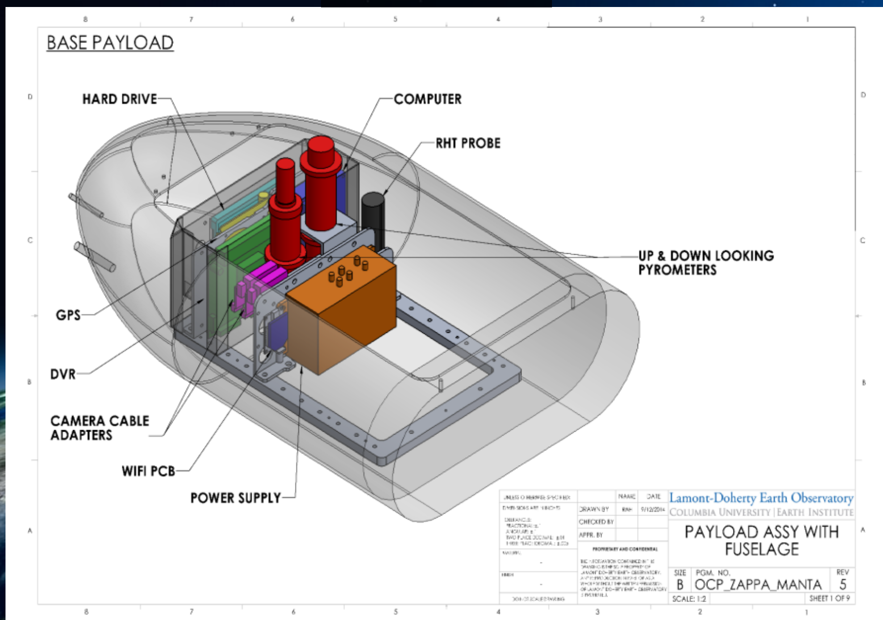
UAS from Ships – Lessons Learned

- Pitch and roll of the deck posed a less significant challenge than anticipated.
- High Wind (>25 knots) posed a problem… the large steel structure of the ship was significant enough to cause a significant transitional turbulent boundary layer over the aft deck that made **manual** operation difficult.
- Solution: More powerful VTOL engines as well as dGPS for automated take off and landing.
- Latitude Engineering has increased the VTOL system control authority (power, responsiveness) for future operations… currently on HQ-90. More to come.
- Autonomous VTOL will require the addition of the dGPS system… future R/V Falkor Cruise in December 2019.

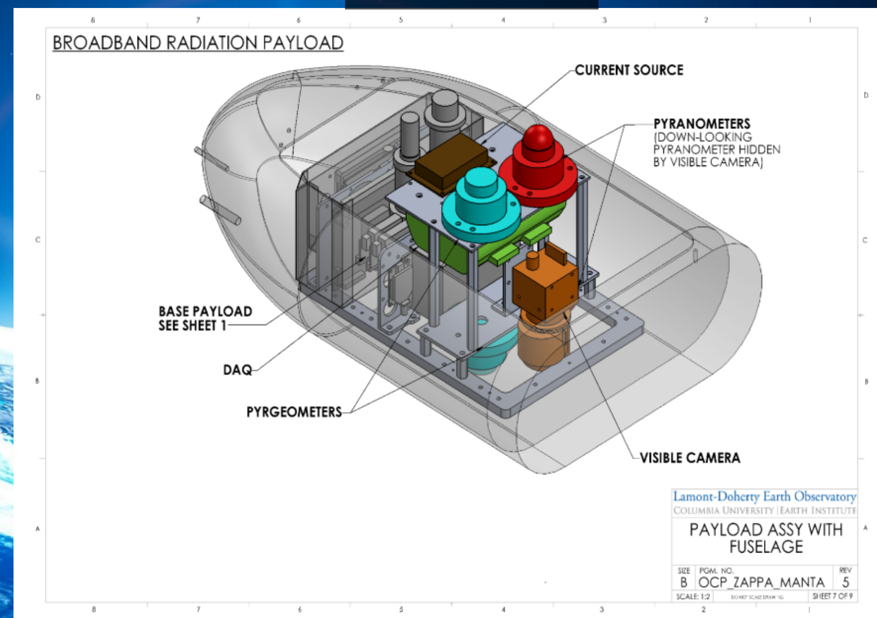
SCHMIDT OCEAN INSTITUTE

UAS Payload Development

BASE Payload



Sensor Module



BASE payload allows for quick change between sensor payloads

GORDON AND BETTY MOORE FOUNDATION

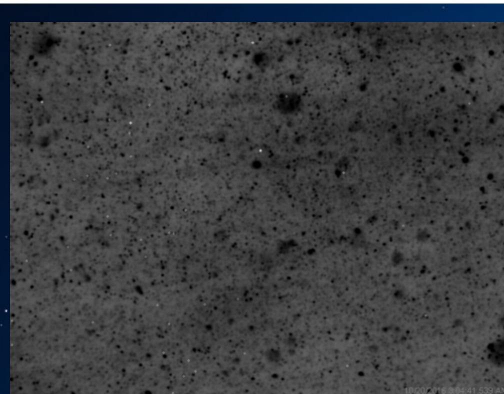
UAS Payloads

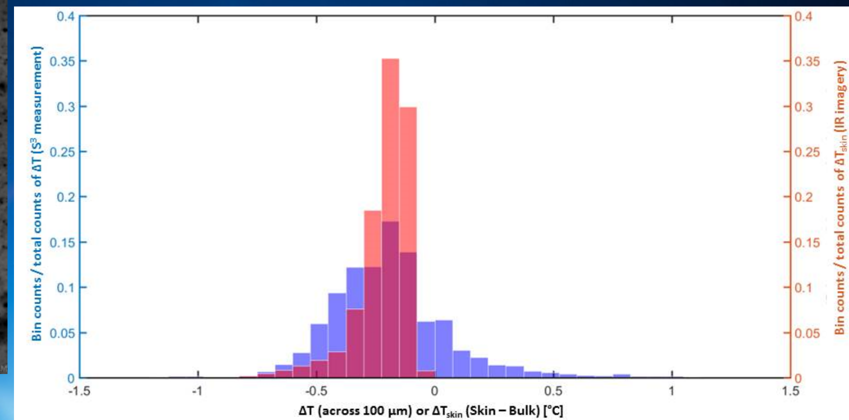
Table 1: Implemented science payloads and applications

Payload	Sensing technologies
VIS-TIR*	High-resolution broadband visible (400-700 nm) imager, uncooled microbolometer (8-14 µm) imager sensitive to 0.05°C for skin sea surface temperature (SST) mapping, whitecapping, and other upper ocean processes.
Hi-TIR*	Cooled infrared (7.7 – 9.5 µm) imager sensitive to 0.02°C for skin SST mapping, whitecapping, and other upper ocean processes.
HYP-VNIR*	Hyperspectral visible (300-1000 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the upper-ocean to determine ocean color and biogeochemical mapping. Upward-looking narrow FOV spectrometer provides measurements for estimates of spectral albedo of varying surfaces including ocean.
HYP-NIR*	Hyperspectral near-infrared (900-1700 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the near-surface ocean to determine ocean color and biogeochemical mapping.
Li-MET	LiDAR for wave height and surface roughness; fast response 3D wind speed and direction (100 Hz), fast response temperature (50 Hz), fast response relative humidity (100 Hz) for estimating momentum, latent heat and sensible heat turbulent fluxes.
RAD*	Upward- and downward-looking pryanometer (broadband solar 285-3000 nm) and pyrgeometer (broadband longwave; 4.5-40 µm) to measure full hemispheric irradiance to understand the surface energy budget and map albedo of varying surfaces including the ocean. High-resolution broadband visible (400-700 nm) imaging is used to map whitecapping and other upper ocean processes.
DDµD*	Drone-Deployed Micro-Drifters with launcher for in-flight ejection of up to four micro-dropsonde packages. The DDµD measures temperature, pressure, and relative humidity as it descends through the atmosphere. Once it lands on the ocean's surface, it deploys a string of sensors that measures temperature and salinity of the upper 2-3 meters of the ocean at fifteen minute intervals for up to two weeks as a buoy. The ocean sensors on the DDµD collect and store data and then transmit the data back to the UAS on subsequent flights from up to 10 miles away.

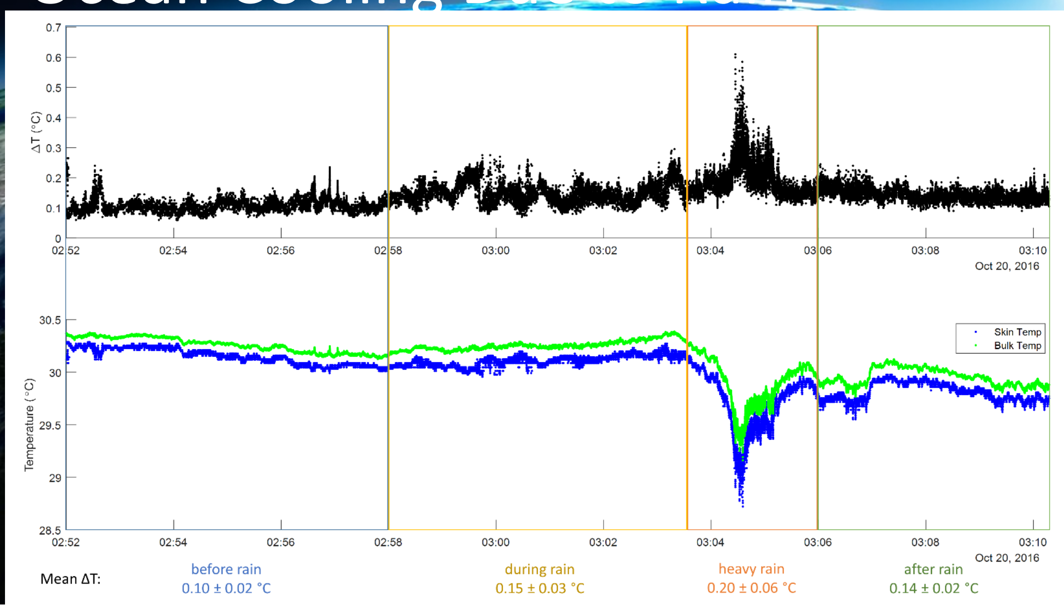
***also included upward- and downward-looking pyrometers (8-14 µm) to measure narrow field-of-view (FOV) skin SST and ice-surface temperature.**

GORDON AND BETTY MOORE FOUNDATION



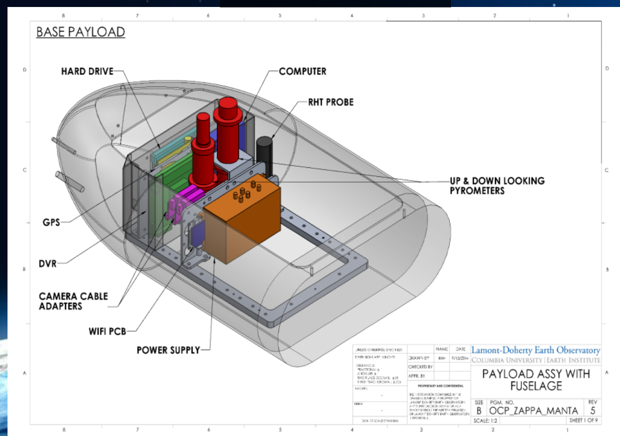


Ocean Cooling Due to Rain

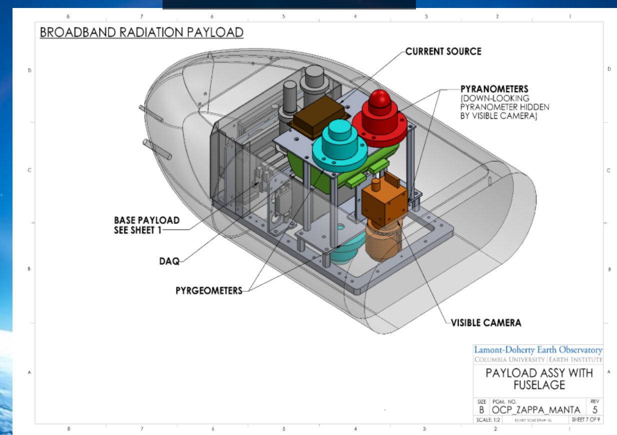


UAS Payload Development

BASE Payload



Sensor Module



BASE payload allows for quick change between sensor payloads

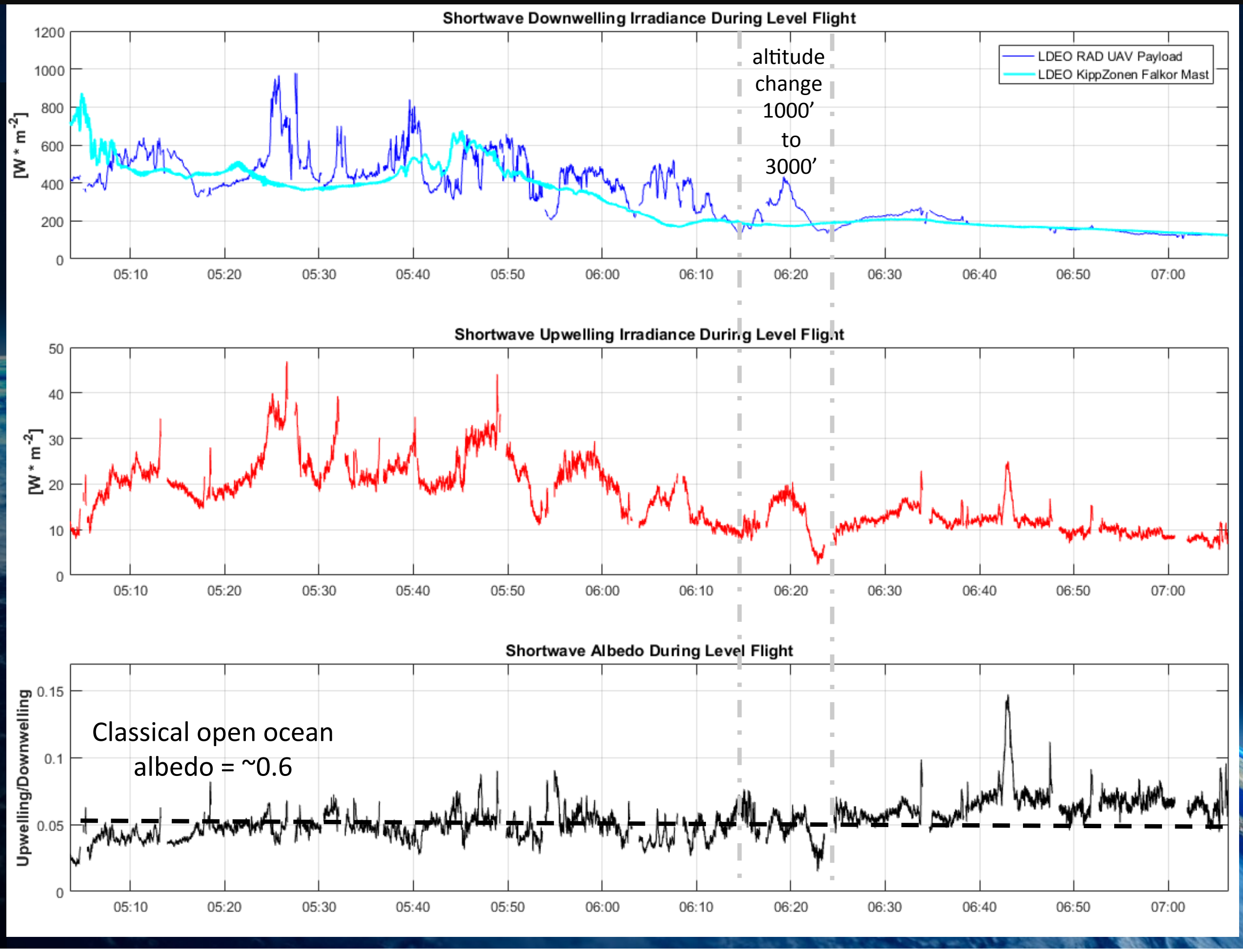
$U_{10} = 7\ m \cdot s^{-1} – 10\ m \cdot s^{-1}$ from West

Flight001 RAD UAV Payload visible image taken 28 Oct 2016, 0624 UTC

GORDON AND BETTY MOORE FOUNDATION

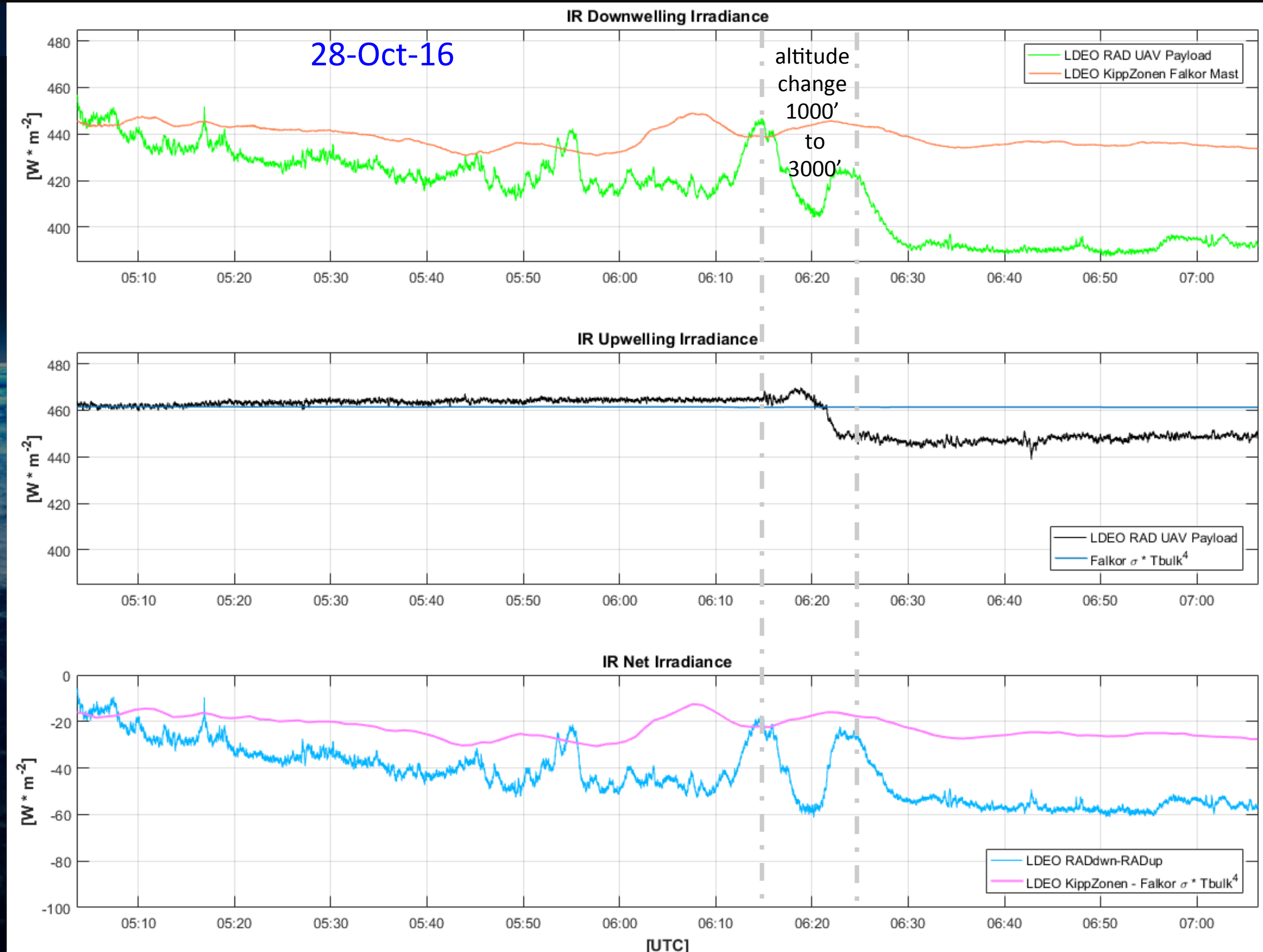
Shortwave Irradiance Summary – RAD Payload

