Using Saildrone autonomous in situ data for satellite validation and research into upper ocean physics and ecology

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Sensors

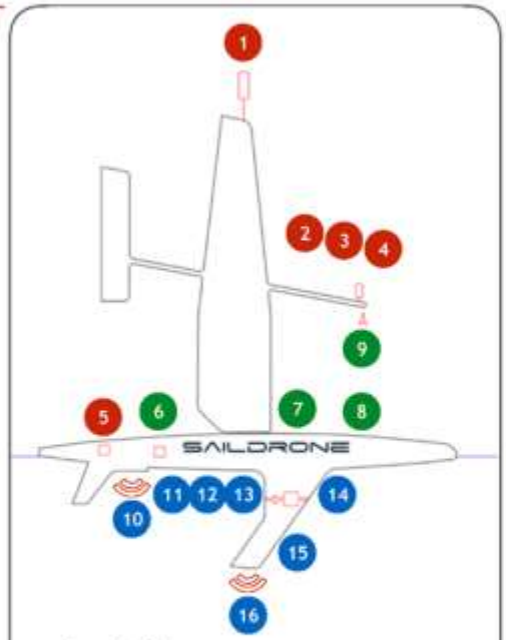
SAILDRONE GEN 4 SPECIFICATIONS AND SENSOR SUITE

Atmospheric Measurements

- Wind Speed, Wind Direction → 1 — Anemometer @ +4.5m, Gill Windmaster 3D ultrasonic 20H
- Sunlight → 2 — Su… Py… eter @ +2.2m; 3 — Py… 2m
- Air Temperature, Humidity → 4 — Meteorological Probe @ +2.2m, Rotronic HC2 - S3 with rad shield
- Air Pressure → 5 — Digital Barometer @ +0.2m, Vaisala BAROCAP PTB210

Oceanic Surface Measurements

- Wave Height & Period → 6 — Dual GPS & IMU, Vectornav / KVH
- pCO_2 → 7 — CO_2 System @ +0.3m, PMEL ASVCO$_2$
- Ma… ield → 8 — Magnetometer @ 0m, Barrington MAG 648
- Skin Temperature → 9 — SST IR Pyrometer @ +2.2m, Heitronics KT15 II

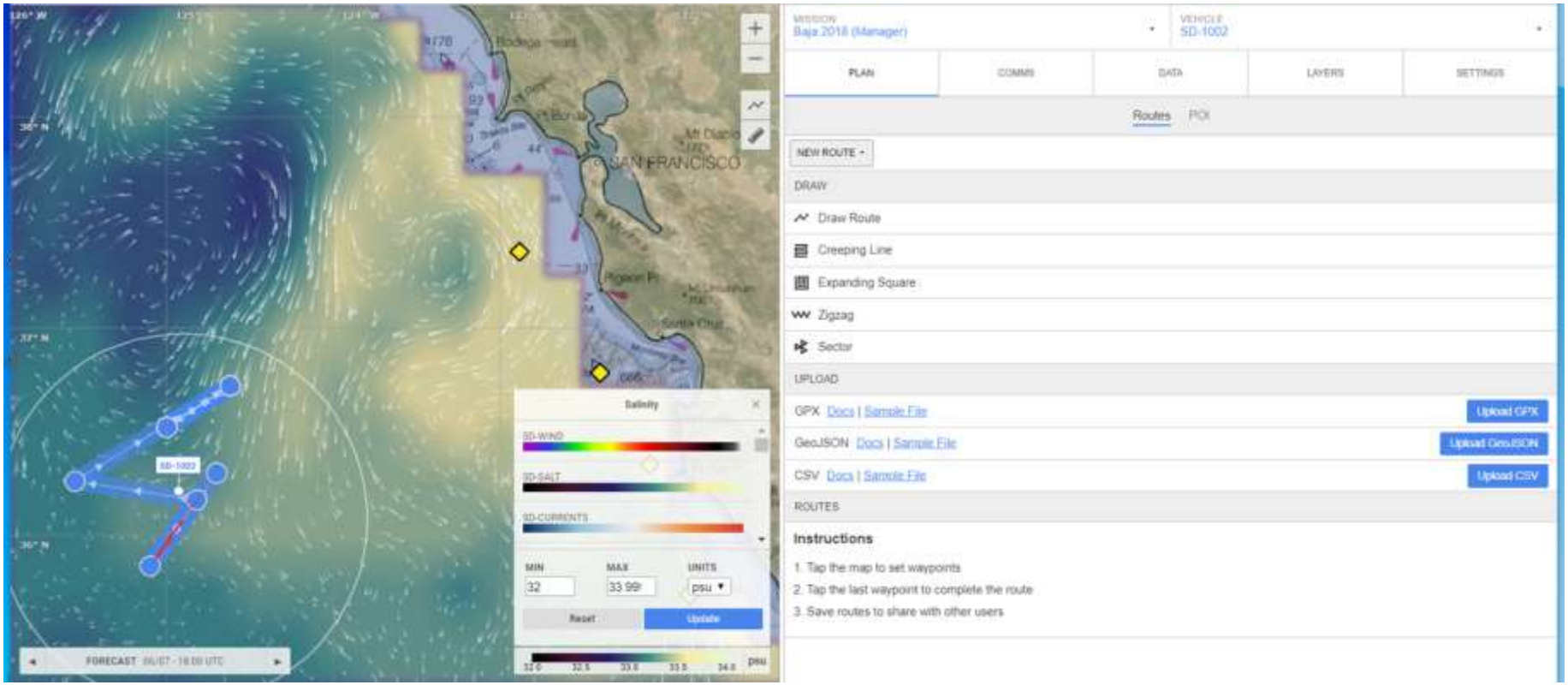


Length: 23 ft
Height: 15 ft
Depth: 7 ft
Weight: 1200 lbs, loaded
Speed: Transit - 3 Kt, Max - 8 Kt
Payload Power: 30w Steady state
Payload Capacity: 250 lbs
Max deployed duration: 12 months
Longest voyage: 10,000 miles

Oceanic Sub-Surface Measurements

- Ocean Currents → 10 — ADCP @ -0.2m, Teledyne RDI Workhorse 300 kHz
- Chla, CDOM Concentration, Red Backscatter → 11 — Fluorometer @ -0.2m, Sea-bird Scientific WET labs Eco Triplet
- Dissolved Oxygen → 12 — Oxygen Optode @ -0.5m, Aanderaa 4831
- pCO_2 → 13 — CO_2 System @ -0.5m, PMEL ASVCO$_2$, Sea-Bird Scientific SBE Prawler, Honeywell Durafet
- Water Temperature, Salinity → 14 — Thermosalinograph @ -0.5m, Teledyne RDI Citadel TS-NH
- Mari… …mal Presence → 15 — Passive Acoustic Recorder, Greenridge Sciences Inc. Acousonde
- F… …mass, Bathymetry → 16 — WBAT @ -2.5m, SIMRAD EK 80; Multi-beam Sonar @ -2.5m, Norbit iWBMS

Direct and task USV



Data explorer : web interface for tasking USV. This allows for control of the USV to sample fronts and adjust the track as they move. Points are set, with a ‘width’ set that controls the distance the USV is allowed to vary from the track.

