New observing technology and systems in Southern Ocean observations

Notes from the Arctic: Accelerating Science Driven Innovation

N.Lawrence[1], C.Mordy[2], S.Stalin[1], H.Tabisola[2], C.Meinig[1], J.Cross[1], A. Sutton[1], N.Cokelet[1], D.Zhang[2], M.Cronin[1], and many additional engineering staff and scientists

[1]National Oceanic and Atmospheric Administration

[2]Cooperative Institute for Climate, Ocean, and Ecosystem Studies

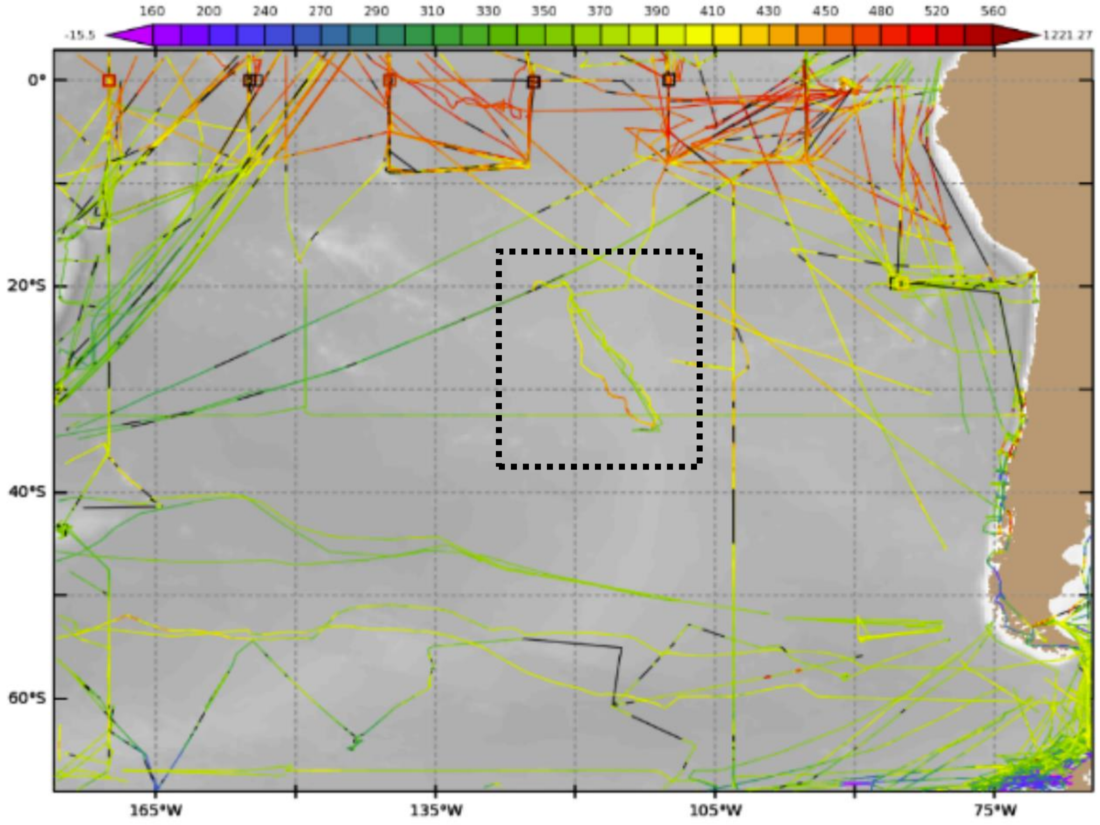
PACIFIC MARINE ENVIRONMENTAL LAB | SEATTLE, WA

CICOES

NOAA RESEARCH
PACIFIC MARINE ENVIRONMENTAL LABORATORY

Filling gaps has impact in other regions of the S. Hemisphere

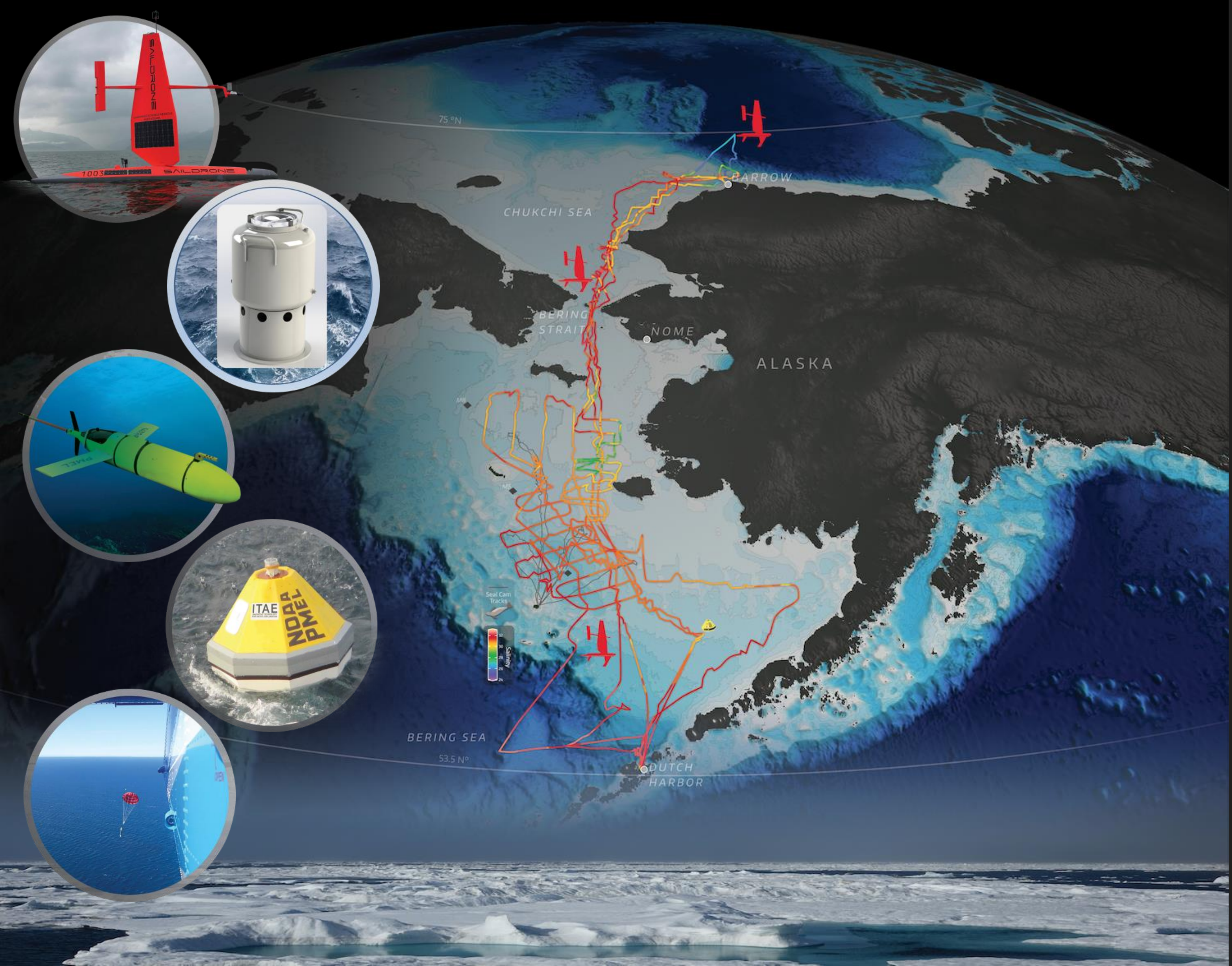
Preliminary work by Dave Munro, Amanda Fay, Stew Sutherland as part of the Takahashi Legacy Project



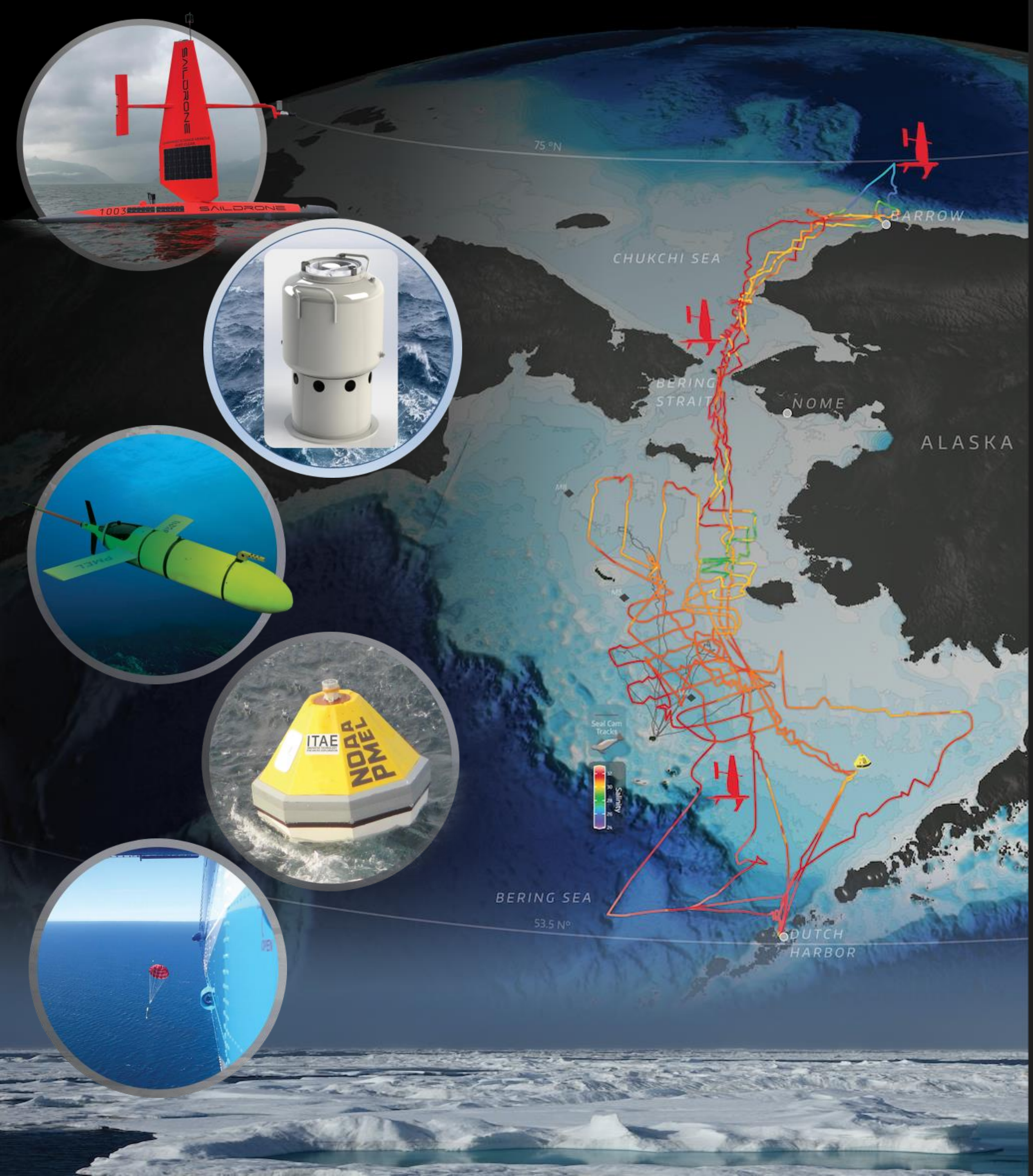
All *f*CO_2 observations in the last 20 years

South Pacific Wave Glider USV data set:

- ~4300 measurements in a climatology of ~30 million
- Changes global CO_2 flux climatology by 0.1 Pg or ~5%



Remote
Vast
Harsh
Changing

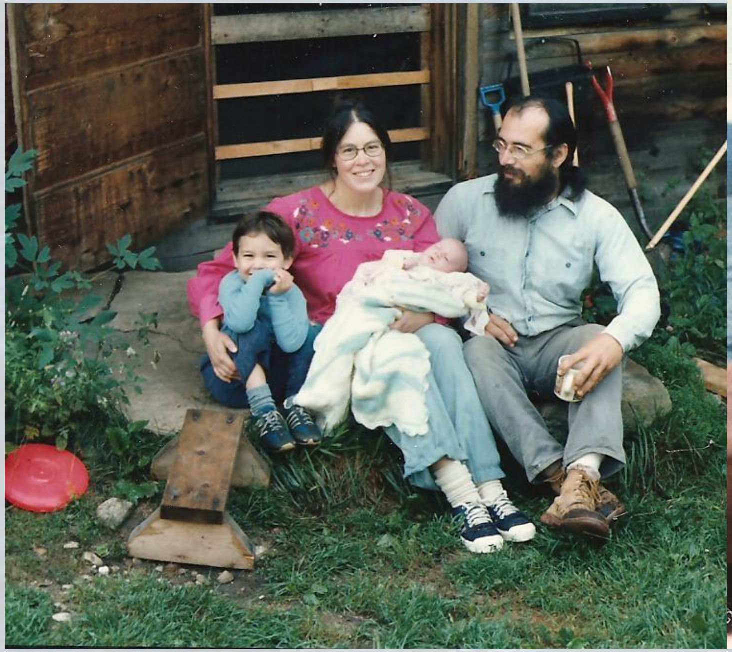


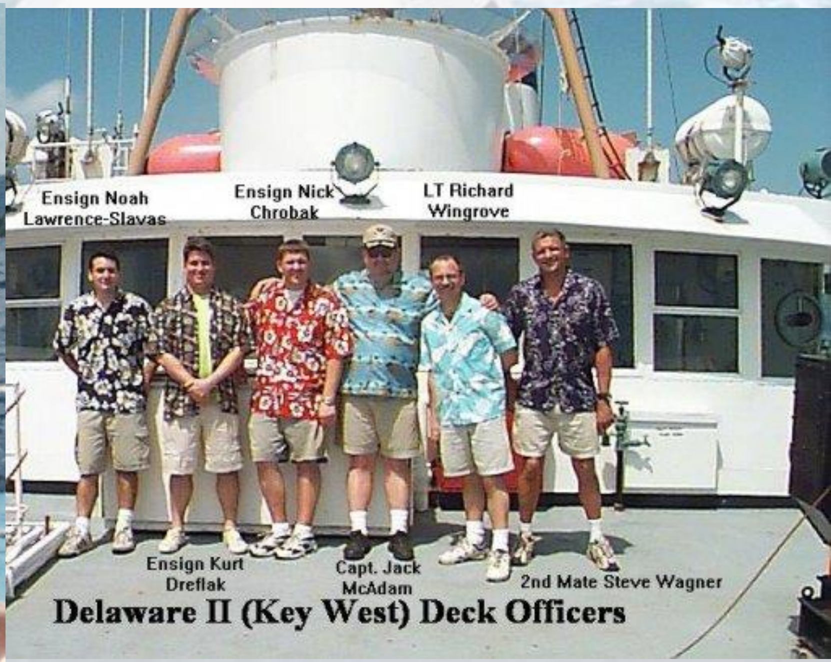
Rapid Change

- My road to here and now
- The case for focused technology development
- Technology development approaches
  - w/ examples

Why?

Societal implications of ocean change ≠ capacity of ocean research community





- Conduct R&D to enhance NOAA's observational capabilities.
- Develop and operate large global observational arrays.