- LDEO UAV-based shortwave albedo shows good agreement with classical values of ~0.6 for open ocean (Payne 1972)
- Comparing downwelling irradiance from LDEO UAV-based to LDEO ship-based measurements shows the two data sets broadly track
- Differences in UAV-based vs ship-based shortwave downwelling measurements highlight ship-based errors introduced by superstructure



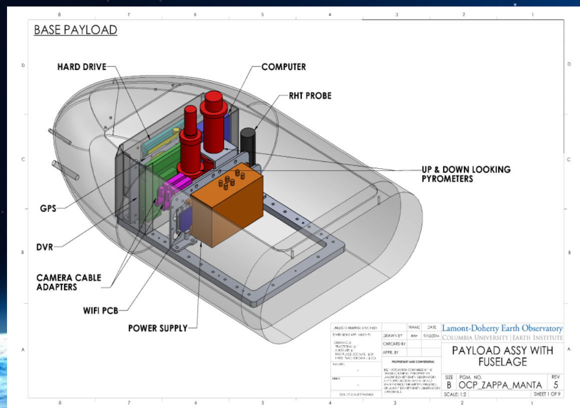
Shortwave Irradiance Summary – RAD Payload

- Comparing downwelling irradiance from LDEO UAV-based to LDEO ship-based measurements shows the two data sets broadly track
- Note a decrease in both up- and down-welling longwave irradiance at higher altitude
- Differences in UAV-based vs ship-based longwave downwelling measurements highlight ship-based errors introduced by superstructure

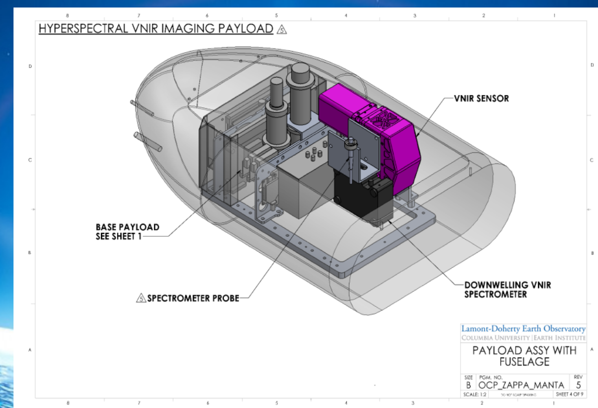


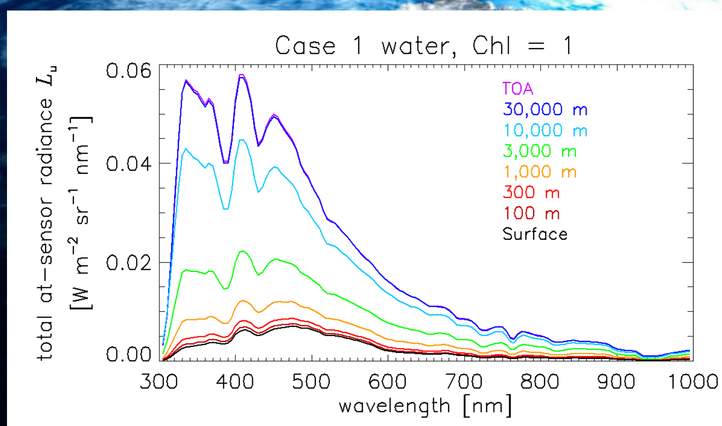
Hyperspectral Payload Development

BASE Payload

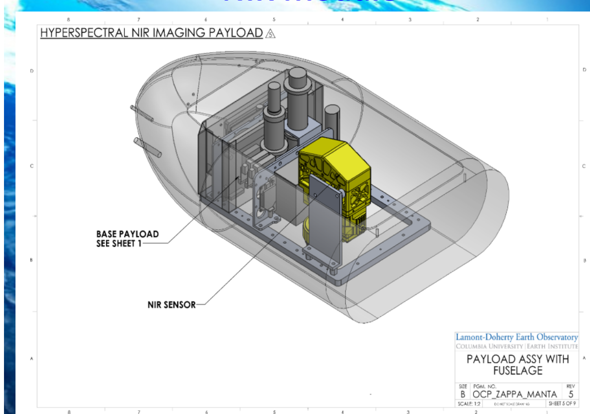


VNIR Module

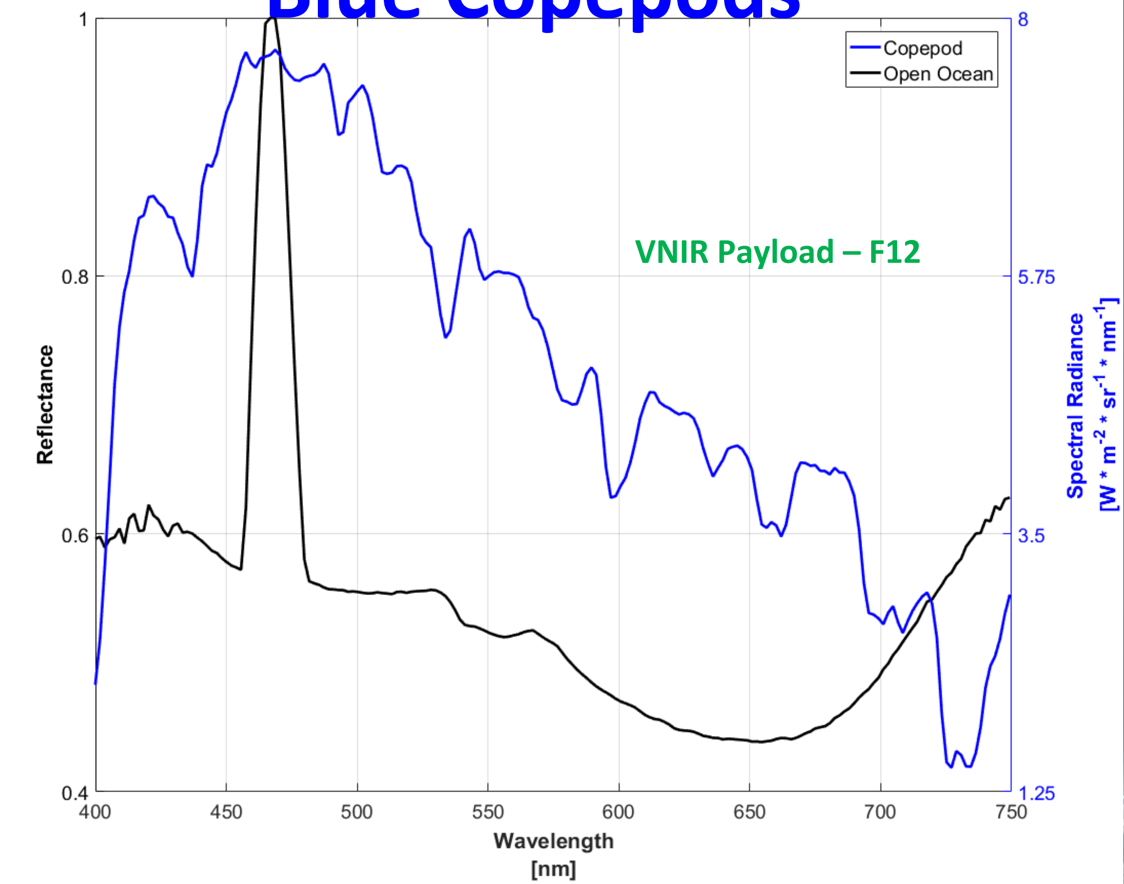




NIR Module



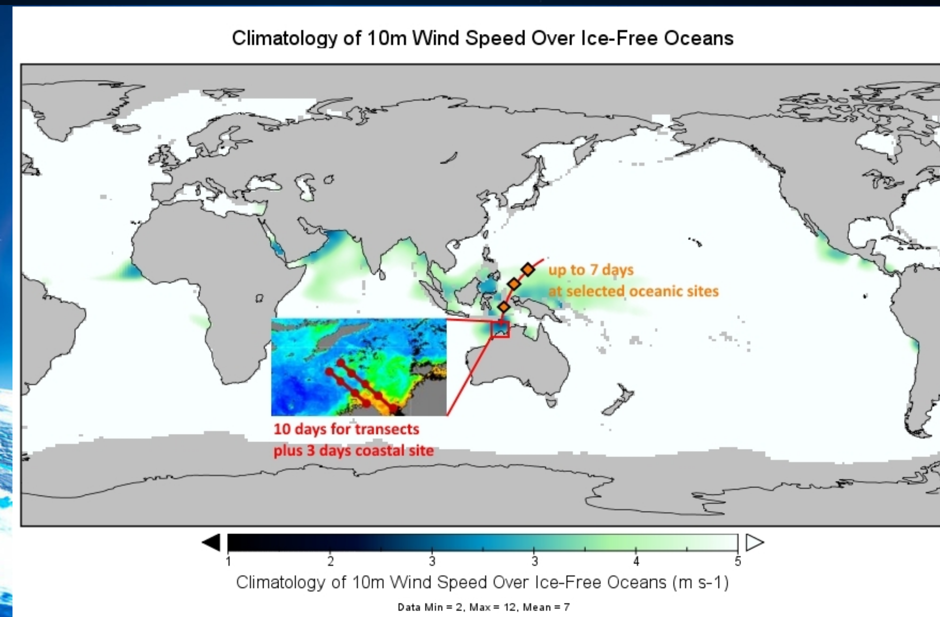
Blue Copepods



Blue copepods evolved predatory camouflage to be same as peak ocean color

Rahlff et al., (2018) *Scientific Reports*, *8*(11510), 10.1038/s41598-018-29869-7.

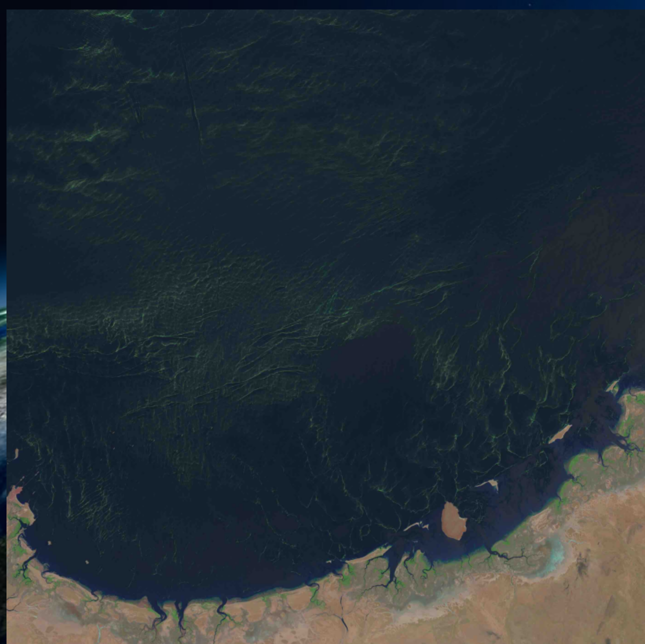
Current Directions – R/V Falkor



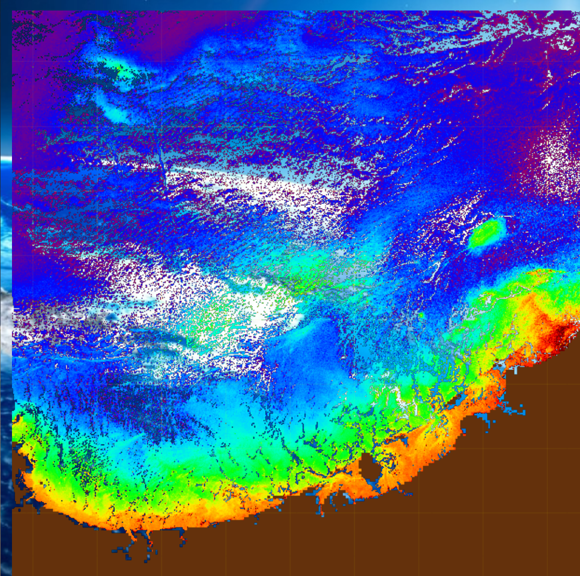
- Cruise from R/V Falkor in the Northwest Australian Continental Shelf
- Payloads developed for Manta UAS will be integrated onto Latitude Engineering HQ-60.
- Airborne surveys of the Sea Surface Microlayer from Latitude UAVs as well as in situ measurements of the SSM chemistry and biology from catamaran, drifters, and buoys.
- Measurements: ocean surface gravity-capillary wave spectra (*O*(1-0.001)m) using LIDAR and polarimetric imaging; complete chemical and biological quantification and characterization of the biogenic slicks from autonomous catamarans; and quantification and characterization of the near-surface ocean temperature, salinity, TKE dissipation rate, and currents from a drifting spar buoy and in the mixed-layer from autonomous sub-surface profiling

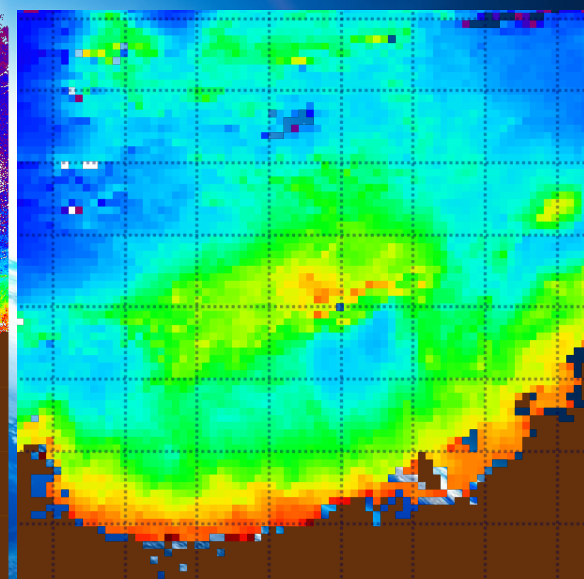
Current Directions – R/V Falkor

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.

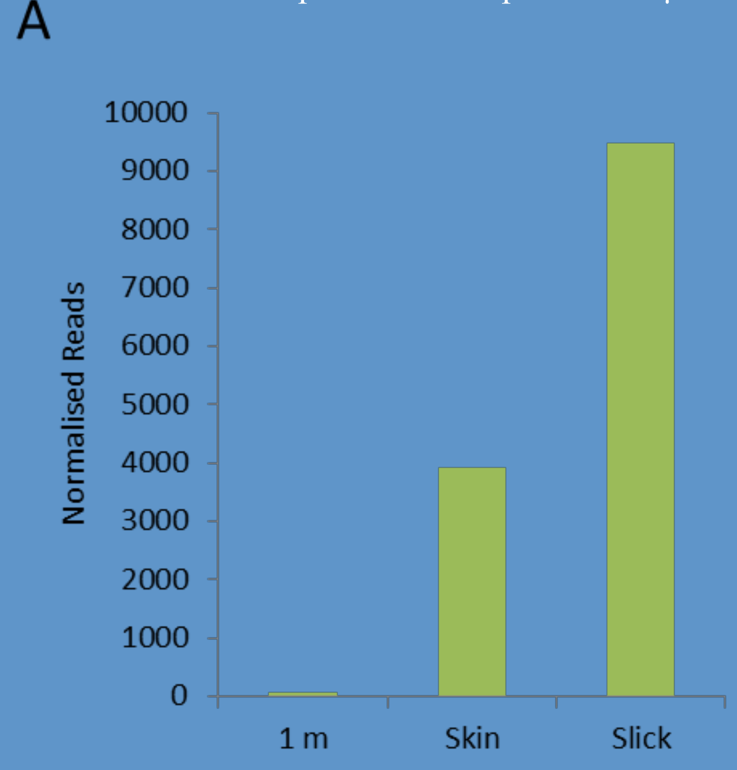
Current Directions – R/V Falkor

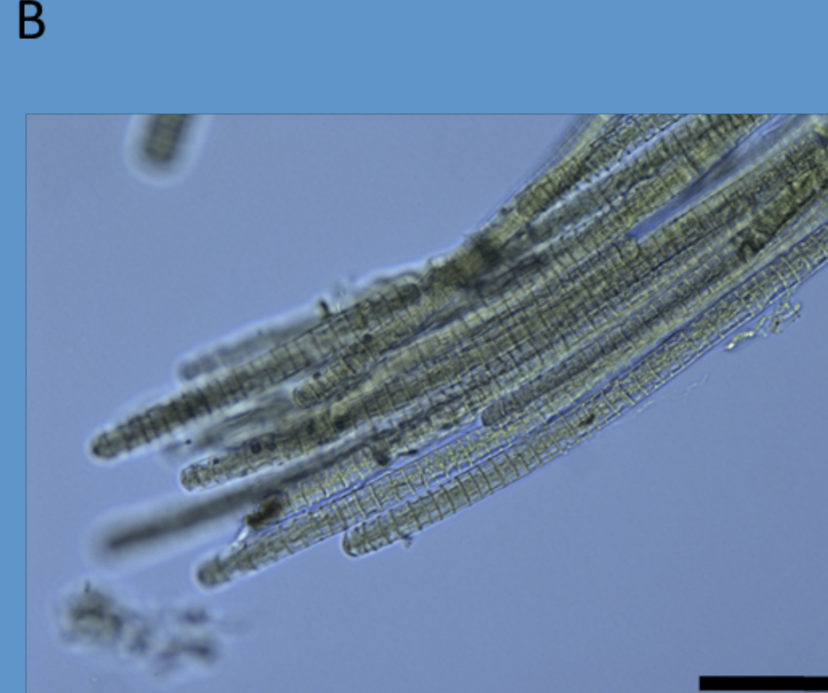
Trichodesmium

Trichodesmium

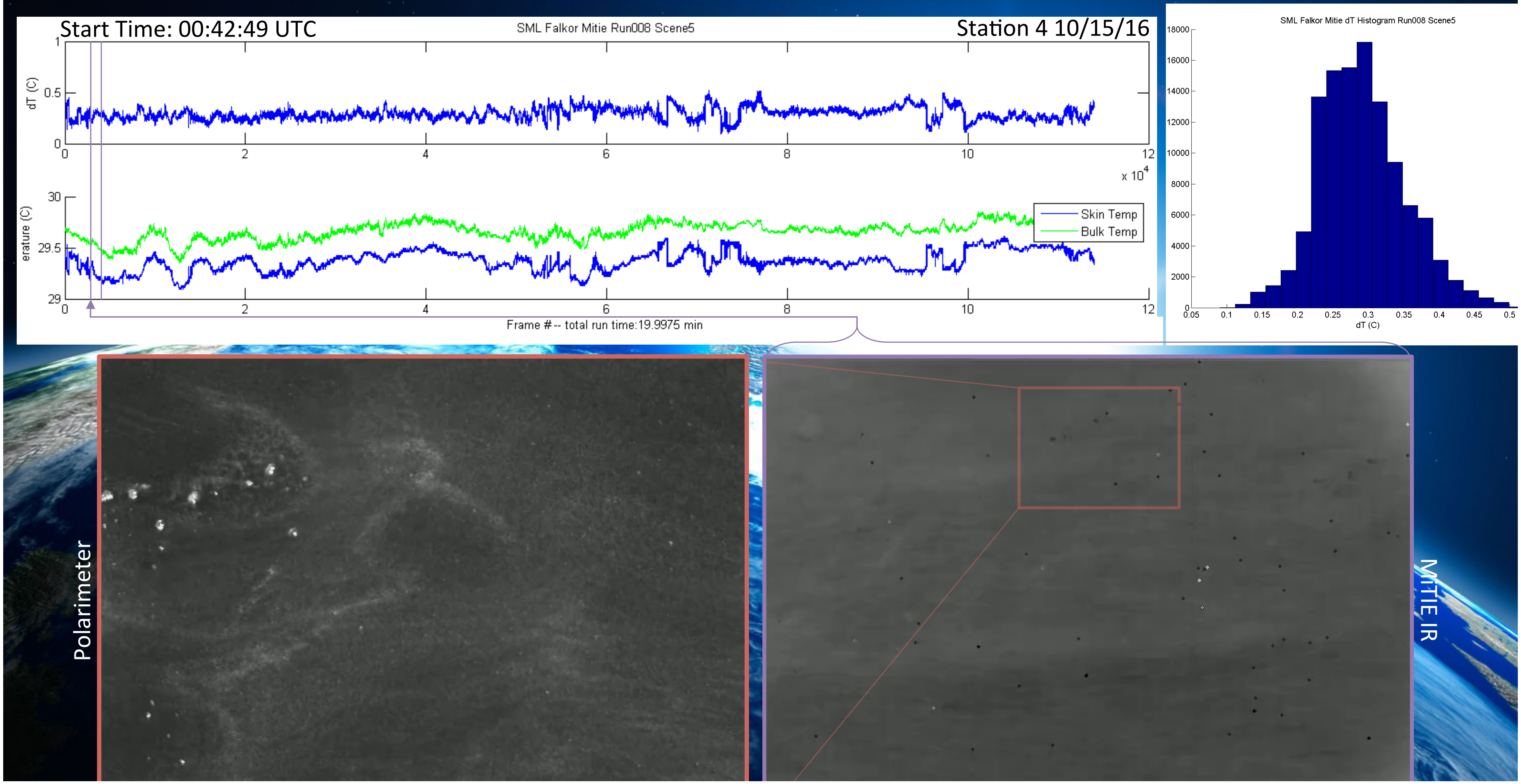
Current Directions – R/V Falkor

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.