April 11 - June 11, 2018

4 temperature loggers added by NASA Physical Oceanography Program

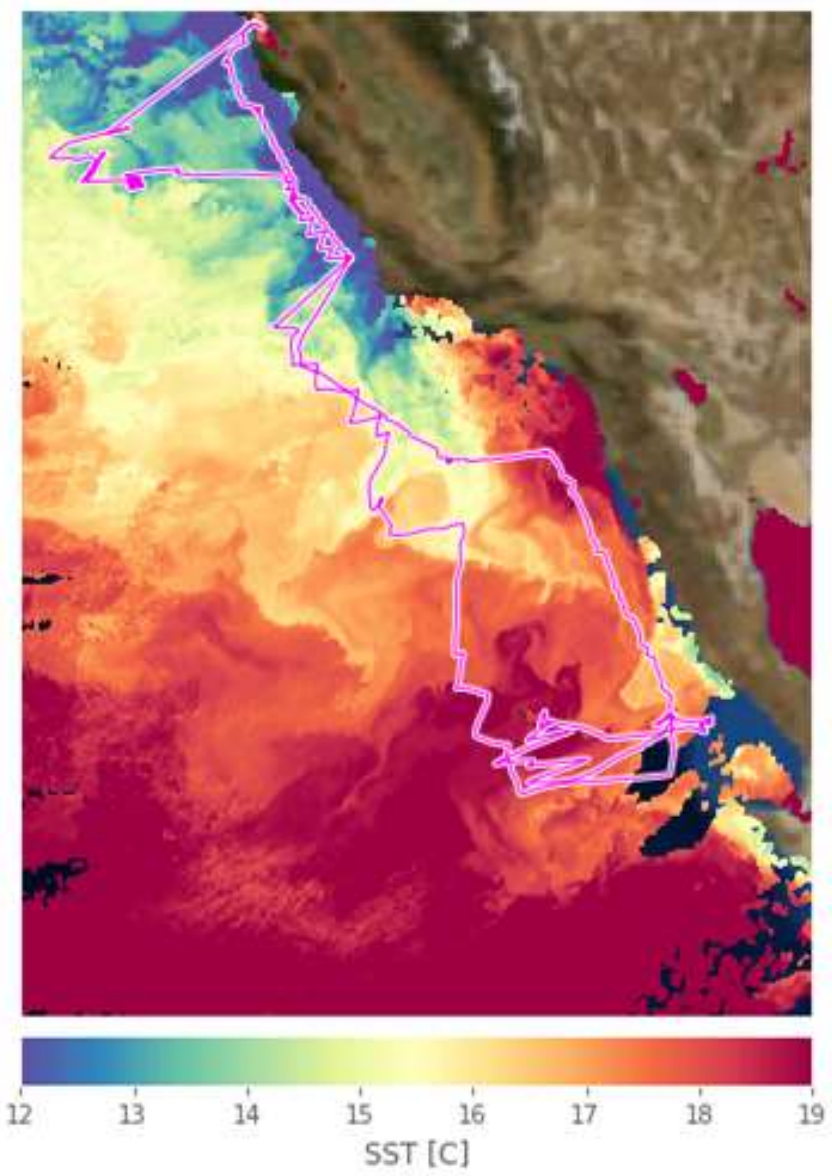
Baja Cruise

11 April – 11 June 2018
60-day cruise

Along-wind and across wind sampling of fronts

Data freely available NASA.PODAAC from CC-BY-NC license

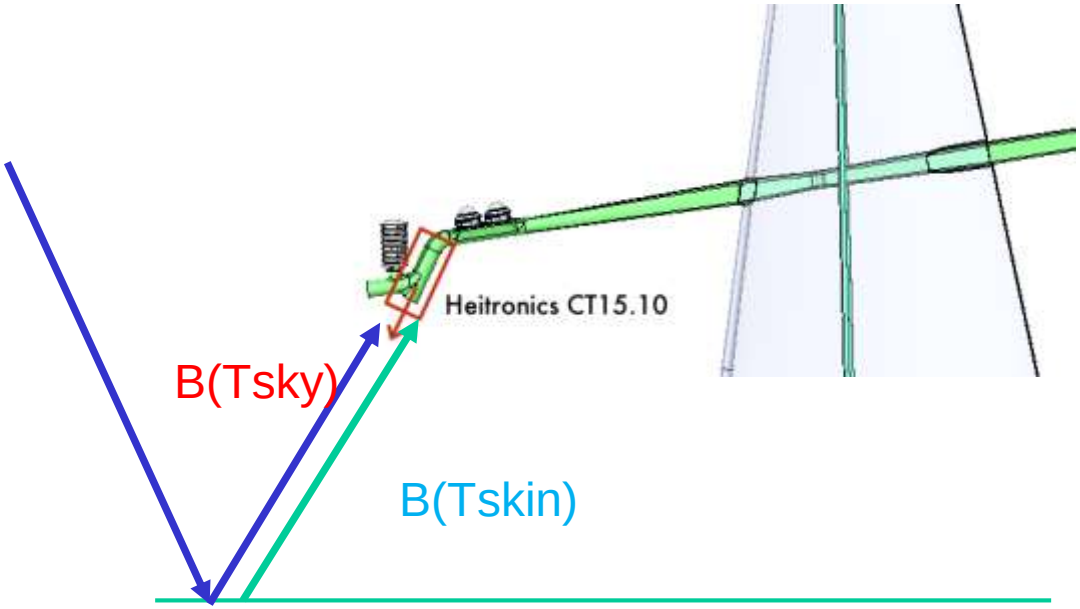
Software repository for project: https://github.com/cgentemann/Saildrone



