# Saildrones: Global Class Autonomous Surface Vehicles for Air-Sea Interaction Observation

*Dongxiao Zhang (JISAO/UW and NOAA/PMEL)*
*Meghan F. Cronin, Christian Meinig (NOAA/PMEL)*
*Richard Jenkins (Saildrone Inc.)*


## Workshop: Observational campaigns for better weather forecasts

**ECMWF | Reading | 10-13 June 2019**

OOMD
Ocean Observing and Monitoring Division

TECHNOLOGY OVERVIEW

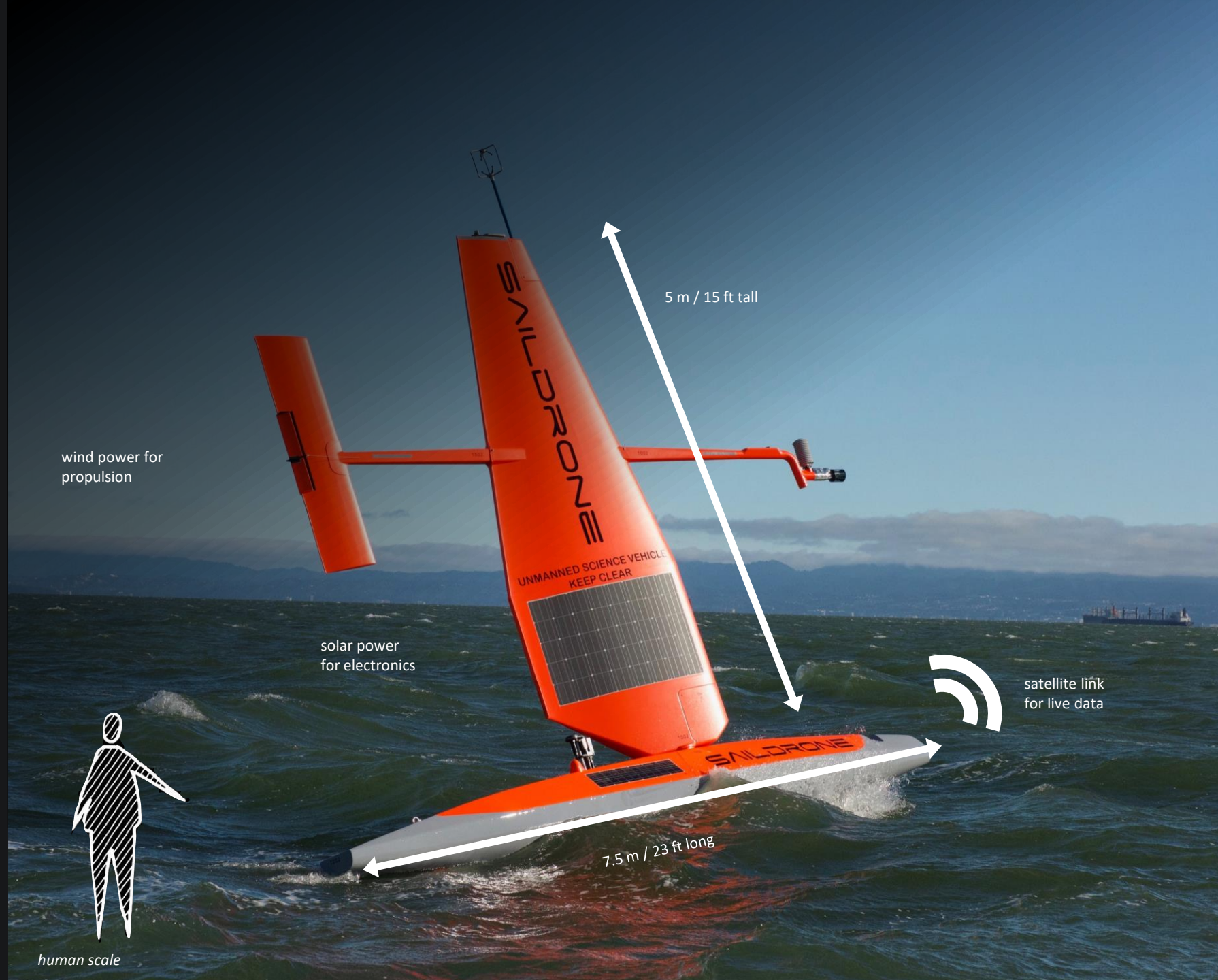
# SAILDRONE

## Unmanned Surface Vehicle (USV)

**Green Tech.:**
*Wind propulsion; Solar power electronics.*

**Long Endurance:**
*12-month; 16,100 km.*

**Large Payload:**
*>100 kg; Large number of sensor packages.*



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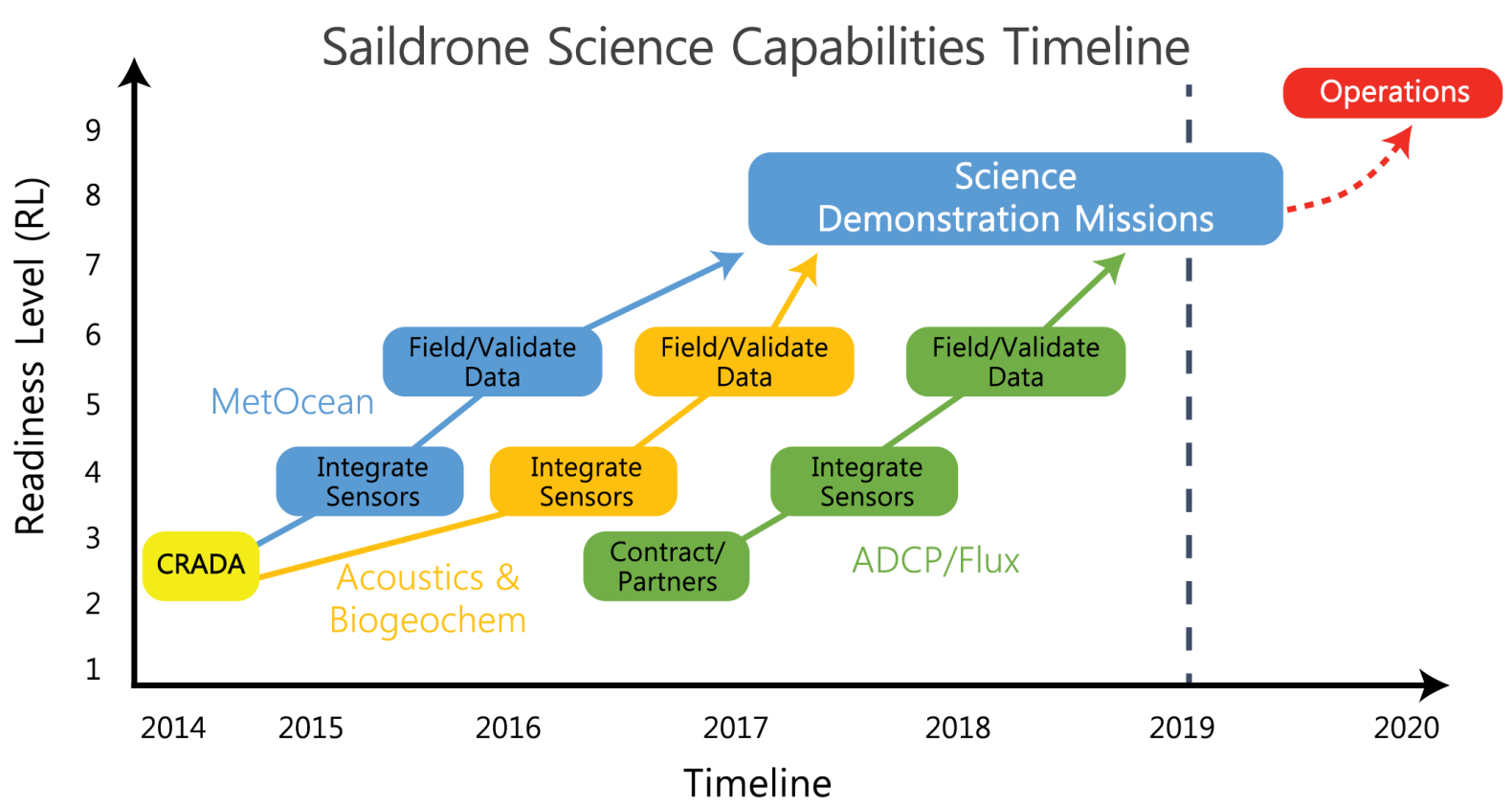



Meinig et al. 2019 OceanObs'19

- ***CRADA PMEL-Saildrone Inc 2014***
- ***Bering Sea summer 2015 2016 (surface MetOcean, acoustic fish biomass)***
- ***Tropical Pacific Observing System (TPOS) and NOAA Tech. Development 2016-2019 (Air-sea heat, momentum and $CO_2$ fluxes, ADCP upper ocean currents)***

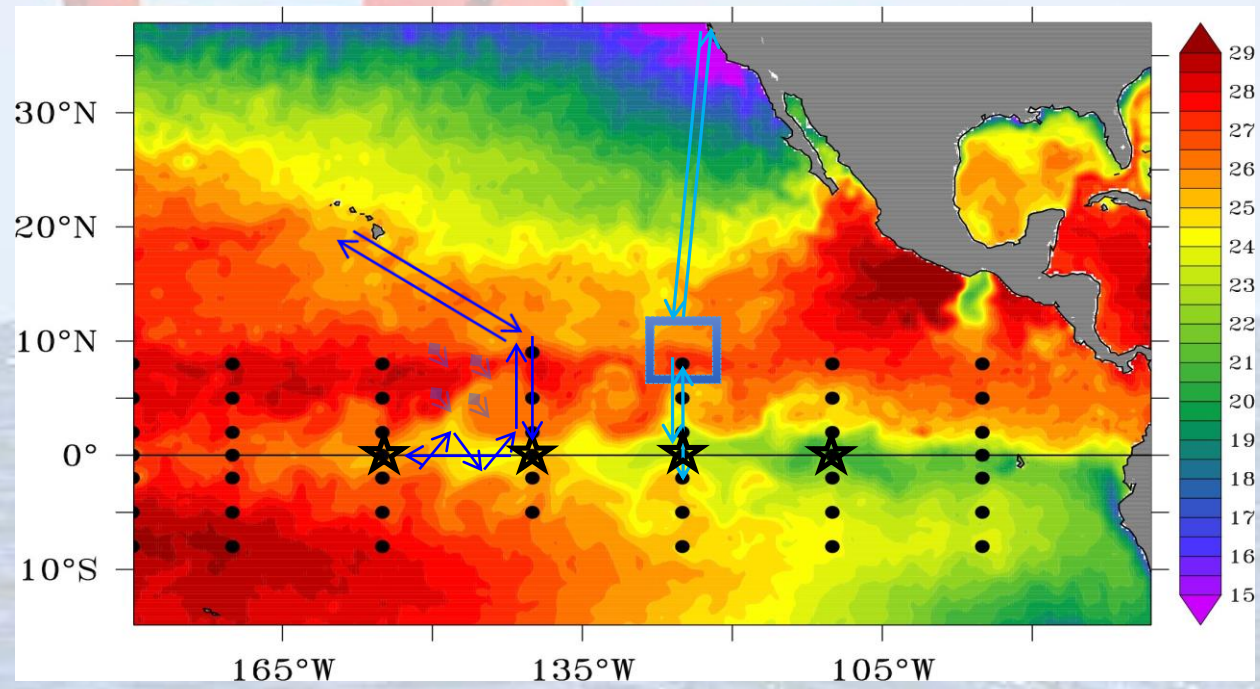
# Autonomous Surface Vessels as Low-Cost TPOS Platforms for Observing the Planetary Boundary Layer and Surface Biogeochemistry

*Co-PIs: M. Cronin, D. Zhang, A. Sutton, C. Meinig*
*Postdoc: Samantha Wills*

*Testing the ability of Saildrone to make* ***climate-quality*** *measurements in the Tropics*

**Three 6-month missions:**

1) NASA salinity study (SPURS II) and 125°W section (Sept.2017)
2) Equatorial sections 140°W, with and against currents (Oct. 2018)
3) Cluster of 4 drones, adaptive sampling around 140°W (June 2019)


**Legend:**

- TAO buoys
- TAO buoy with $CO_2$ flux sensors
- NASA SPURS II Study Site
- Saildrone Mission #1
- Saildrone Mission #2
- Saildrone Mission #3