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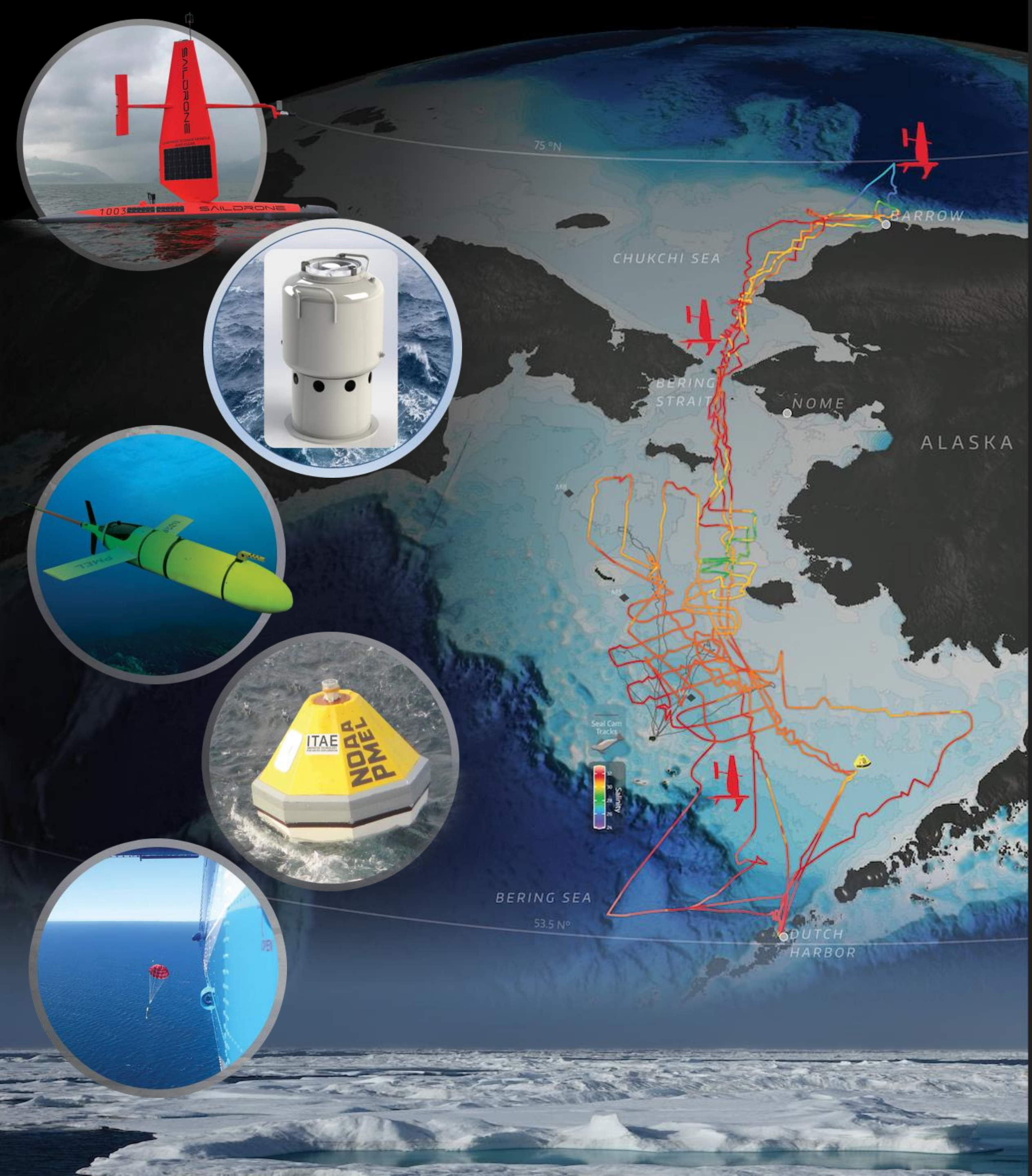

- My road to here and now
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  - w/ examples

New observing technology and systems in Southern Ocean observations

Slido questions for discussion:

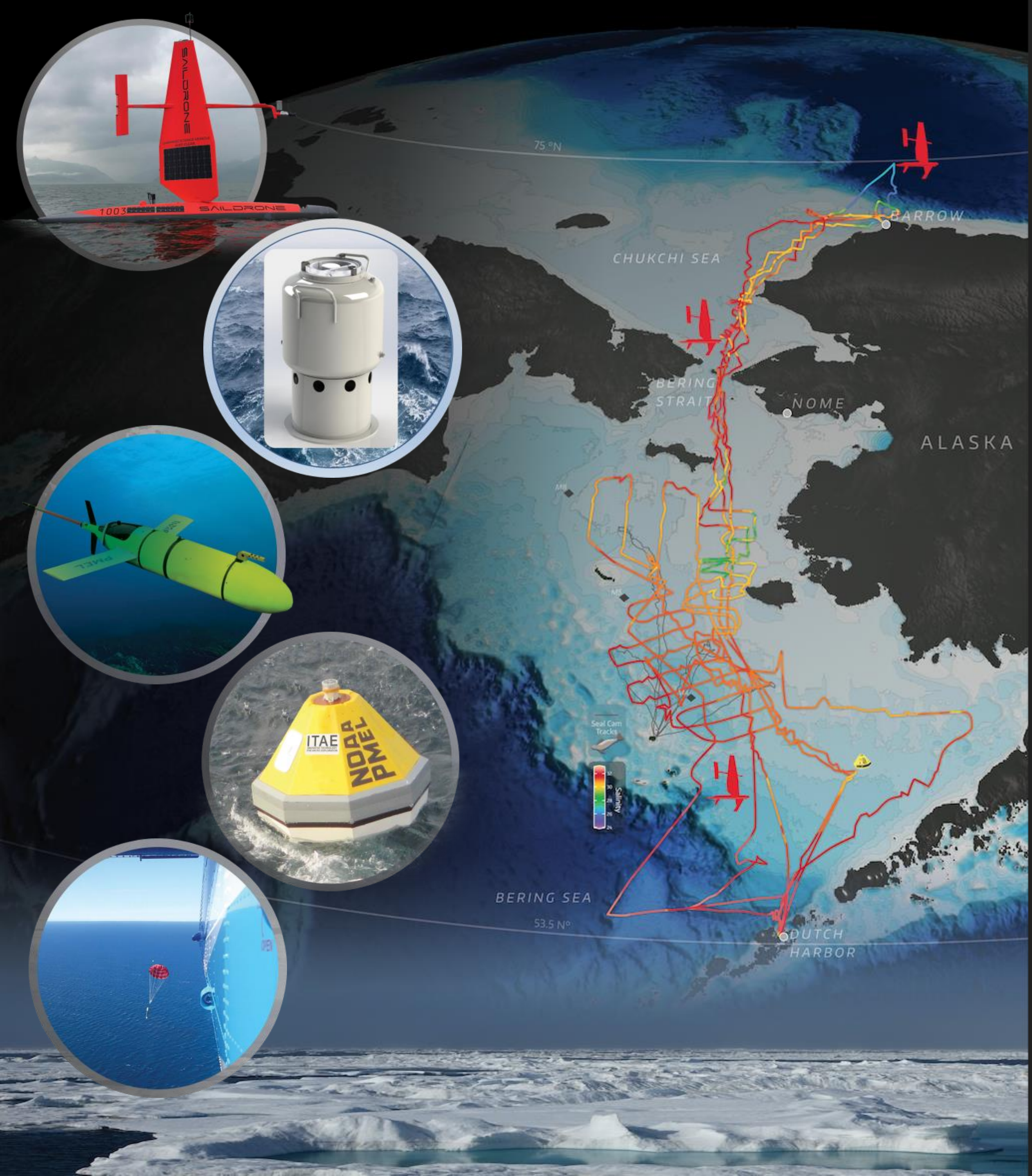
1. What are your SOOS scientific questions or engineering challenges that need to be answered?
    1. ?
    2. ?
2. What are the technology limitations that are keeping you from meeting these challenges?
    1. ?
    2. ?

* Please respond with problems and needs, not solutions

EDD Arctic Drivers:

- Question #1: Engineering Challenge:
  - The ocean environment is changing faster than our ability to measure and understand it

- Question #2: Technology Limiters:
  - Making ocean observations is too hard
  - Ocean observation technology development is too slow



- My road to here and now
- The case for focused technology development
- Technology development approaches
  - Increasing access
  - Accelerating innovation
    - Targeted funding
    - Leveraging partnerships

Expanding access to ocean carbon technology

Smaller, more flexible, easier to use…

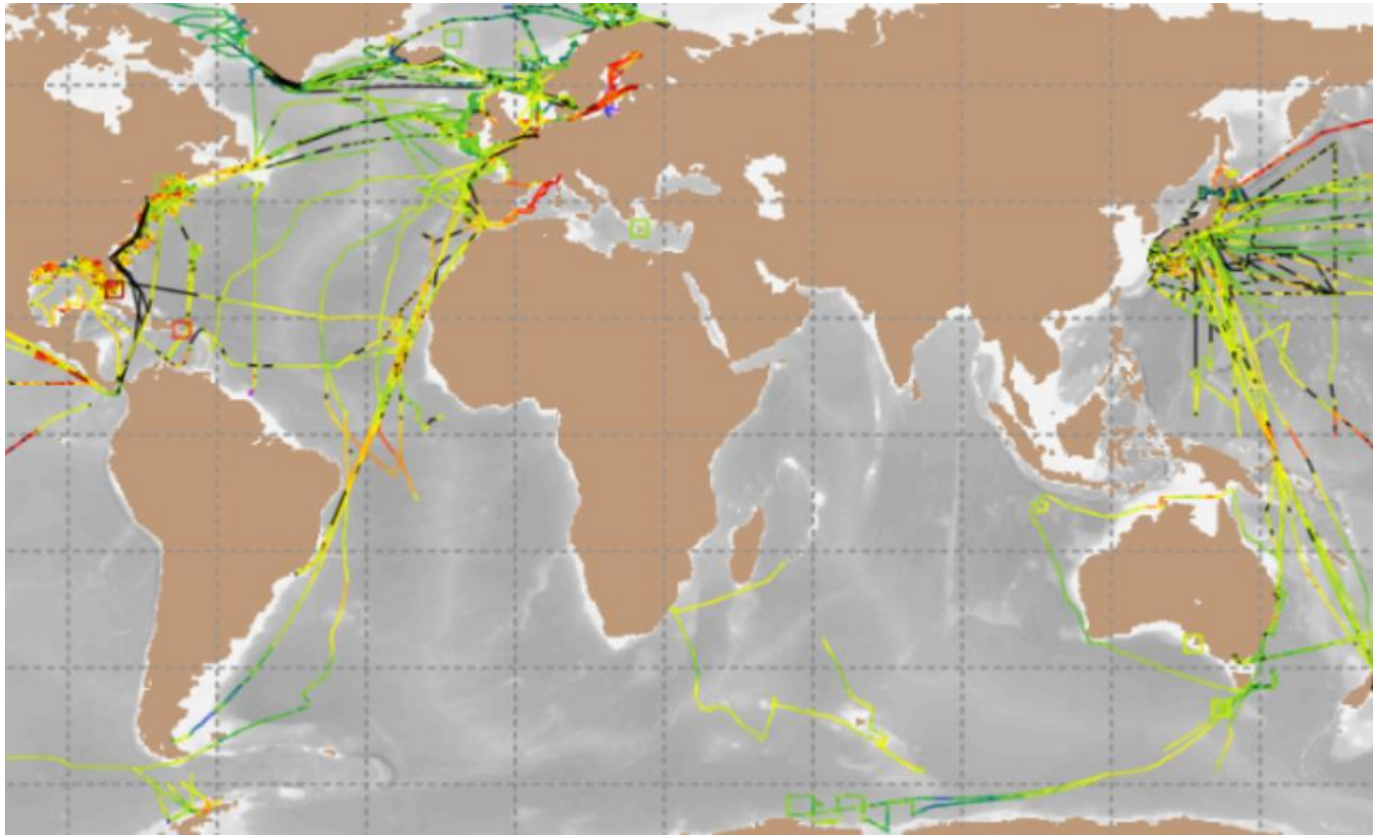
same quality, endurance

ASVCO2™

Autonomous Surface Vehicle CO_2 Sensor

NOAA GLOBAL OCEAN MONITORING & OBSERVING

About Us | The Ocean | Research | Education | News



LATEST OCEAN CARBON DATA ATLAS SHOWS A SIGNIFICANT DECLINE IN OCEAN CO2 MEASUREMENTS

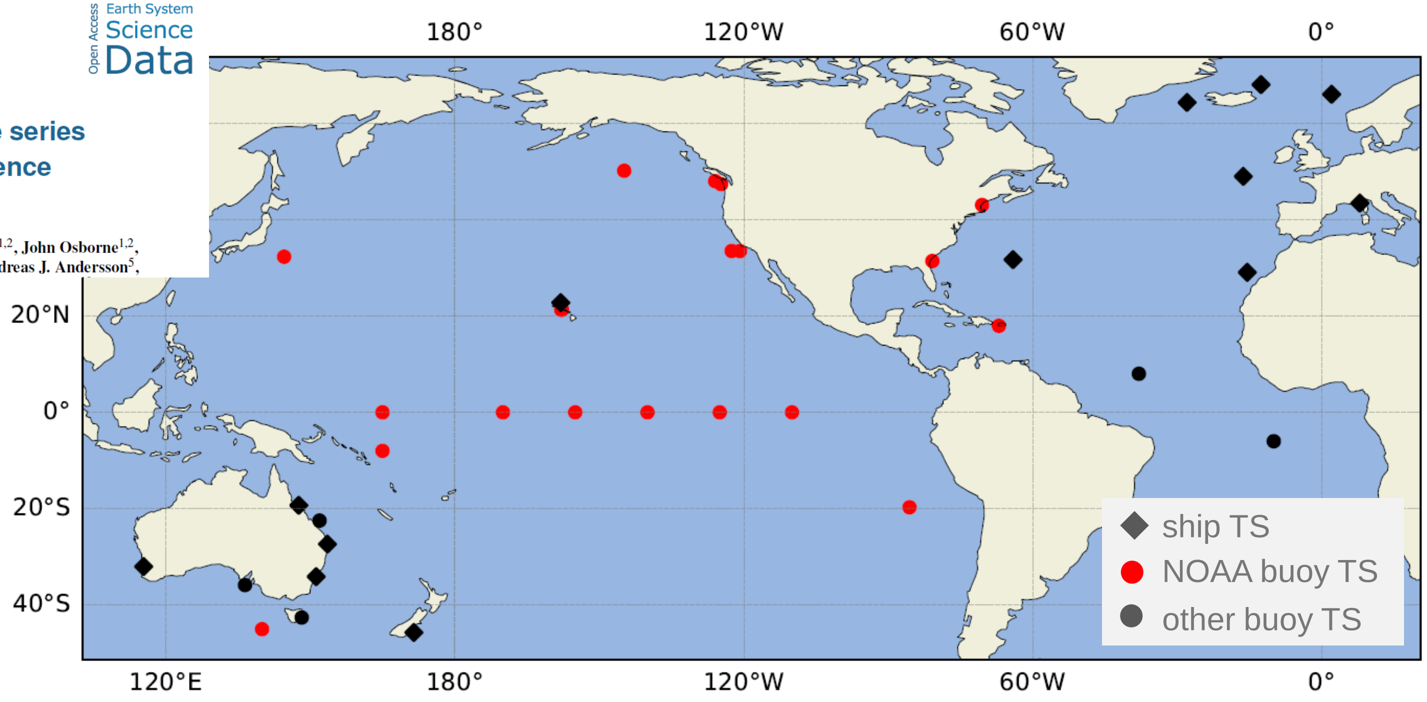
News / By Jessica Gwinn / July 12, 2023 / carbon dioxide, global carbon budget, SOCAT

Earth Syst. Sci. Data, 11, 421–439, 2019
https://doi.org/10.5194/essd-11-421-2019

Open Access Earth System Science Data

Autonomous seawater pCO_2 and pH time series from 40 surface buoys and the emergence of anthropogenic trends