Physics of observation

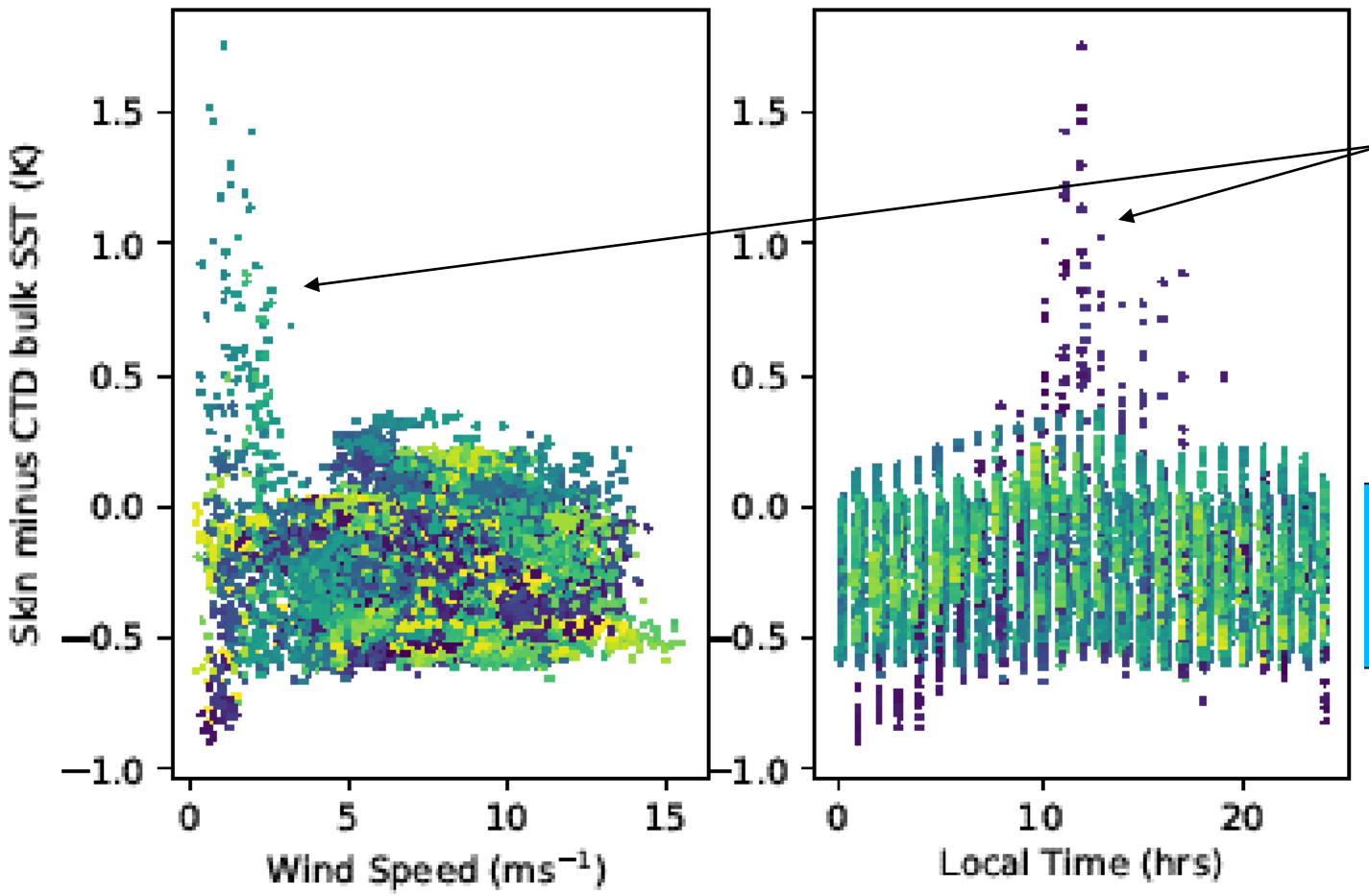
CT15 is measuring the skin temperature and reflected sky temperature

$$L_{sea}(\lambda) = \varepsilon B T_{skin} + (1 - \varepsilon) L_{sky}$$



At 55 deg there is .96 emissivity
Changes with angle of observation
In reality reflected radiance is quasi-specular

Skin minus bulk difference



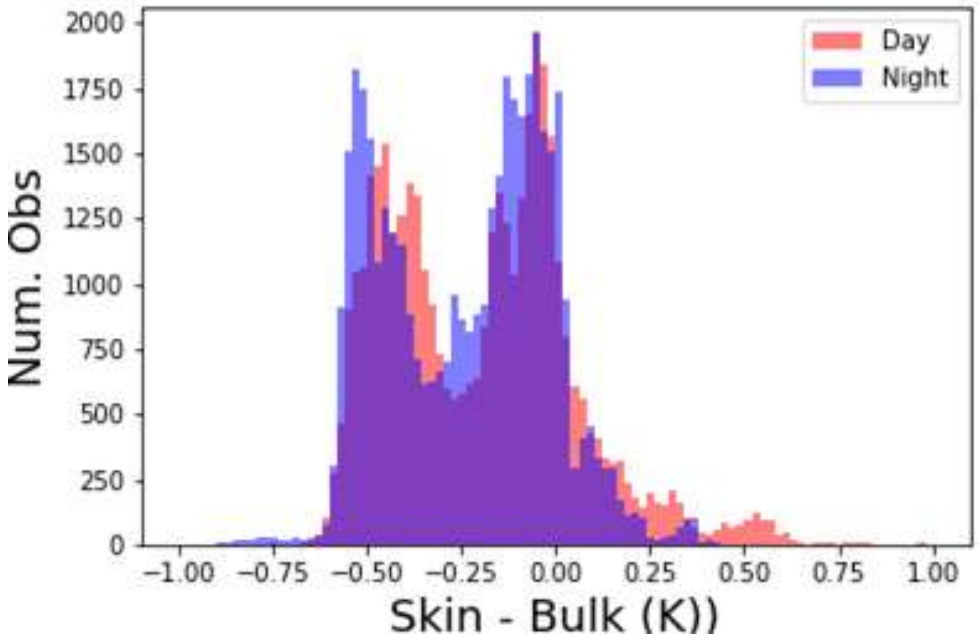
Diurnal warming of surface skin layer

Noise due to reflected sky radiation ?

Bulk SST

Two measurements of ‘bulk’ SST at 0.6 m depth from the O2 sensor and a CTD. Comparison between the two ‘bulk’ SSTs below. There is a *very* small difference that is wind speed dependent, but they essentially are independently measuring the same temperature to O(0.01)

	SST (K)		
	mean	SD	#
SB1 – SB4	0.003	0.076	77708
SB2 – SB4	0.002	0.065	77708
SB3-SB4	0.001	0.054	77708
CTD – SB4	0.002	0.042	77478
O2-SB4	-0.014	0.042	77478
IR-SB4	-0.212	0.229	76997