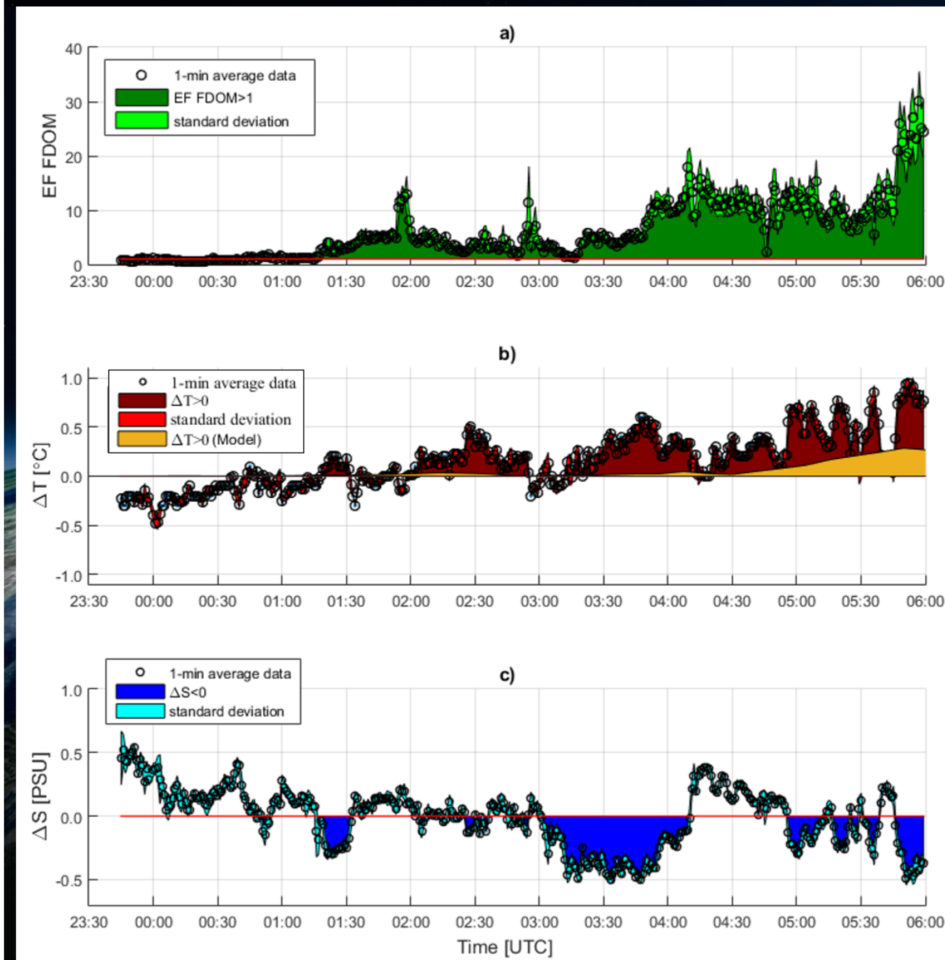


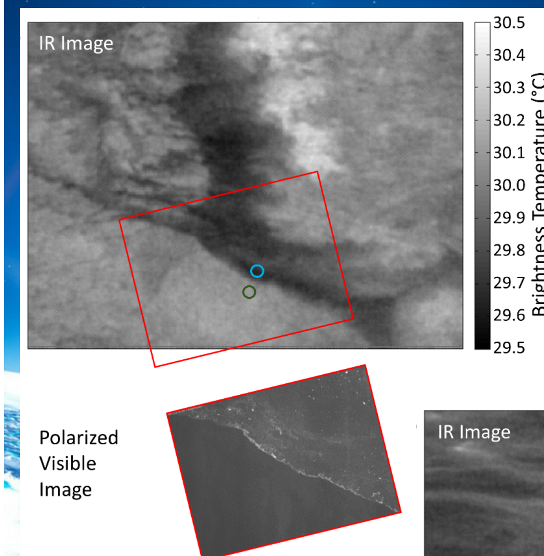
Surfactants (Sta 4&5, Timor Sea)

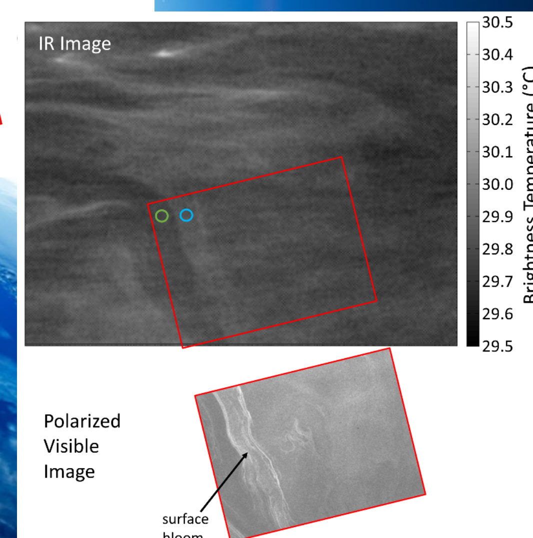


Current Directions – R/V Falkor

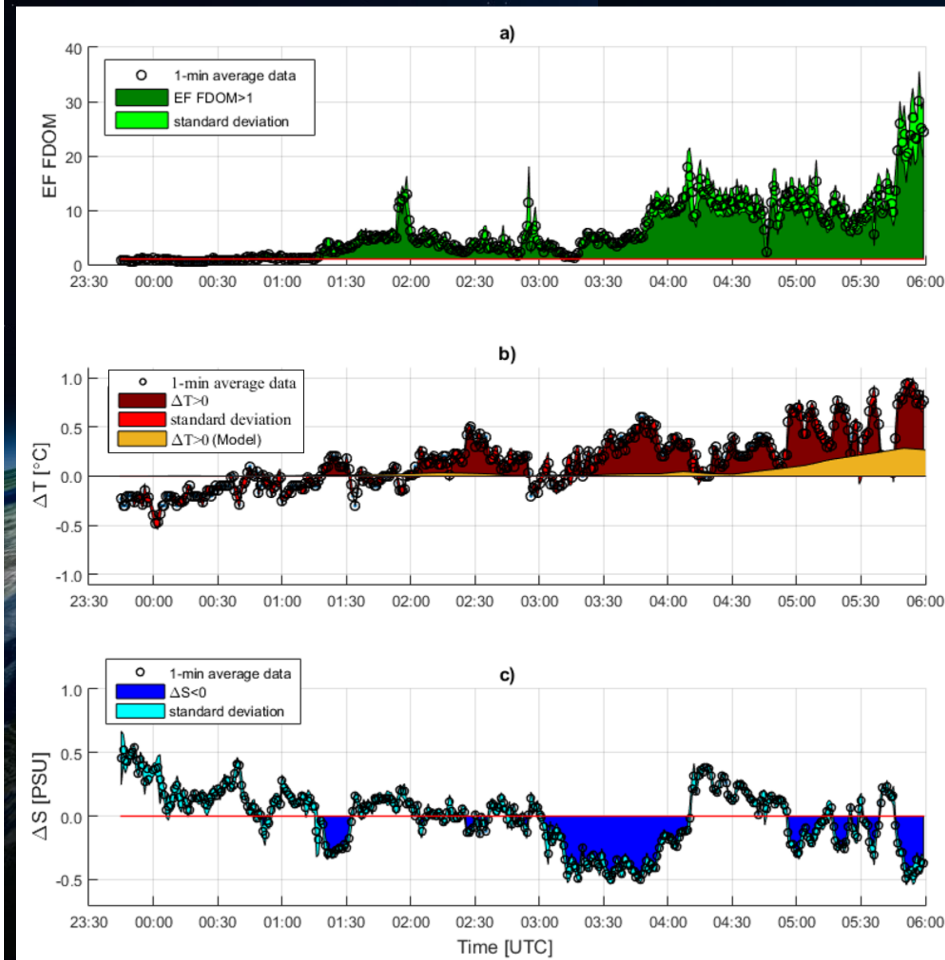
Trichodesmium



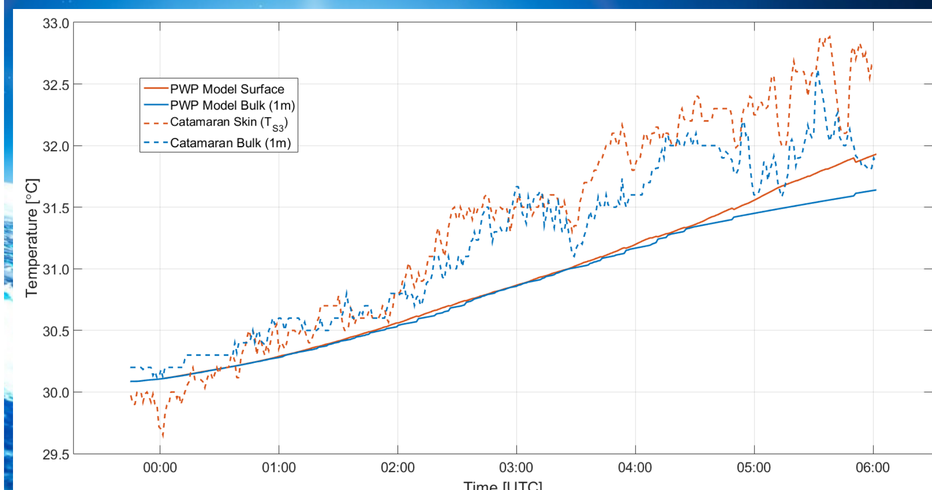




Current Directions – R/V Falkor



Trichodesmium



Wurl et al., (2018), *Geophys. Res. Lett.*, *45*(9), 4230-4237, doi:10.1029/2018GL077946.

Current Directions – R/V Falkor

Trichodesmium

Enhancements to HQ-90B for Ship Deployment

SCHMIDT OCEAN INSTITUTE

GORDON AND BETTY MOORE FOUNDATION

- 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.

Enhancements to HQ-90B for Ship Deployment

- 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.

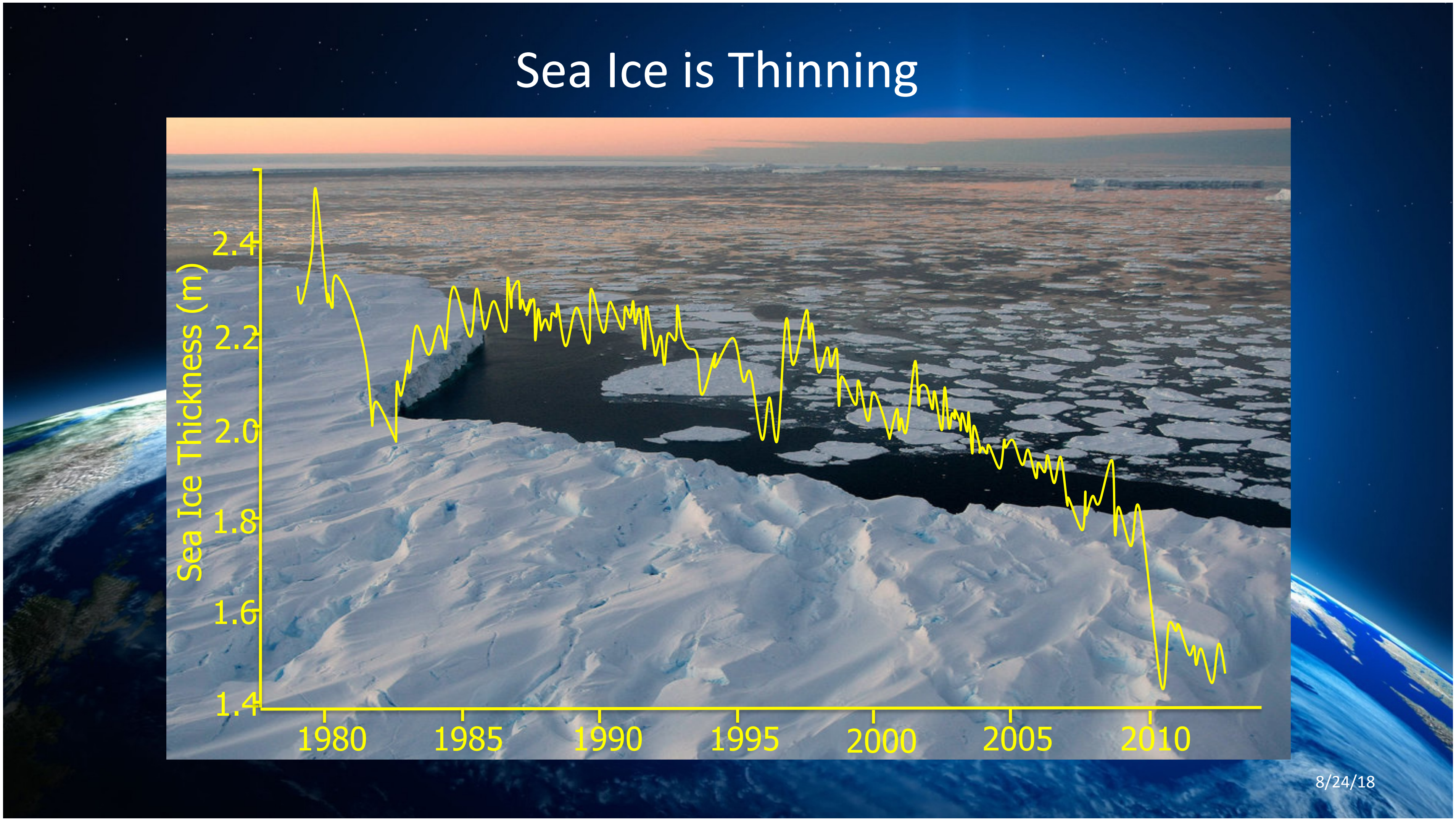
  b. Mother aircraft at high altitude to provide relay link to a squadron or fleet of UAVs flying at low altitude.

GORDON AND BETTY MOORE FOUNDATION

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)
2.4
2.2
2.0
1.8
1.6
1.4
1980
1985
1990
1995
2000
2005
2010
8/24/18

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

GORDON AND BETTY MOORE FOUNDATION

Indigenous Knowledge

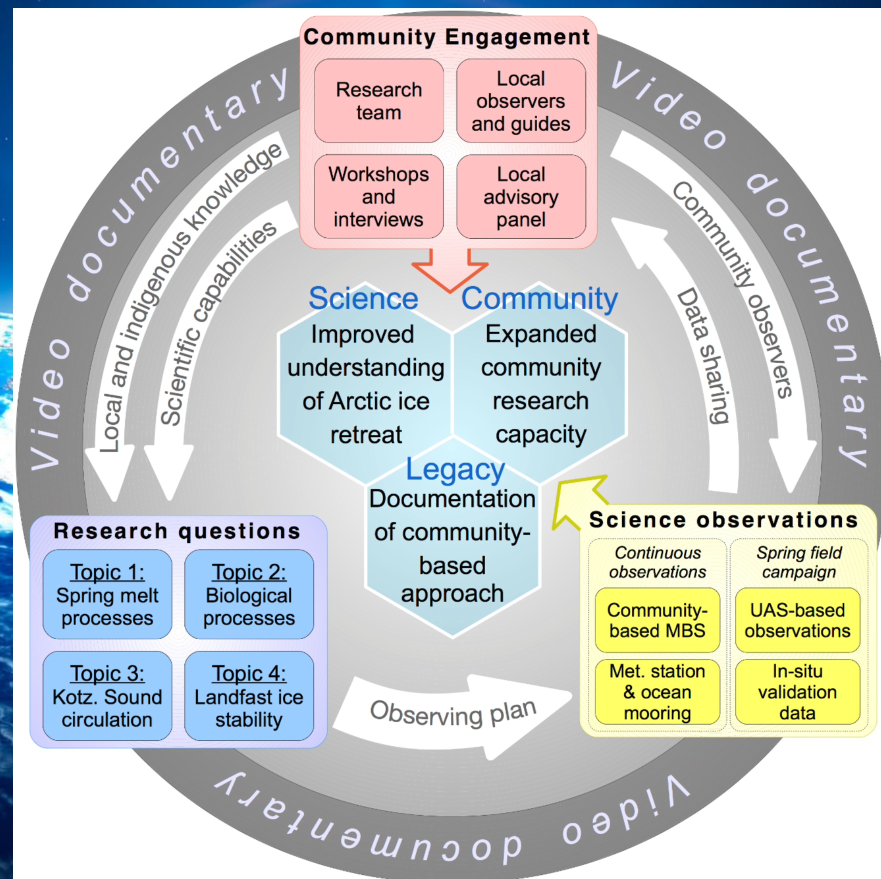
Indigenous knowledge is “a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has 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