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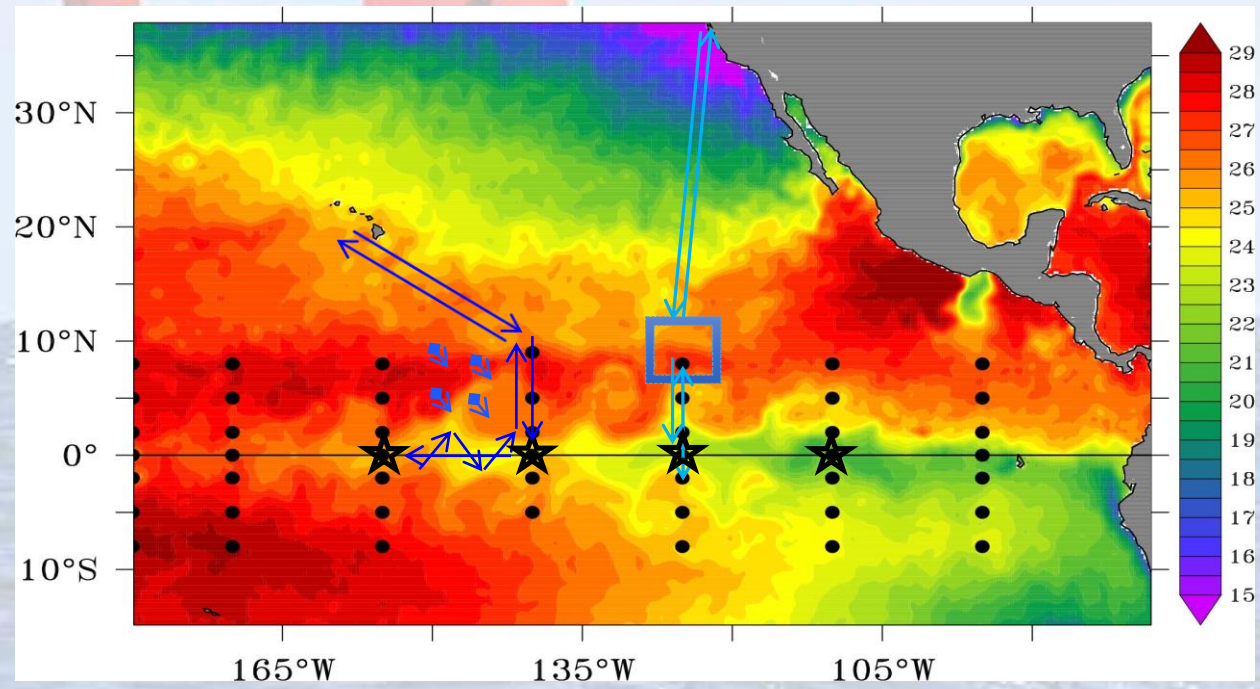


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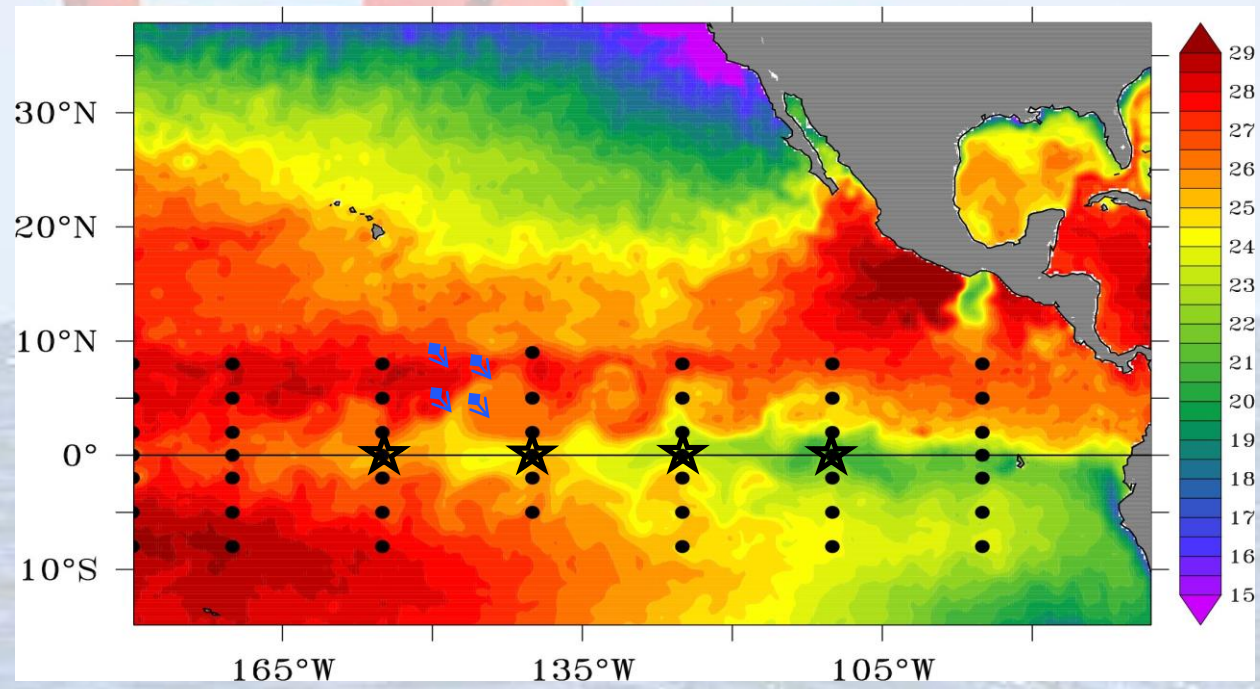


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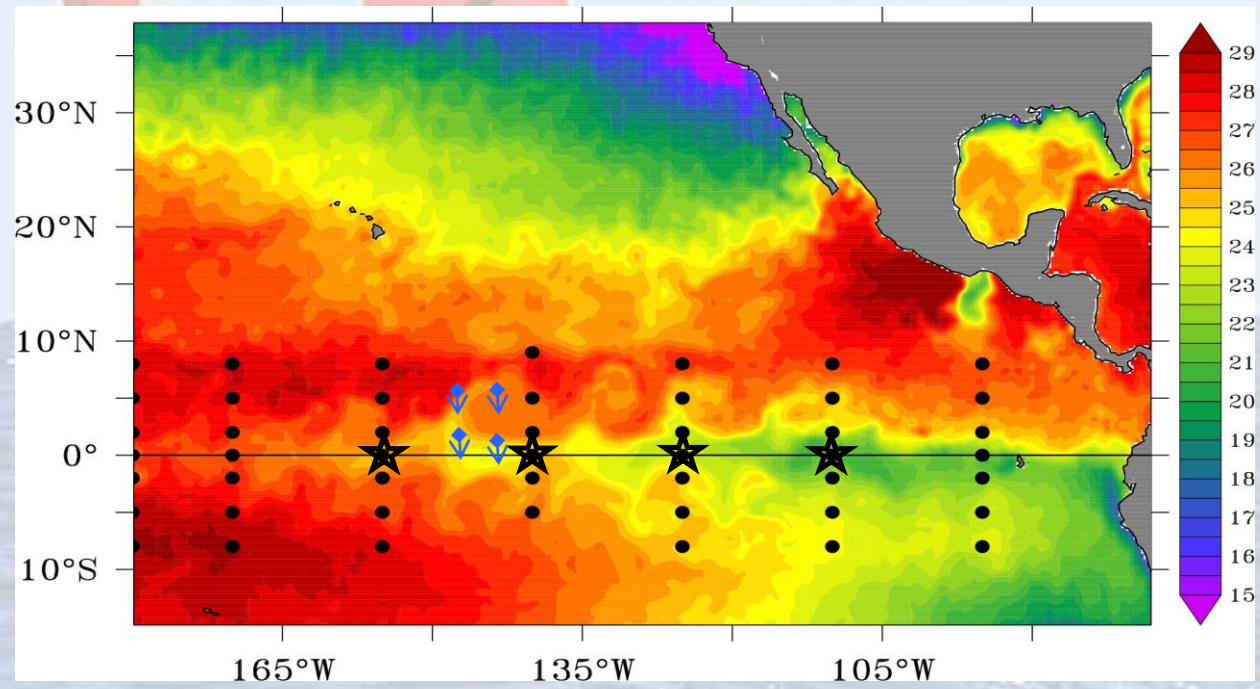


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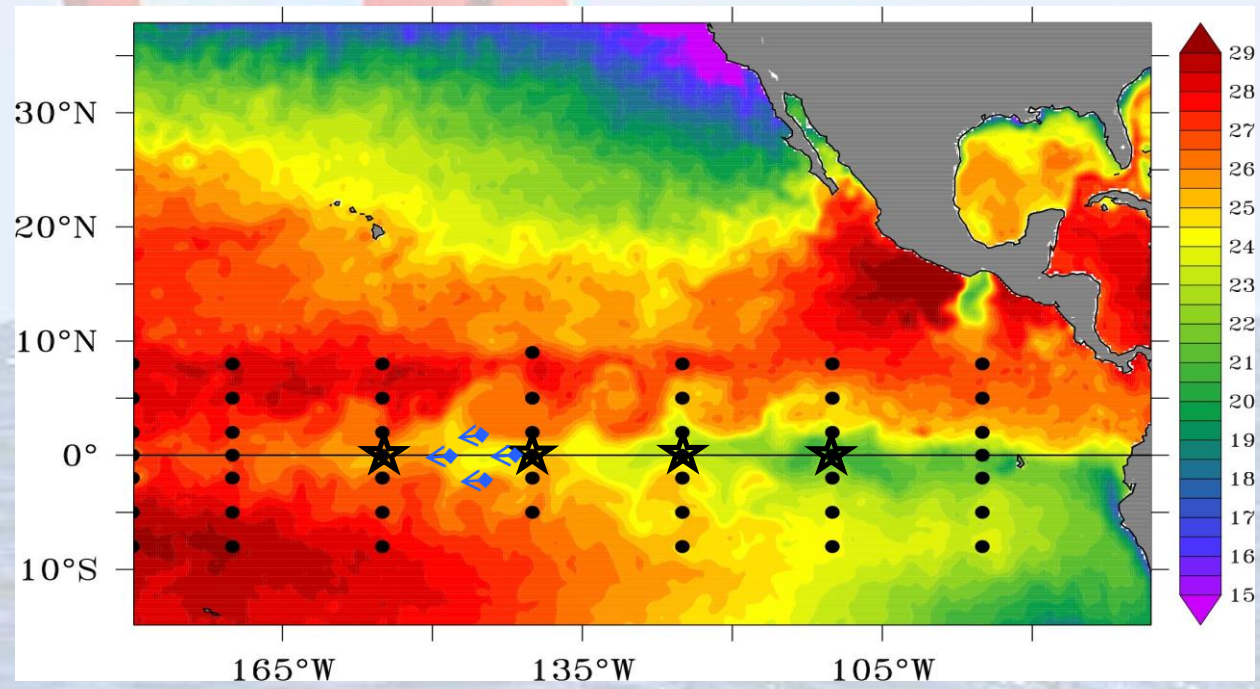


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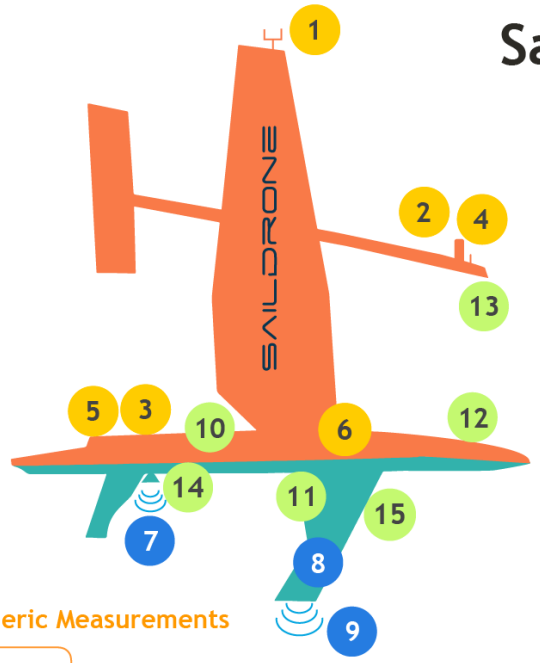
*Please advise:*
*grid spacing, where, etc.*




# 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
- Sunlight & Infrared Radiation → 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 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

## 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

## *15 Sensor Packages 22 Essential Variables*

**Off-the-shelf Sensors (data put on GTS):**

- Air Temperature and Relative Humidity
- Air Pressure
- SST (@0.6m)

