2019 Arctic Saildrone Cruise

NASA Physical Oceanography, NOAA PMEL, and Saildrone

NASA grant #80NSSC18K0837

15 May to 11 October 2019

Important information: For this cruise, all measurements are unvalidated at this time. From initial analysis, all measurements appear to be of high quality except the retrieval of skin SST. Skin SST for this cruise is of uncertain utility due to the current lack of confirmation of the accuracy of the correction for reflected sky radiation. Please see the vehicle description for more information. Also, for periods of the cruise, the vehicles were ice-bound and this may affect sub-surface sensors performance and wave estimates. Email the cruise PI: cgentemann@faralloninstitute.org for up-to-date information about any additional data flagging that might be necessary before use.

Saildrone vehicle deployment in Dutch Harbor, Alaska. Image credit: Saildrone, Inc.


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Saildrone Arctic 2019 Cruise Science Team

Table 1. Science Team

Name	Role	Research Focus	Email
Chelle Gentemann	Chief Scientist	air-sea interactions, diurnal warming, validation of obs	cgentemann@faralloninstitue.org
Peter Minnett	Co-Investigator	diurnal warming, satellite comparisons	pminnett@rsmas.miami.edu
Michael Steele	Co-Investigator	Arctic Oceanography	mas@apl.washington.edu
Sandra Castro	Partner	SST validation and uncertainties, DW	sandrac@colorado.edu
Peter Cornillon	Partner	fronts, small scale variability in the upper ocean	pcornillon@me.com
Ed Armstrong	Partner	data distribution	edward.armstrong@jpl.nasa.gov
Jorge Vazquez	Partner	application of salinity and sst to coastal upwelling/validation	jvazquez@jpl.caltech.edu
Vardis Tsontos	Partner	Data archival/distribution	vtsontos@jpl.nasa.gov
Edward Cokelet	Partner	data validation / distribution	edward.d.cokelet@noaa.gov

Saildrone Arctic 2019 Cruise Saildrone Team

Table 2. Saildrone team

Name	Role	Focus	Email
Richard Jenkins	Chief Executive Officer	Vehicle Design / Assembly / Operations	richard@saildrone.com

Sebastien De Halleux	Chief Operations Officer	Mission Development / Management	sebastien@saildrone.com
Dave Peacock	Director of Robotics	Vehicle Software	dave@saildrone.com
Kimberly Sparling	Senior Product Manager, Data Services	Data Management / Client Relations	kim@saildrone.com
Dalton Nonweiler	Mechanical Engineer	Vehicle Operations	dalton@saildrone.com

Cruise Narrative

The Saildrone vehicles collected data on a 150-day cruise from Dutch Harbor, Alaska, within the Bering and Chukchi Seas to the ice edge and back during 15 May 2019 to 11 October 2019. Scientific objectives include collecting upper ocean temperature profiles with a full suite of ocean measurements, which could lead to significant improvements in modeling of diurnal warming. Additionally, these new data will provide additional Arctic SST observations to benefit SST algorithm development and validation, and collected additional data for studies of air- sea-ice interactions. The vehicles first encountered the ice edge around 15 June 2019 and by the beginning of August 2019 low power levels due to lack of sunlight resulted in payloads being turned off or reduced sampling intervals.

This cruise consisted of six Saildrones (sd-1033, sd-1034, sd-1035, sd-1036, sd-1037 and sd-1041; the GTS WMO header is IOBX03 KWNB for all six Saildrones, and their IDs are: 4803911, 4803912, 4803913, 4803914, 4803915, 4803916) and was a joint effort between NASA, NOAA's Pacific Marine Environmental Laboratory (PMEL) and Alaska Fisheries Science Center (AFSC), and the NOAA/University of Washington Joint Institute for the Study of the Ocean and Atmosphere (JISAO). This report only covers the NASA funded vehicles, data from which are openly available at the NASA PO.DAAC. Those interested in the NOAA funded vehicles should contact NOAA directly.