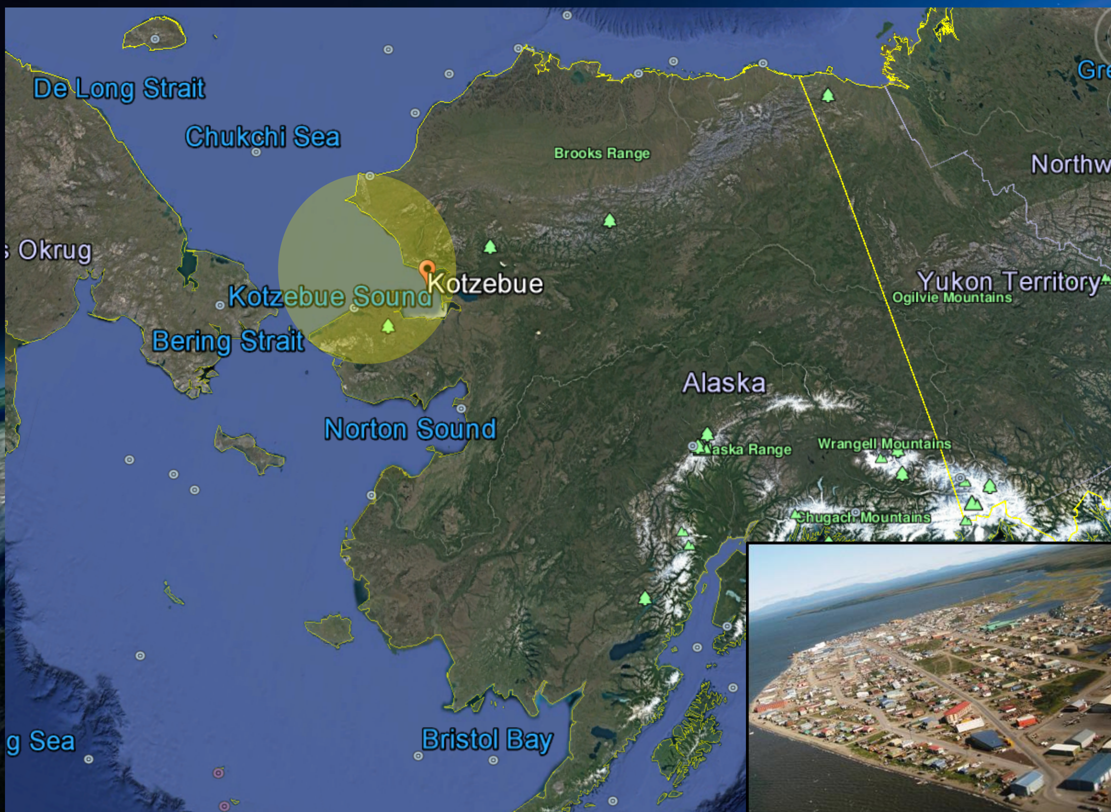
Science	**Improve understanding of the mechanisms, impacts, and implications of sea ice retreat in the Arctic for the global science community and local stakeholders**
Community	Develop partnerships between scientists and local residents to increase the capacity of local communities to address their research needs
Legacy	Document the progress of the project as a potential model for future community-based collaborative science endeavors in the Arctic

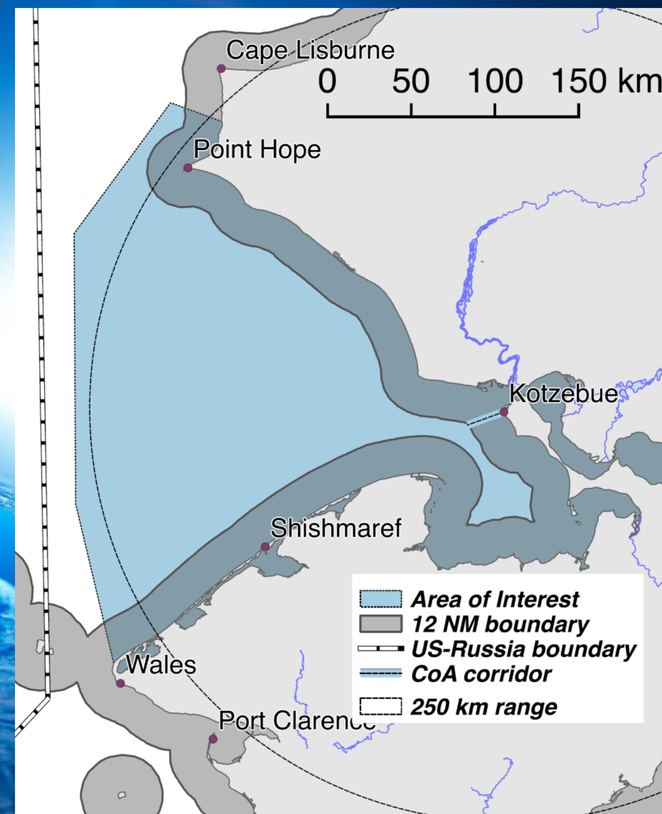
Community-based research design

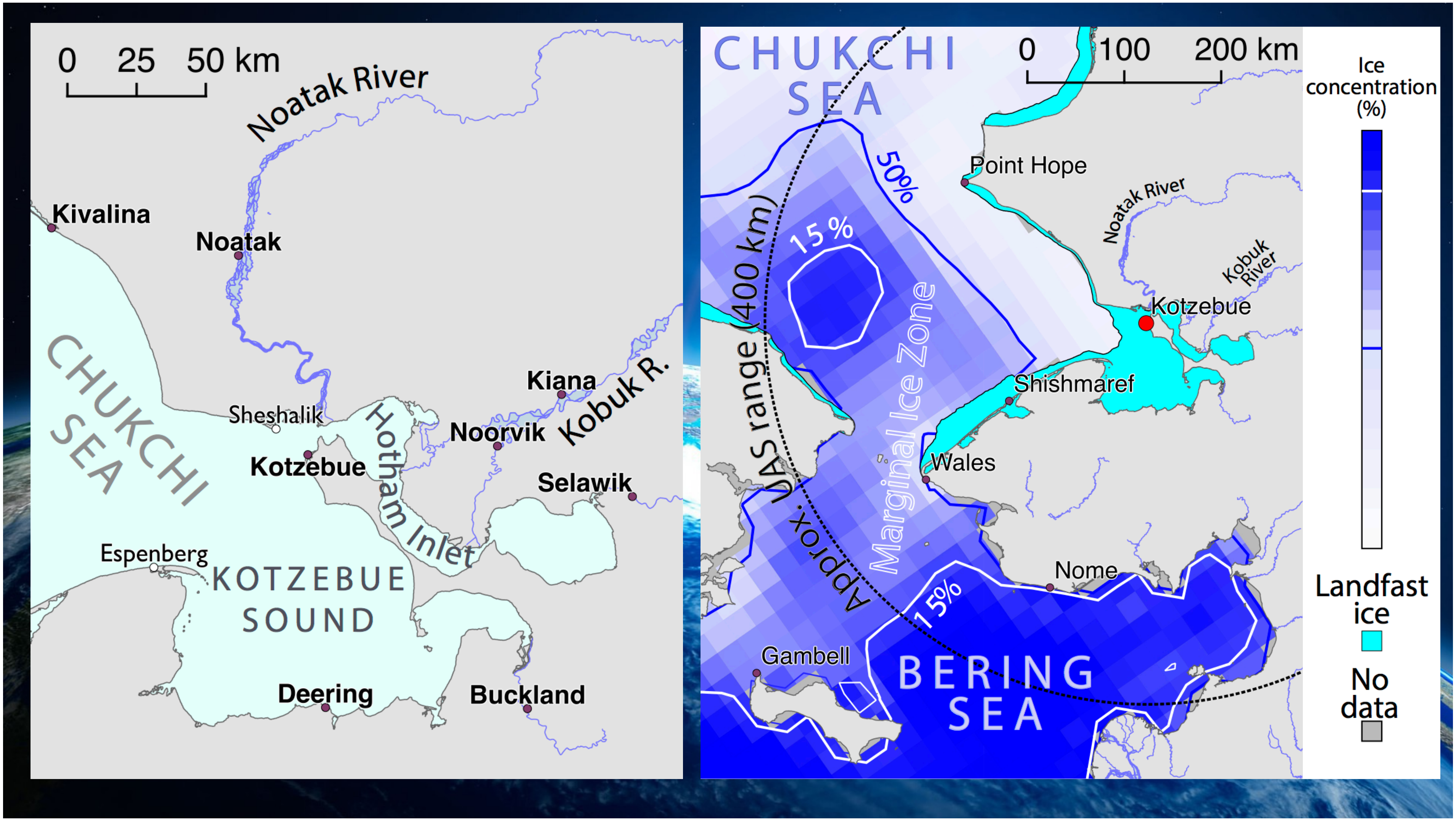
- Begins with community engagement
- Before research questions have been defined
- Ensures our observing plan meets our science, community, and legacy goals



Village of Kotzebue







0 25 50 km
Noatak River
Kivalina
Noatak
CHUKCHI SEA
Sheshalik
Hotham Inlet
Kiana
Kobuk R.
Noorvik
Kotzebue
Selawik
Espenberg
KOTZEBUE SOUND
Deering
Buckland
CHUKCHI SEA
0 100 200 km
Ice concentration (%)
50%
Point Hope
Noatak River
Kobuk River
Kotzebue
15 %
Approx. UAS range (400 km)
Marginal Ice Zone
Shishmaref
Wales
Nome
15%
Gambell
BERING SEA
Landfast ice
No data


LATITUDE
HQ 90 SYSTEM
GORDON AND BETTY
MOORE
FOUNDATION

HQ-90 AIRFRAME SPECIFICATIONS

PARAMETER	PERFORMANCE	VALIDATION METHOD
Line of Sight Range	60 Nautical miles nominal*	Flight Test
Maximum Endurance	20+ hours	Flight Test**
Mission Speed	40kts	Flight Test
Payload	12-20lbs	Flight Test
Max Gross Takeoff Weight	105lbs	Flight Test
Design Operational Altitude	15,000ft.	Design Goal

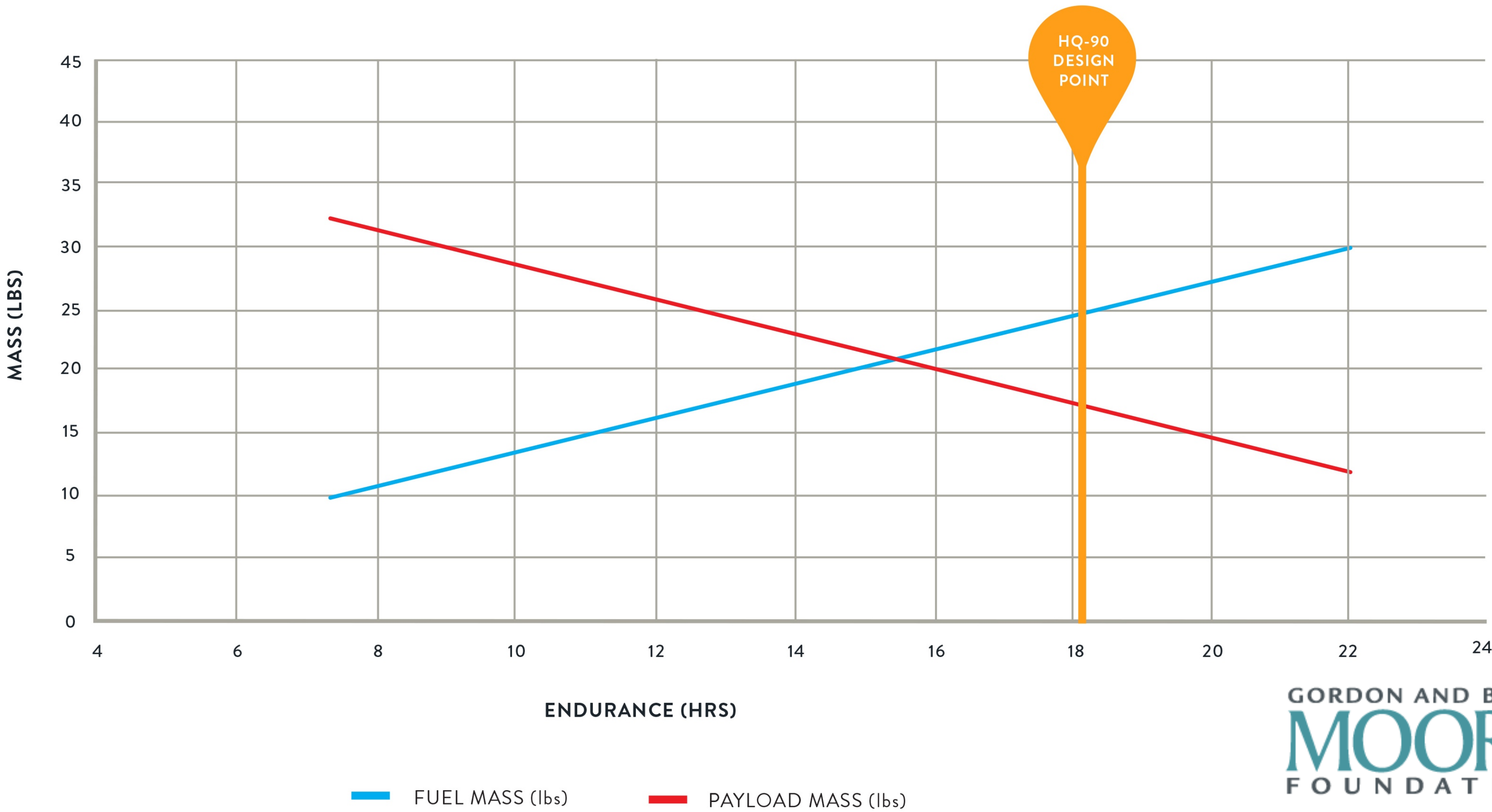
** with wave relay*

***Longest flight to date is 22.5 hours with 6lb payload and 5 hours fuel remaining on landing*

- 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

GORDON AND BETTY MOORE FOUNDATION

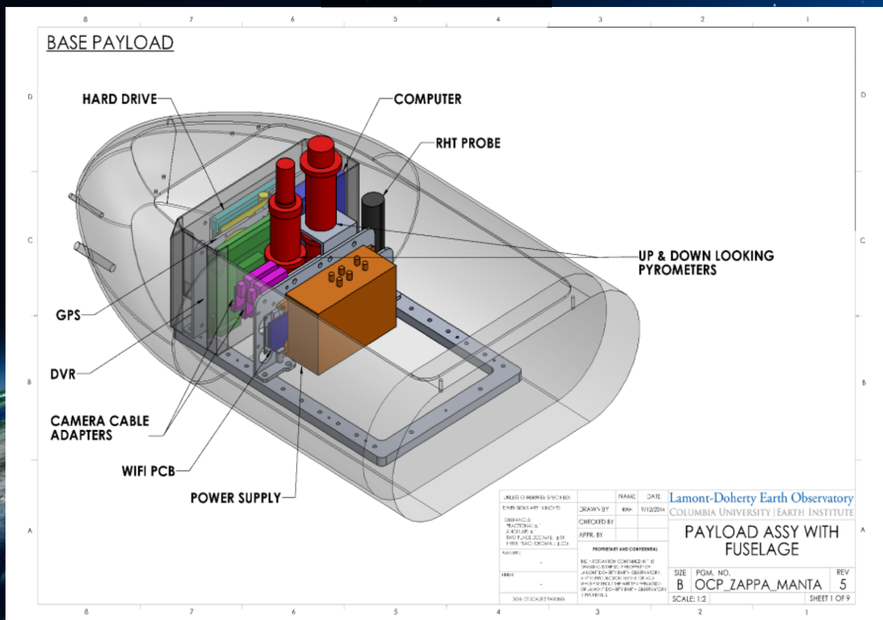
HQ-90 Airframe Endurance / Payload Tradeoff



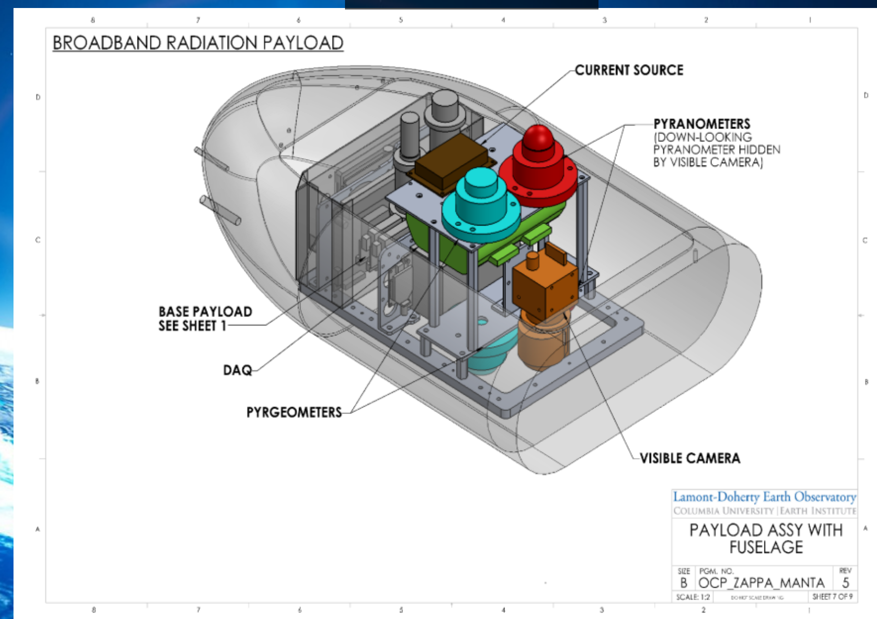
GORDON AND BETTY MOORE FOUNDATION

UAS Payload Development

BASE Payload



Sensor Module



BASE payload allows for quick change between sensor payloads

GORDON AND BETTY MOORE FOUNDATION

UAS Payloads

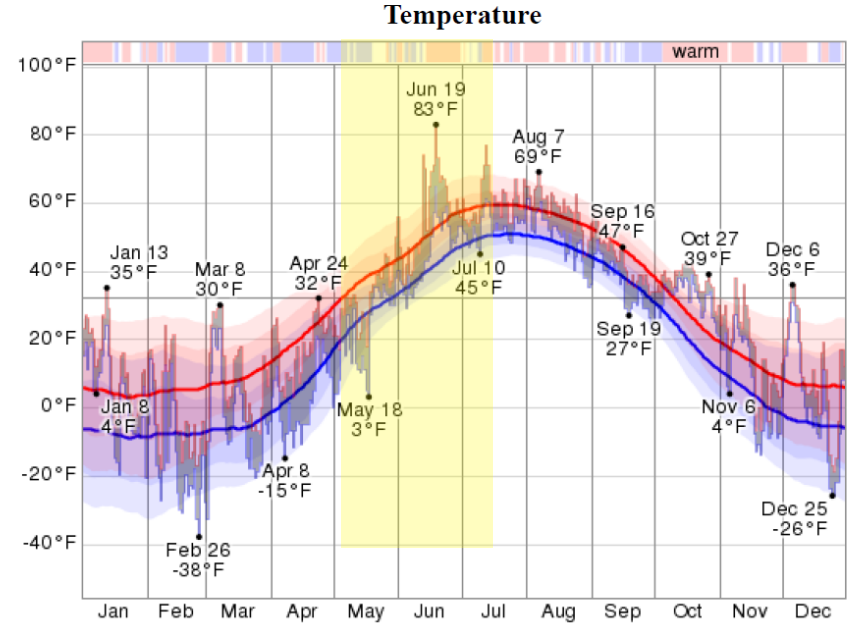
Table 1: Implemented science payloads and applications	
Payload	Sensing technologies
VIS-TIR*	High-resolution broadband visible (400-700 nm) imager, uncooled microbolometer (8-14 µm) imager sensitive to 0.05°C for skin sea surface temperature (SST) mapping, whitecapping, and other upper ocean processes.
Hi-TIR*	Cooled infrared (7.7 – 9.5 µm) imager sensitive to 0.02°C for skin SST mapping, whitecapping, and other upper ocean processes.
HYP-VNIR*	Hyperspectral visible (300-1000 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the upper-ocean to determine ocean color and biogeochemical mapping. Upward-looking narrow FOV spectrometer provides measurements for estimates of spectral albedo of varying surfaces including ocean.
HYP-NIR*	Hyperspectral near-infrared (900-1700 nm) imaging spectrometer with better than 3 nm spectral resolution for spectral radiance measurements of the near-surface ocean to determine ocean color and biogeochemical mapping.
Li-MET	LiDAR for wave height and surface roughness; fast response 3D wind speed and direction (100 Hz), fast response temperature (50 Hz), fast response relative humidity (100 Hz) for estimating momentum, latent heat and sensible heat turbulent fluxes.
RAD*	Upward- and downward-looking pryanometer (broadband solar 285-3000 nm) and pyrgeometer (broadband longwave; 4.5-40 µm) to measure full hemispheric irradiance to understand the surface energy budget and map albedo of varying surfaces including the ocean. High-resolution broadband visible (400-700 nm) imaging is used to map whitecapping and other upper ocean processes.
DDµD*	Drone-Deployed Micro-Drifters with launcher for in-flight ejection of up to four micro-dropsonde packages. The DDµD measures temperature, pressure, and relative humidity as it descends through the atmosphere. Once it lands on the ocean's surface, it deploys a string of sensors that measures temperature and salinity of the upper 2-3 meters of the ocean at fifteen minute intervals for up to two weeks as a buoy. The ocean sensors on the DDµD collect and store data and then transmit the data back to the UAS on subsequent flights from up to 10 miles away.
***also included upward- and downward-looking pyrometers (8-14 µm) to measure narrow field-of-view (FOV) skin SST and ice-surface temperature.**	