**Wind and Wind Stress** (Bulk and covariance)

**ADCP currents** (upper 100m)

**Air-sea heat fluxes** (LW and SW radiation, bulk latent heat and sensible heat)

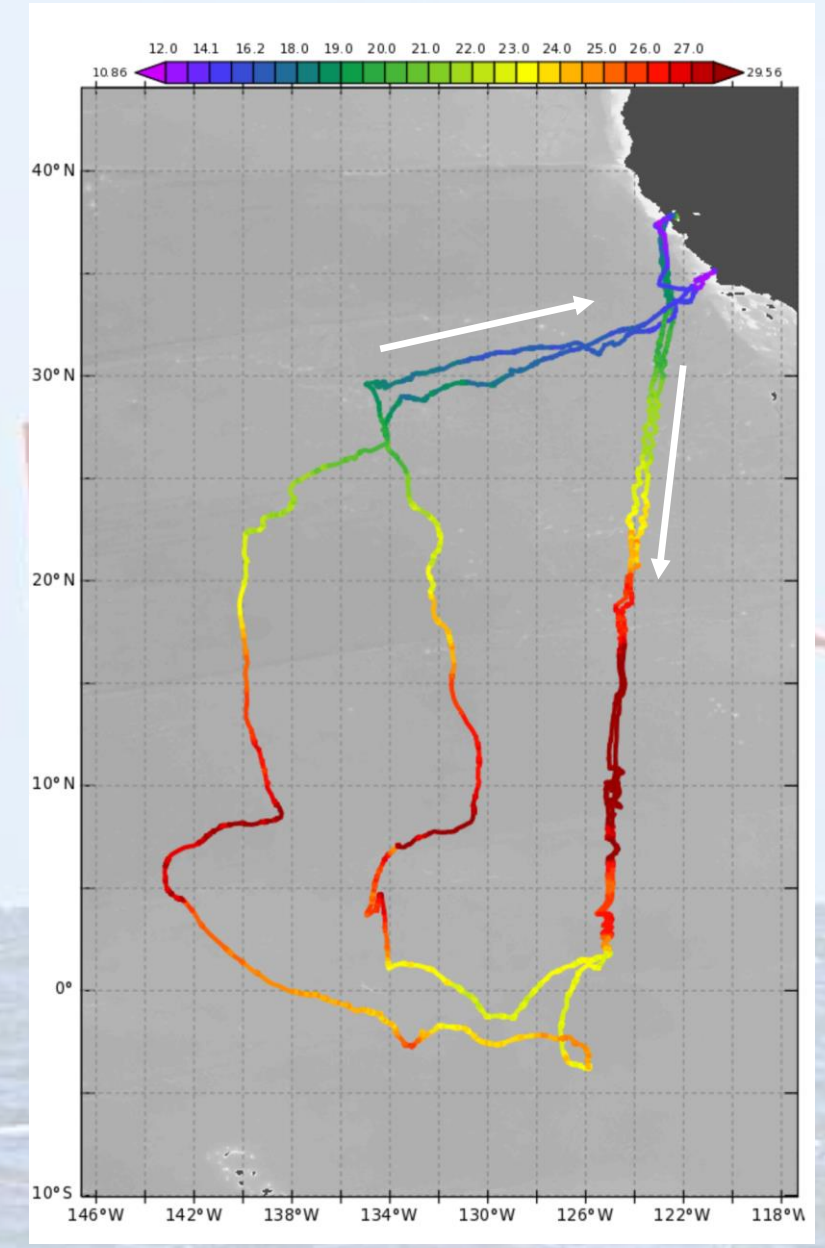
**Waves** (significant wave height and period)

**BGC Suite**

- Air pCO2
- Sea surface pCO2 and pH
- Dissolved Oxygen
- Chla, CDOM, Red Backscatter

# Tropical Pacific TPOS Mission 1: San Francisco – San Francisco

SST

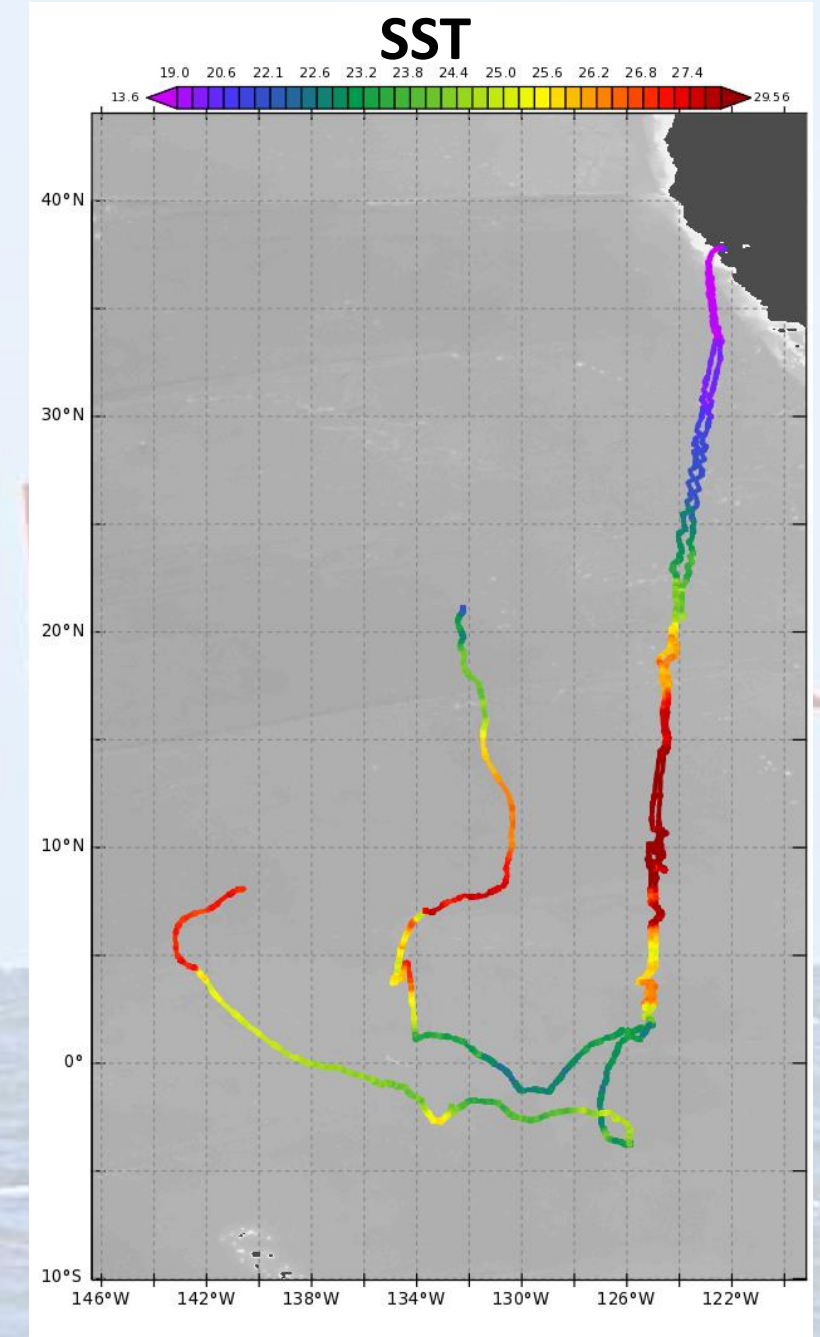




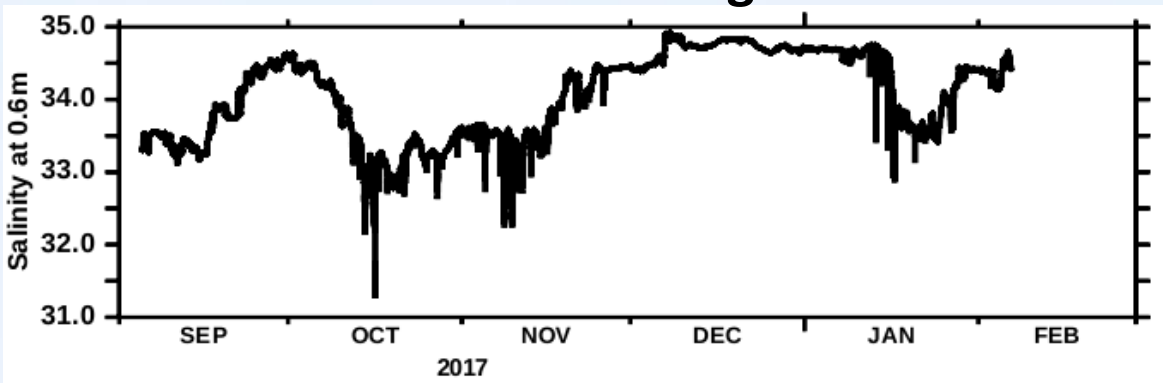
**Two TPOS Saildrones launched from dock in San Francisco Bay, for return trips of the Equatorial Pacific. No ship time!**

# Tropical Pacific TPOS Mission 2017: San Francisco – San Francisco

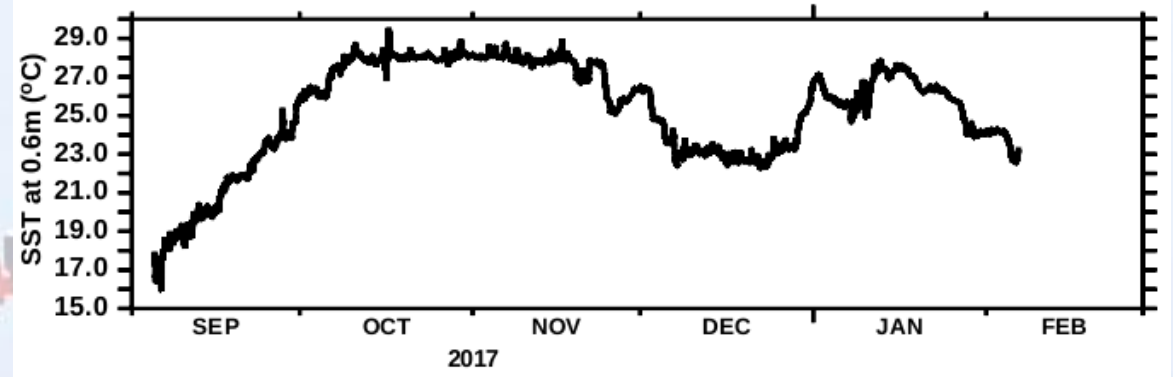
## SST




## Time series of SST and SSS along one Saildrone track




SSS




SST

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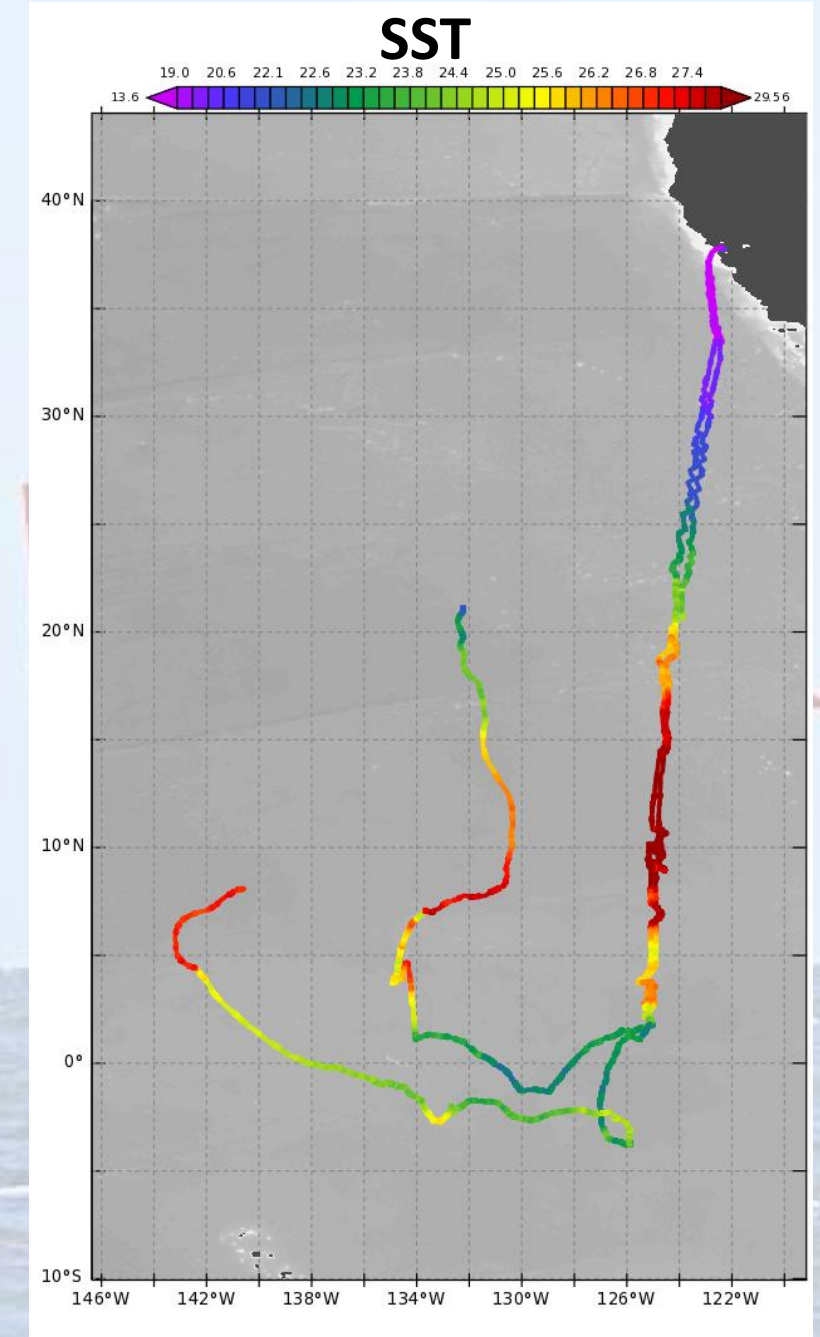