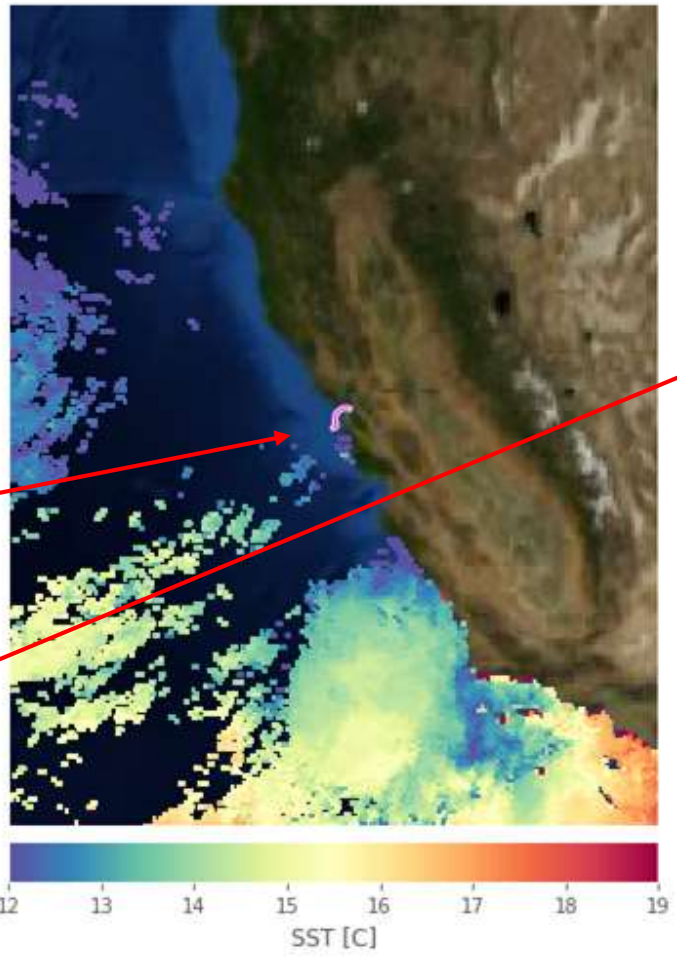


Bulk SST is a high quality observation, bias is NOT in the bulk SST

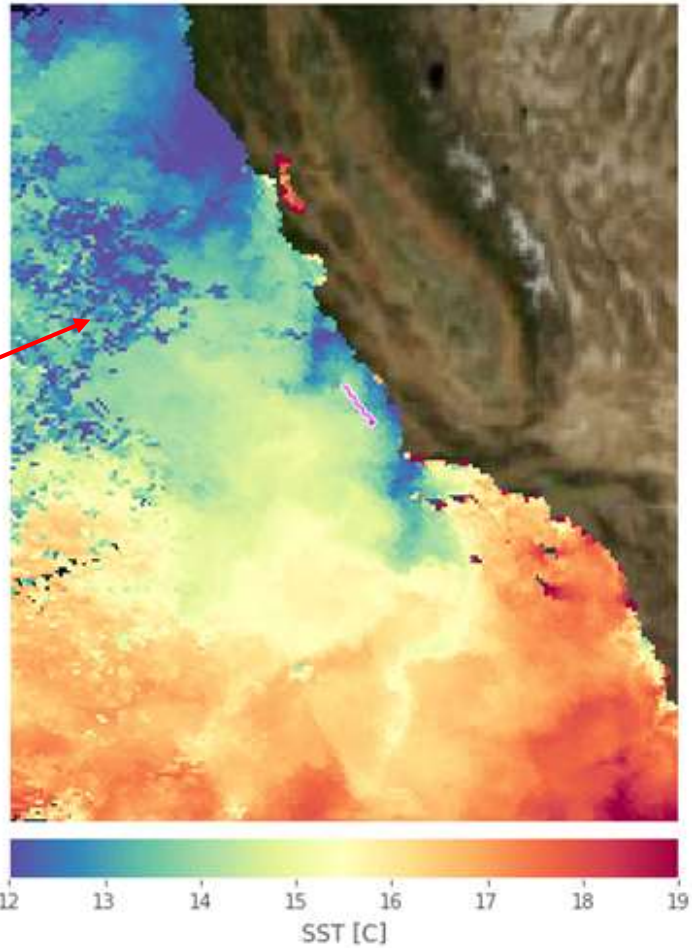
Collocated Saildrone data with GOES 16 SST data

SD track for day shown in pink. 24 hour average of GOES SSTs shown in image. Missing data means that it was cloudy. Cold ‘speckle’ shows cloud contamination in SSTs. Cloud mask not perfect.

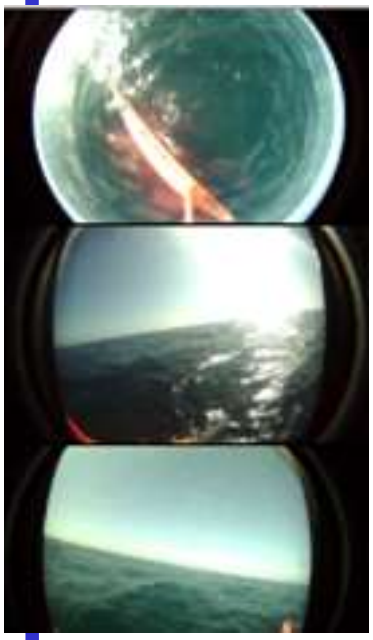
Cloudy day in SD area

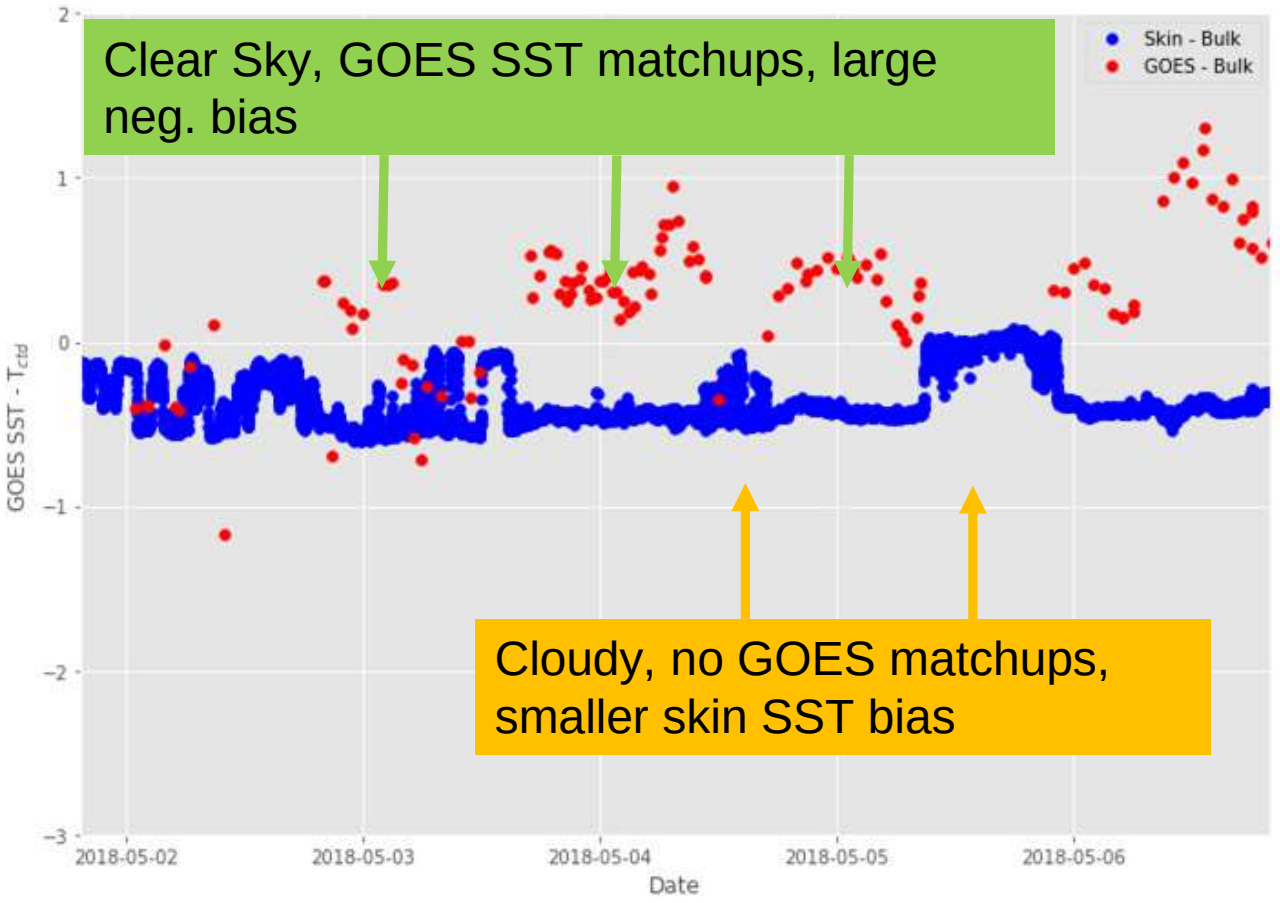


Clear sky in SD area, cloud contamination in other areas



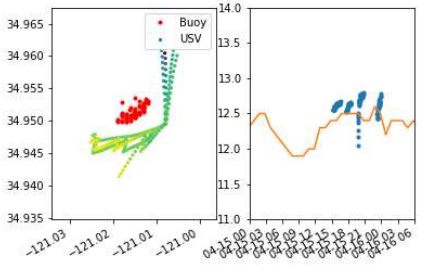
Time series of collocated GOES and SD data