Adrienne J. Sutton[1], Richard A. Feely[1], Stacy Maenner-Jones[1], Sylvia Musielwicz[1,2], John Osborne[1,2], Colin Dietrich[1,2], Natalie Monacci[3], Jessica Cross[1], Randy Bott[1], Alex Kozyr[4], Andreas J. Andersson[5],



decade-long ocean carbon time series (TS) stations

$MAPCO_2$ transferred

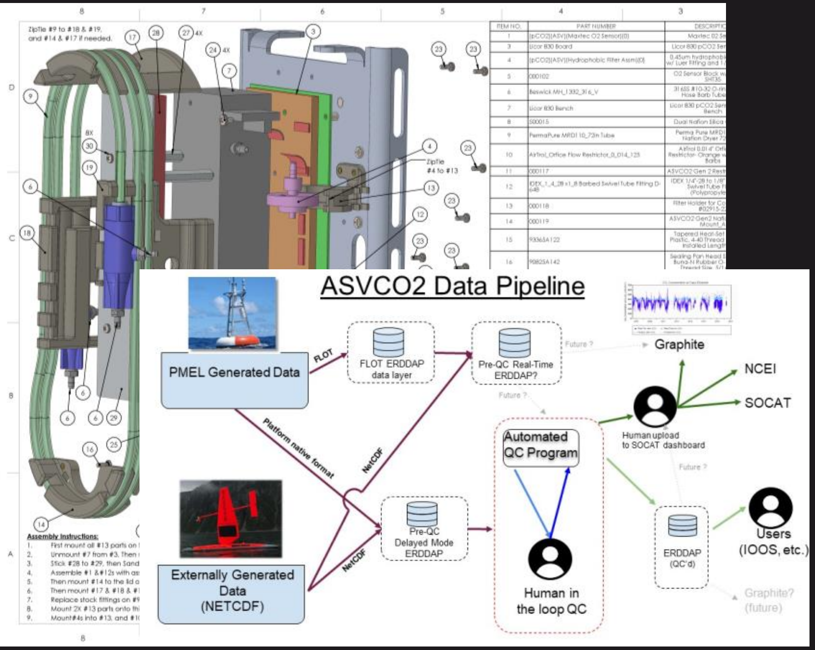
2004 … 2009 … 2015 2016 2017 2018

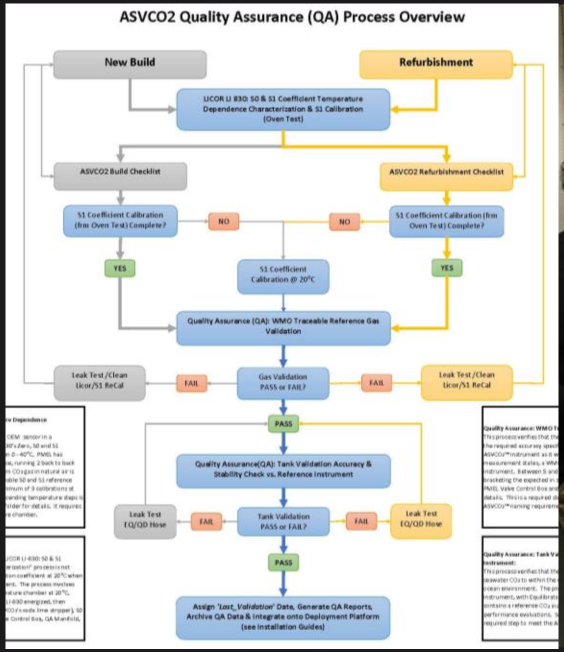
TAO array hosts 1st PMEL-modified $MAPCO_2$

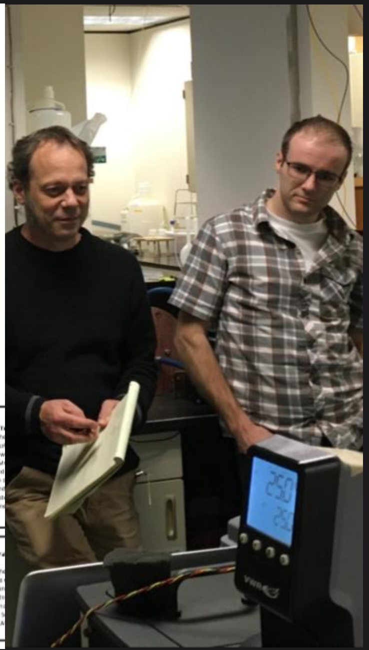
$MAPCO_2$ obsolescence issues emerge

industry partner ends $MAPCO_2$ program

Increasing Community Access: Holistic Instrument Development







ASVCO2™
Autonomous Surface Vehicle CO_2 Sensor

Dedicated Funding

Science Driven Design

Increase Access

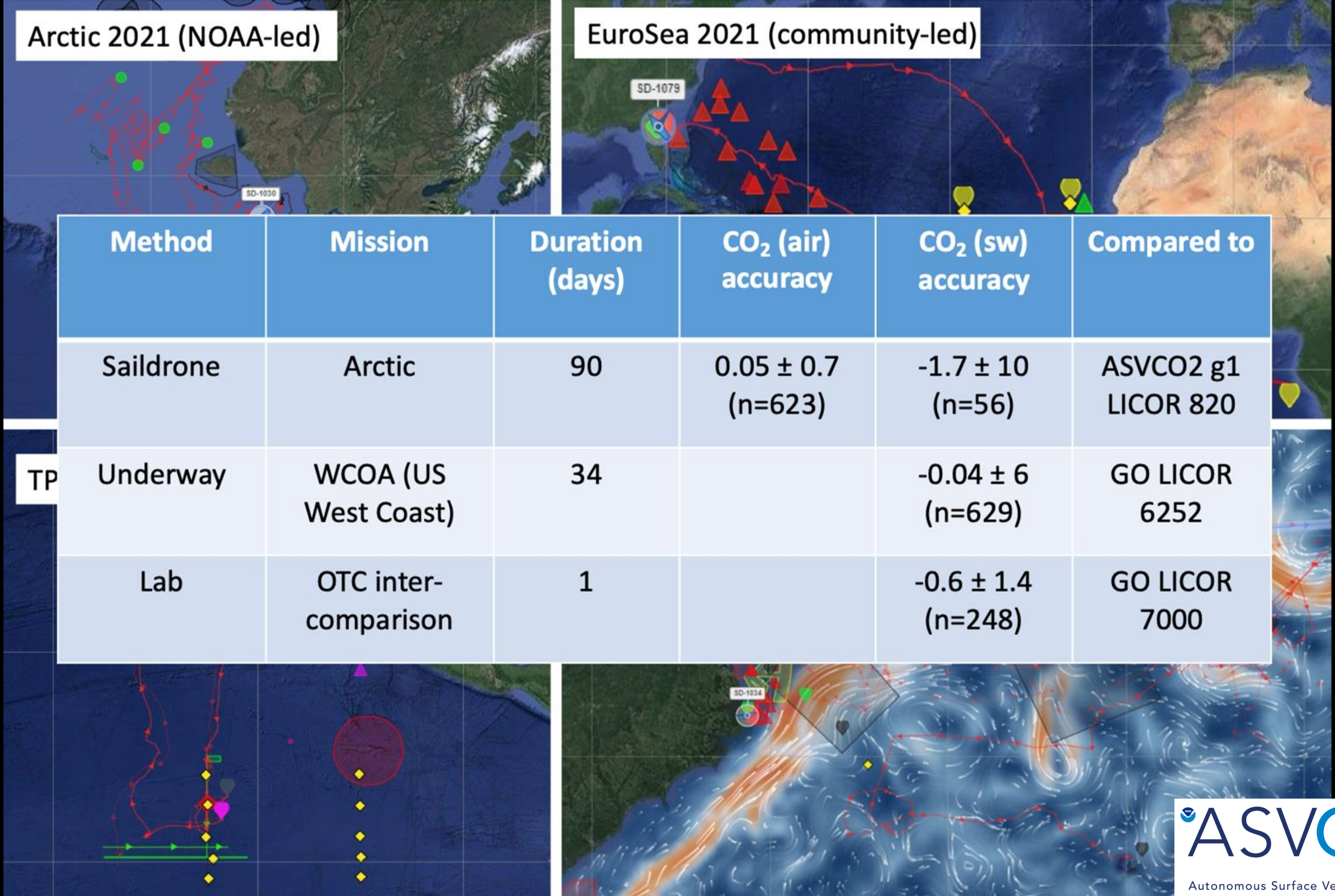
Ease of Use

- Community developed
  - QA & QC
  - Requirements

Enable Observations:

- Transfer technology.
- Protect data quality:

BYOB

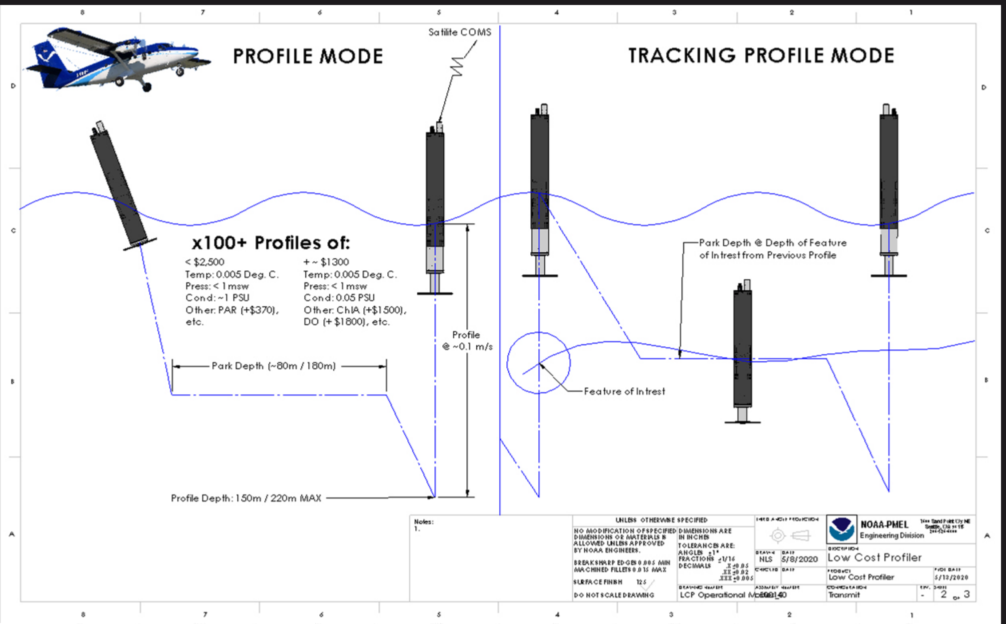


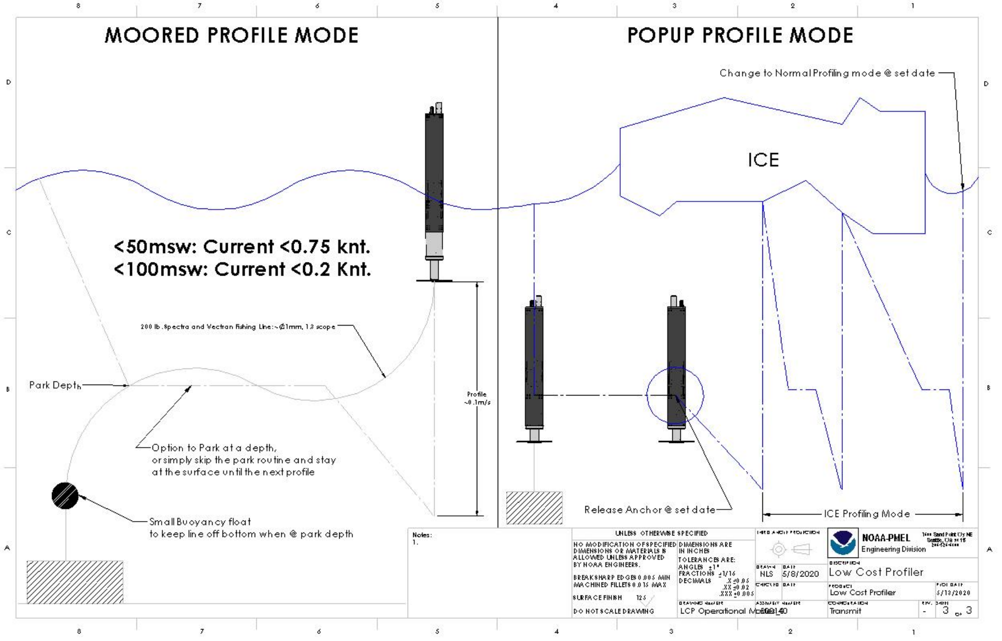
Method	Mission	Duration (days)	CO_2 (air) accuracy	CO_2 (sw) accuracy	Compared to
Saildrone	Arctic	90	0.05 ± 0.7 (n=623)	-1.7 ± 10 (n=56)	ASVCO2 g1 LICOR 820
Underway	WCOA (US West Coast)	34		-0.04 ± 6 (n=629)	GO LICOR 6252
Lab	OTC inter-comparison	1		-0.6 ± 1.4 (n=248)	GO LICOR 7000

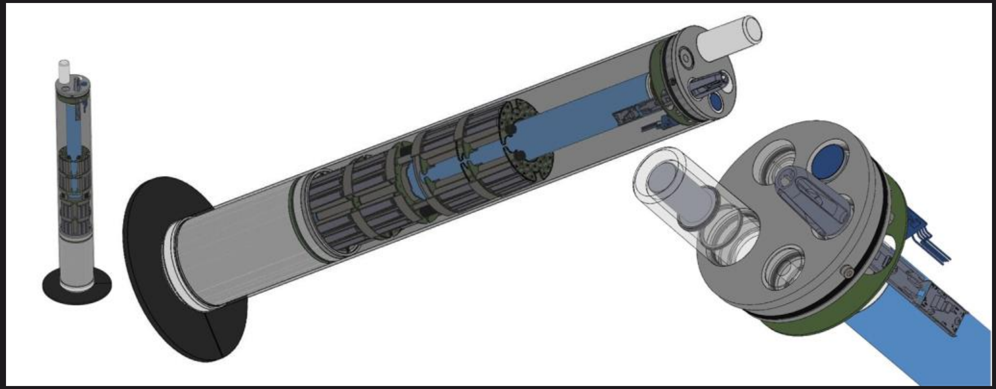
ASVCO2™
Autonomous Surface Vehicle CO_2 Sensor

Open Source Instruments: Design for accessibility

Increase Access





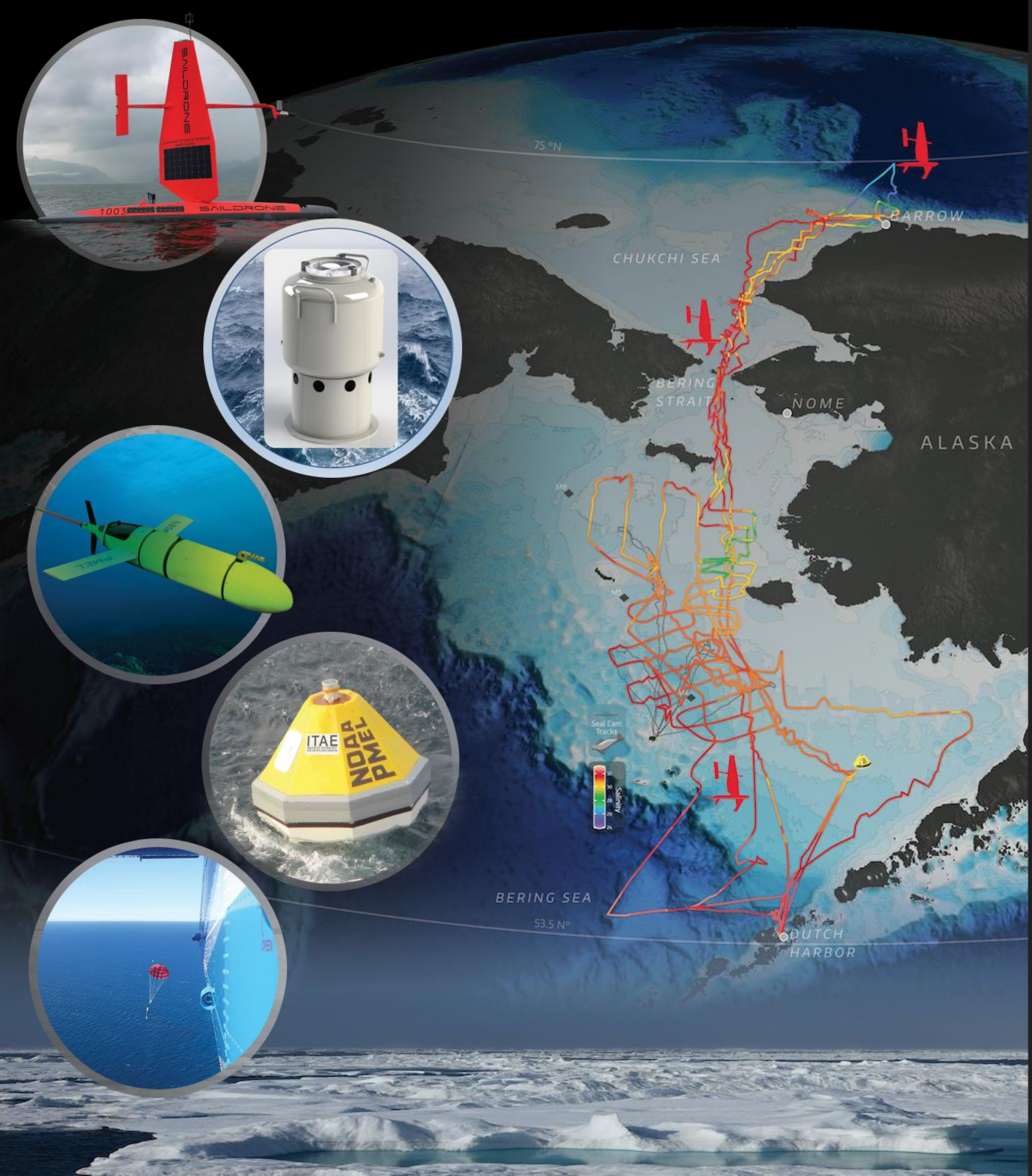


ITAE
Innovative Technology for Arctic Exploration

open source initiative®

open source hardware

- Design:
  - True low cost research grade profiler.
  - OEM sensors ensure data quality.
  - Multi-mission capability.
- Community:
  - Researchers can build their own, avoid 4x cost markup.
  - Reduces the burden of support, can assist in system upgrades.