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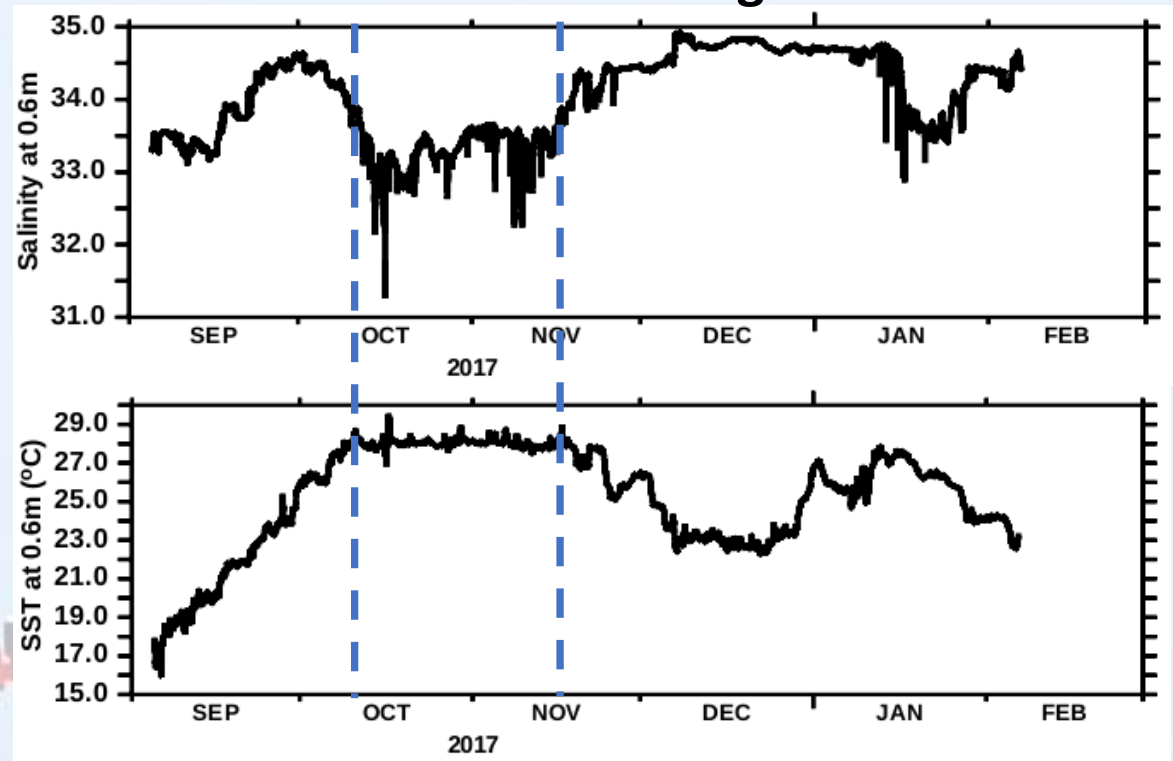
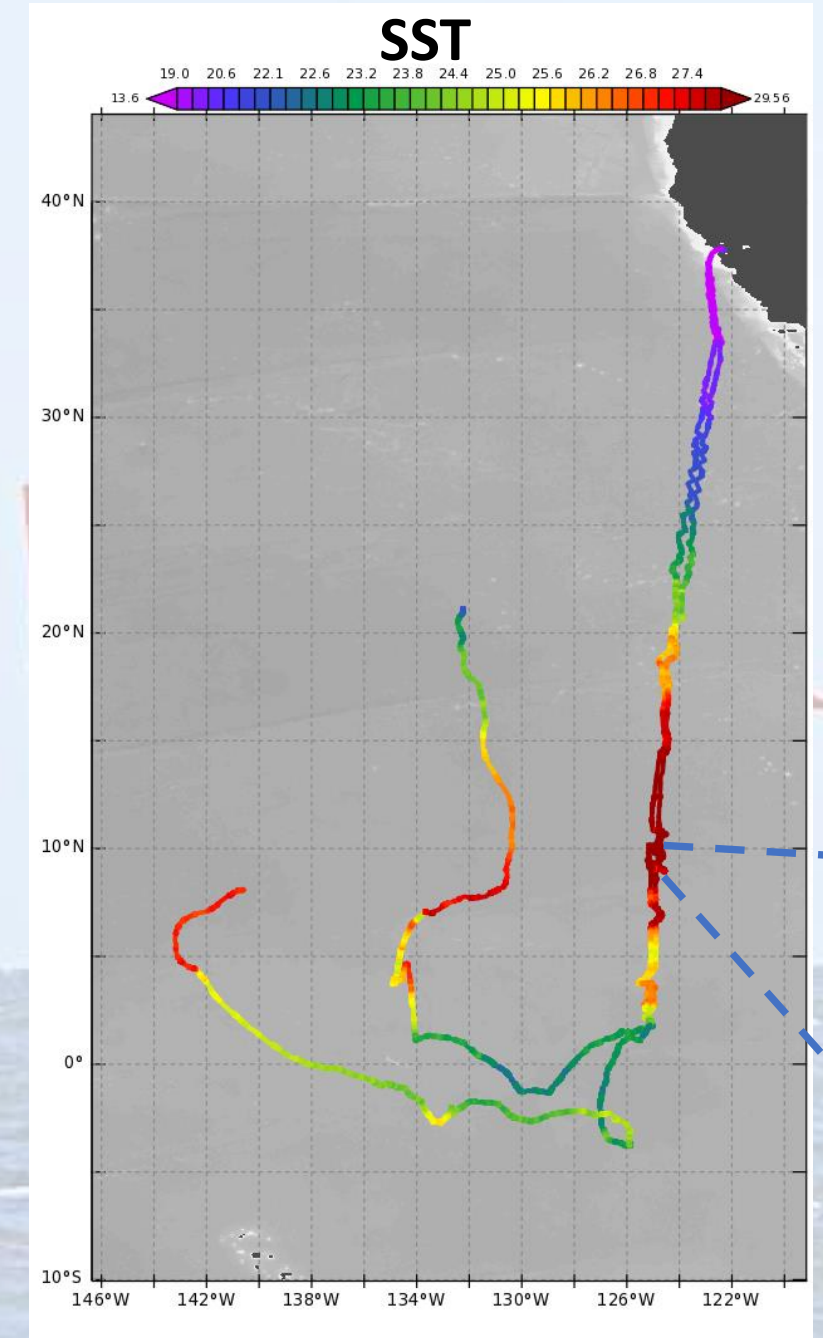



SSS

SST

# Tropical Pacific TPOS Mission #1, 2017: San Francisco – San Francisco

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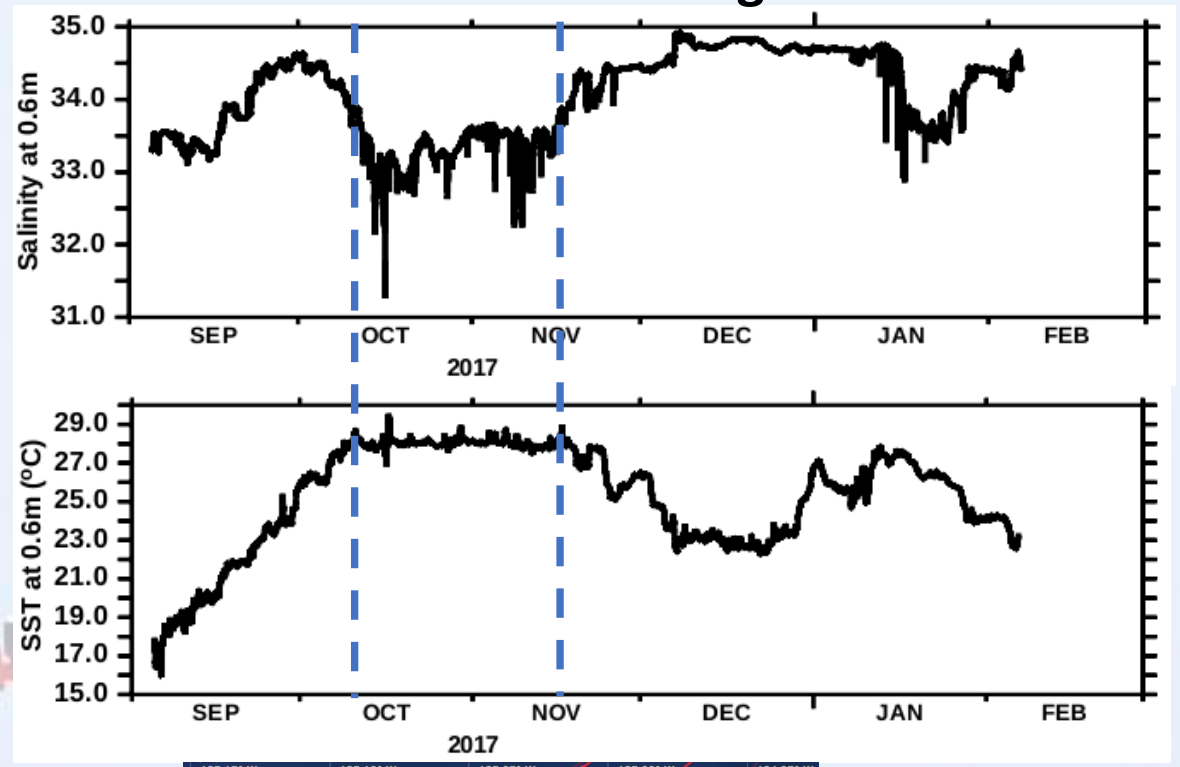


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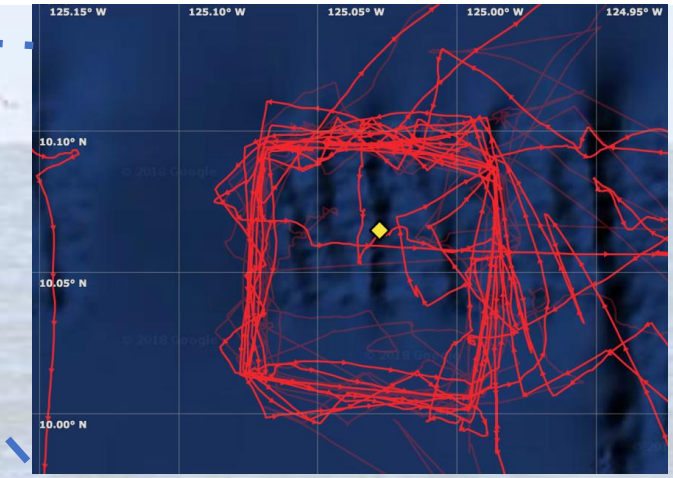