Sea Ice Radar Development – Built on experience from IcePOD at LDEO

GORDON AND BETTY MOORE FOUNDATION

Kotzebue Temperatures

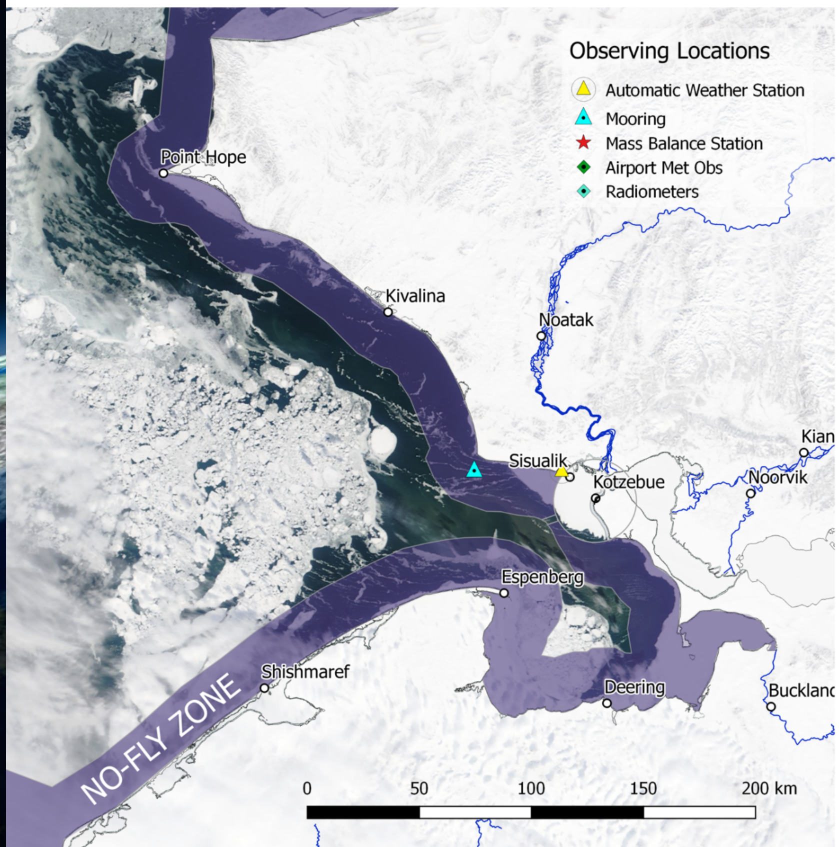
UAS: Maximum Temperature 100.4F and Minimum Temperature -4F

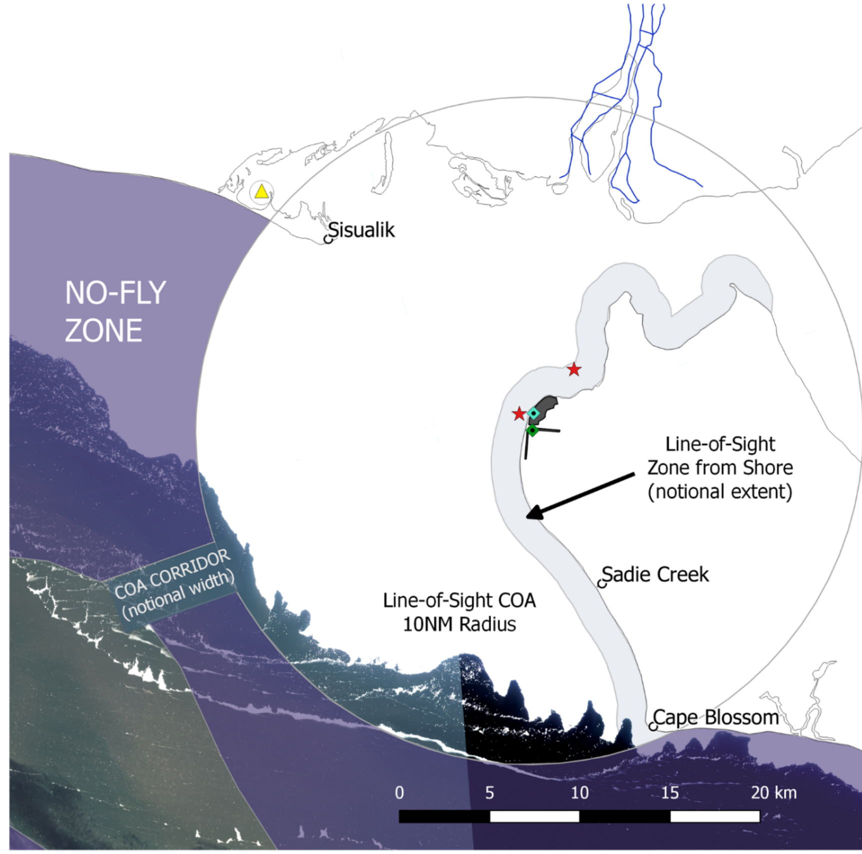


The daily low (blue) and high (red) temperature during 2013 with the area between them shaded gray and superimposed over the corresponding averages (thick lines), and with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile). The bar at the top of the graph is red where both the daily high and low are above average, blue where they are both below average, and white otherwise.

GORDON AND BETTY MOORE FOUNDATION

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).

GORDON AND BETTY MOORE FOUNDATION

UAS in Kotzebue – Takeoff

N AND BETTY MOORE FOUNDATION

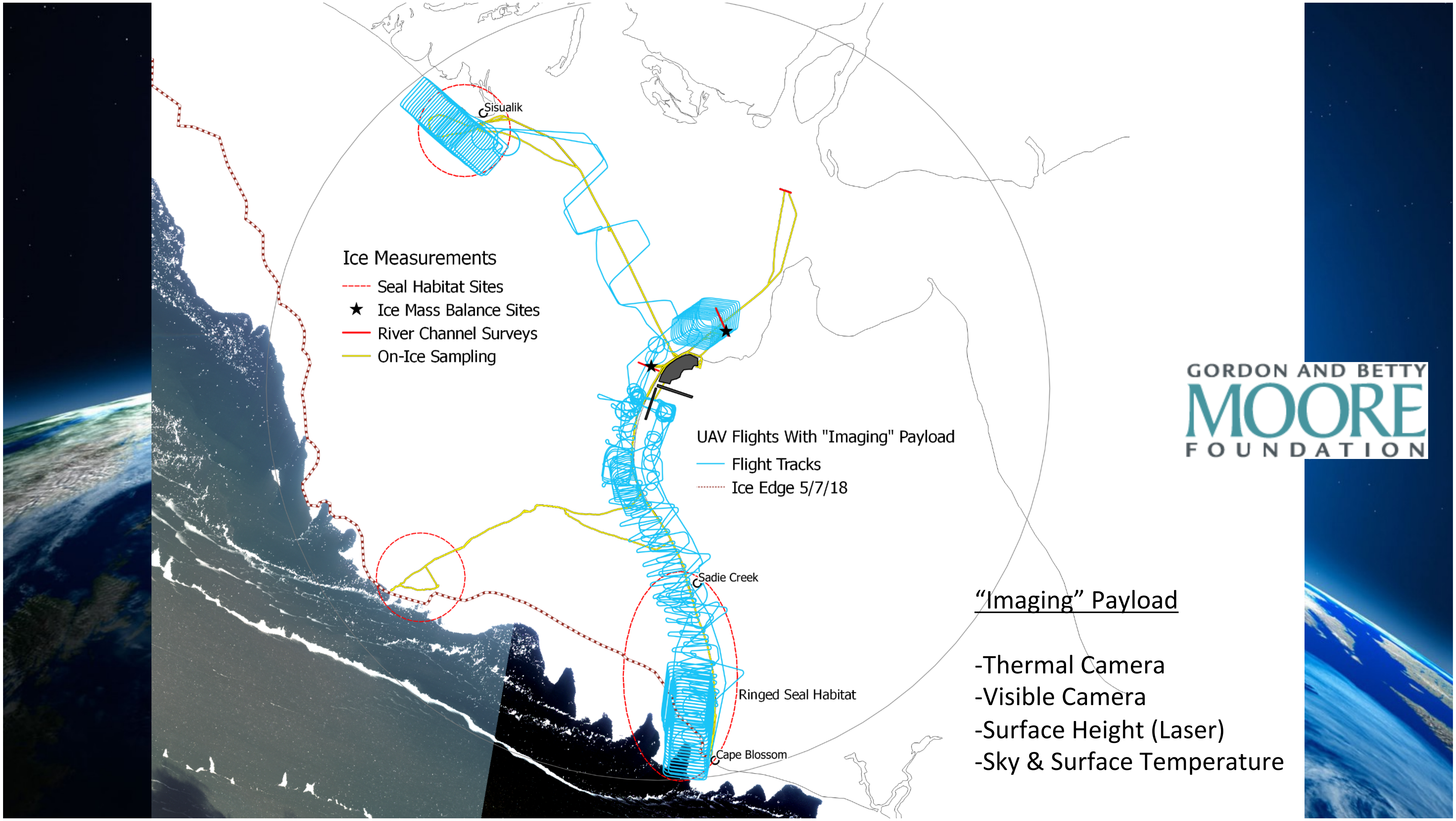
UAS in Kotzebue – Flight Summary

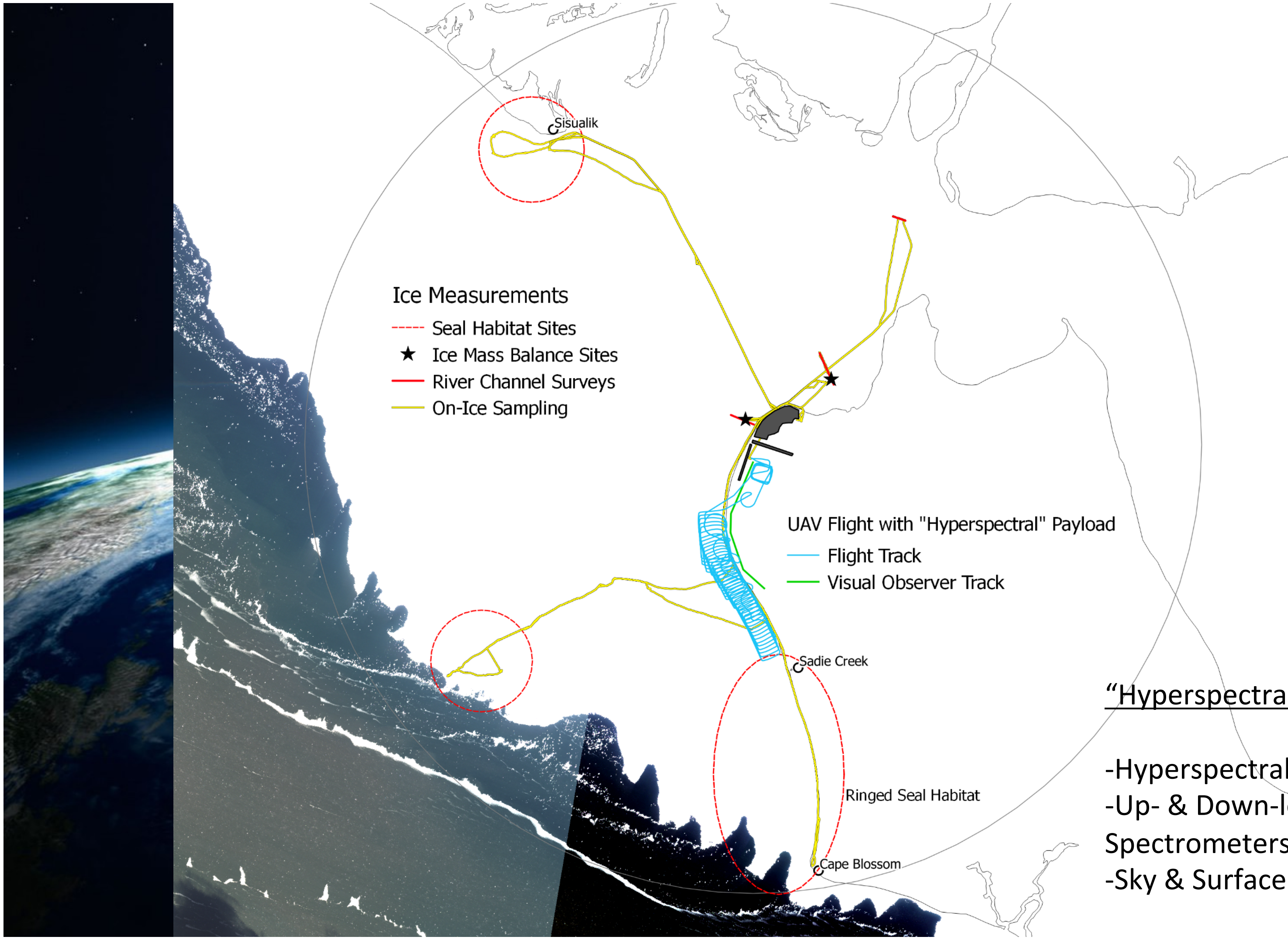
- **Tucson Integration:**
  - 7 Total Flights (3 hours)
  - 2 Functional Check Flight (FCF) with Hover Test
  - 5 Flights with Payloads (2 hours)
    - ATOM, RAD, VNIR, DDuD payloads

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

GORDON AND BETTY MOORE FOUNDATION

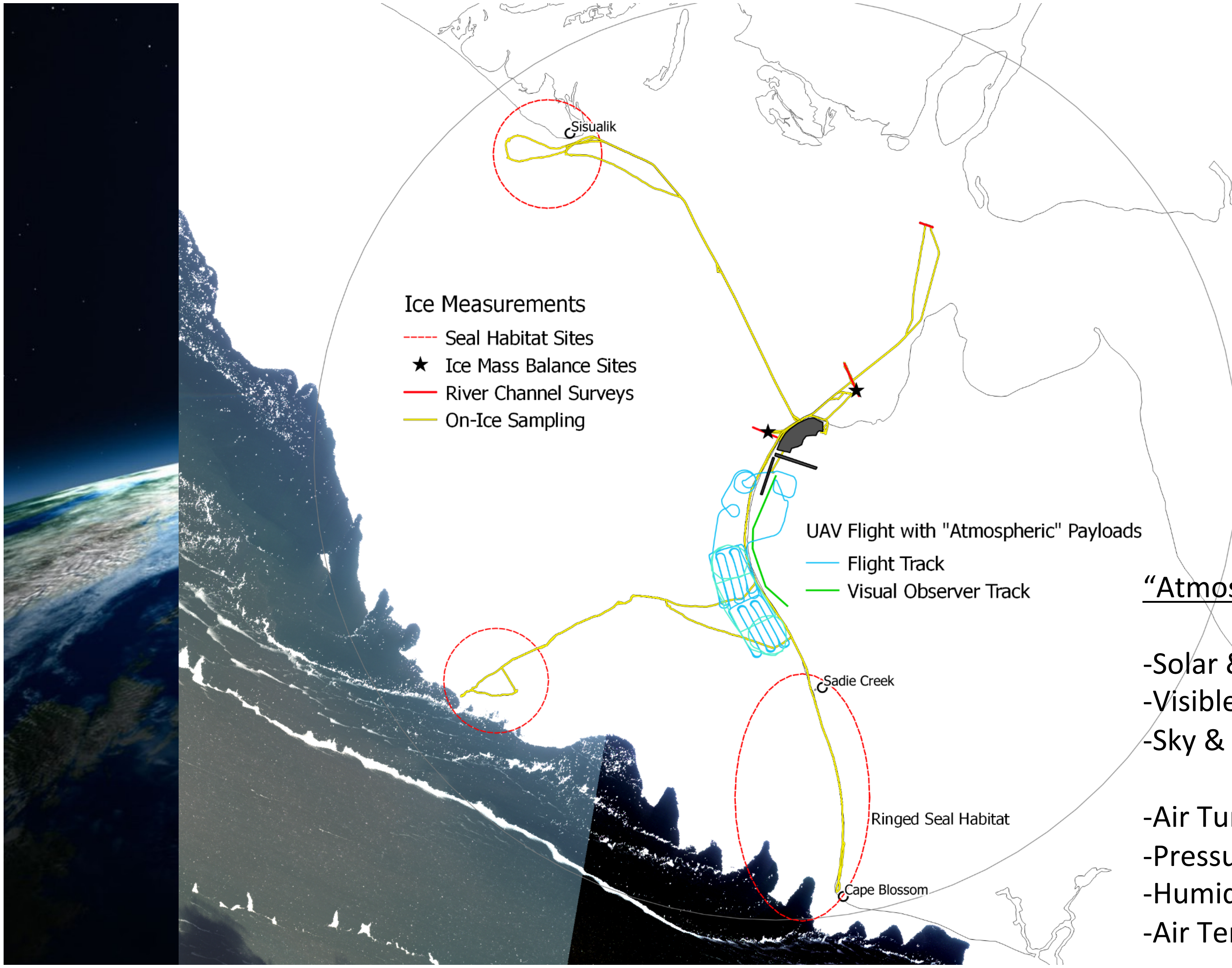

Sisualik
Ice Measurements
Seal Habitat Sites
Ice Mass Balance Sites
River Channel Surveys
On-Ice Sampling
UAV Flights With "Imaging" Payload
Flight Tracks
Ice Edge 5/7/18
Sadie Creek
Ringed Seal Habitat
Cape Blossom
GORDON AND BETTY
MOORE
FOUNDATION
“Imaging” Payload
-Thermal Camera
-Visible Camera
-Surface Height (Laser)
-Sky & Surface Temperature



GORDON AND BETTY MOORE FOUNDATION

<u>“Hyperspectral” Payload</u>

-Hyperspectral Camera
-Up- & Down-looking Spectrometers
-Sky & Surface Temperature