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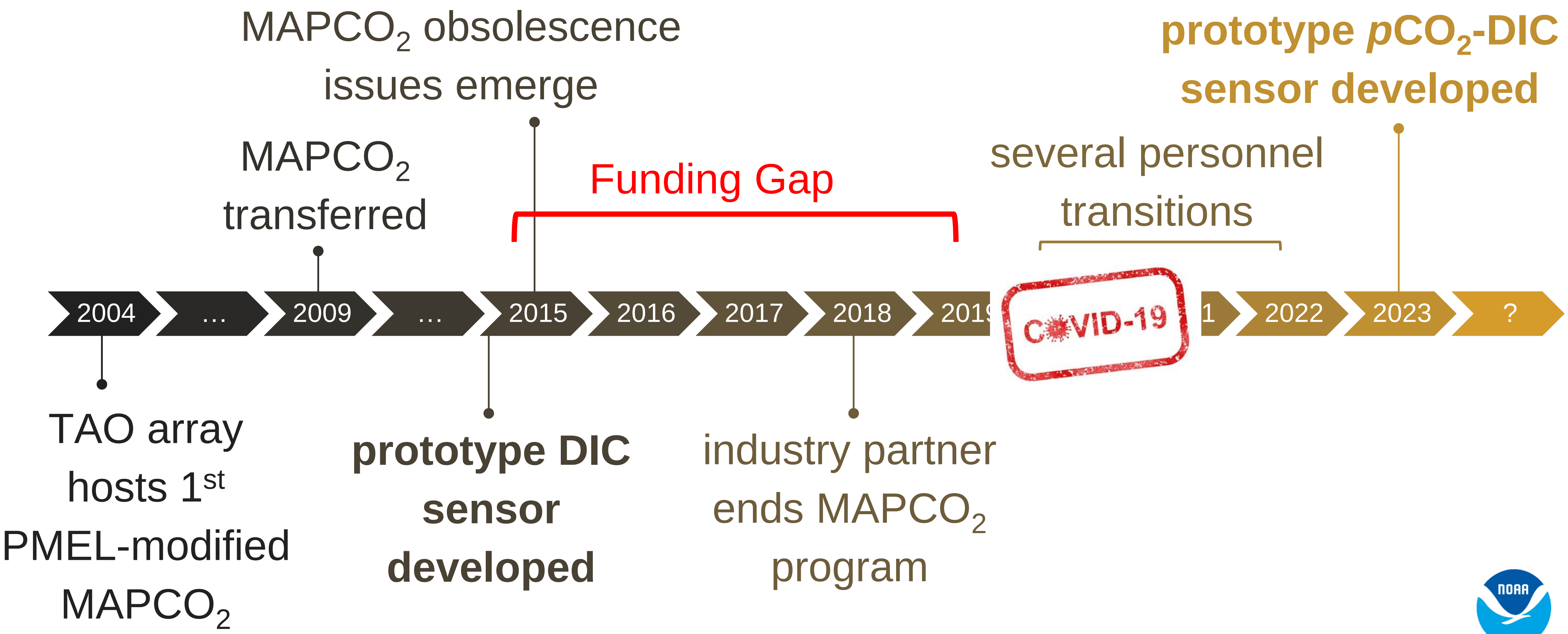
Societal implications of ocean change ≠ capacity of sensor development community

the $MAPCO_2$ story as an example



Innovative Technology for Arctic Exploration program (ITAE)

Deliver innovative technologies to support scientific and engineering communities and lead the future of ocean observations pole to pole.

Calvin Mordy (PI), Scott Stalin (PI), Heather Tabisola (Program Coordinator), Chris Meinig (PI, PNNL), Jessica Cross (PI)

Accelerate Innovation

PMEL
Pacific Marine Environmental Laboratory
CICOES

OPPORTUNITY

Identify science driver/gap, NOAA mission, and funding

Court & form partnerships

+

INNOVATION

EDD & partner innovation and design

Prototyping & field tests

+

DEMONSTRATION

Fabrication, integration & collaborative research deployment

Evaluation and feedback

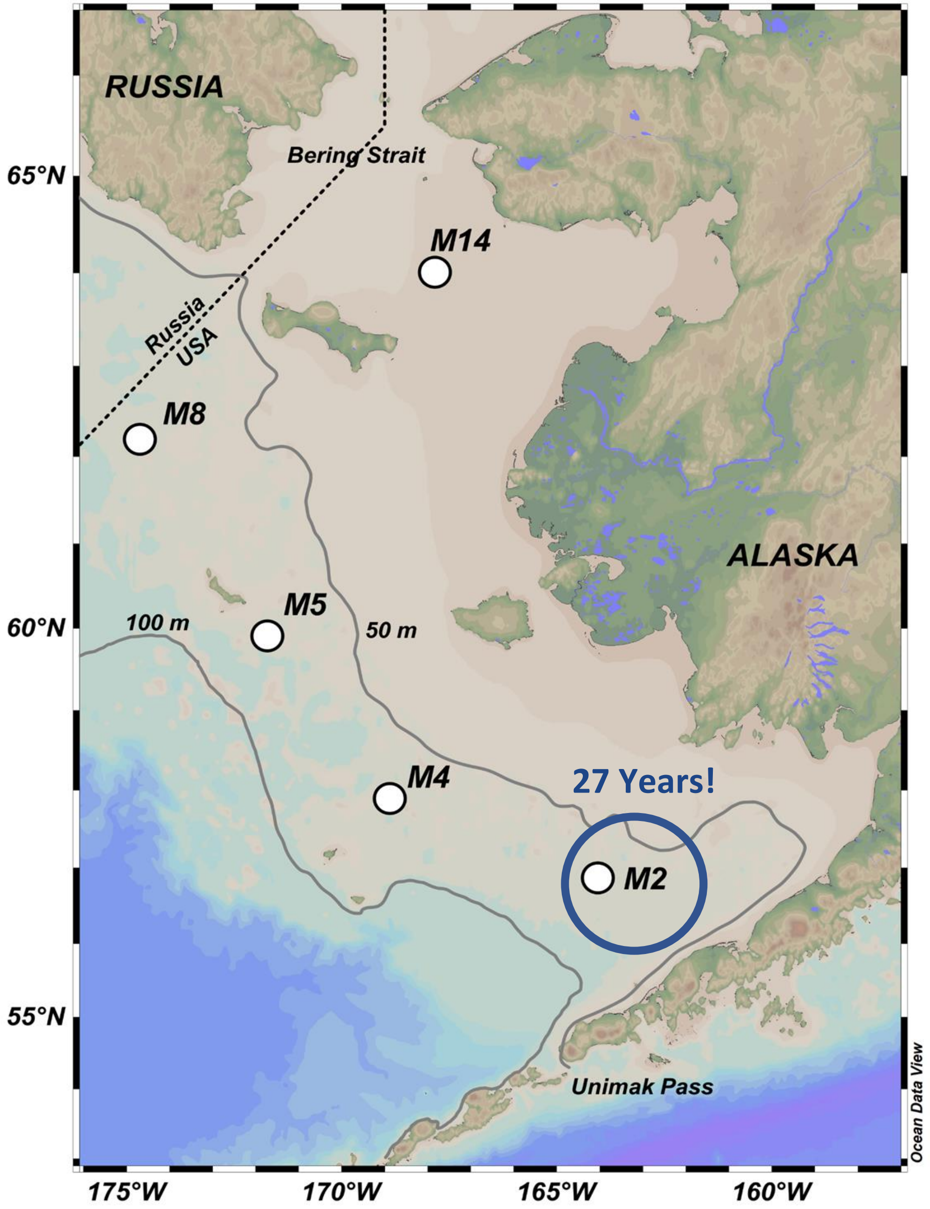
TRANSITION

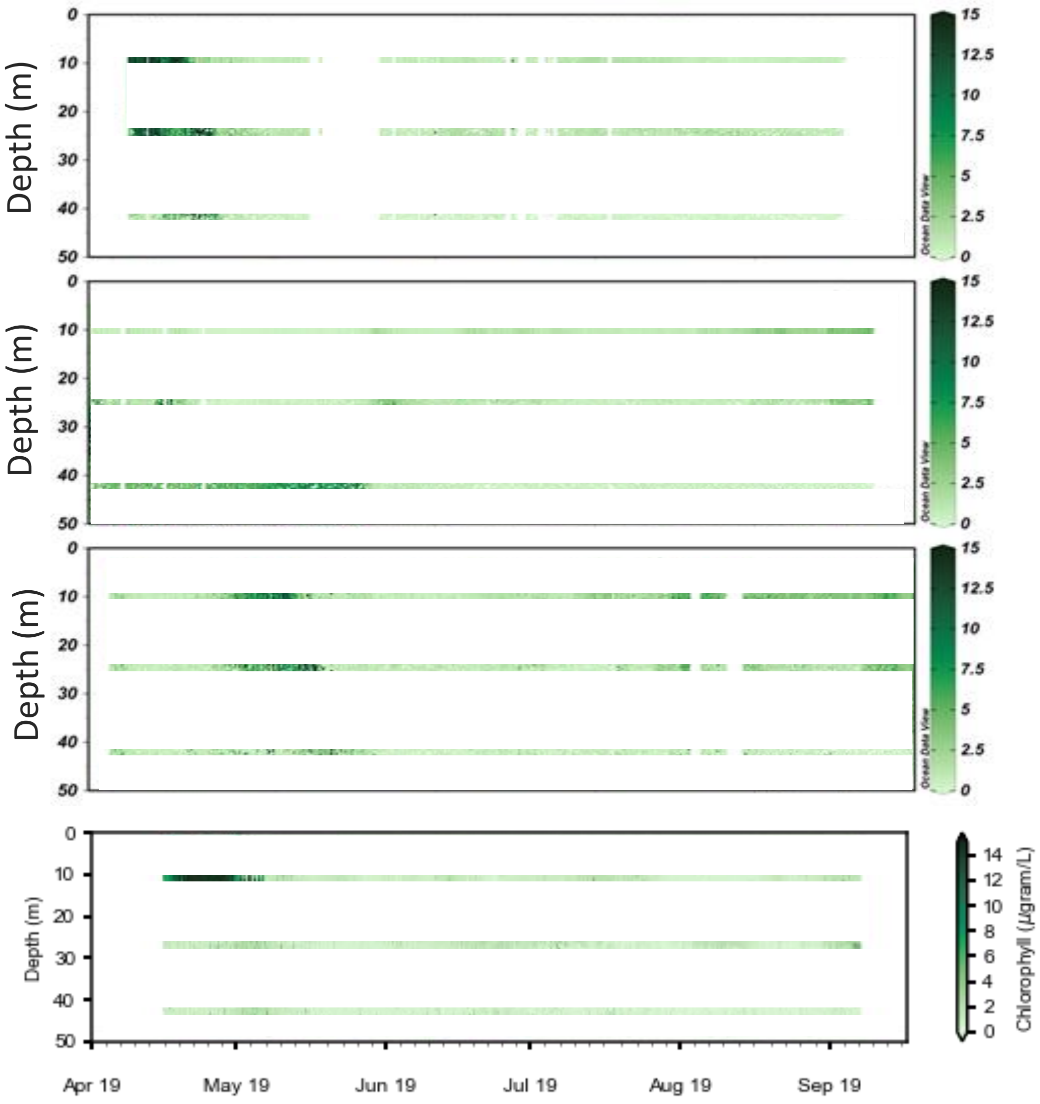
HOW ITAE WORKS

	TECHNOLOGY	PUBLIC/PRIVATE	SCIENCE PI
1	FLOATS ● ALAMO/L0W COST PROFILER ● POP-UP	● MRV / NOAA ● NOAA	● J. Zhang (PMEL, CICOES) ● P. STABENO (PMEL, NOAA)
2	MOORING ● PRAWLER ○ O_2/N_2 ○ Indices ● ICE PRAWLER // RISE ○ ACOUSTIC TRIGGER ● BENTHIC INCUBATOR // iRAS	● McLane ○ OSU ○ NOAA & BIGELOW ● NOAA ● NOAA ● UWashington	EcoFOCI program has operationalized M2 Prawler ● L. JURANEK (Oregon State University) ● J. NIELSEN, L. EISNER (AFSC) & M. LOMAS (BIGELOW) ● P. STABENO (PMEL, NOAA) ● R. DZIAK (PMEL, NOAA) ● C. Mordy (PMEL, CICOES)
3	VEHICLES ● SAILDRONE ● OCULUS	● SAILDRONE +40 ● U Washington	Operationalized with global applications ● STABENO (PMEL, NOAA)
4	MACHINE LEARNING & IMAGING ● PHYTOPLANKTON ML ● ZOOPLANKTON ● FISH ● NORTHERN FUR SEAL	● NOAA/UW ● PSSC/Lynker ● NOAA/WASSOC ● NOAA/CATS	● J. GANN, J. NIELSEN, L. EISNER (AFSC) & M. LOMAS (BIGELOW) ● D. KIMMEL, D. CROUSER (AFSC, NOAA) ● A. DE ROBERTIS (AFSC, NOAA) ● C. KUHN (AFSC, NOAA)