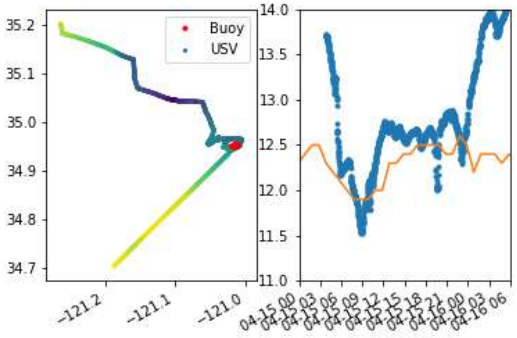


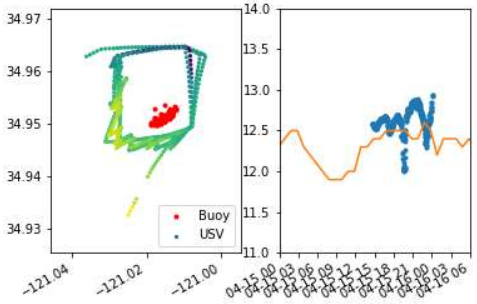


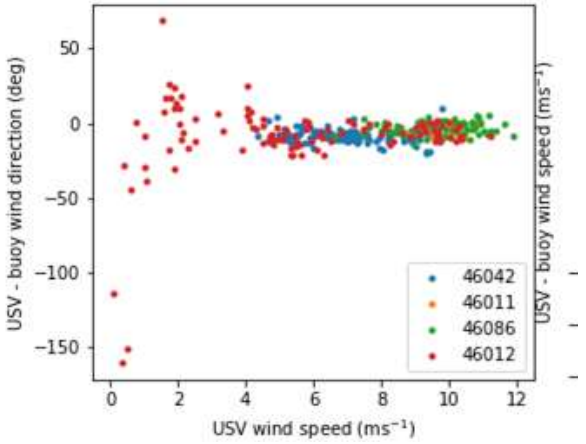
In situ Buoy Validation

	Mean bias	Median bias	Correlation	Standard deviation	Robust standard deviation	MAE	#
SST(K)	-0.01	-0.03	0.99	0.22	0.16	0.16	87
Air Temp (C)	0.01	0.00	0.98	0.17	0.12	0.13	87
Air Pres. (hPa)	-13.31	-16.12	0.61	6.29	0.34	13.47	87
Wind speed (ms^{-1})	0.32	0.30	0.98	0.52	0.54	0.49	307
Wind dir (deg)	-6.26	-6.59	0.95	5.77	5.32	7.08	278



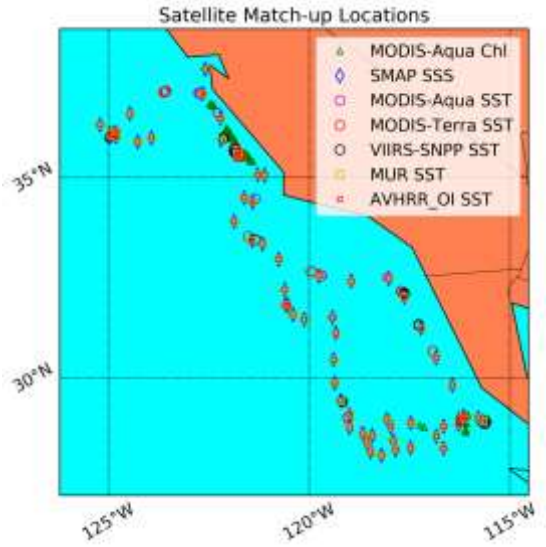






Satellite validation

Parameter	Comparison Data	Mean Bias	Median Bias	Correlation	Standard Deviation	Robust Standard Deviation	MAE	#
SST	MUR SST	0.32°C	0.29°C	0.98	0.41°C	0.34°C	0.4	5833
	AVHRR_OI SST	-0.03°C	0.050°C	0.95	0.59°C	0.652°C	0.603	60
	MODIS-Aqua SST, nighttime	0.123°C	0.156°C	0.99	0.314°C	0.190°C	0.271	20
	MODIS-Terra SST, nighttime	-0.008°C	0.343°C	0.93	0.896°C	0.155°C	0.215	40
	VIIRS-SNPP SST, nighttime	0.131°C	0.065°C	0.99	0.255°C	0.146°C	0.202	31
SSS	JPL SMAP SSS	-0.16 PSU	0.212 PSU	0.61	0.33 PSU	0.248 PSU	0.756	60
Chl (multiplicative metrics)	MODIS-Aqua OCI Chl	237.6%	250.4%	N/A	N/A	N/A	337.6%	176
Wind speed	RSS CCMP V2 vector wind	0.09 m/s	-0.02 m/s	0.90	1.05 m/s	0.85 m/s	0.76	492
Wind direction	RSS CCMP V2 vector wind	-3.44 deg	-3.06 deg	0.58	14.03 deg	6.39 deg	7.78	492

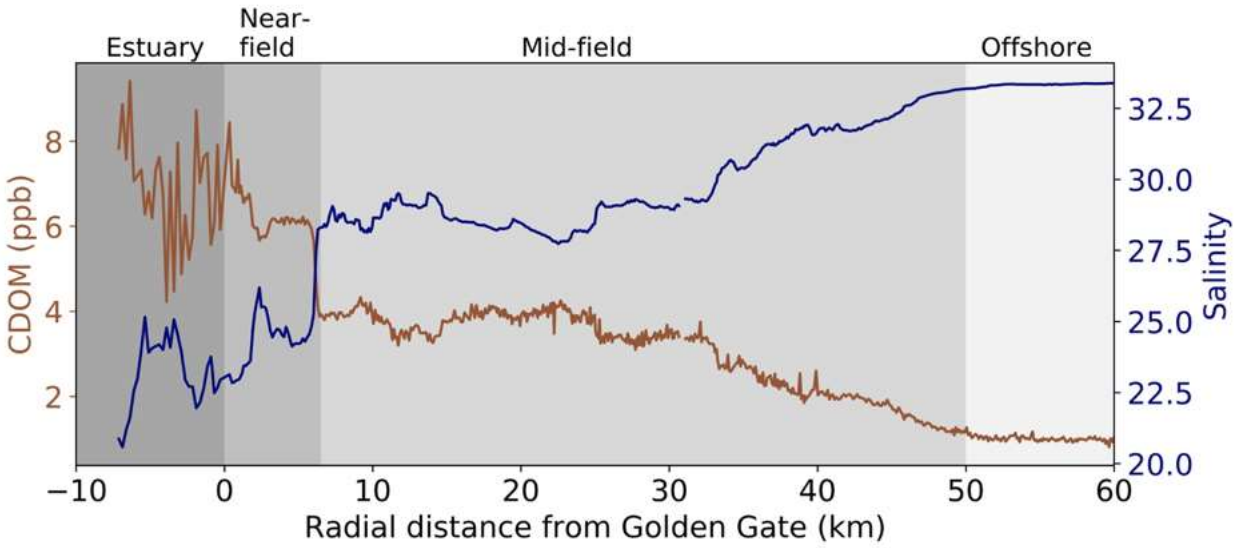


Validation Summary

- Results are good for all except skin (physics) and pressure (sensor)
- Saildrone has no inhouse calibration facility at this time. They depend on the calibration by manufacturers. This is not unusual.
- The pressure sensor used for our cruise was used for a previous cruise and it may have been exposed to some moisture causing a problem for our cruise. This problem was apparent immediately.