GORDON AND BETTY MOORE FOUNDATION

“Atmospheric” Payloads

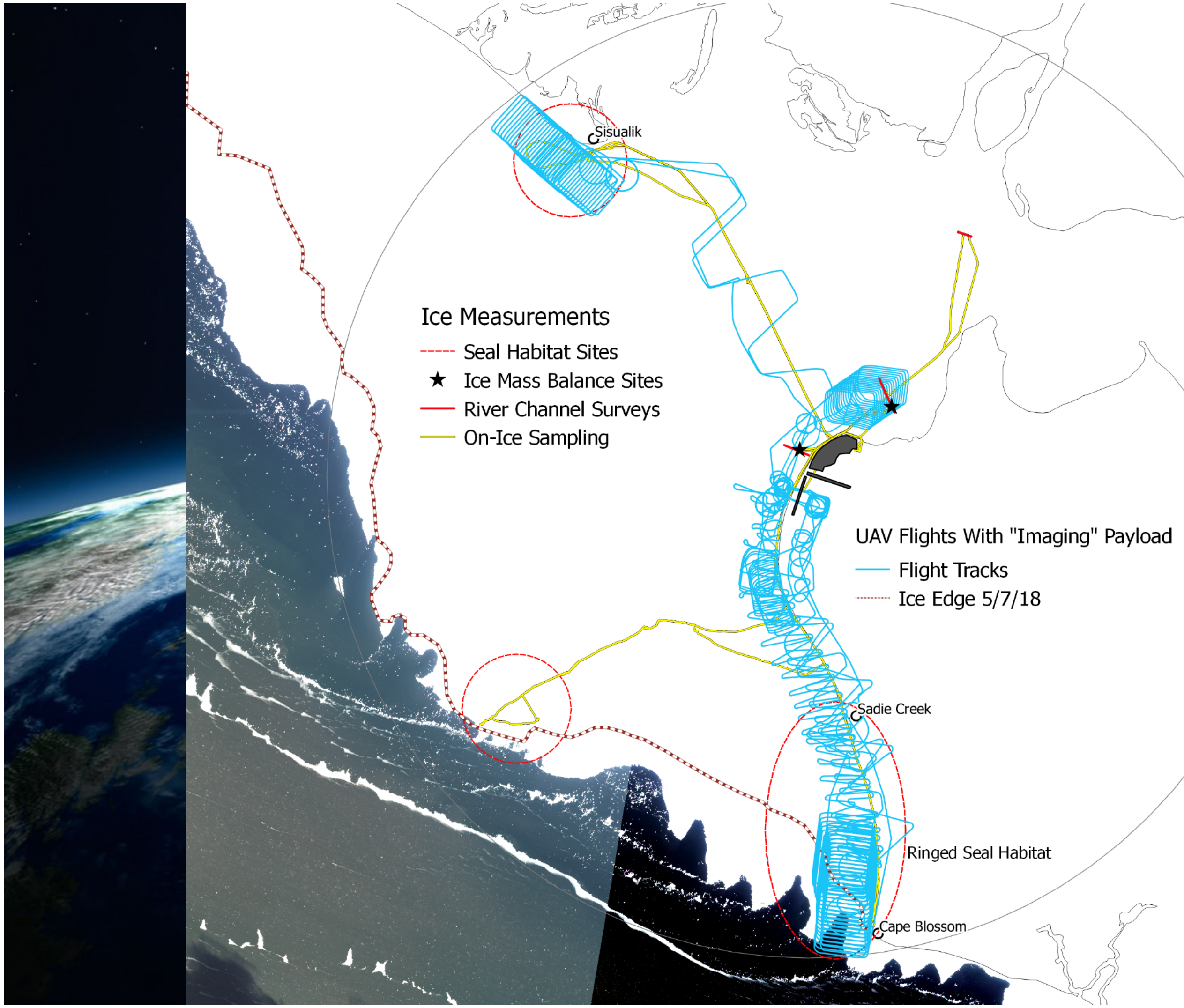
-Solar & Longwave Radiation
-Visible Camera
-Sky & Surface Temperature

-Air Turbulence
-Pressure
-Humidity
-Air Temperature

UAS in Kotzebue – Accomplishments

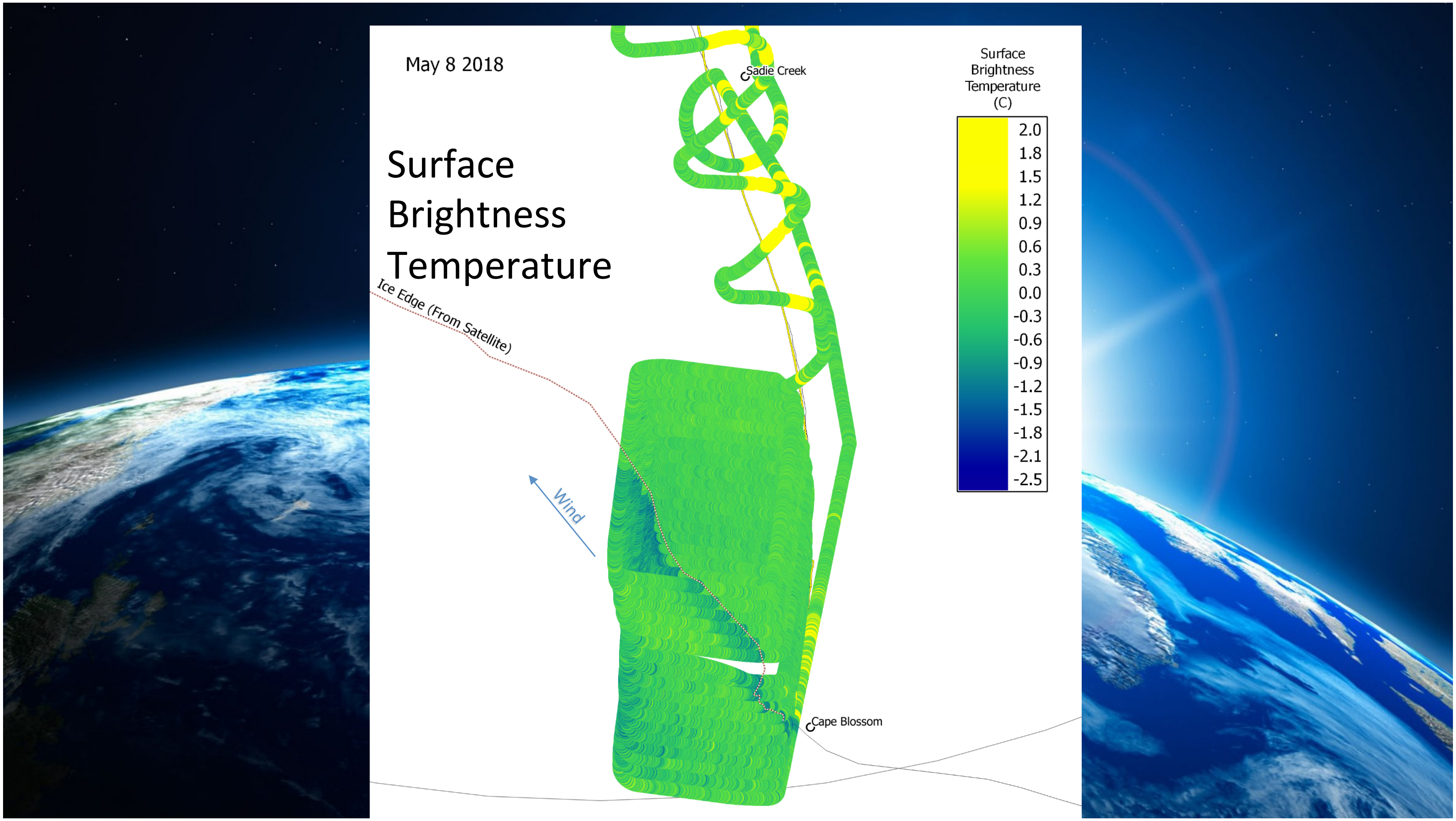
- 24 Total Successful Flights (42 hours) with HQ-90B
- 17 Successful Flights with payloads.
- Flights were conducted with takeoff directly into the wind.
- Demonstrated the ability to operate the HQ technology autonomously.
- Demonstrated the ability to operate the HQ technology in cold weather conditions.

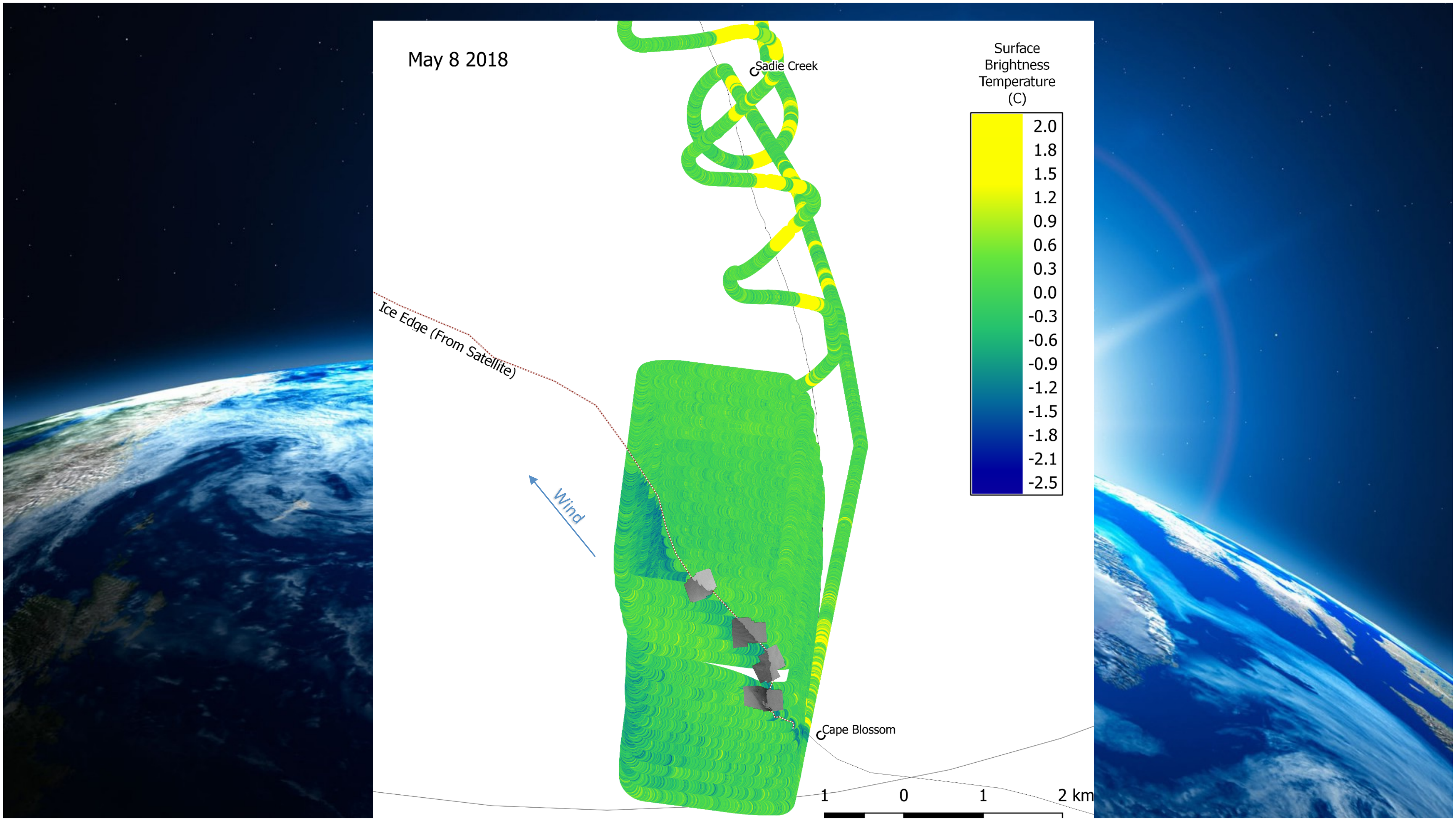
GORDON AND BETTY MOORE FOUNDATION



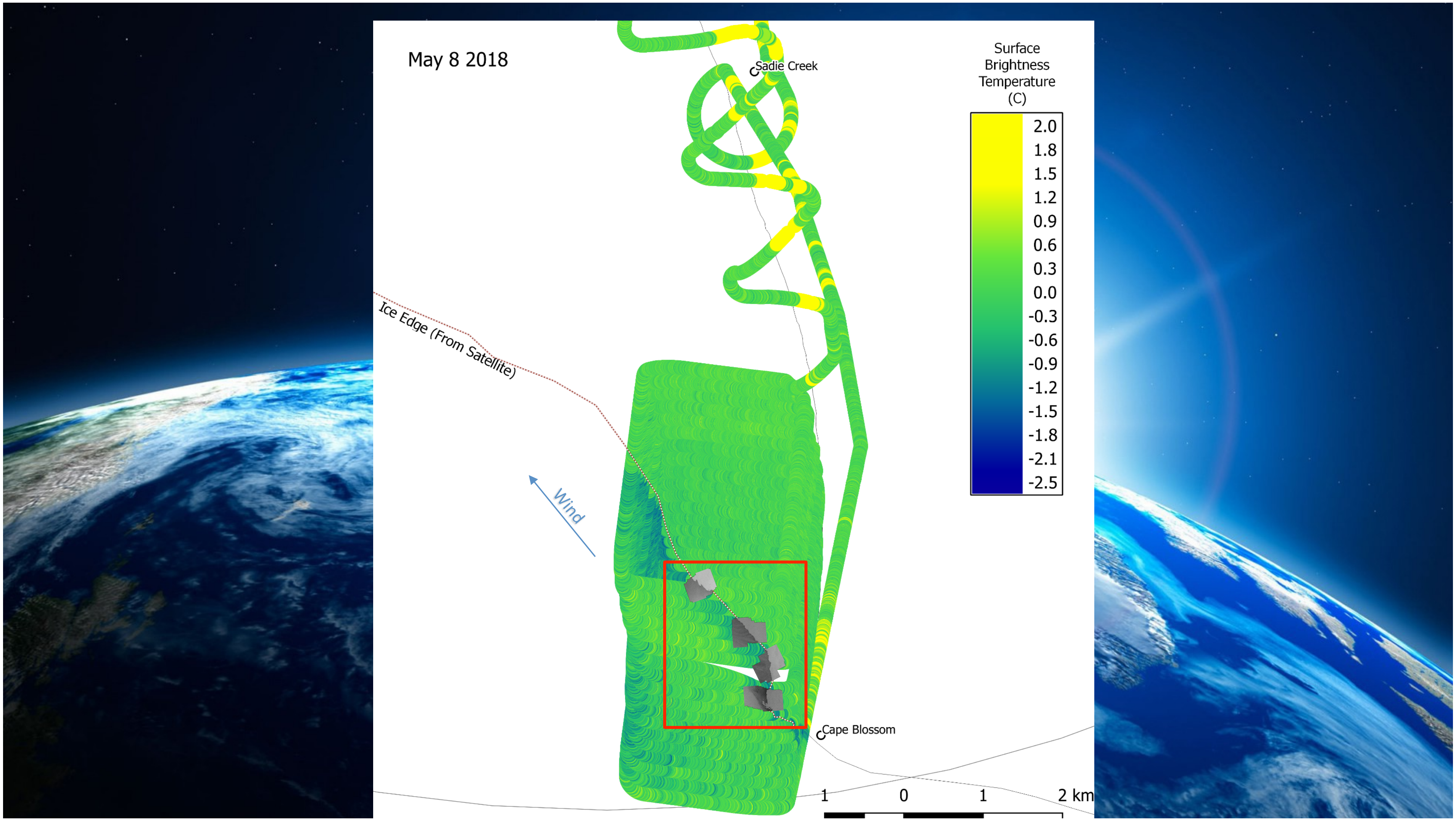
<u>“Imaging” Payload</u>

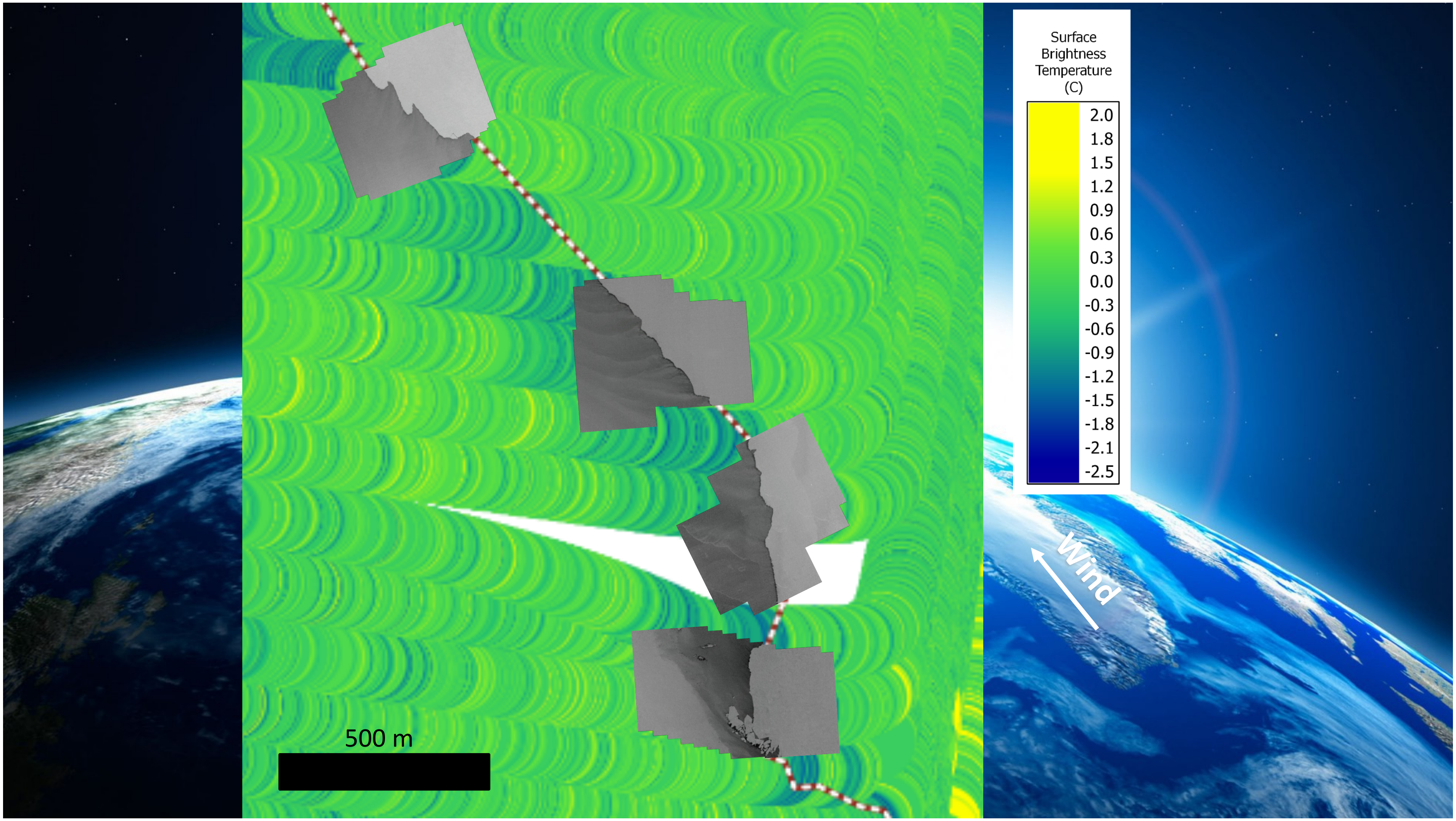
-Thermal Camera
-Visible Camera
-Surface Height (Laser)
-Sky & Surface Temperature


May 8 2018
Surface
Brightness
Temperature
Sadie Creek
Ice Edge (From Satellite)
Wind
Cape Blossom
Surface
Brightness
Temperature
(C)
2.0
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
-2.1
-2.5