Saildrone tracks around SPURS2 WHOI buoy ◆

COMPARING AIR-SEA FLUX MEASUREMENTS FROM

# A NEW UNMANNED SURFACE VEHICLE AND PROVEN PLATFORMS

DURING THE SPURS-2 FIELD CAMPAIGN

Zhang et al. 2019

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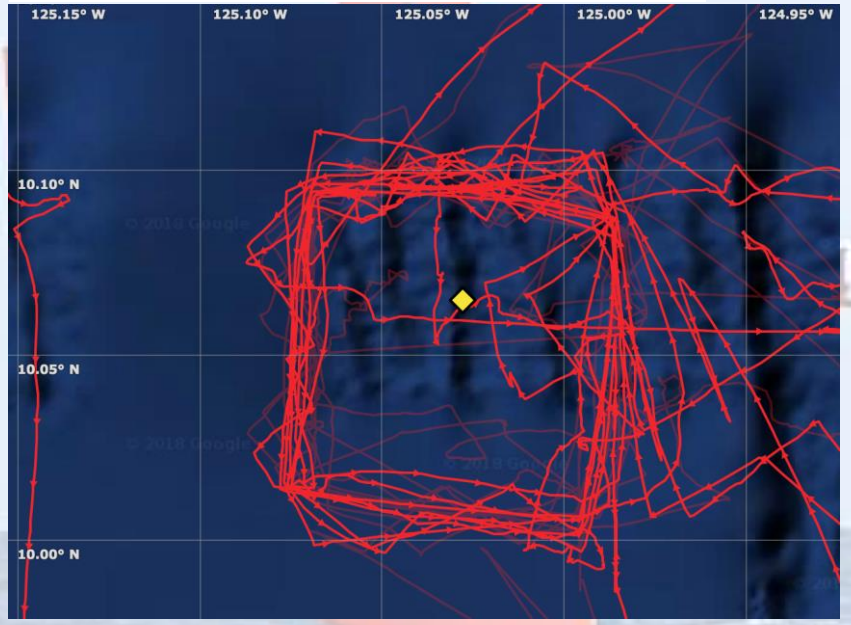
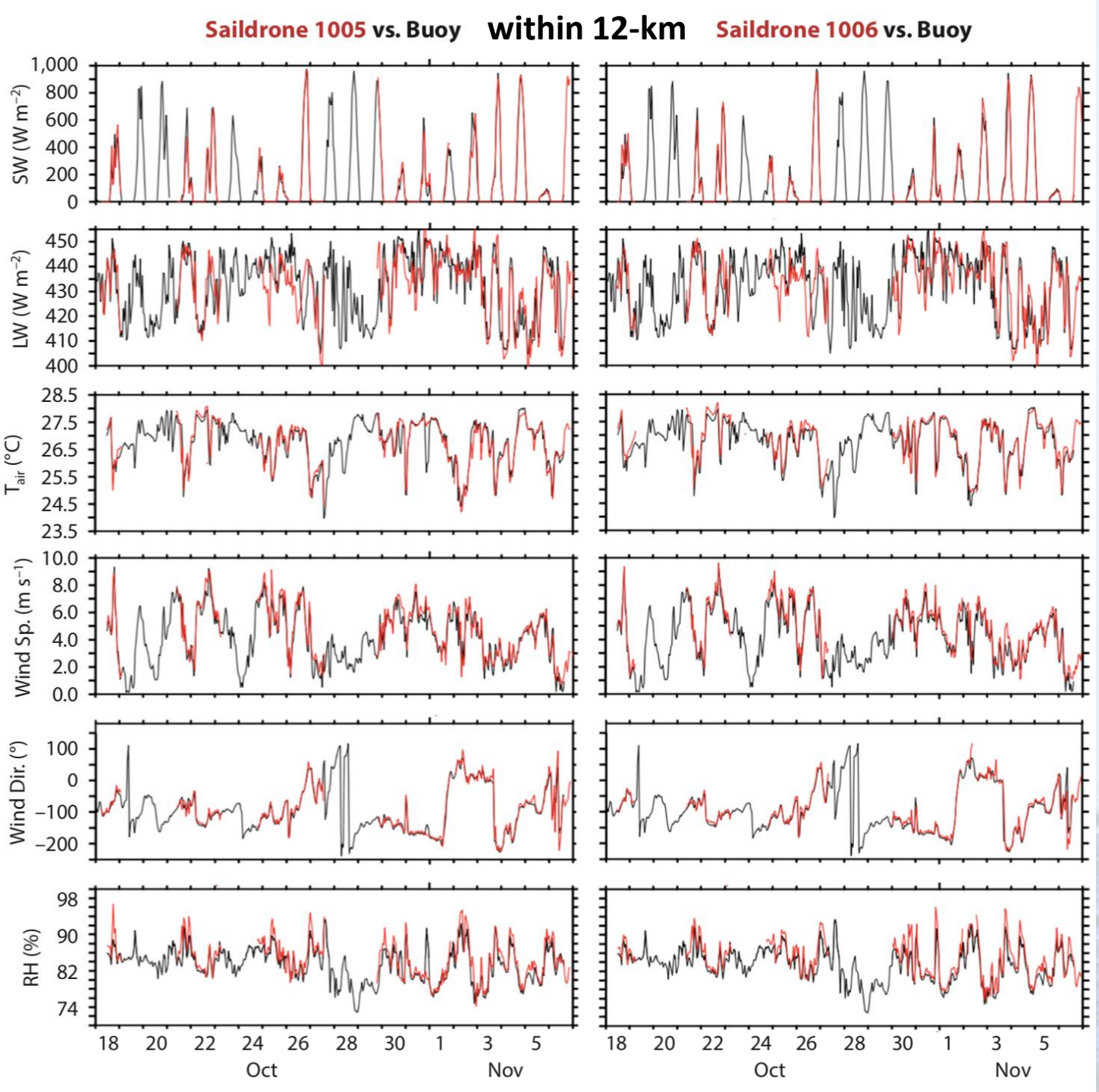
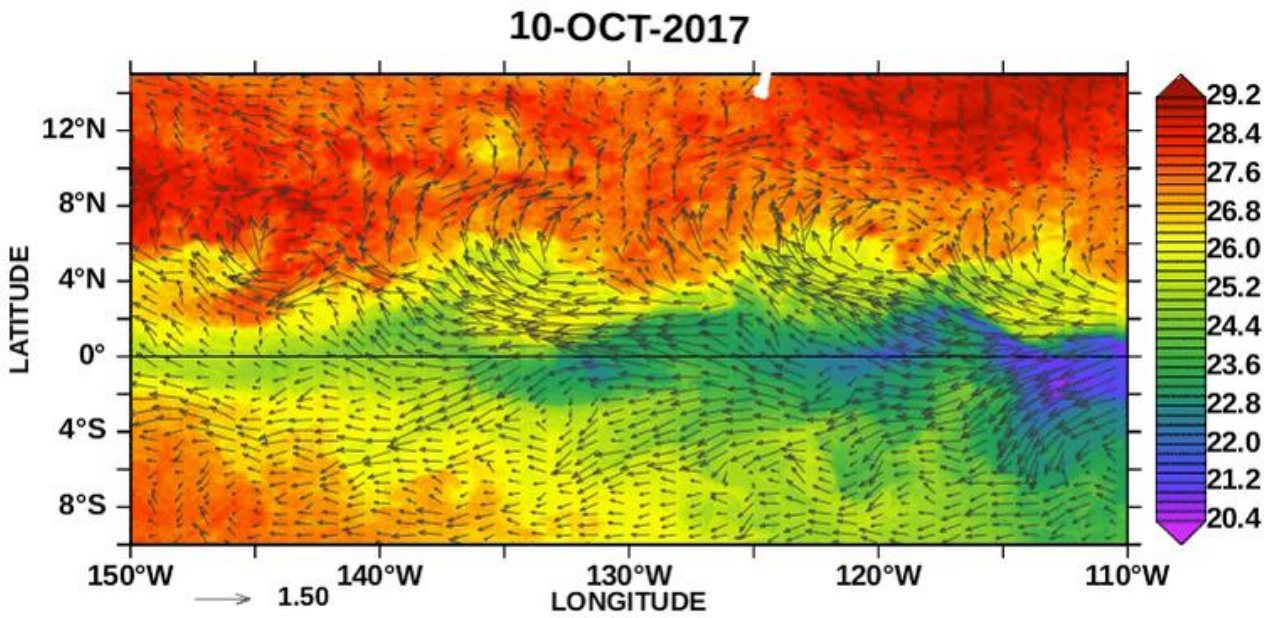
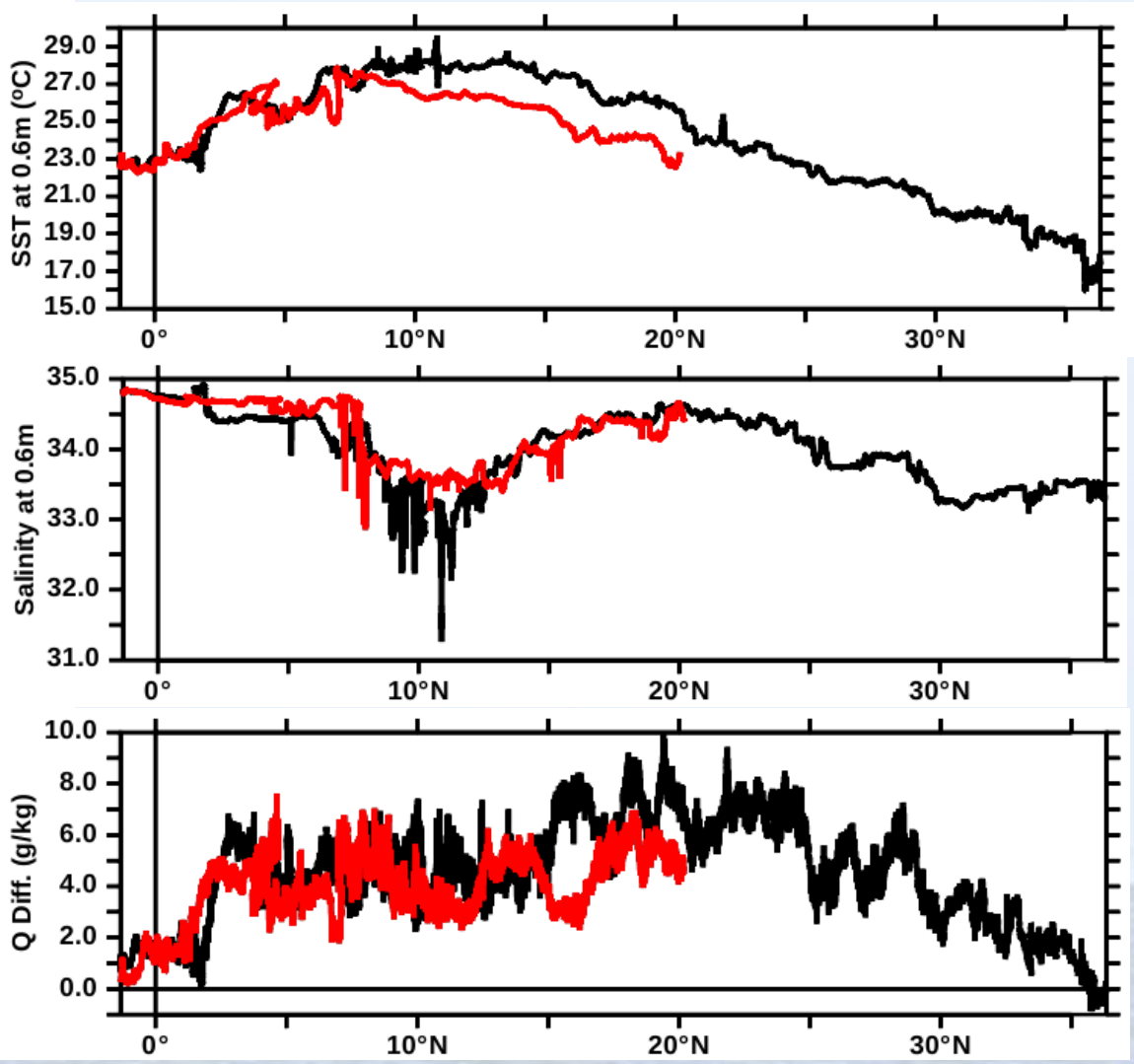