HOW ITAE WORKS

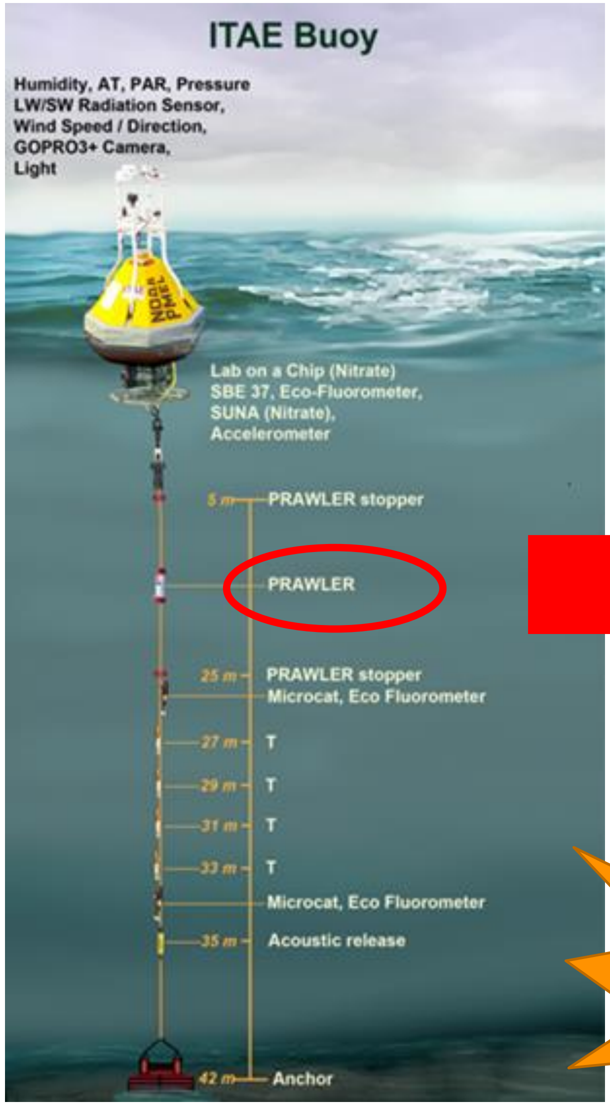
Conventional Instrument Spacing

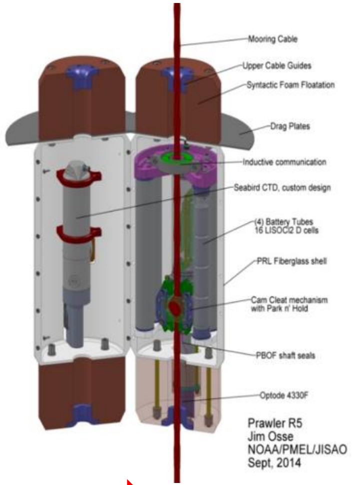




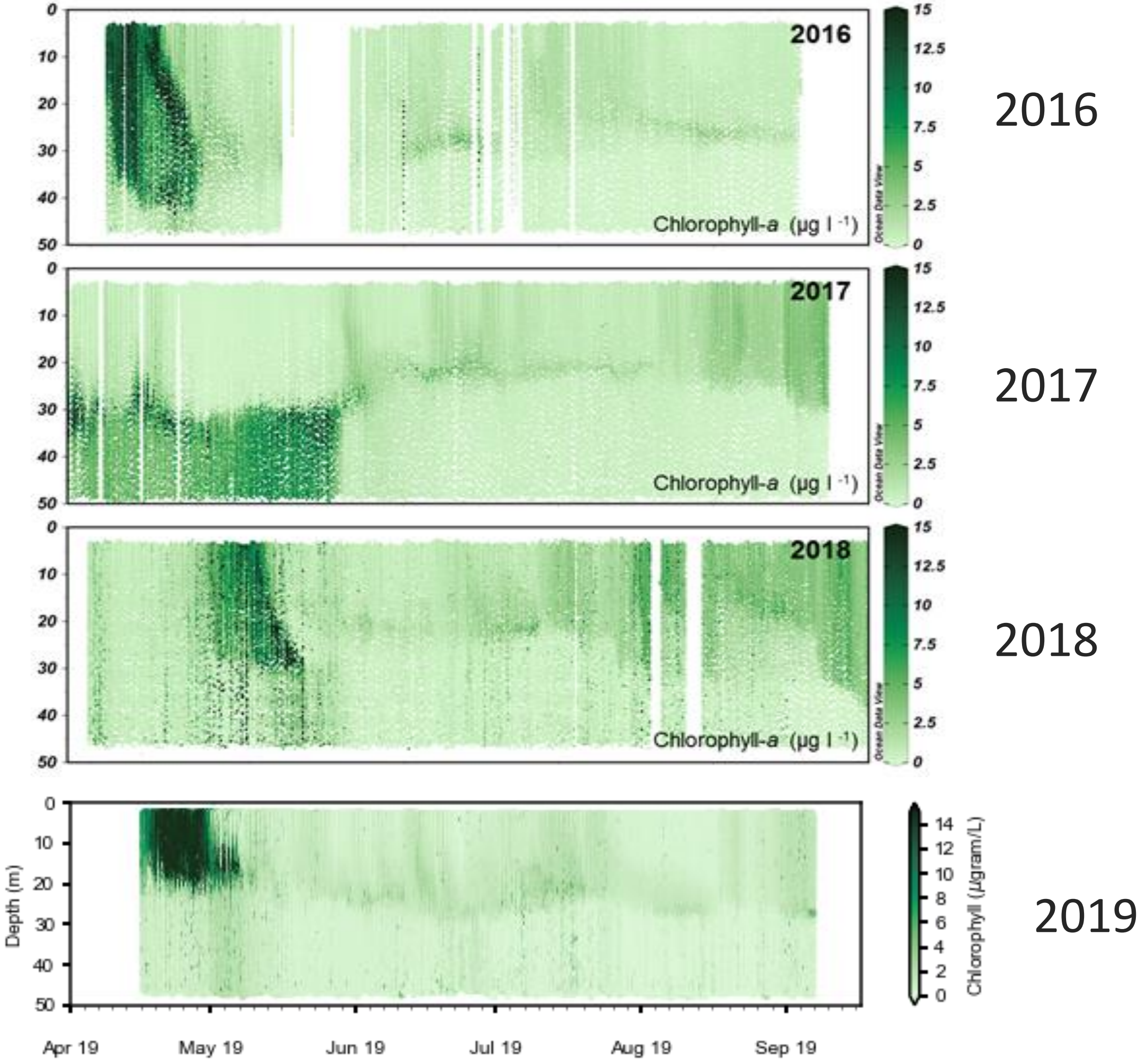
ITAE
Innovative Technology for Arctic Exploration

PRAWLER (PRofiler+crAWLER)





Increase Access

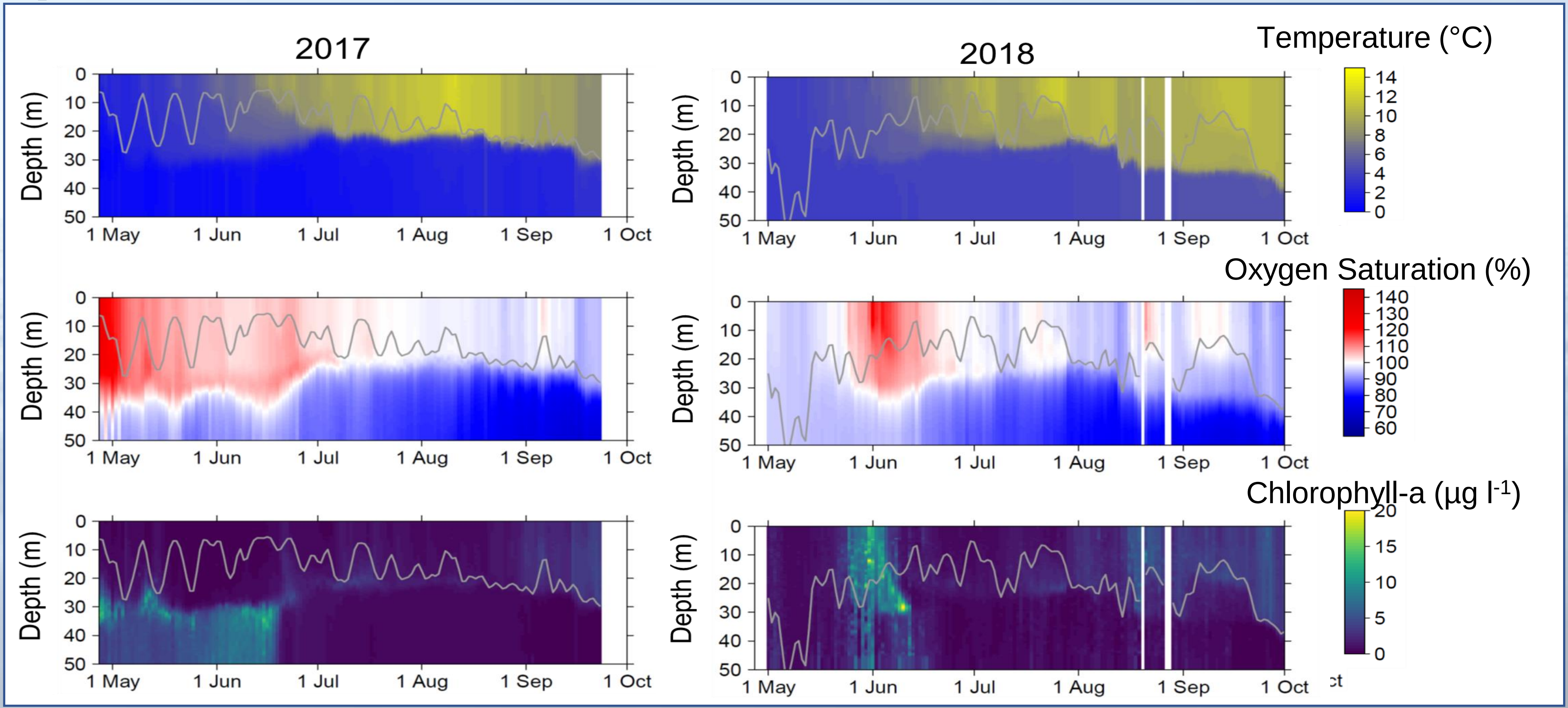


Global Ocean Monitoring and Observing
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

ITAE
Innovative Technology for Arctic Exploration

M2 PRAWLER Primary Production Time Series (2016-2021)

Multi-method approach to assess seasonal gross, net primary production and net community production

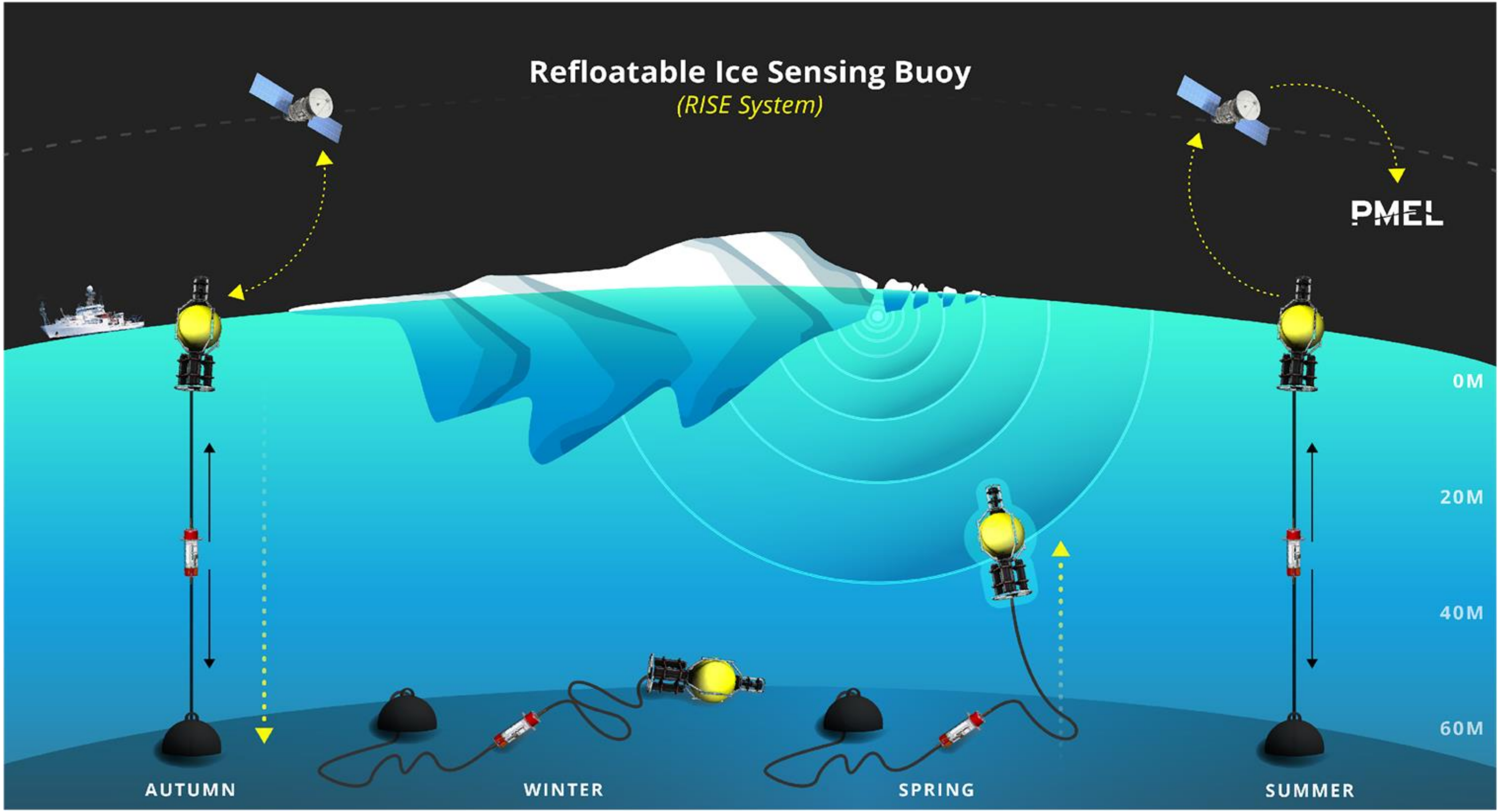


Metrics for the Bering Sea Ecosystem Status Report

Cynar et al., N_2/O_2 methodology in the arctic, DSRII, Submitted.

Nielsen et al., Multi-method study of seasonal dynamics of primary production, J. Geophys. Res. submitted

ITAE



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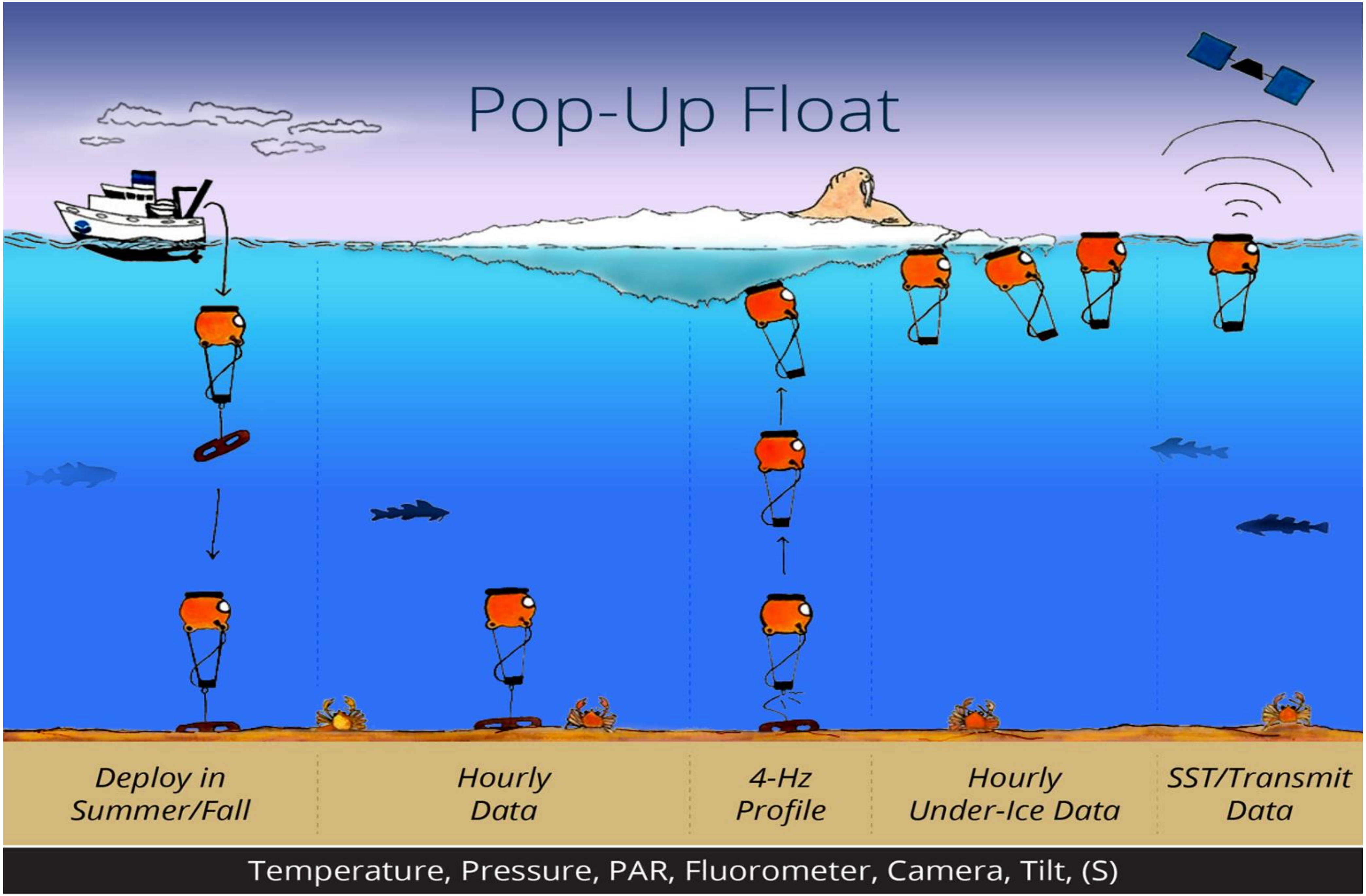