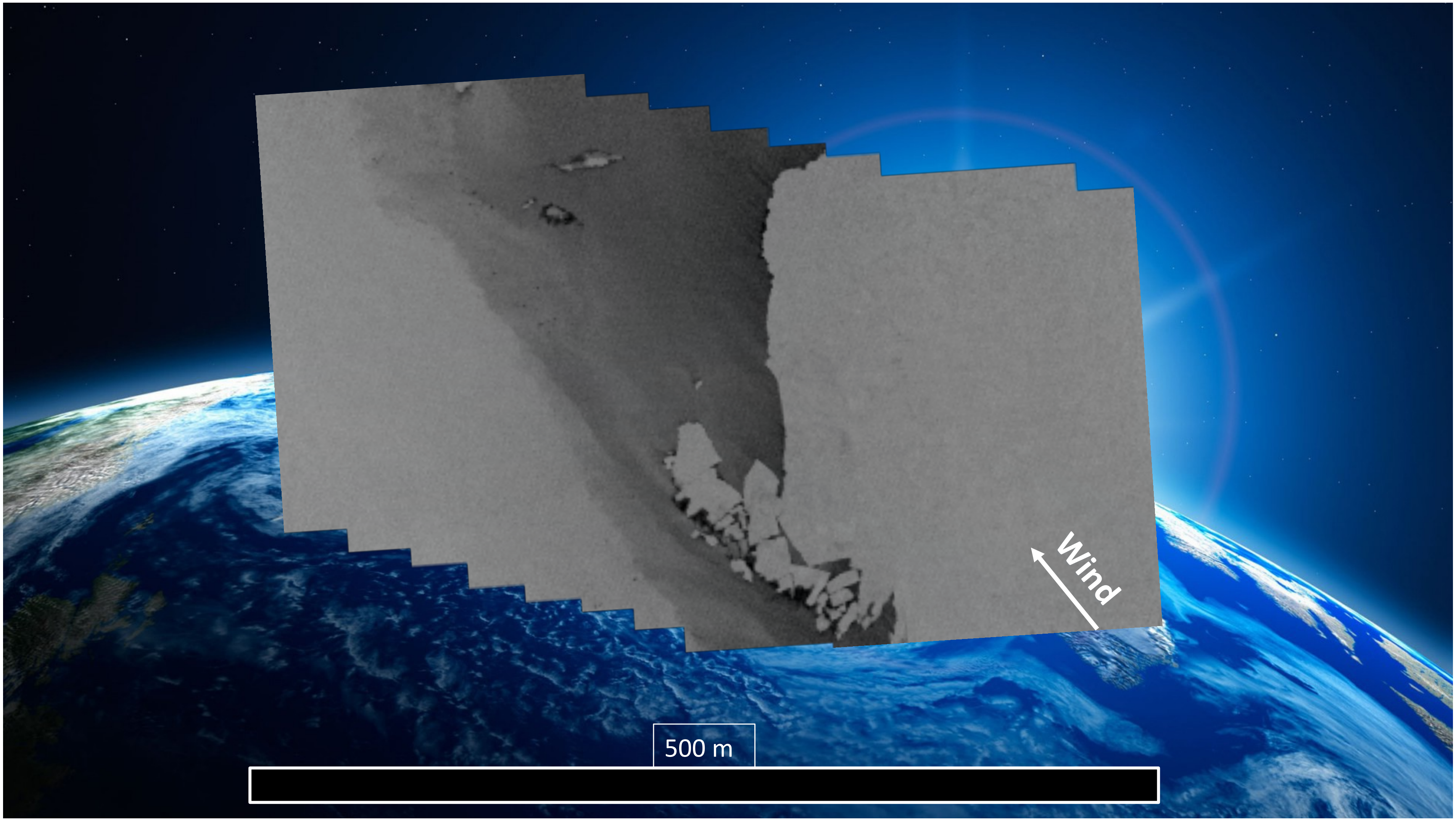


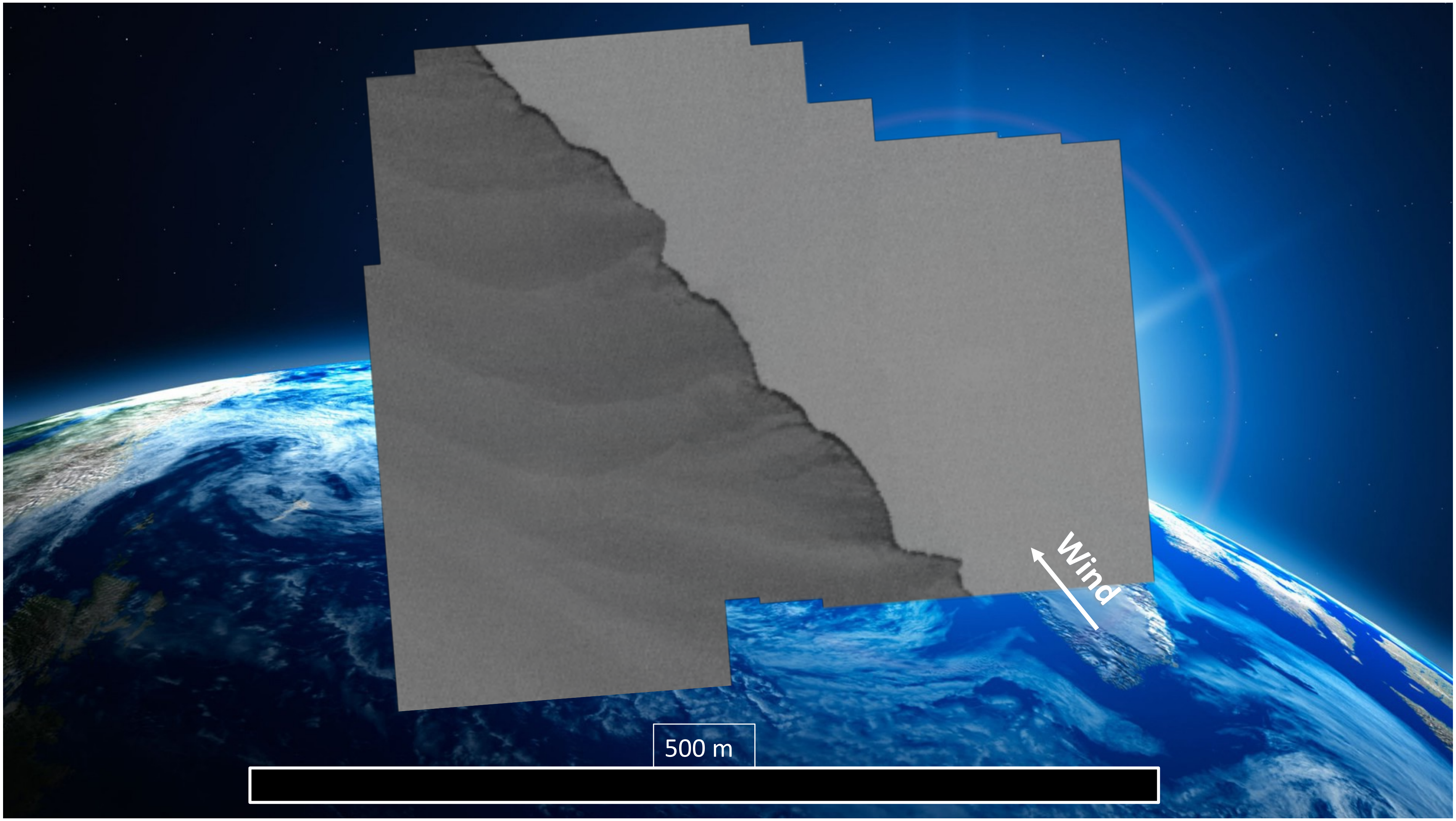
May 8 2018
Surface Brightness Temperature (C)
2.0
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
-2.1
-2.5
Sadie Creek
Ice Edge (From Satellite)
Wind
Cape Blossom
1 0 1 2 km


May 8 2018
Sadie Creek
Surface
Brightness
Temperature
(C)
2.0
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
-2.1
-2.5
Ice Edge (From Satellite)
Wind
Cape Blossom
1
0
1
2 km

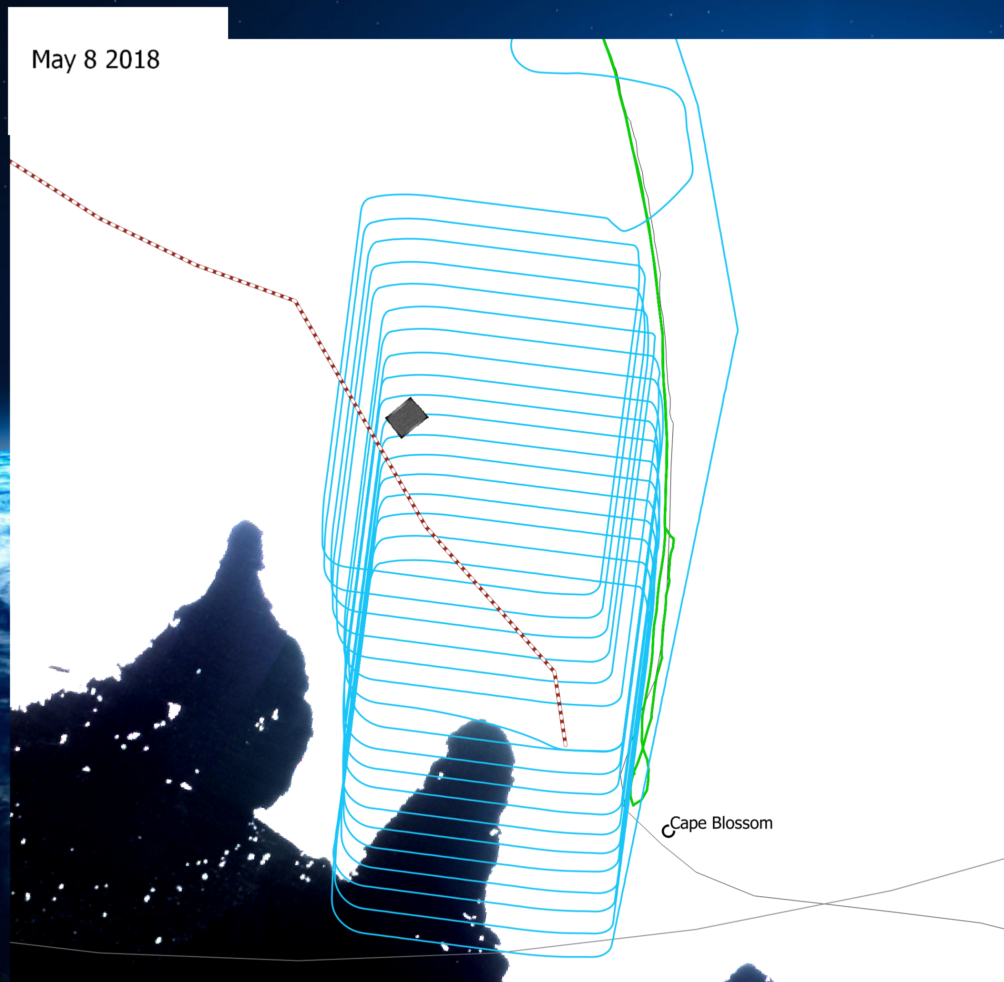


Surface Brightness Temperature (C)
2.0
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
-2.1
-2.5
500 m
Wind