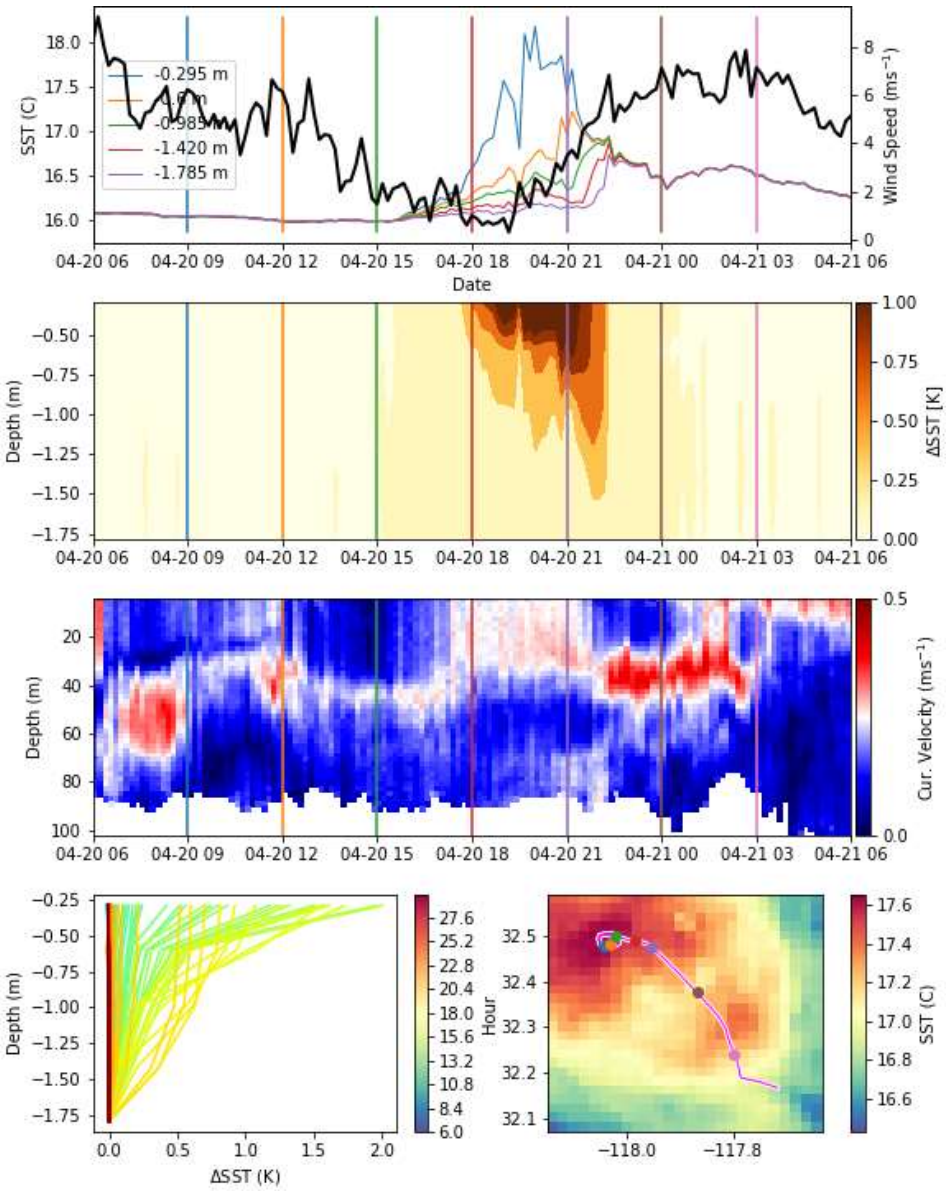
- Saildrone now performs pre-cruise checklist.

SF Bay plume



Near-surface salinity and colored dissolved organic matter (CDOM) as a function of radial distance from the Golden Gate Bridge obtained by the Saildrone on 11-12 of April, 2018. Negative distances refer to the San Francisco Bay estuary, and positive refer to the adjacent continental shelf in the Gulf of the Farallones.

Diurnal Warming



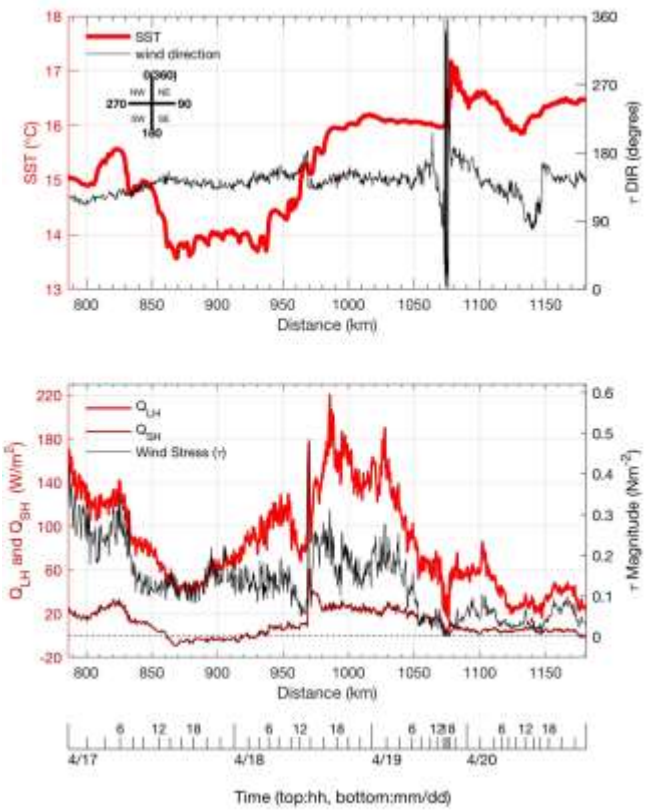
Timeseries of temepratures from different depth sensors.
Wind speed in black.