Sketch by Sarah Donohoe and Sarah Battle

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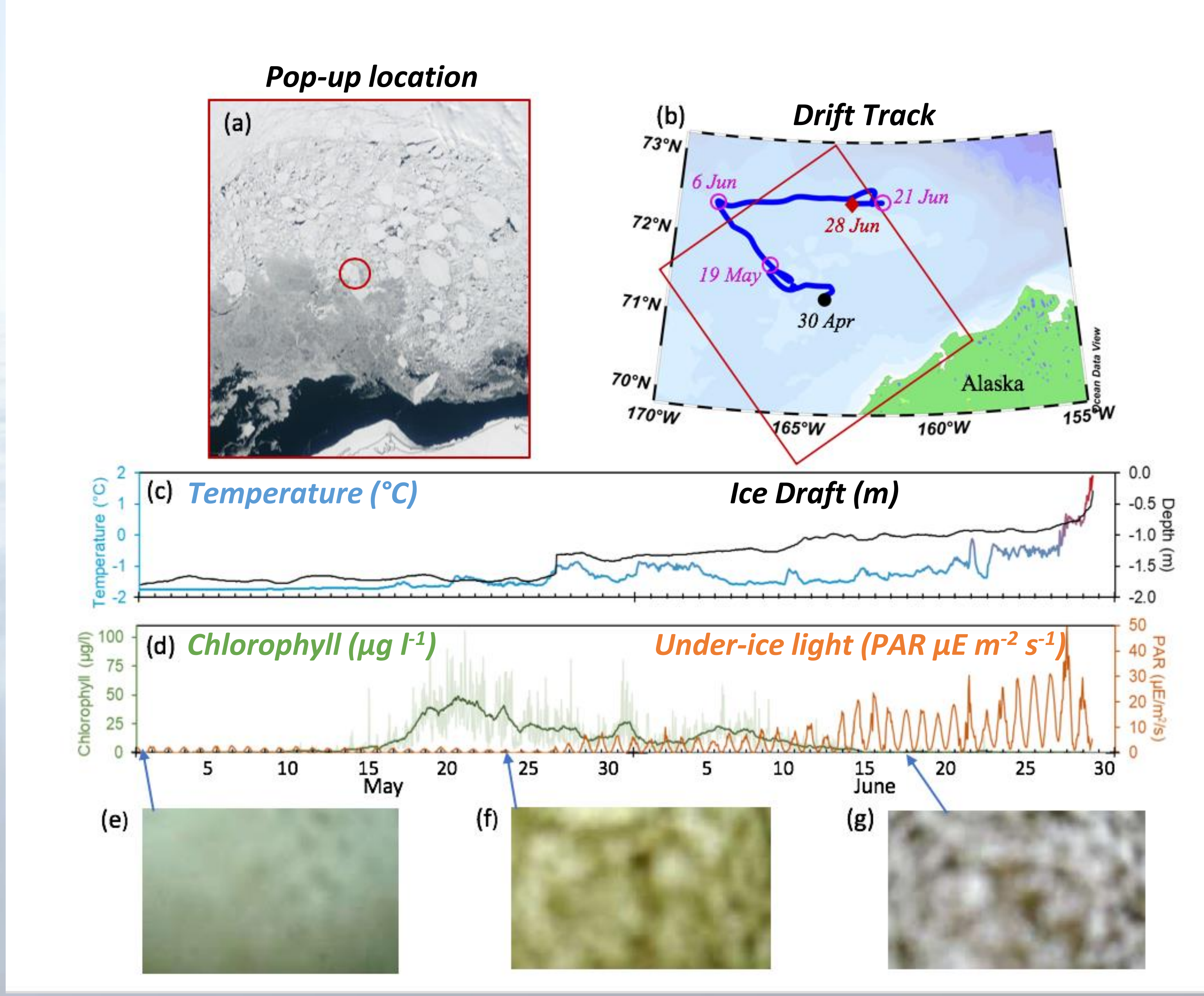
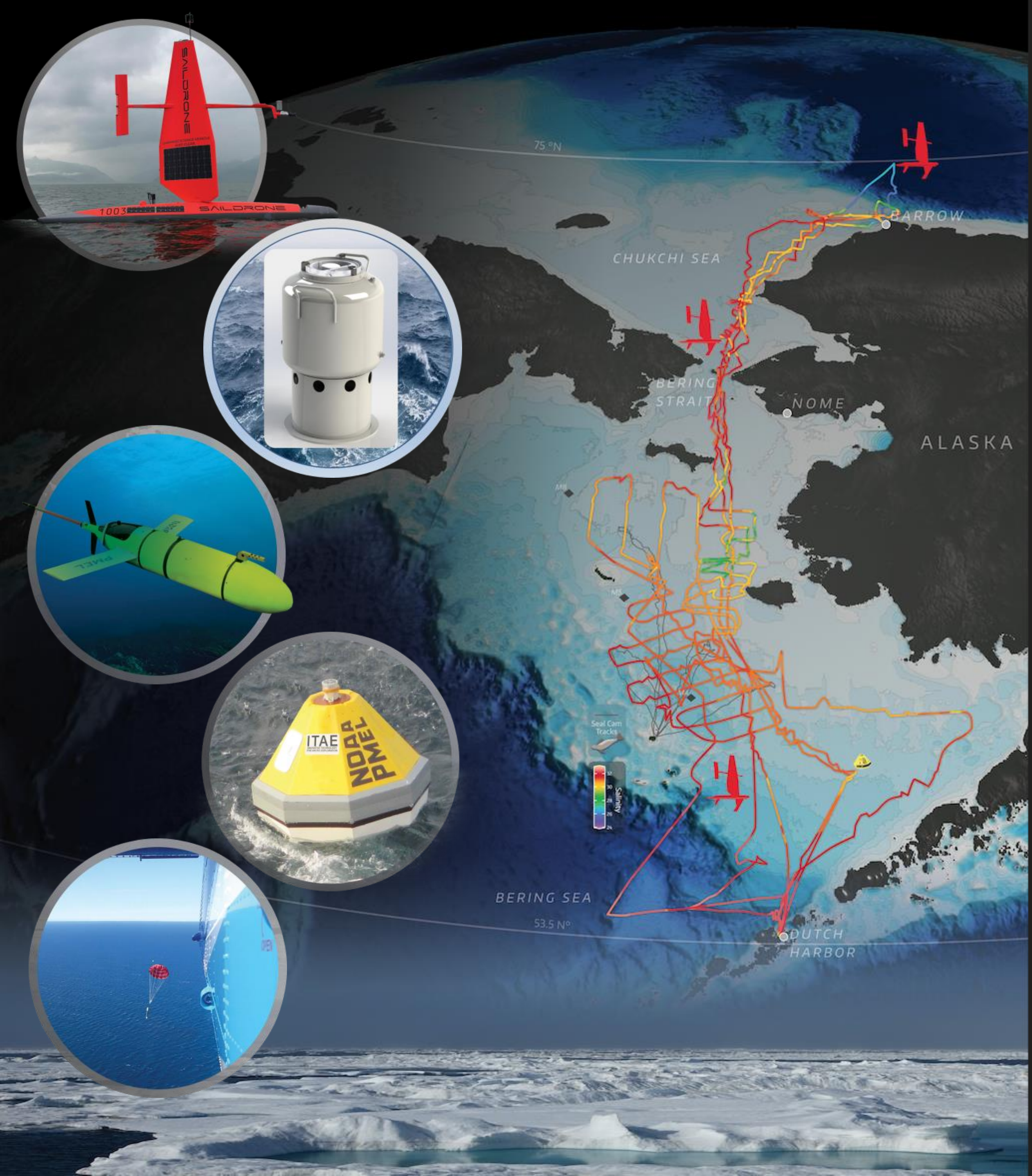
2019 Chukchi Sea Pop-Up Float



Stabeno et al., 2020. Seasonal patterns of near-bottom chlorophyll fluorescence in the eastern Chukchi Sea: 2010–2019. DSRII



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Power of Partnerships: Leverage the community

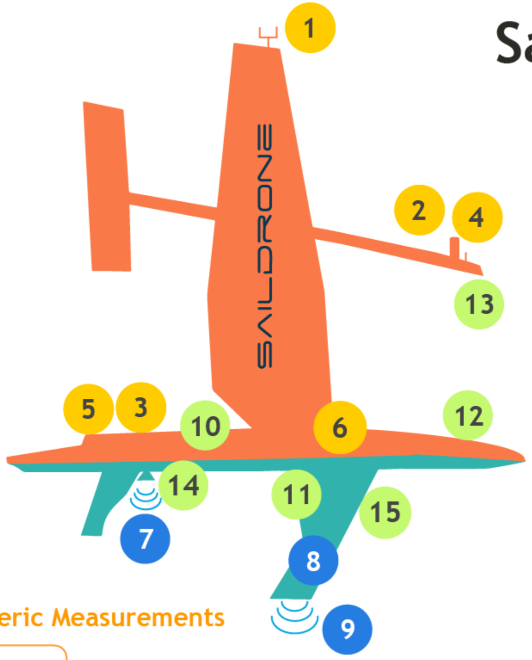
Increase Access

- PPP
  - Expertise
  - Rapid development
  - Community access = more data
  - Access alternative funding sources
- Research Organizations
  - Co-develop instrumentation
  - Speed up community acceptance
  - Develop working groups and standards
  - Share successes, failures, expertise

Accelerate Innovation

UMS SCIENCE TOOL:
HIGH QUALITY DATA

Saildrone Sensor Suite



Specifications

Length: **7 m**
Height: **4.6 m (above water line)**
Depth: **2 m**
Weight: **545 kg, (fully loaded)**
Speed: **Transit - 3 Kt, Max - 8 Kt**
Payload Power: **30W Steady state**
Payload Capacity: **100 kg**
Max deployed duration: **12 months**
Longest voyage: **16,100 km**

Atmospheric Measurements

- Wind Speed, Wind Direction — 1: **Anemometer @ +5.0m** Gill WindMaster 3D Ultrasonic 20Hz
- Sunlight & Infrared Radiation — 2: **Sunshine Pyranometer @ +2.5m** Delta-T Devices SPN1; 3: **Pyrgeometer +0.7m** Eppley PIR
- Air Temperature, Humidity — 4: **Meteorlogical Probe @+2.4m** Rotronic HC2 - S3 with rad shield
- Air Pressure — 5: **Digital Barometer @ +0.3m** Vaisala BAROCAP® PTB210
- Air pCO_2 — 6: **CO_2 System @ +0.5m** PMEL $ASVCO_2$

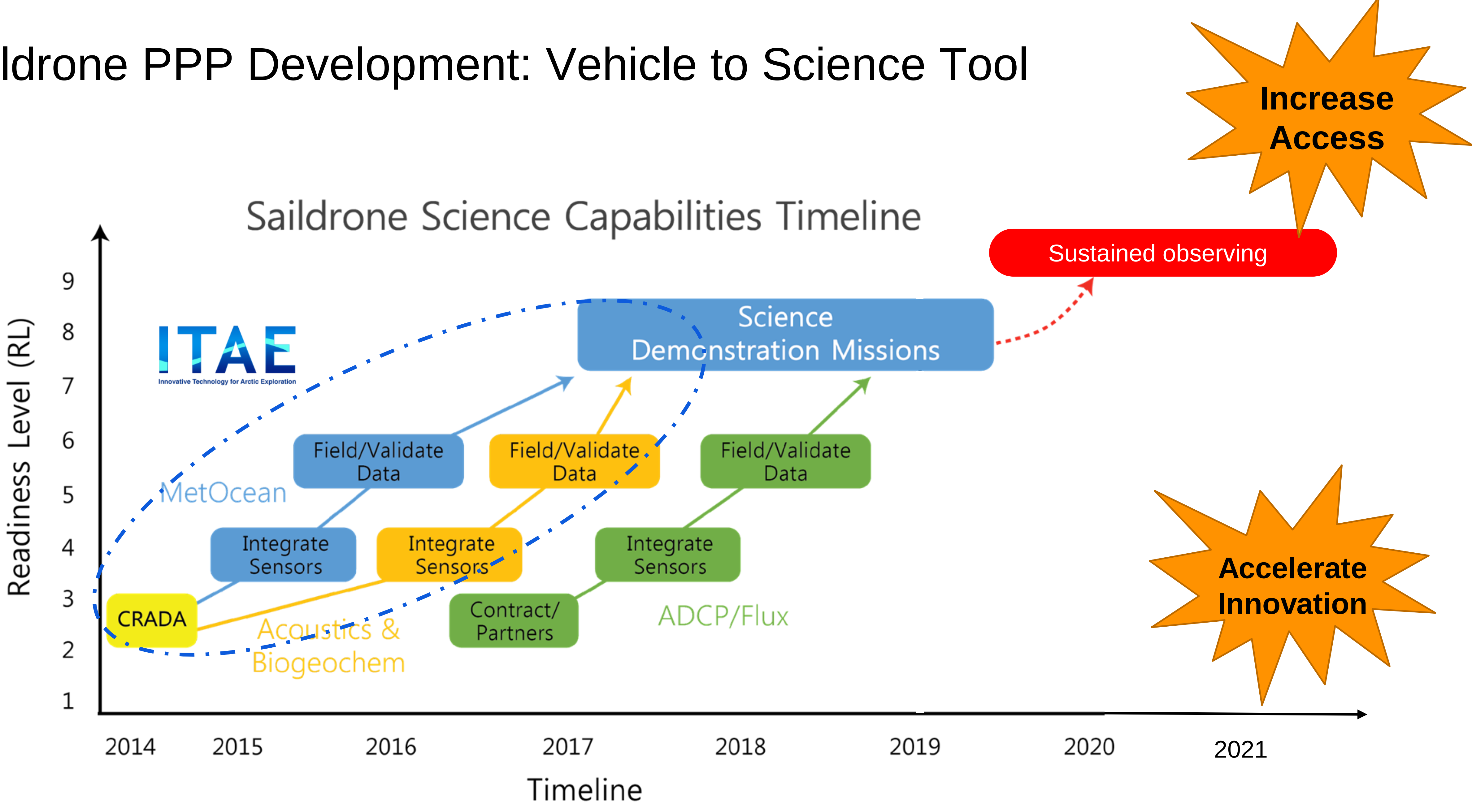
Oceanic Subsurface Measurements

- Ocean Current — 7: **ADCP @ -0.3m** Teledyne RDI 300 kHz Workhorse Sentinel
- Marine Mammal Presence — 8: **Passive Acoustic Recorder @ -1.3m** Greenridge Sciences Inc. Acousonde
- Fish Biomass, Bathymetry — 9: **Scientific Echosounder @ -1.8m** SIMRAD WMINI; **Multi-beam Sonar @ -1.8m** Norbit iWBMS

Oceanic Surface Measurements

- Wave Height & Period — 10: **Dual GPS & IMU** Vectornav / KVH
- Seawater pCO_2 & pH, Dissolved Oxygen, Water Temperature, Salinity — 11: **CO_2 System** PMEL $ASVCO_2$ @ -0.5m; Honeywell Durafet @ -0.5m; Aanderaa Optode @ -0.5m; Sea-Bird Scientific SBE PRAWLER @ -0.6m
- Magnetic Field — 12: **Magnetometer** Barrington MAG 648
- Skin Temperature — 13: **SST IR Pyrometer @ +2.2m** Heitronics KT15 II
- Chla, CDOM Concentration, Red Backscatter — 14: **Fluorometer and Backscatter @ -0.2m** Sea-Bird Scientific WET Labs Eco Triplet
- Water Temperature, Salinity — 15: **Thermosalinograph CTD @ -0.6m** Teledyne RDI Citadel TS-NH