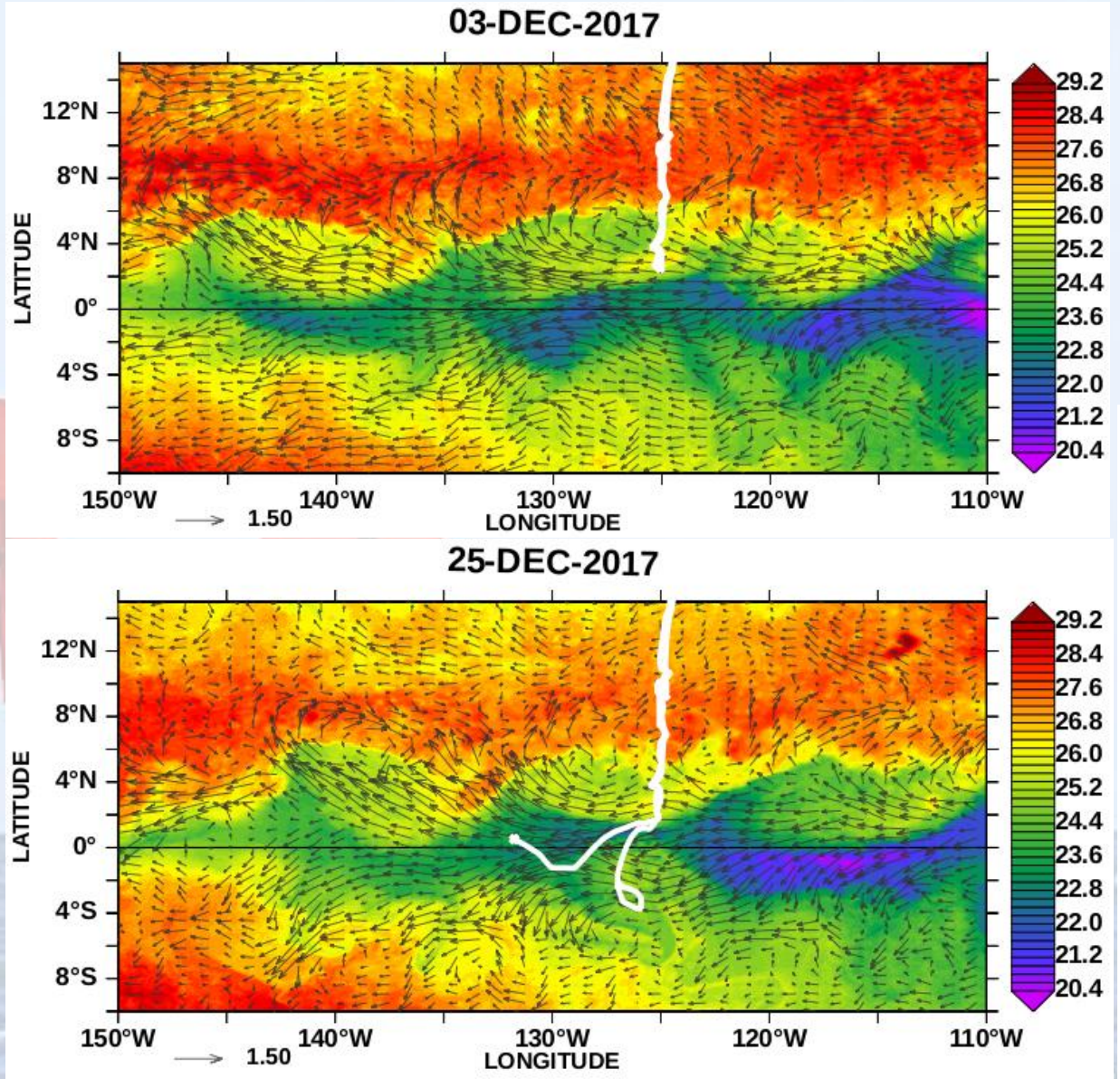



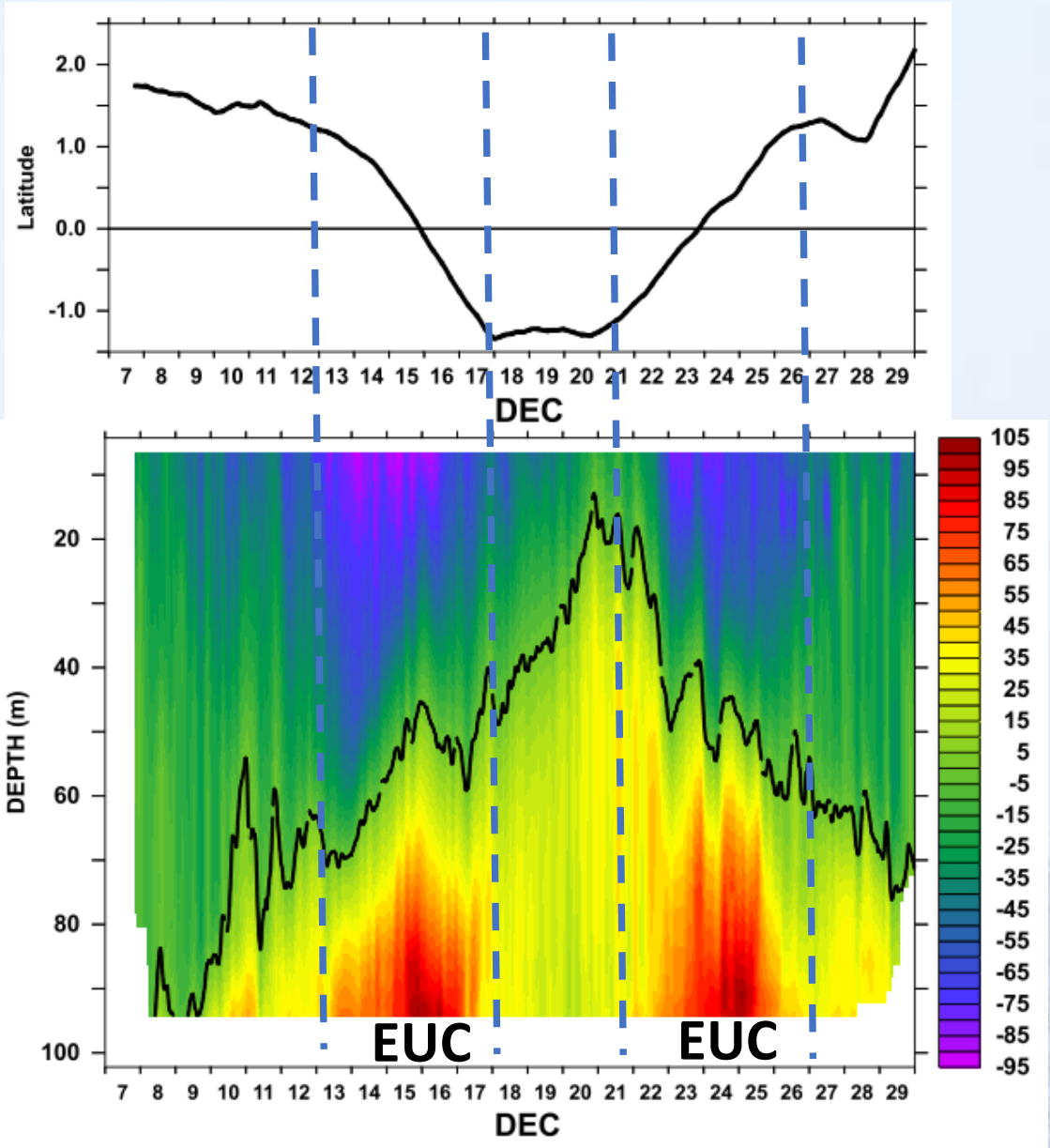
# Saildrone Tracks over JPL MUR SST and HYCOM Surface Currents



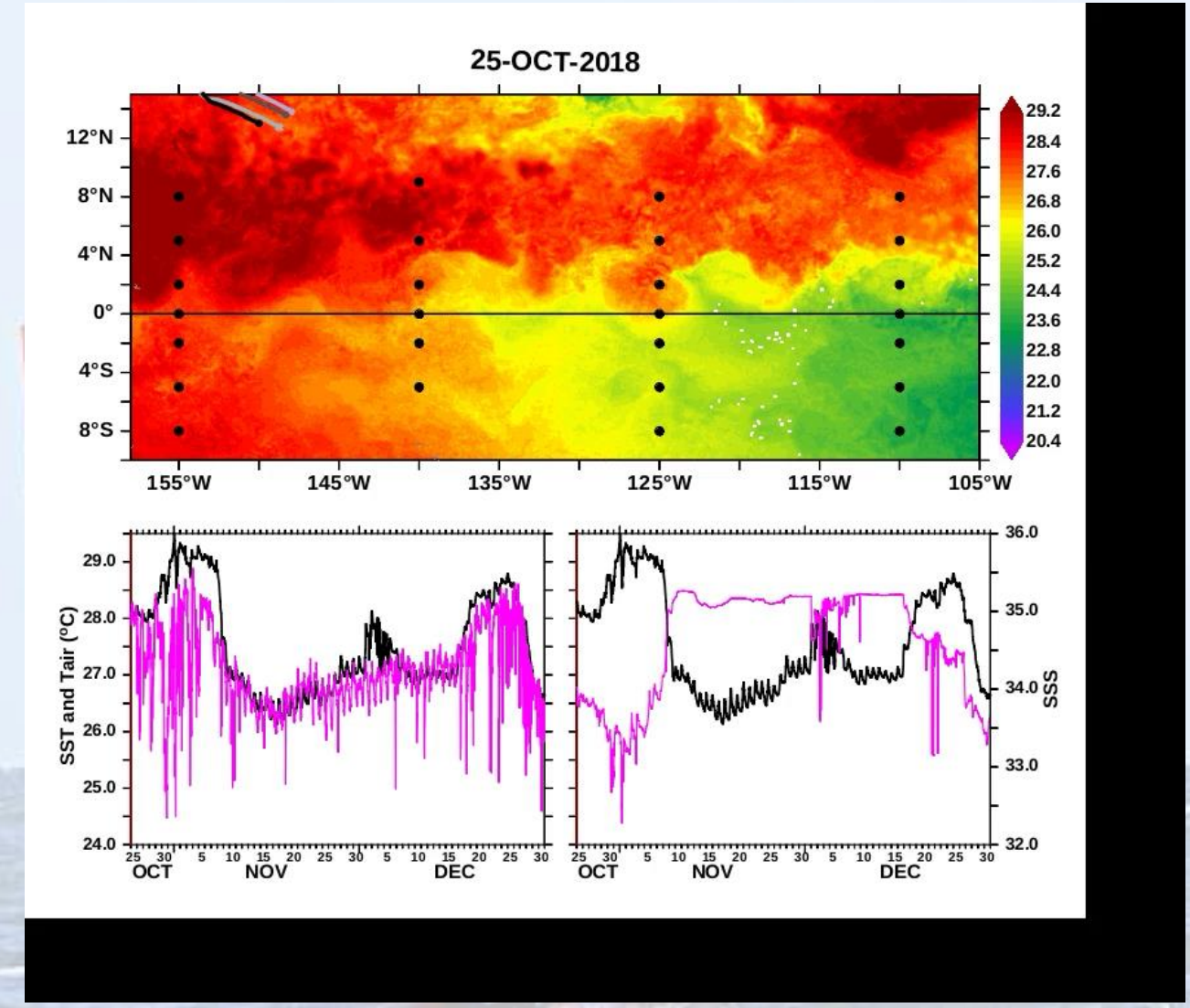
# Saildrone ADCP:
# Equatorial Undercurrent (EUC) during the two crossings of Equator



# TPOS Mission #2, 2018: Honululu - Honululu

## 7-day Saildrone tracks

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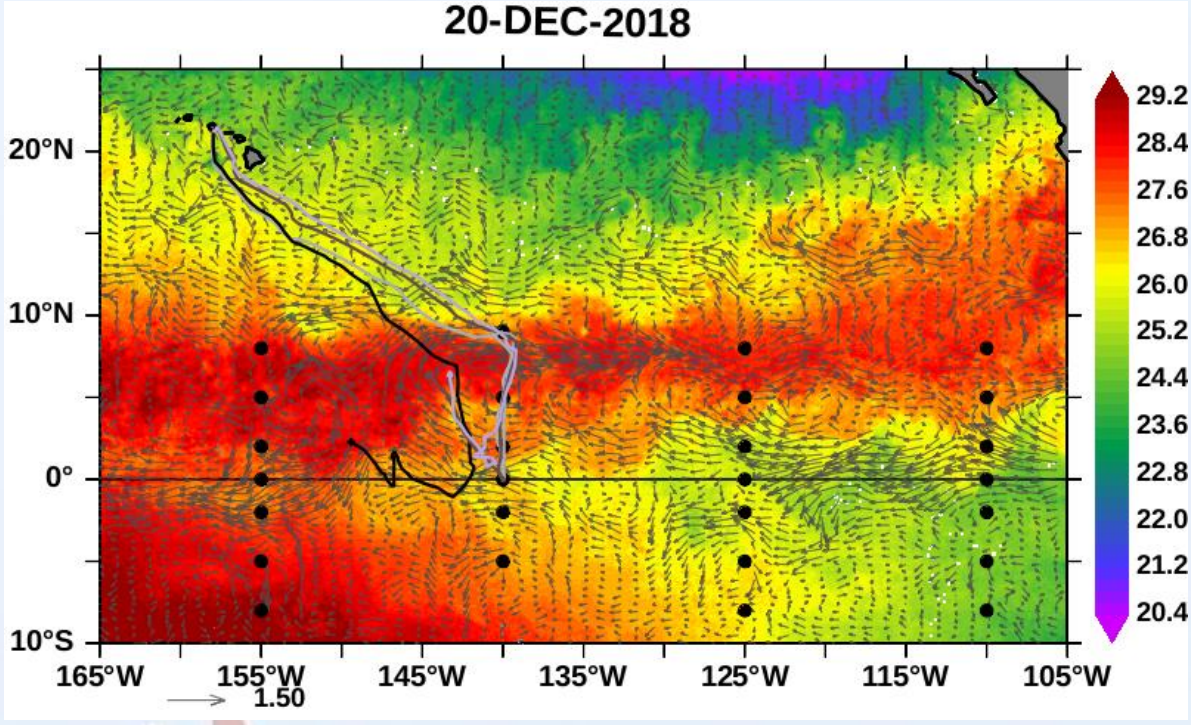