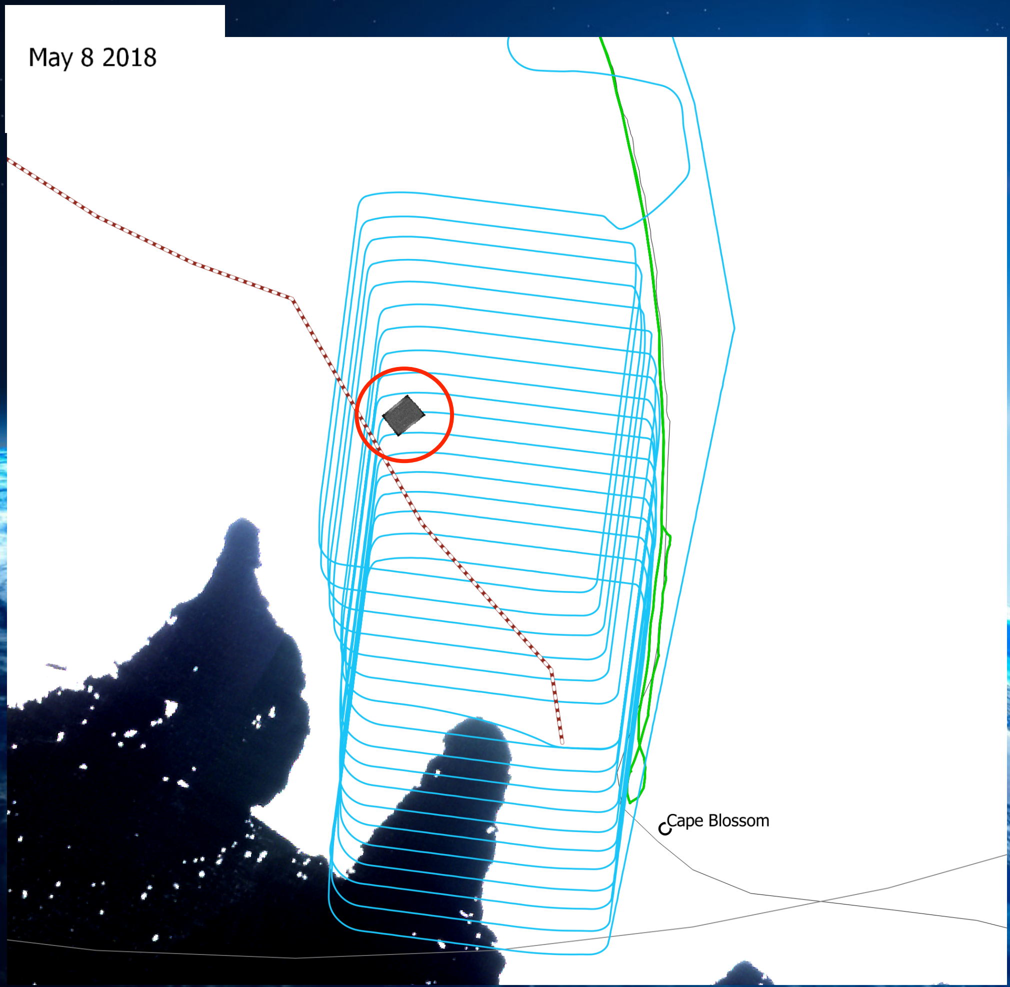

Wind
500 m


Wind
500 m

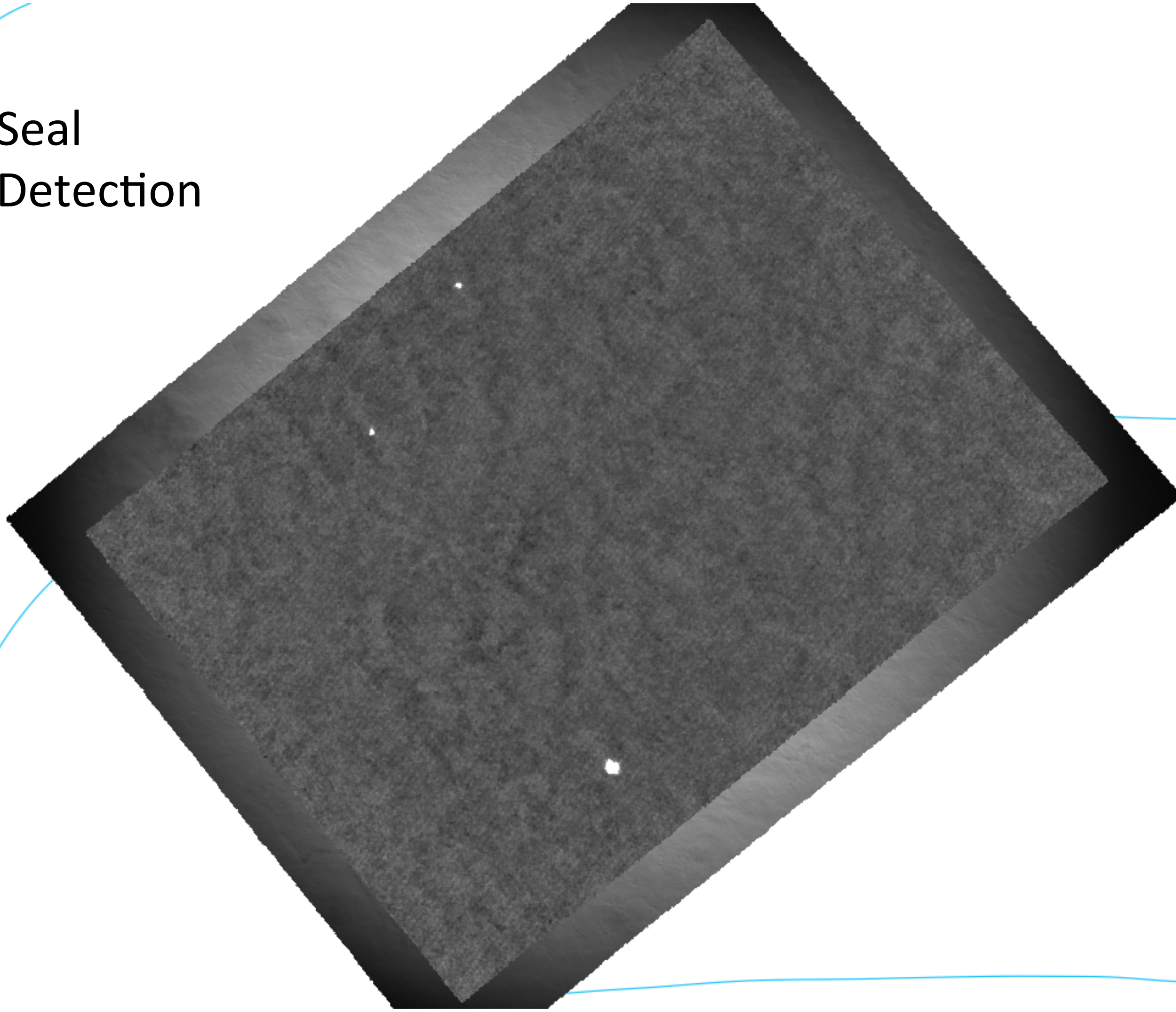
Seal Detection



Seal Detection

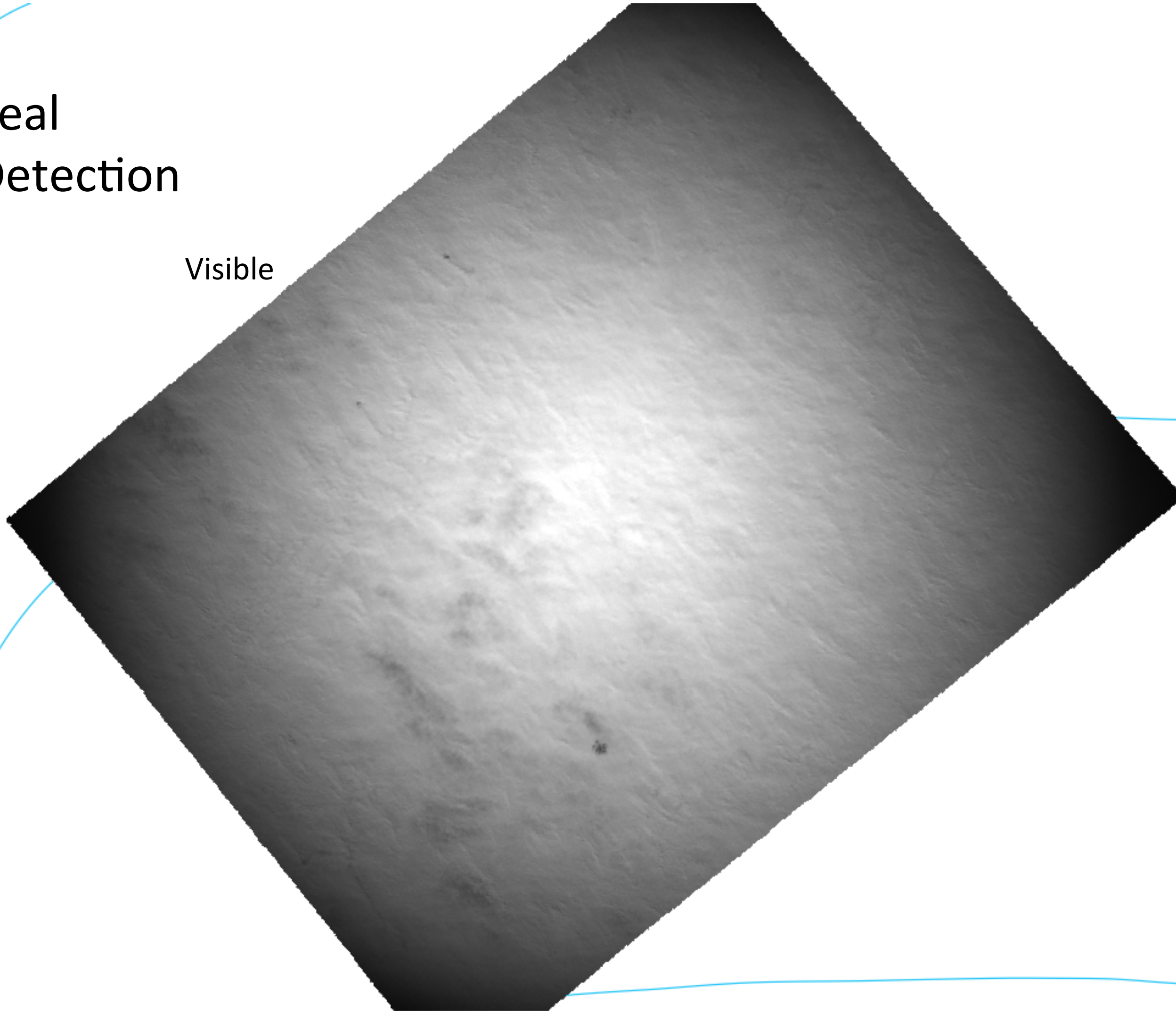


Seal Detection



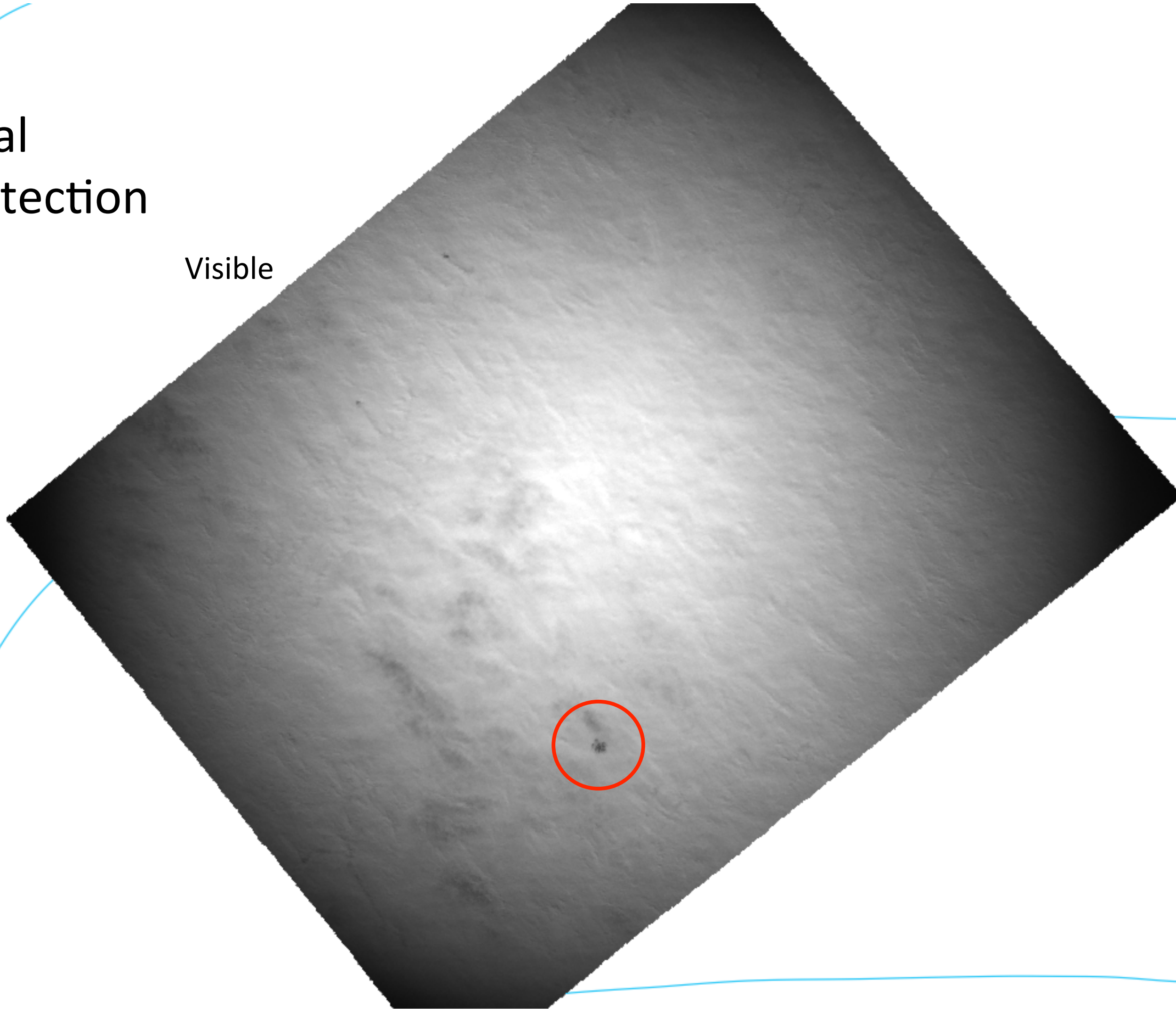
Seal Detection

Visible

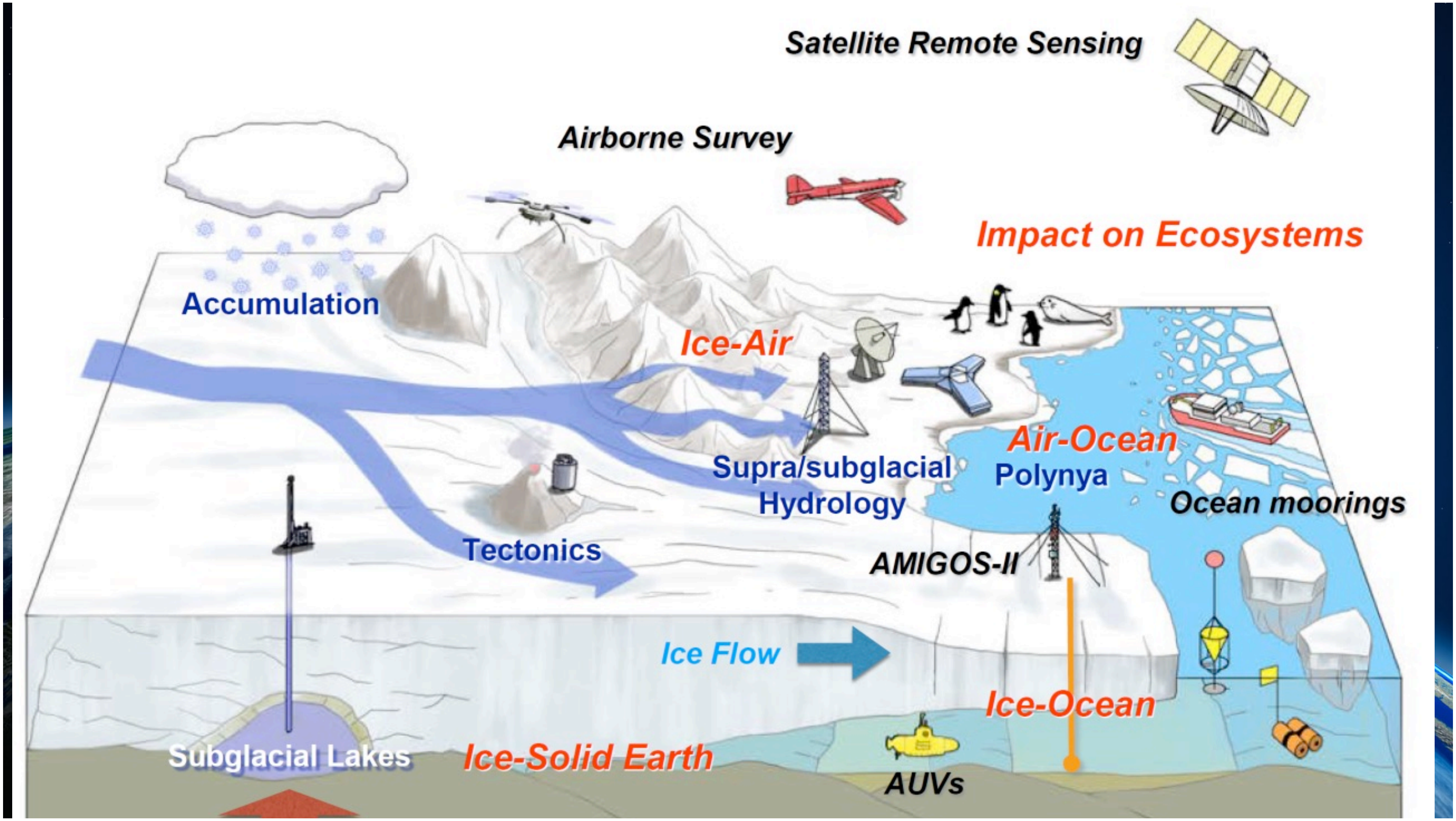


Seal Detection

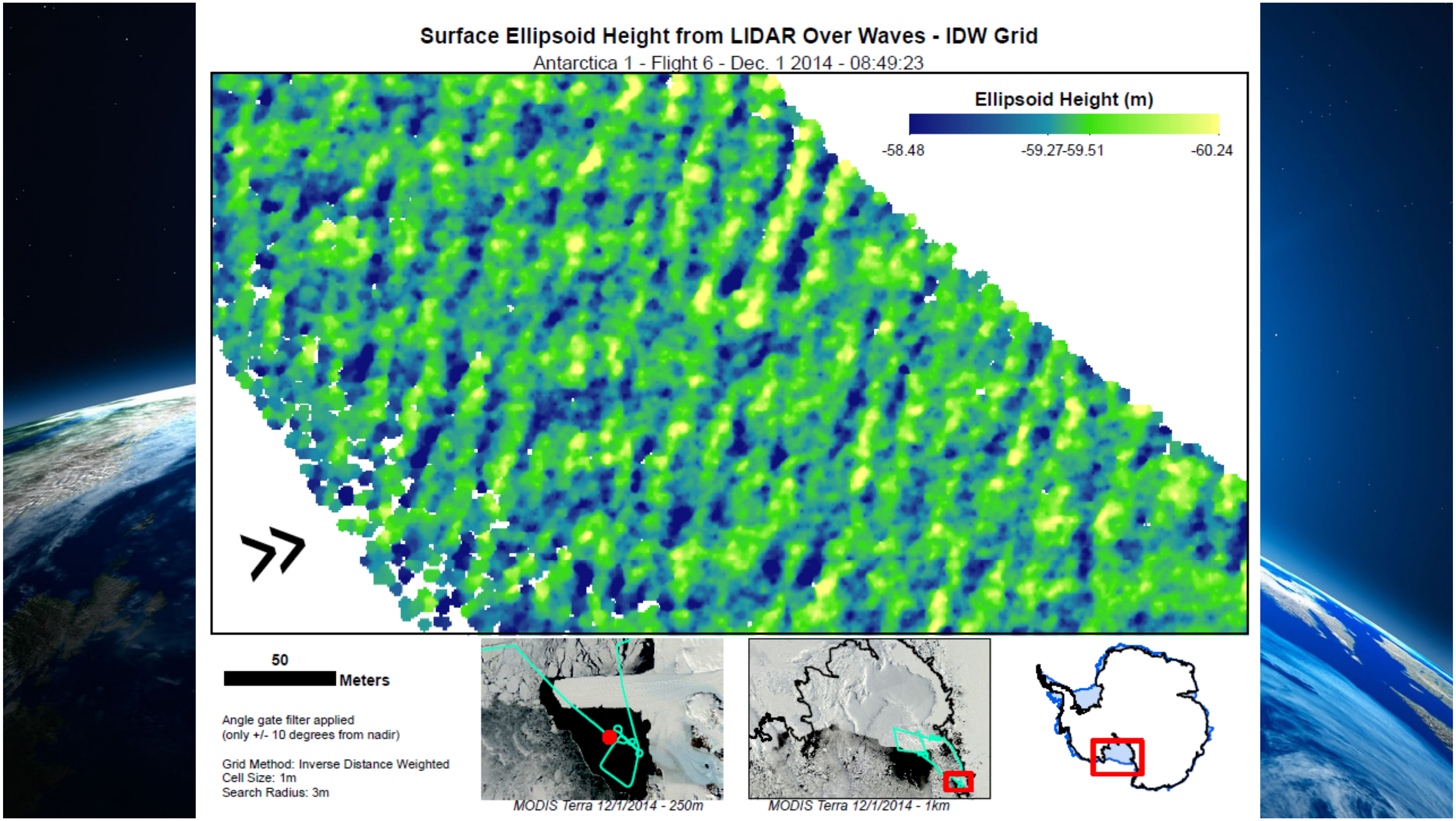
Visible

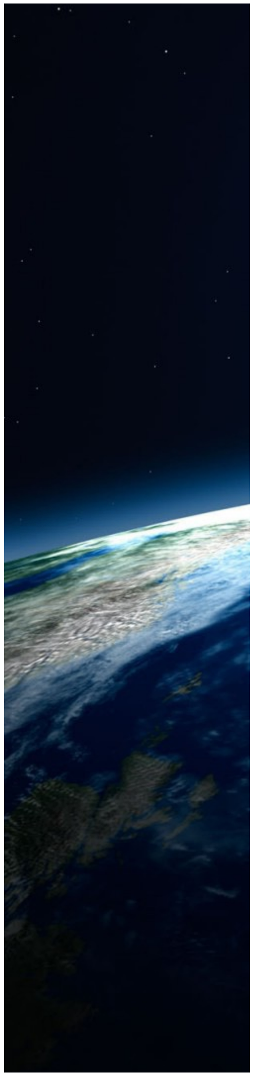


Seal Detection


Satellite Remote Sensing
Airborne Survey
Impact on Ecosystems
Accumulation
Ice-Air
Air-Ocean
Polynya
Supra/subglacial
Hydrology
Ocean moorings
Tectonics
AMIGOS-II
Ice Flow
Ice-Ocean
Subglacial Lakes
Ice-Solid Earth
AUVs

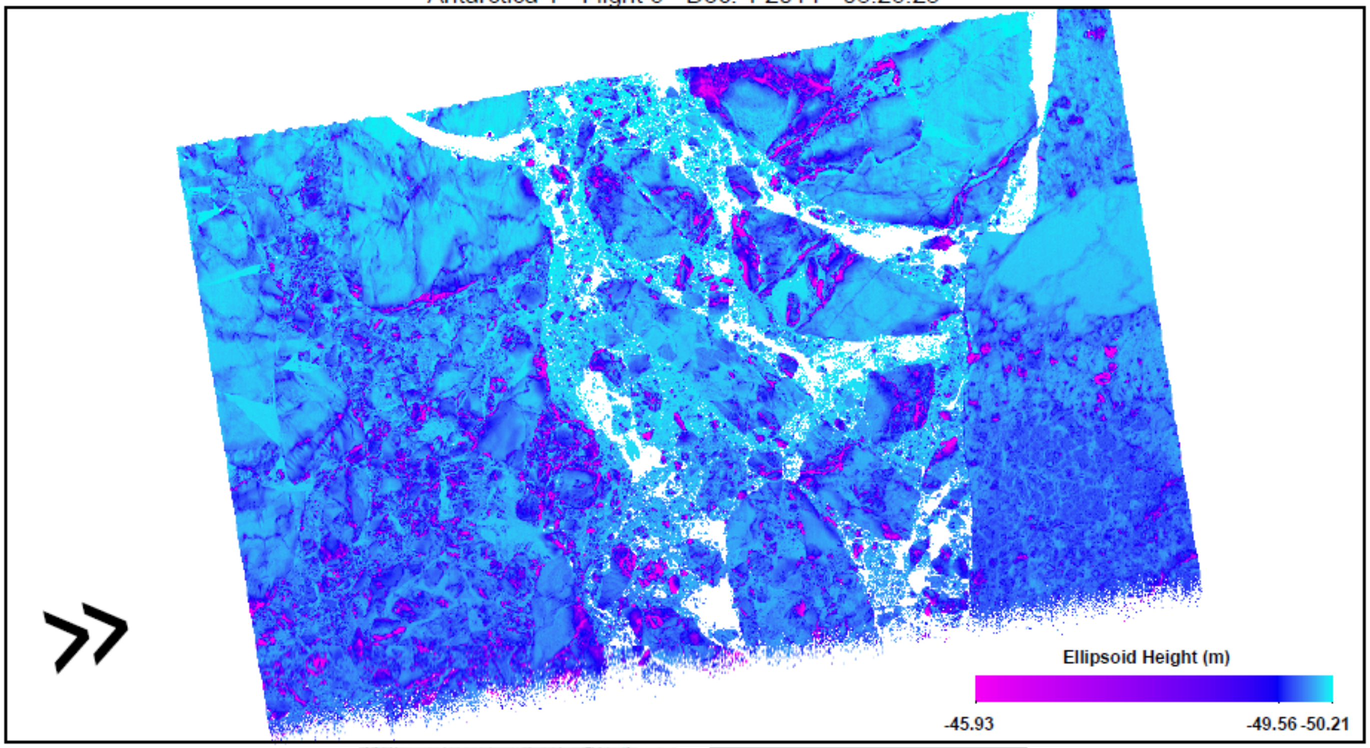
R/V Araon


Surface Ellipsoid Height from LIDAR Over Waves - IDW Grid
Antarctica 1 - Flight 6 - Dec. 1 2014 - 08:49:23
Ellipsoid Height (m)
-58.48
-59.27-59.51
-60.24
50
Meters
Angle gate filter applied
(only +/- 10 degrees from nadir)
Grid Method: Inverse Distance Weighted
Cell Size: 1m
Search Radius: 3m
MODIS Terra 12/1/2014 - 250m
MODIS Terra 12/1/2014 - 1km



Surface Ellipsoid Height from LIDAR Over Sea Ice - IDW Grid

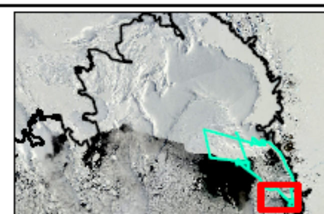
Antarctica 1 - Flight 6 - Dec. 1 2014 - 08:26:23



200
Meters

Grid Method: Inverse Distance Weighted
Cell Size: 20cm
Search Radius: 80cm

MODIS Terra 12/1/2014 - 250m



MODIS Terra 12/1/2014 - 1km


QUESTIONS?