Saildrone PPP Development: Vehicle to Science Tool



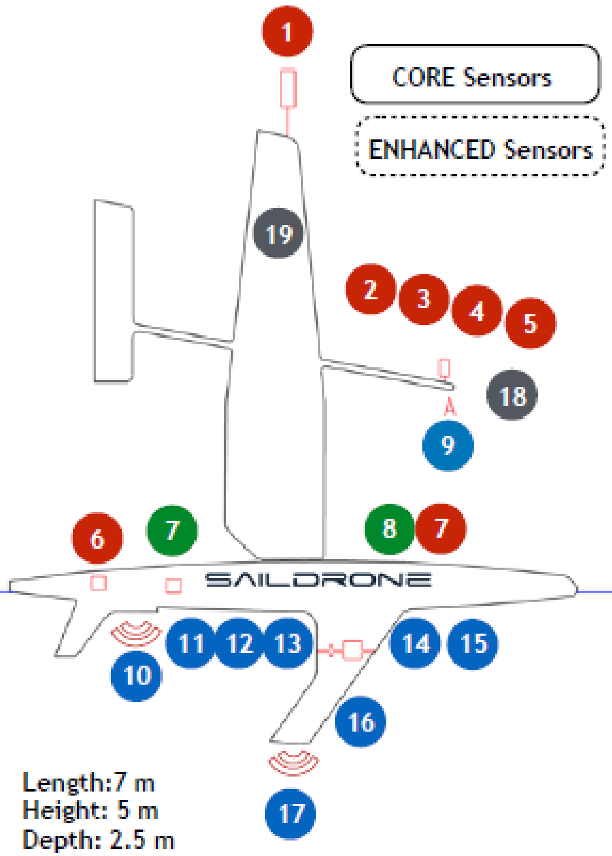
SAILDRONE SENSOR SUITE

Atmospheric Measurements

Measurement	No.	Sensor
Wind Speed, Wind Direction	1	Anemometer @ +5 m Gill Windmaster 3D ultrasonic 20Hz
Radiation	2	Photosynthetically active radiation (PAR) @ +2.2 m Li-Cor LI-192SA
Radiation	3	Sunshine Pyranometer @ +2.2 m Delta-T Devices SPN1
Radiation	4	Pyranometer @ +2.2 m Eppley PSP & PIR
Air Temperature, Relative Humidity	5	Meteorological Probe @ +2.2 m Rotronic HC2 - S3 with rad shield
Pressure	6	Digital Barometer @ +0.2 m Vaisala BAROCAP PTB210
pCO_2	7	Atmospheric pCO_2 @ +0.2m PMEL $ASVCO_2$

Physical Measurements

Measurement	No.	Sensor
Wave Height & Period	7	Dual GPS aided IMU
Magnetic Field	8	Magnetometer @ 0 m Barrington MAG 648
Depth	17	SIMRAD Echo Sounder @ -2.5 m SIMRAD EK80 (WBT Mini)



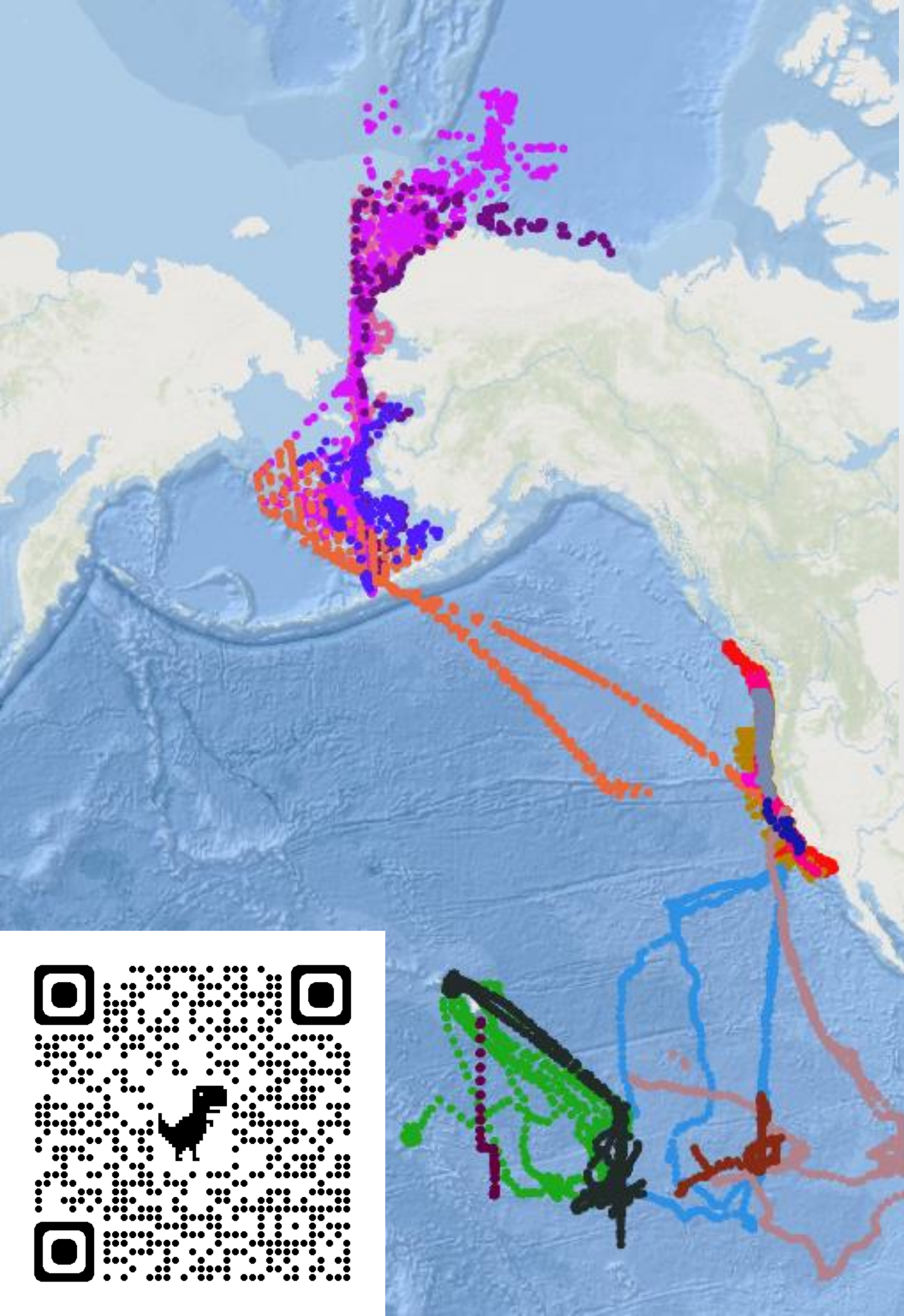
Length:7 m
Height: 5 m
Depth: 2.5 m
Speed: Transit ~ 2-3 Kt, Max ~ 8 Kt
Payload Power: 30w Steady state
Max deployed duration; 12 months

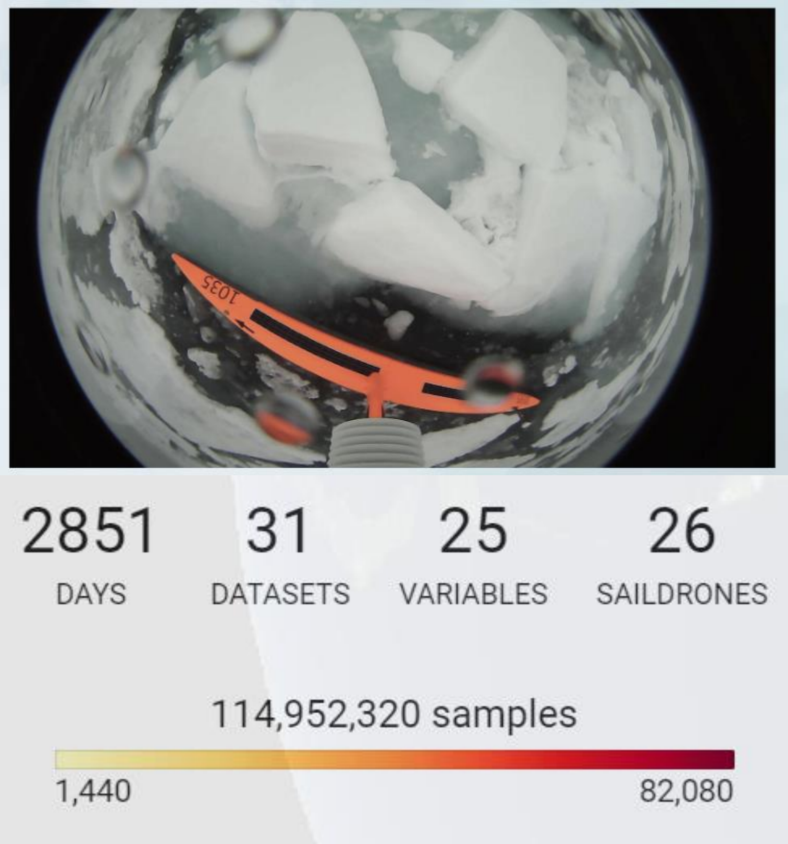
Maritime Domain Awareness

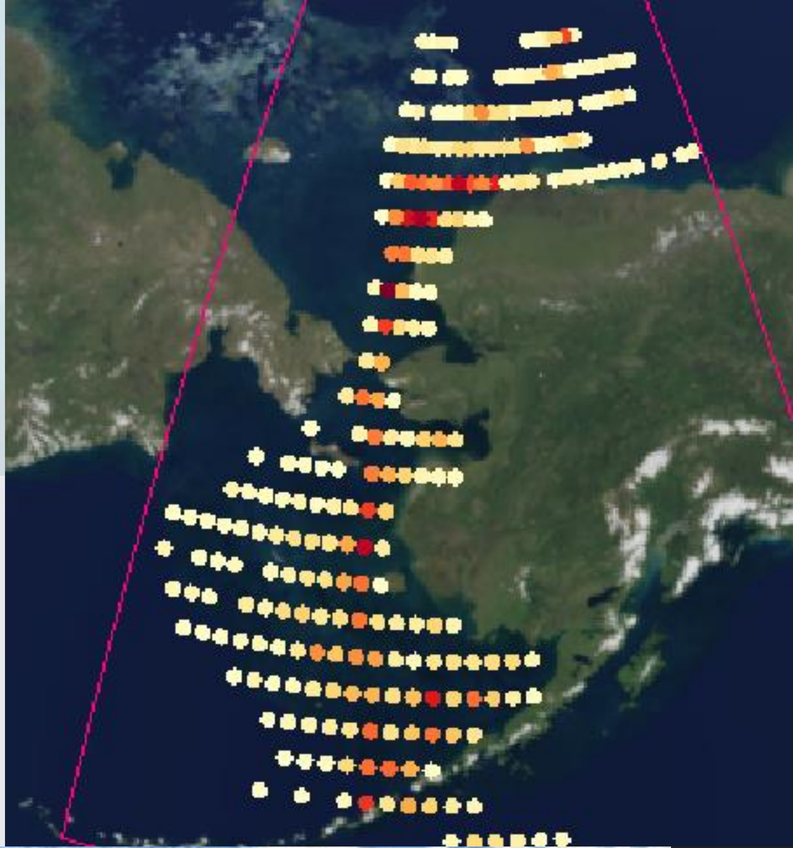
Measurement	No.	Sensor
Surface cameras	18	360 deg cameras Saildrone custom
AIS	19	AIS transceiver SRT Cobalt class B

Ocean Measurements

Measurement	No.	Sensor
Skin Temperature	9	SST IR Pyrometer @ +2.2 m Heitronics CT15.2
Ocean Currents	10	ADCP @ -0.2 m Teledyne RDI Workhorse 300 kHz
pH	11	pH Sensor @ -0.5m Honeywell Durafet
Chl - *a*, CDOM Concentration, Red Backscatter	12	Fluorometer @ -0.2 m RBR Chl-a Fluorometer or Seabird Scientific WET labs Eco Triplet
Dissolved Oxygen	13	Oxygen Optode @ -0.5 m Aanderaa 4831 or RBR DO
pCO_2	14	Dissolved pCO_2 @ -0.5 m PMEL $ASVCO_2$
Water Temperature, Salinity	15	Thermosalinograph @ -0.5 m RBR CTD or Teledyne RDI Citadel TS-NH or Sea-Bird Scientific CTD
Marine Mammal Acoustics	16	Passive Acoustic Recorder Acousonde
Fish Biomass	17	SIMRAD Echo Sounder @ -2.5 m SIMRAD EK80 (WBT Mini)