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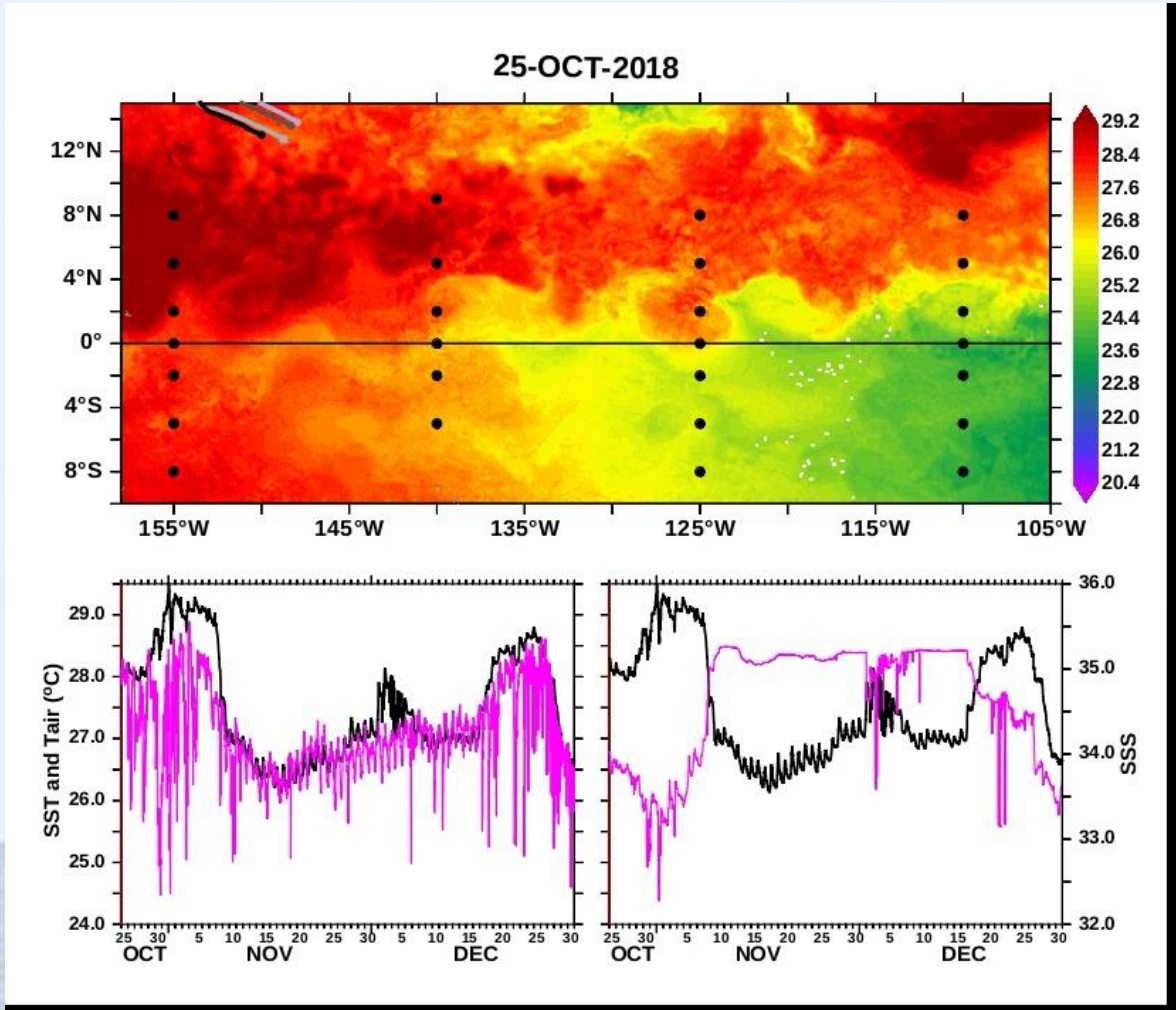
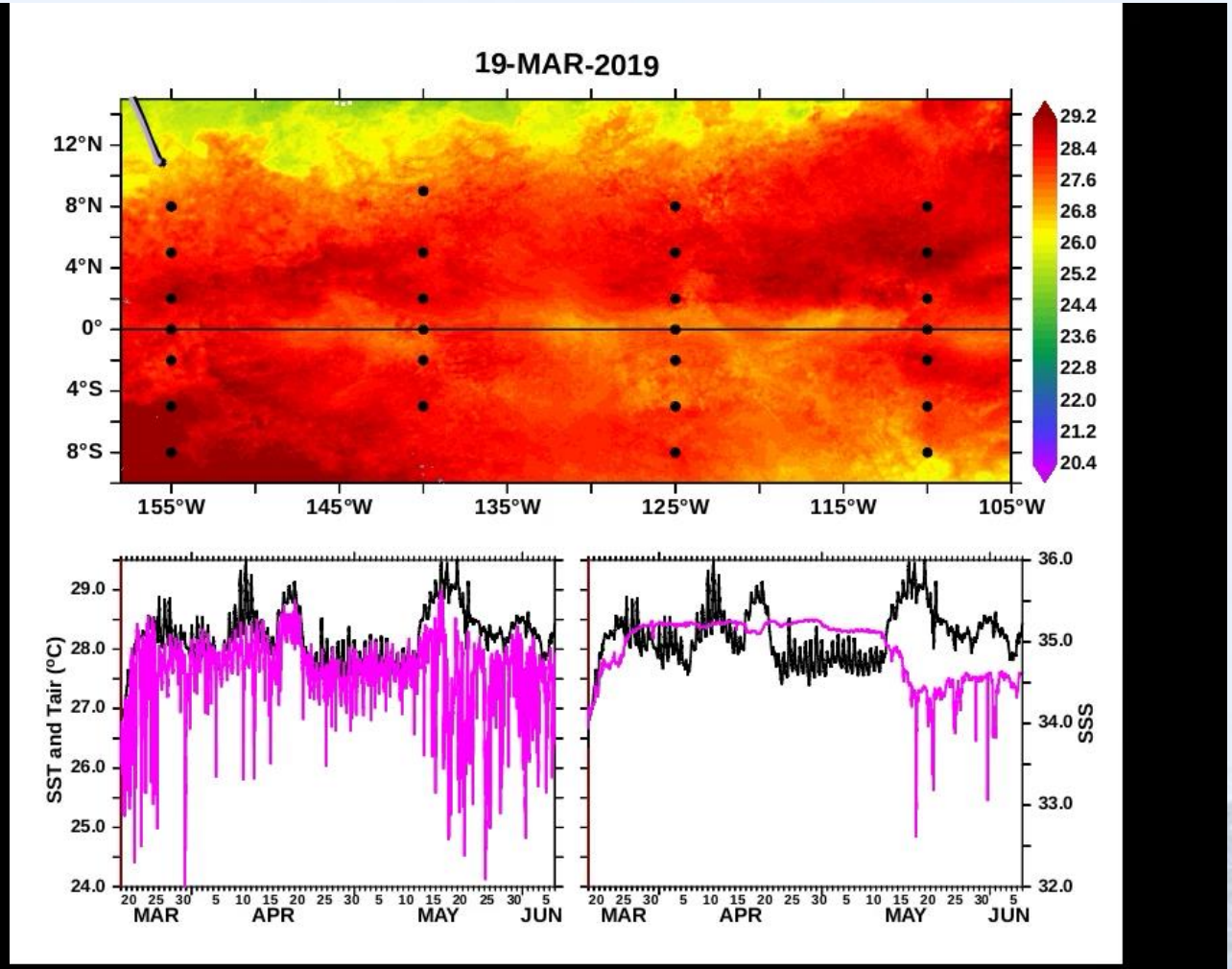
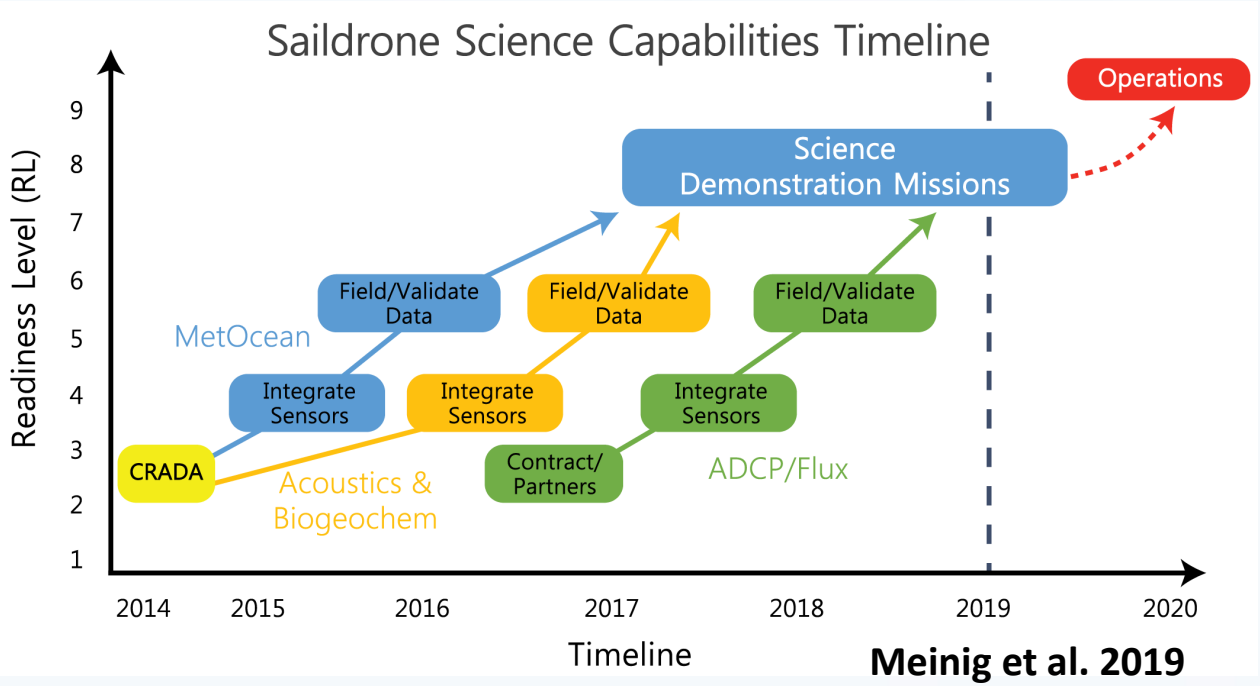


# Conclusion

**Saildrones have proven to be**

1. **Reliable, long-range, long-endurance, GREEN autonomous ocean observing platforms, especially ideal for observing fronts and adaptive sampling.**
2. **Capable of making measurements of 22 Essential Ocean and Atmospheric Variables, including air-sea heat, momentum, CO2 fluxes, and upper ocean currents, critical for understanding air-sea interaction processes.**




# Future Work *(transition to operation)*

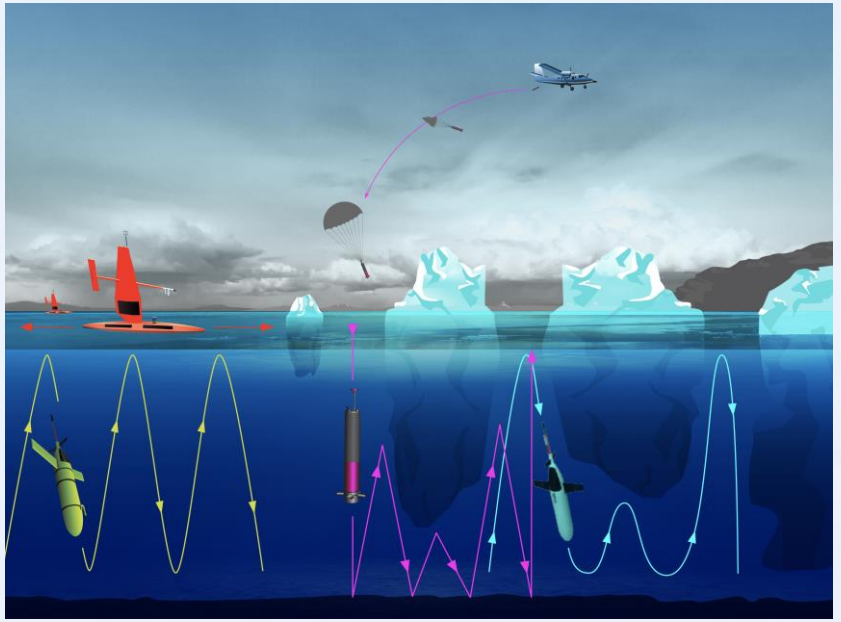
1. **Test and Improve strategies in navigating and target-sampling complex ocean and atmospheric environments and processes.** ***"Better use of forecast for observational campaigns"***
2. **Evaluate the benefits of saildrone data (high frequency simultaneous ocean and atmospheric measurements, crossing fronts, adaptive) to Numerical Weather Prediction (NWP) models.** ***"Better diagnose model errors and improve forecasts"***

# NWP forecasts benefit Saildrone operation

## 2019 Joint Mission for Observing Arctic Sea Ice Environment

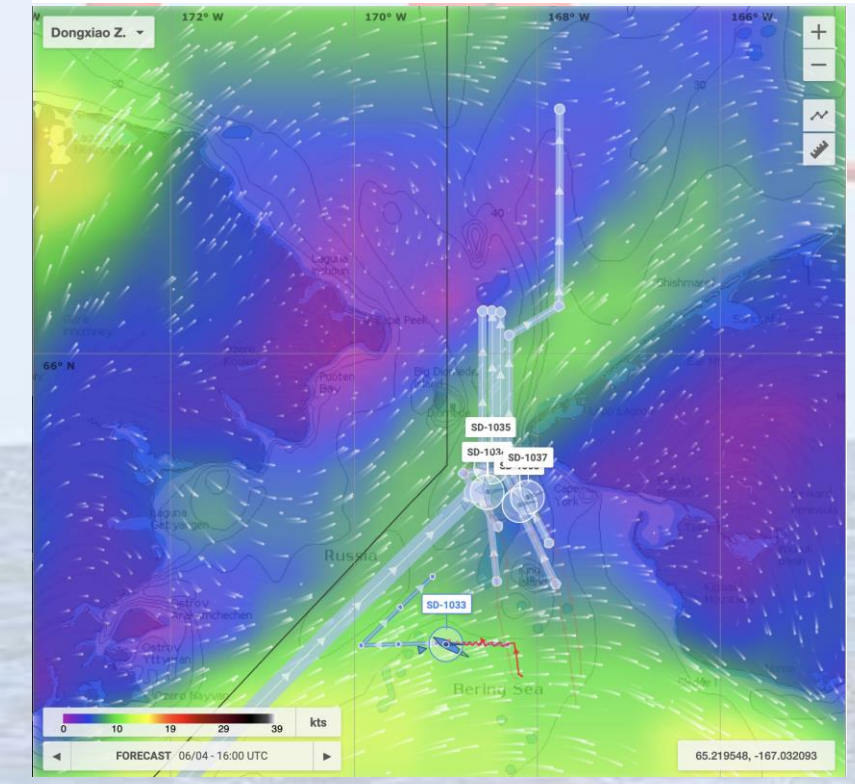
***PMEL, UW/JISAO, ESR, UW/APL, and Saildrone, Inc.***