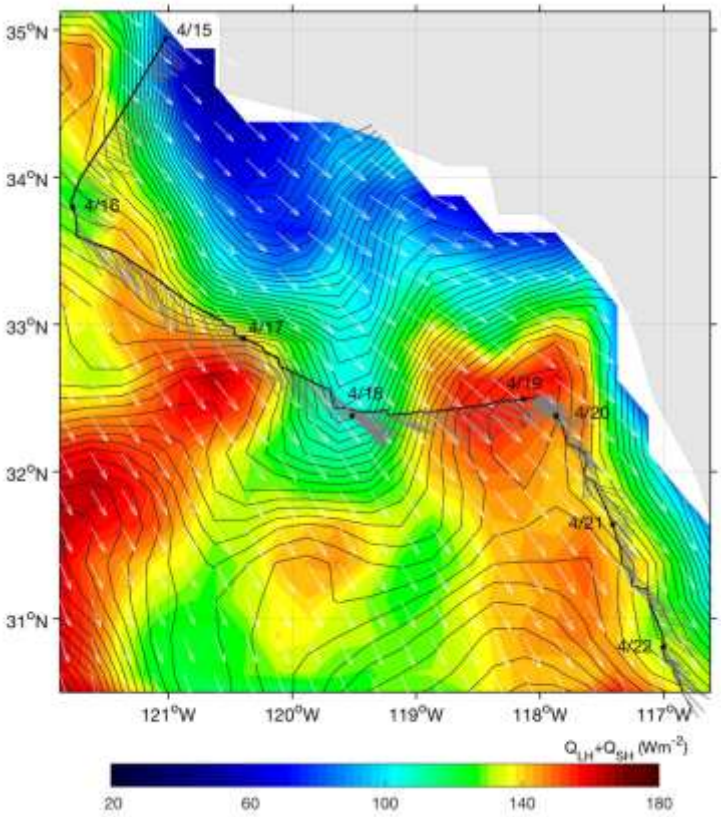
Temperature at different depths

ADCP horizontal velocity, jet appears under warming

Vertical shape of warming
SST distribution in area

Air-sea fluxes





(left) Top: Time series of USV measurements of SST (red) and wind stress direction (black) during April 17 – 20 (see the time mark placed at the bottom) (corresponding to the distance between 780 – 1180 km that is marked on the x-axis). Bottom: Time series of wind stress (black), surface latent (QLH; red) and sensible (QSH; dark red) fluxes derived from USV surface meteorological measurements. (Right) Daily-mean field of wind stress (white vectors) and QLH + QSH (colors) on April 18. The USV's track and measurements of wind vectors (gray) are superimposed.

Next steps

- Organize research / publications on topics:
  - Coastal front analysis
  - Offshore front analysis
  - Across / Along winds front differences
  - Circulation in frontal regions
  - Baroclinic Instability waves along fronts
  - Diurnal warming in surface layer

Sea Ice Remnant Svalbard July 17, 2008
Image credit: Camille Seaman

2019-2022: 5 Arctic Cruises

5 operational agencies using data: ECMWF, UK Met Office, US Navy, Environmental Canada, DMI use our data to different extents.

1 testing: NCEP receives the data from GTS but doesn't assimilate them.

NOPP National Oceanographic Partnership Program

SAILDRONE

NASA Physical Oceanography Program

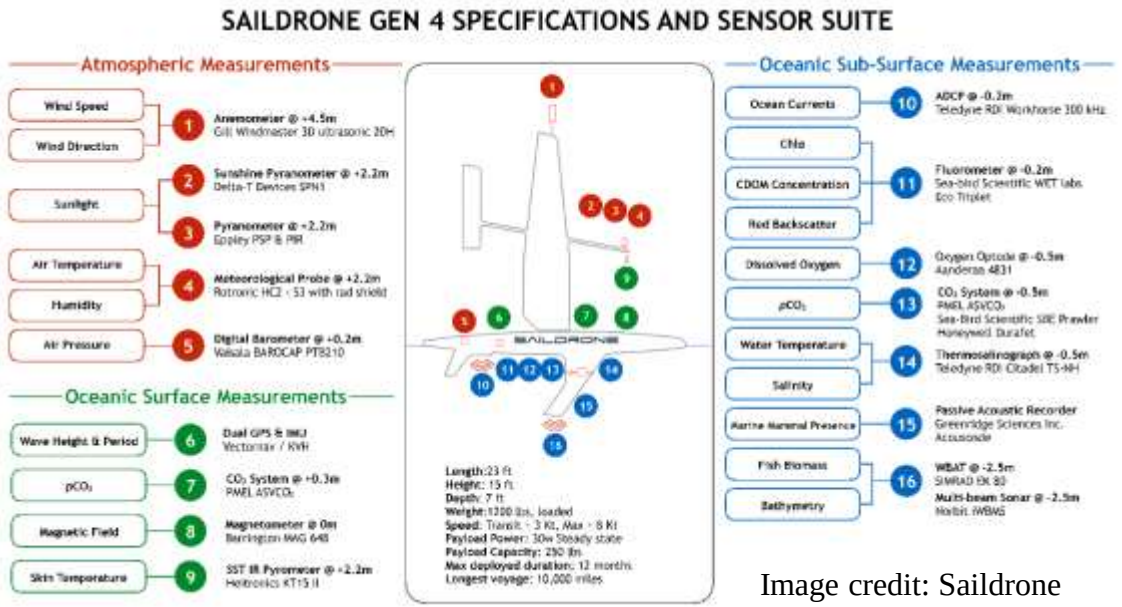


Image credit: Saildrone


1033
1033
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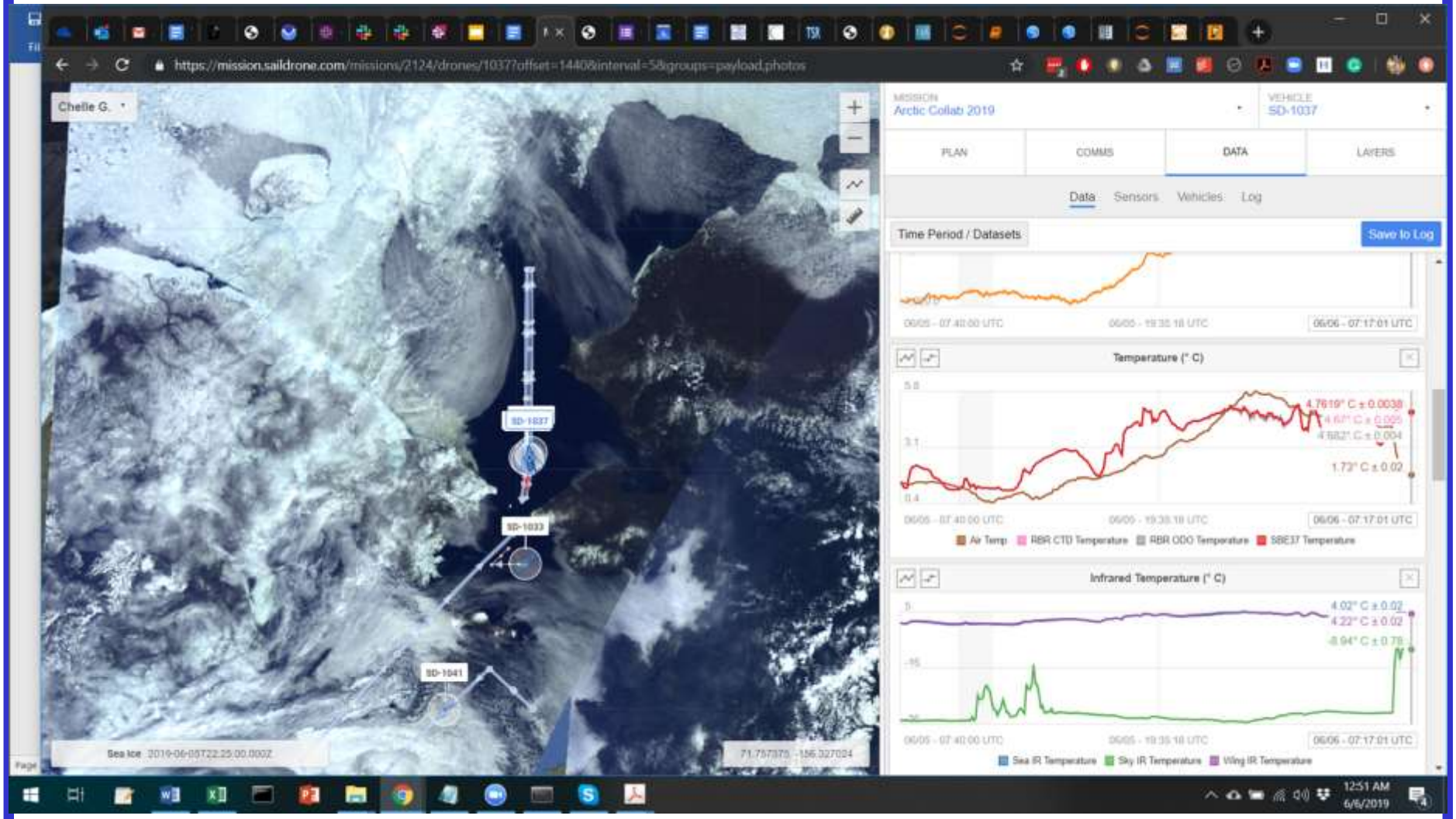