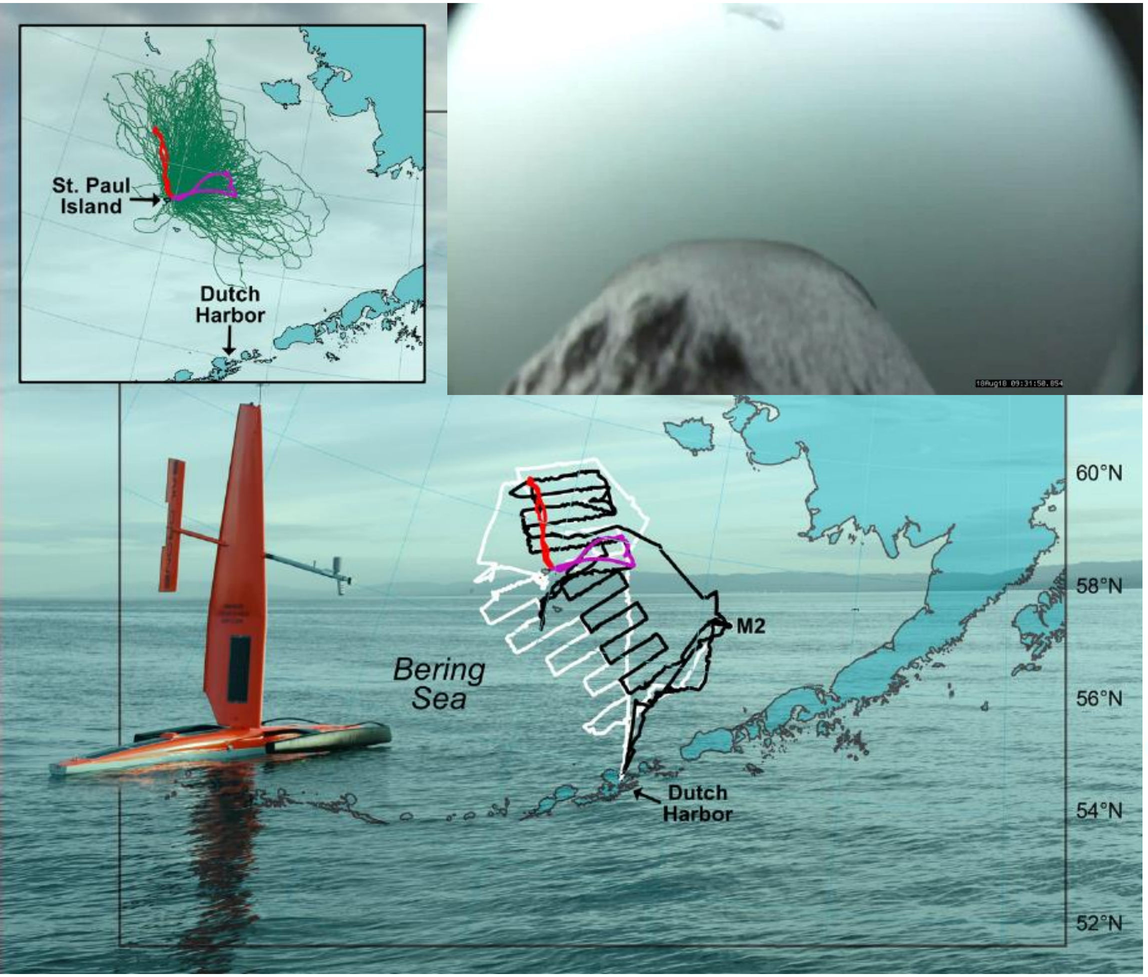


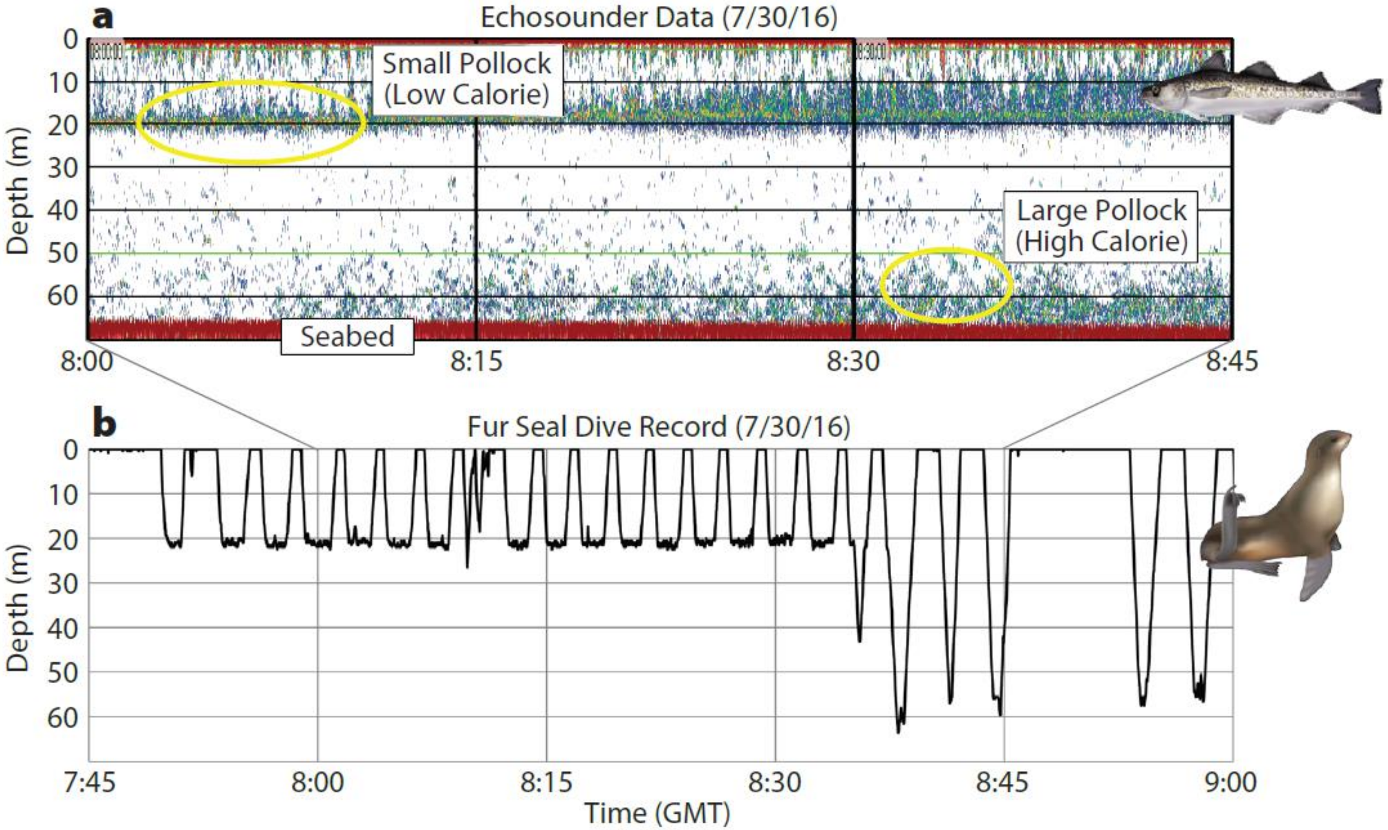
“Saildrone and WHOI buoy meteorological measurements agree to within the acceptable uncertainties for GOOS observations"

-- Dongxiao Zhang

Zhang, D., et al. Comparing air-sea flux measurements from a new unmanned surface vehicle and proven platforms during the SPURS-2 field campaign. *Oceanography*, 2019.

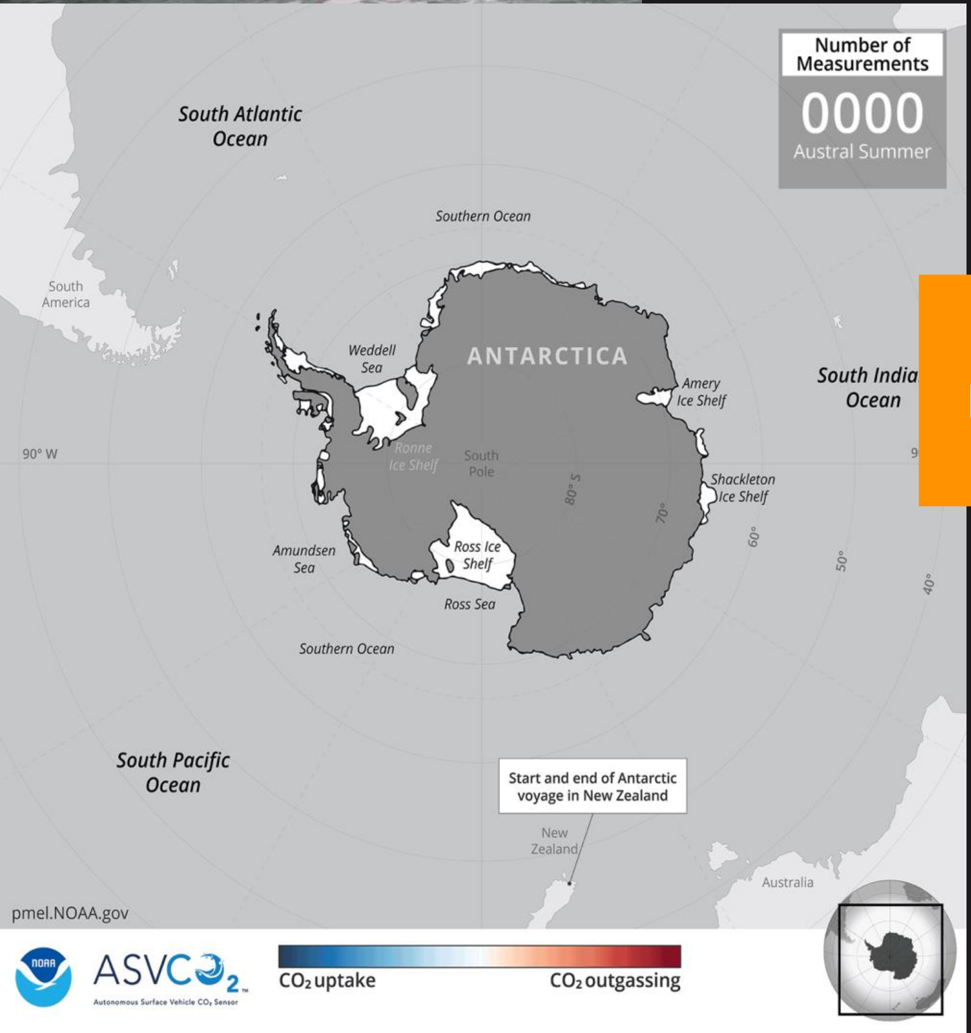
Northern Fur Seals *C. Kuhn, J. Sterling (AFSC)*



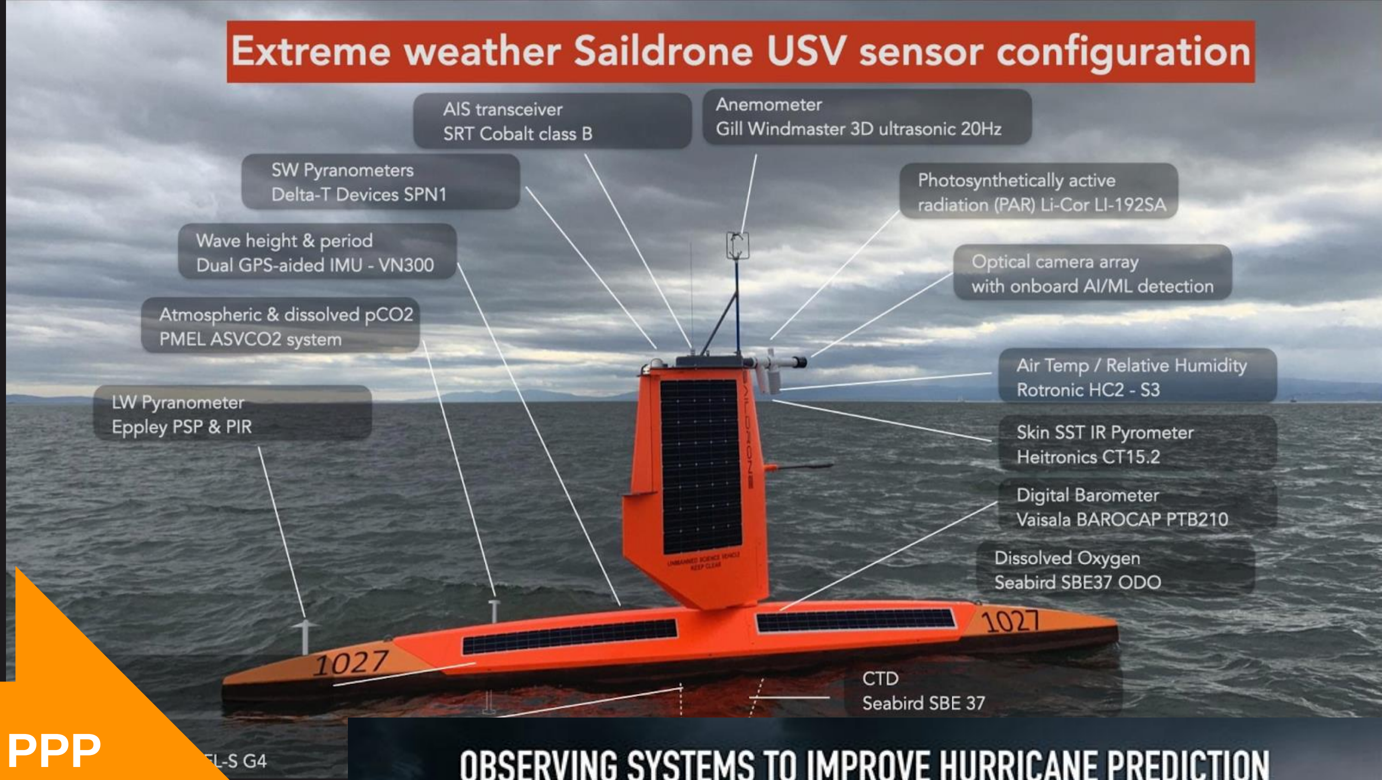


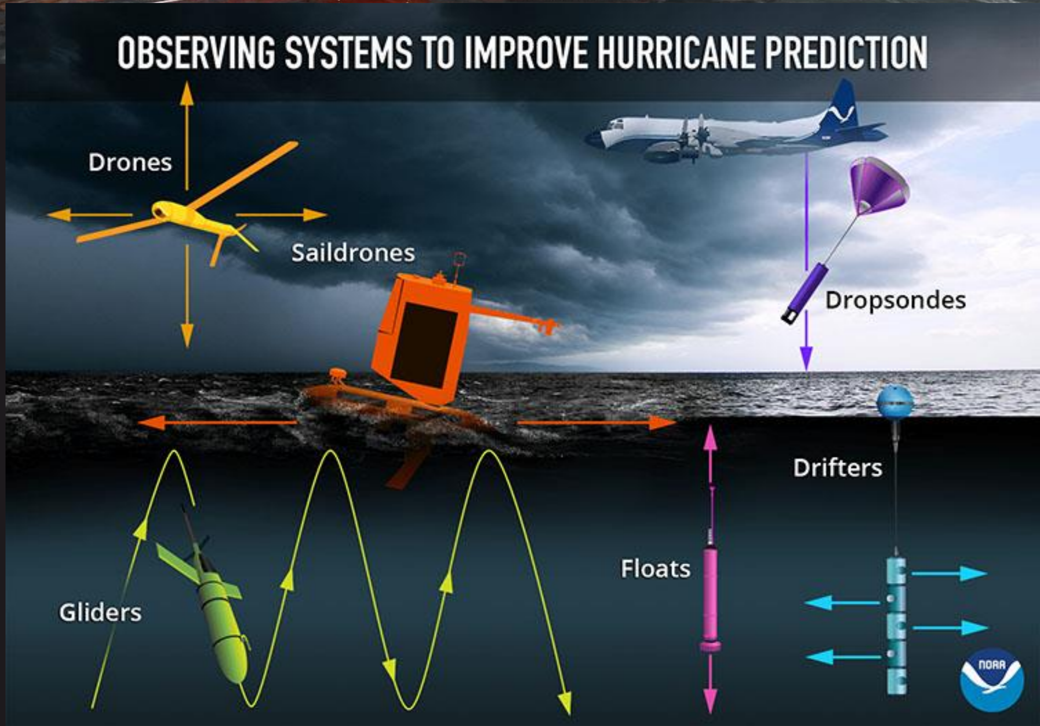
Carey Kuhn, Alex De Robertis (AFSC), Saildrone

Mordy, et al., 2017. Advances in ecosystem research: Saildrone surveys of oceanography, fish, and marine mammals in the Bering Sea. Oceanography



RAPID PPP DEVELOPMENT






Captured by SD 1045's onboard camera during
Category 4 Hurricane Sam, Sept. 30 2021
SAILDRONE
NOAA

Future Directions Achievements and Impacts

A USV network **FILL GAPS** in space, time, disciplines and complement existing GOOS infrastructure

SPACE AND TIME

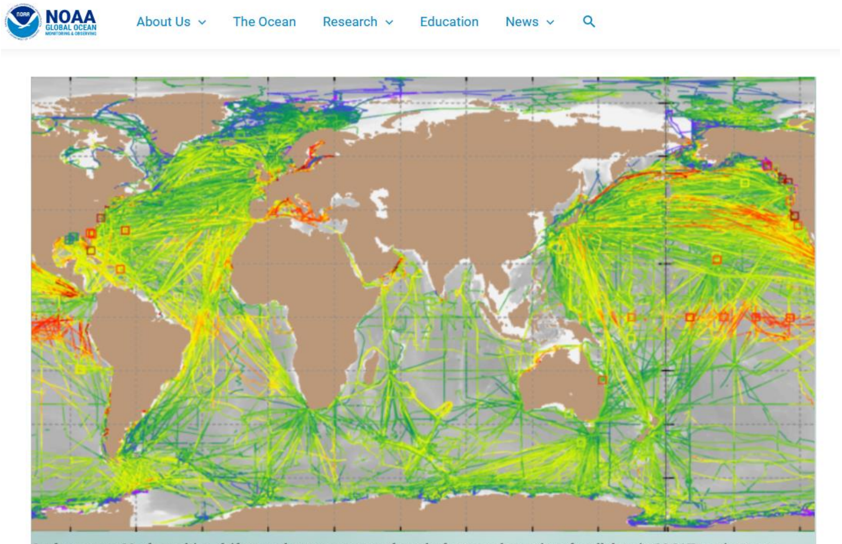
- **Remote locations** of global ocean not currently covered by GOOS infrastructure**, including semi-enclosed seas, gulfs, archipelagos** and **reef networks**
- **Under persistent cloud cover** that can obscure some satellite observations
- **Clusters of USV** that periodically come together to form **"Mesonet"**, then spread apart for greater coverage
- Pairs of USV, in loose **follow-the leader** or **side-by-side formation** to observe EOV and spatial gradient

DISCIPLINARY

- **In severe weather and developing phenomena**
- In **frontal** regions, **and near ice edge**
- In **process studies**
- **Air-Sea interface studies at sub meter scale**

COMPLEMENTARY

- **Spatiotemporal coverage** around **fixed point moorings**
- **Air-sea surface surveys** at **subsurface moorings or glider profiles**
- **Acoustic gateway** data transfers



Surface ocean CO_2 from ships, drifters and autonomous surface platforms and moorings for all data in SOCAT version 2023.

Uncrewed Surface Vehicle Network
for a remote, data-limited
Global Ocean Observing System

Update on an emerging network for OCG

Ruth Patterson*[,1], Meghan Cronin[2], Adrienne Sutton[2], Eugene Burger[2], Jack Reeves Eyre*[,3], Dongxiao Zhang[4], Jim Thomson[5], Sebastiaan Swart[6], Marcel du Plessis*[,6], Tom Farrar[7], Luc Lenain[8], Laurent Grare[8], Iwao Ueki[9], Samantha Wills*[,4], Chris Meinig[2], Jaime Palter[10], Eric Lindstrom[11], Sarah Nicholson*[,12], Pedro Monteiro[12]

Takeaways

- A modest amount of targeted and sustained, technology development funding can accomplish a great deal.
- Public-Private-Partnerships can rapidly accelerate development and increase access to ocean observing.
- Focusing on Fit-for-Purpose designs can accelerate development and scale availability.

Discussion

Live Q&A

Slido Session Key

#SOOSSymposium2023