The overall mission objective was to measure atmospheric, oceanographic, fishery and fur seal conditions in the US arctic. One vehicle (sd-1041) remained in the Bering Sea measuring fish acoustic backscatter and conducting focused followings of threatened fur seals for AFSC. Five Saildrones transited the Bering Strait into the Chukchi Sea. One of those (sd-1033) surveyed lines in Distributed Biological Observatories (DBO) 1–5. The remaining four (PMEL sd-1034, sd-1035 and NASA sd-1036, sd-1037) ran transects in the Chukchi Sea and approached the southern sea ice edge in the Arctic Ocean up to ~75°N to measure air-sea heat and momentum flux near sea ice and to validate satellite sea-surface temperature measurements in the arctic. Each Saildrone was equipped to measure solar irradiance, air temperature and relative humidity, barometric pressure, surface skin temperature, wind speed and direction, wave height and period, seawater temperature and salinity, chlorophyll fluorescence, and dissolved oxygen. Four cameras aboard each vehicle imaged up, down, port and starboard of the wing. Saildrones sd-1033 and sd-1034 had Autonomous Surface Vehicle CO_2 (ASVCO2) systems measuring seawater pH, temperature, salinity and partial pressure of carbon dioxide (pCO_2). Vehicles sd-1033, sd-1034, sd-1035, sd-1036 and sd-1037 measured near surface currents with 300 kHz acoustic Doppler current profilers (ADCP). Sd-1041 carried fisheries echosounders.

There were about two dozen encounters with free-floating sea ice between the four Chukchi Sea/Arctic Ocean Saildrones. On 24 August 2019, sd-1035 was caught in sea ice and rendered barely maneuverable with rudder damage. Its mission ended early on 10 September, 2019 after which it was towed into Point Barrow. The remaining five Saildrones sampled Bering Sea transects. Solar power constraints after about mid-September required some sensors to be turned off until vehicle battery levels could sufficiently recharge. The vehicles returned to Dutch Harbor on 11 October after sailing side-by-side for a few hours for an end-of-mission comparison.

Other supporting measurements were made during this mission. The PMEL/WHOI/JISAO Arctic Heat Open Science Experiment dropped AXBTs on 16–22 July data is available? contact?. USCGC Healy met sd-1033 on 11 August for a pCO_2 cross-calibration. Sd-1034 and sd-1035 sailed near the sites of periodic surfacings of Marine Robotic Vehicles (MRV) Air-Launched Autonomous Micro-Observer (ALAMO) float 9234."

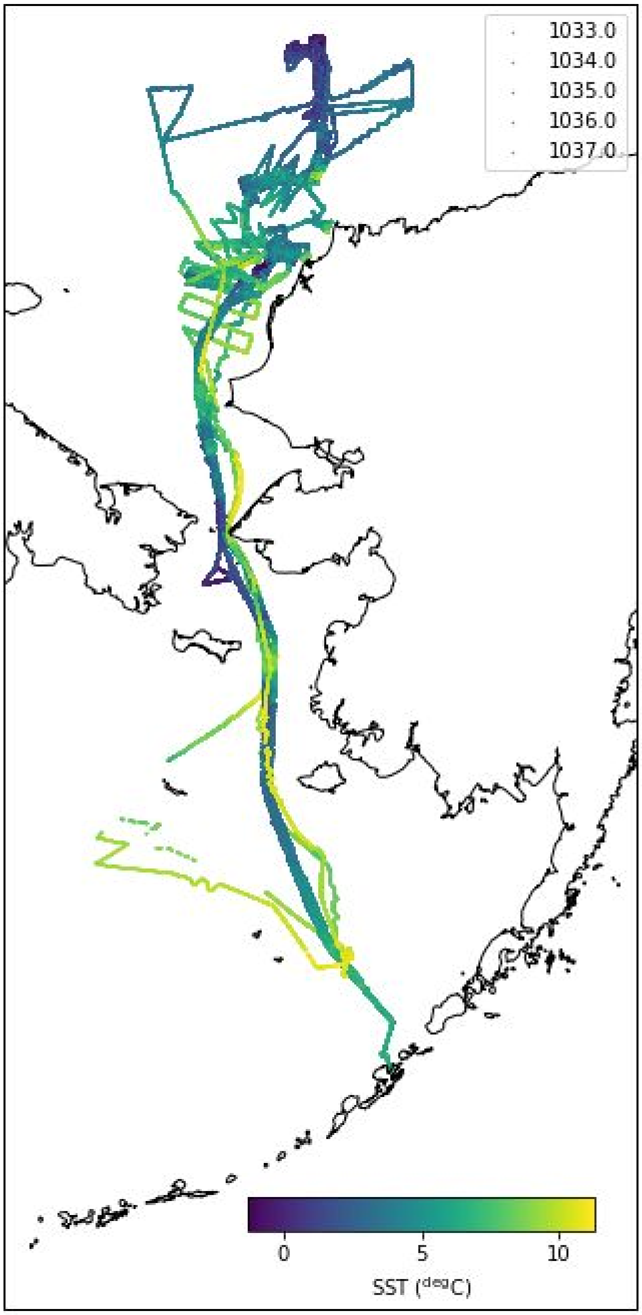

Figure 1. Overall cruise tracks for the 2019 Arctic Saildrone deployments.