**Chidong Zhang et al.**

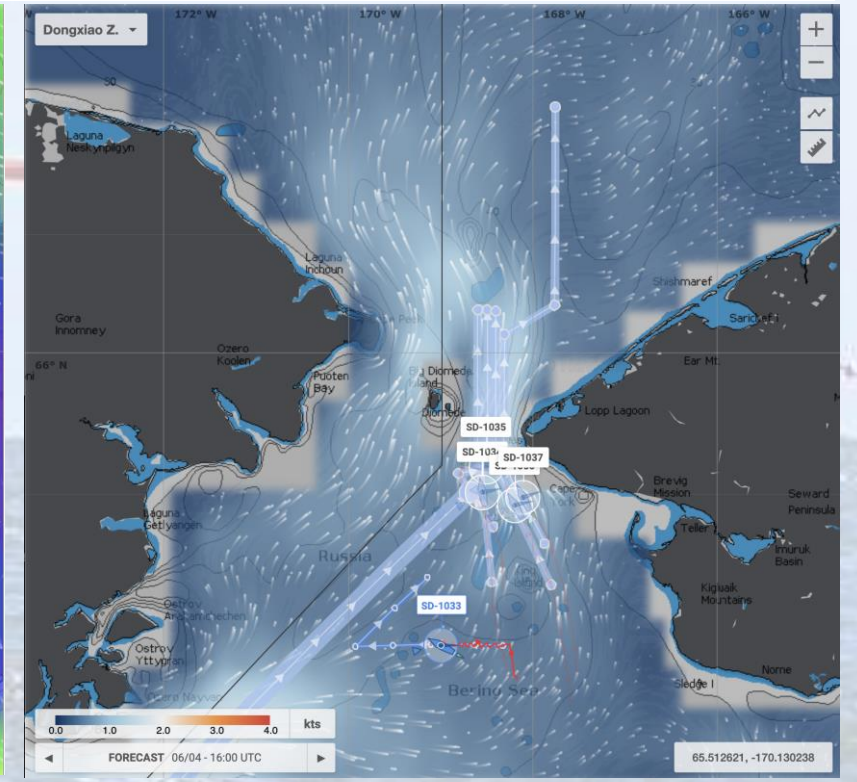


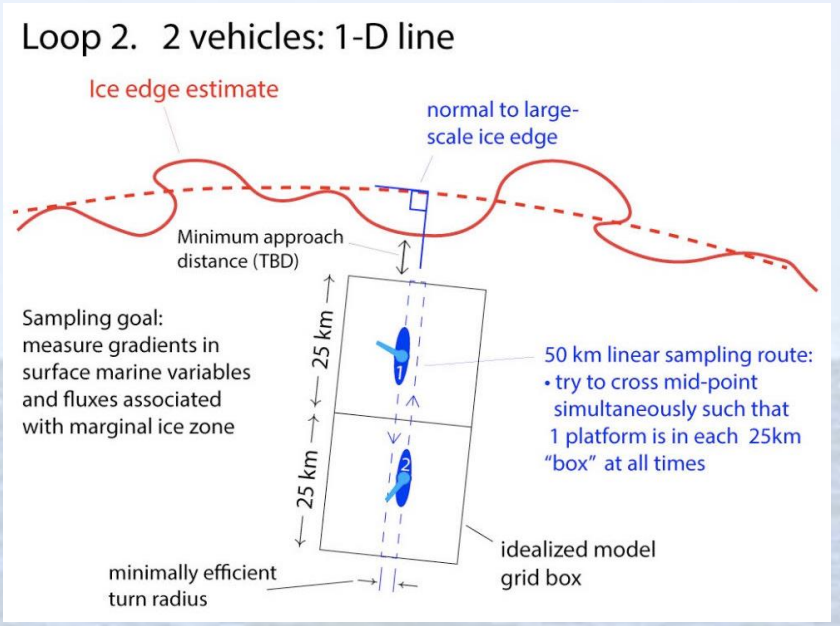
***Through narrow Bering Strait Reaching the Melting Ice Edge***
***Unescorted, Remotely Controlled 1000s km Away***

***NWP GFS wind forecast***




***HYCOM ocean current forecast***



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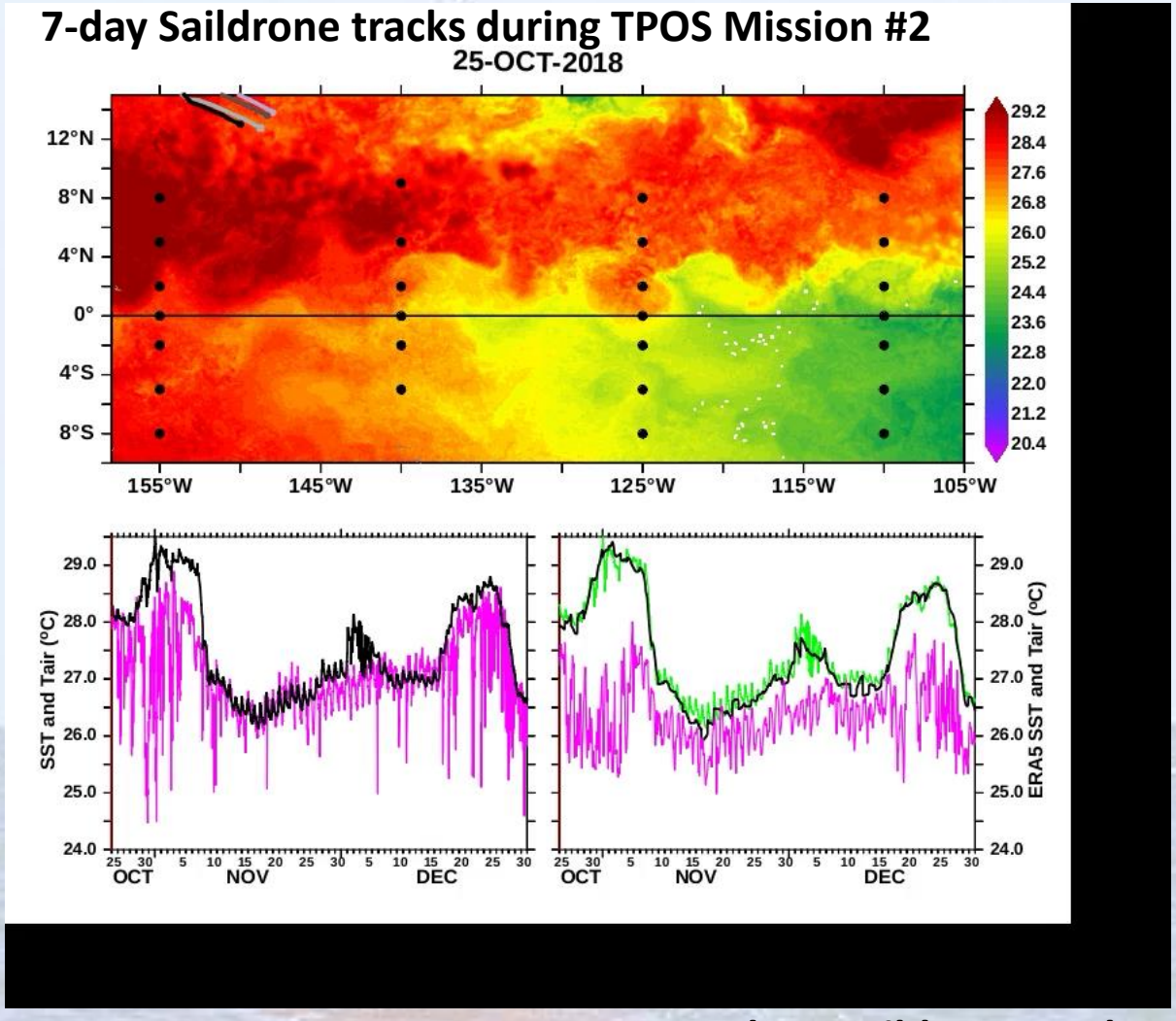
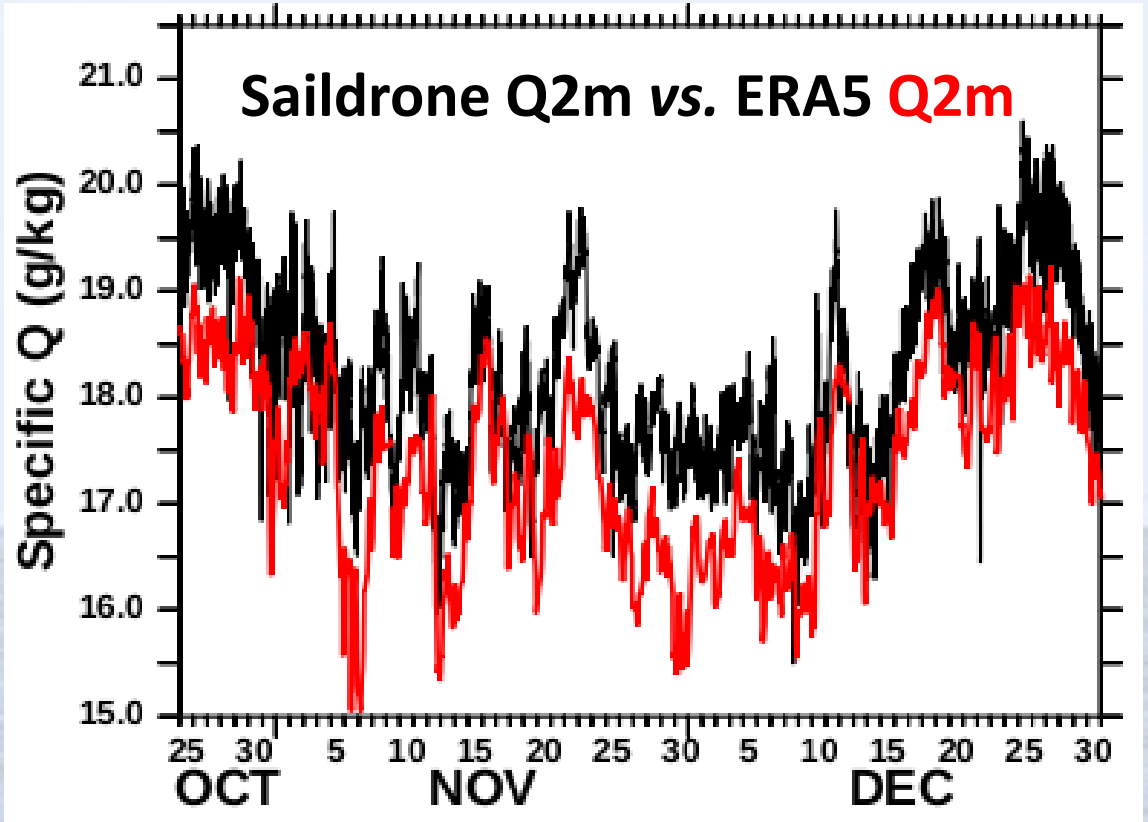



ERA5 along saildrone track



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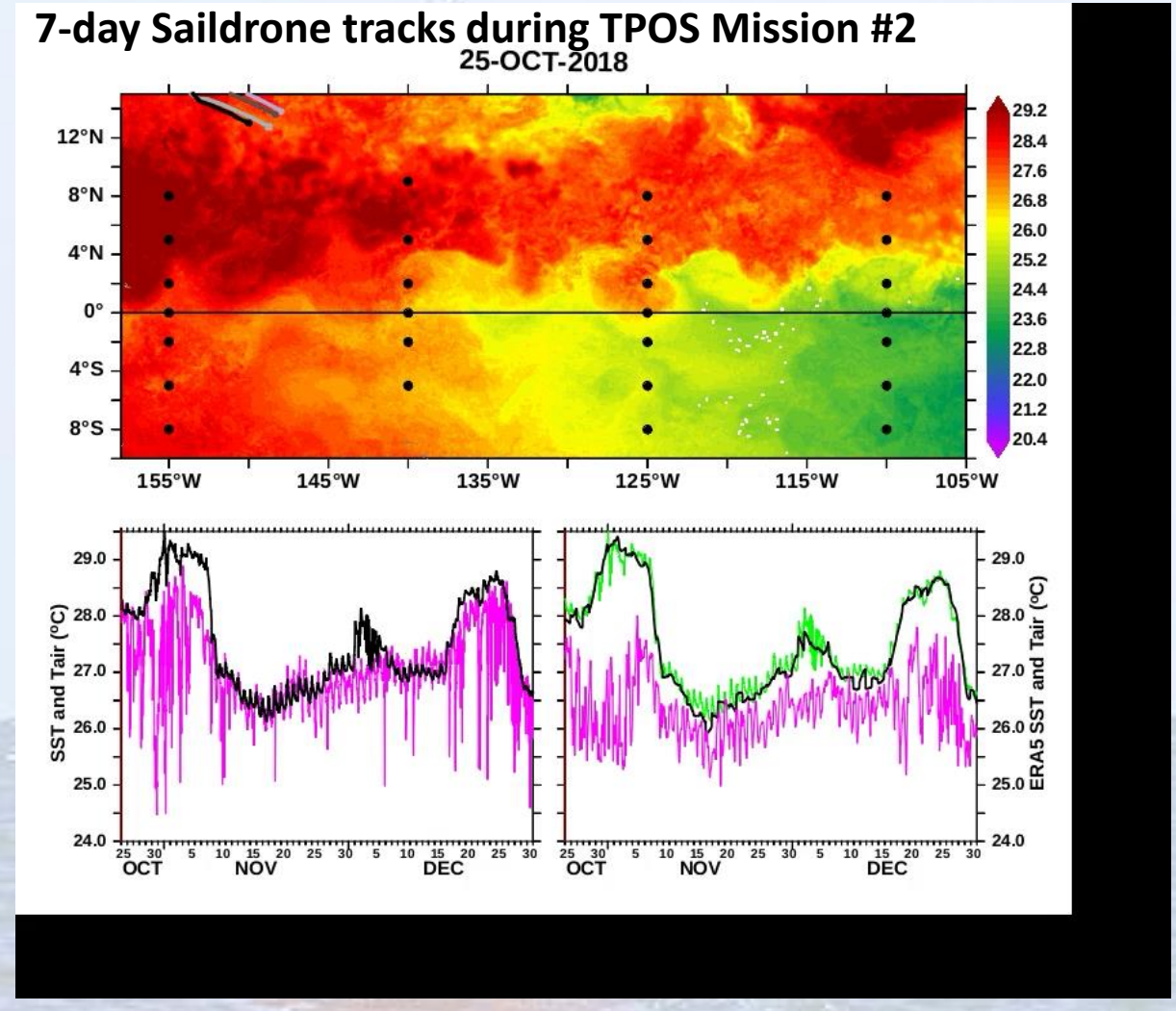


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