https://mission.saildrone.com/missions/2124/drones/1037?offset=1440&interval=5&groups=payload,photos
Chelle G.
MISSION
Arctic Collab 2019
VEHICLE
SD-1037
PLAN
COMMS
DATA
LAYERS
Data
Sensors
Vehicles
Log
Time Period / Datasets
Save to Log
SD-1037
SD-1033
SD-1041
Temperature (° C)
4.7619° C ± 0.0038
4.667° C ± 0.005
4.582° C ± 0.004
1.73° C ± 0.02
06/05 - 07:40:00 UTC
06/05 - 19:35:18 UTC
06/06 - 07:17:01 UTC
Air Temp
RBR CTD Temperature
RBR ODO Temperature
SBE37 Temperature
Infrared Temperature (° C)
4.02° C ± 0.02
4.22° C ± 0.02
-8.94° C ± 0.75
Sea IR Temperature
Sky IR Temperature
Wing IR Temperature
Sea Ice 2019-06-05T22:25:00.000Z
71.757375, -156.327024
12:51 AM
6/6/2019

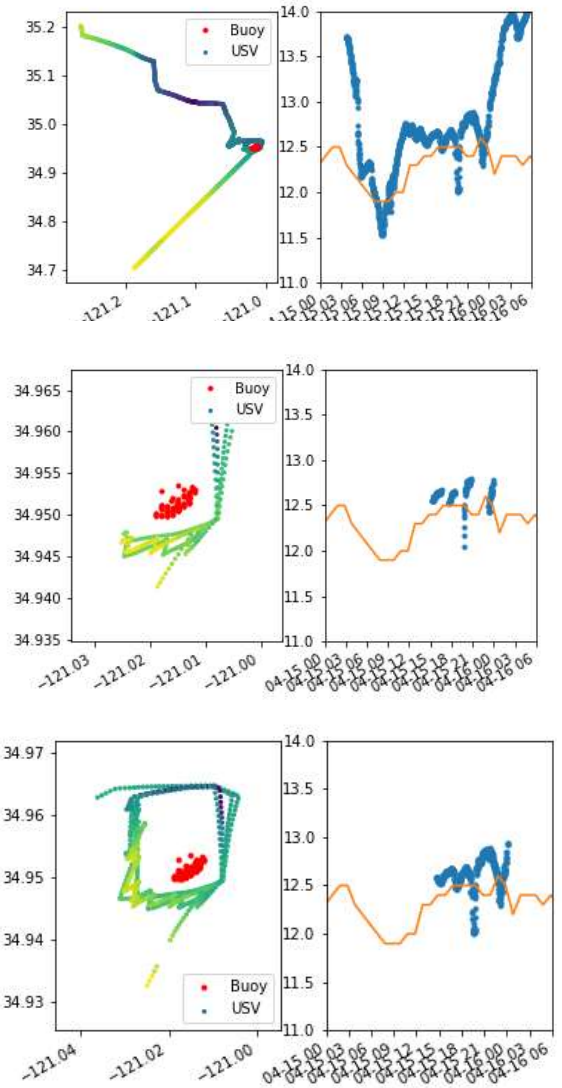
ATL2MED Mission

Starting in Cabo Verde, the overall goal using SAILDRONE unmanned surface vehicles (USVs) is to primarily 1) conduct an eddy hunt and survey of the Coast of Cabo Verde and 2) to connect the ICOS OTC stations with one USV that offers high-accuracy carbon measurements in order to cross-validate carbon measurements between stations.

The mission is planned to start at Cabo Verde 1 November 2019 and the end is in Trieste (Italy) in February 2020. Along this transect are 7 fixed stations (Cabo Verde, ESTOC, DYFAMED, W1M3A, E2M3A, Miramare, PALOMA), 5 of them being part of ICOS OTC.

Extra

In situ Buoy Validation



		Mean bias	Median bias	Correlation	Standard deviation	Robust standard deviation	MAE	#
SST (K)	46011	0.20	0.14	0.77	0.19	0.13	0.22	19
	46012	-0.14	-0.14	1.00	0.01	0.01	0.14	2
	46042	-0.02	-0.03	0.84	0.06	0.04	0.05	13
	46086	-0.06	-0.05	0.93	0.05	0.04	0.06	18
	46028	-0.03	-0.04	0.91	0.31	0.29	0.24	22
	46047	-0.19	-0.19	0.76	0.08	0.08	0.19	13
	ALL	**-0.01**	**-0.03**	**0.99**	**0.22**	**0.16**	**0.16**	**87**
Air temperature (C)	46011	0.23	0.23	0.80	0.13	0.21	0.23	19
	46012	-0.01	-0.01	1.00	0.04	0.06	0.04	2
	46042	0.00	-0.03	0.90	0.07	0.09	0.06	13
	46086	-0.02	-0.02	0.98	0.07	0.07	0.06	18
	46028	-0.17	-0.20	0.95	0.12	0.14	0.18	22
	46047	0.04	0.05	0.94	0.06	0.07	0.07	13
	ALL	**0.01**	**0.00**	**0.98**	**0.17**	**0.12**	**0.13**	**87**
Air pressure (hPa)	46011	-13.67	-16.20	0.39	6.09	0.28	13.79	19
	46012	-15.68	-15.68	1.00	0.12	0.18	15.68	2
	46042	-12.02	-15.84	0.03	7.06	0.19	12.42	13
	46086	-13.73	-16.46	0.23	6.20	0.20	13.77	18
	46028	-13.87	-16.12	0.59	5.67	0.16	13.98	22
	46047	-12.16	-15.94	0.20	6.96	0.15	12.41	13
	ALL	**-13.31**	**-16.12**	**0.61**	**6.29**	**0.34**	**13.47**	**87**
Wind speed (ms^{-1})	46011	0.44	0.41	0.93	0.49	0.44	0.52	112
	46012	0.43	0.23	0.78	0.45	0.52	0.48	13
	46042	0.28	0.30	0.91	0.45	0.51	0.45	74
	46086	0.22	0.13	0.98	0.56	0.58	0.47	108
	ALL	**0.32**	**0.30**	**0.98**	**0.52**	**0.54**	**0.49**	**307**
Wind direction (deg)	46011	-8.39	-8.47	0.89	4.51	3.36	8.73	112
	46012	-4.57	-4.11	0.78	3.05	4.36	4.64	13
	46042	-3.2	-3.37	0.84	4.00	4.33	4.14	74
	46086	-6.37	-6.95	0.96	7.49	7.22	7.91	79
	ALL	**-6.26**	**-6.59**	**0.95**	**5.77**	**5.32**	**7.08**	**278**