Table 3. Comparison of similar measurements from different instruments. The variables listed below are collected by 2 sensors on each vehicle. The difference (mean and standard deviation) between those 2 sensors is shown in the table below.

Variable	Vehicle	difference		
		mean	stdev	num. obs.

0.6m seawater temperature (K)	1036	0.00	0.04	180188
	1037	0.00	0.07	193657
0.6m salinity (psu)	1036	-0.16	0.15	175047
	1037	-0.11	0.24	182530
O2 Conc	1036	10.17	5.61	180188
	1037	-10.81	10.90	193657
Chlor	1036	3.77	5.69	175178
	1037	2.49	6.23	209898

General Timeline for Saildrone SD-1002, 11 April - 11 June 2018

May 15 : Depart Dutch Harbor for Bering Strait
June 3: Bering Strait, head towards ice edge
June 14: Stuck in ice for short period, head away from ice edge
June 21: Stuck in ice for short period, head away from ice edge
July 1: Sample pattern across front, towards West ice edge
July 12: Towards the ice edge again
August 8: Sample in formation edge of cold tongue then back to ice edge
August 10: Stuck in ice briefly, continue sampling cold tongue
August 14: Back/forth transects
August 17: Sample strong front (1037), follow APL glider in bow-tie pattern
October 11: Arrive Dutch Harbor

Vehicle description

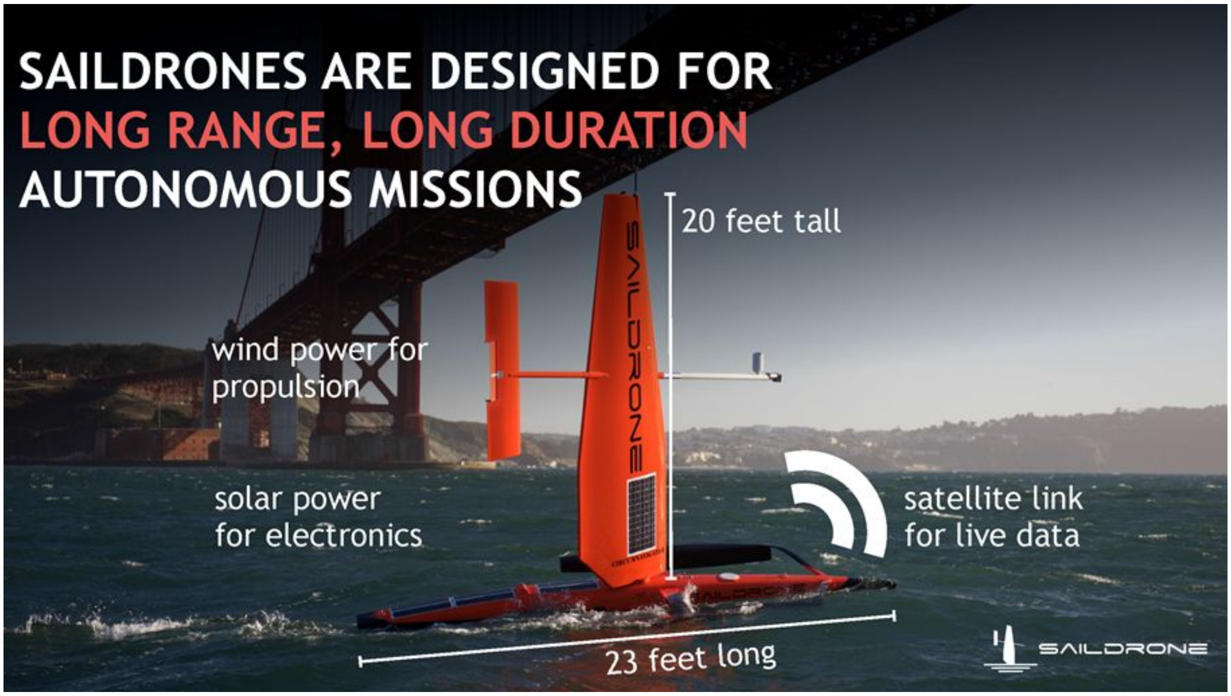

Figure 2. Dimensions of the vehicle. Figure credit Saildrone, Inc.

Figure 3. Installation of temperature loggers along keel.

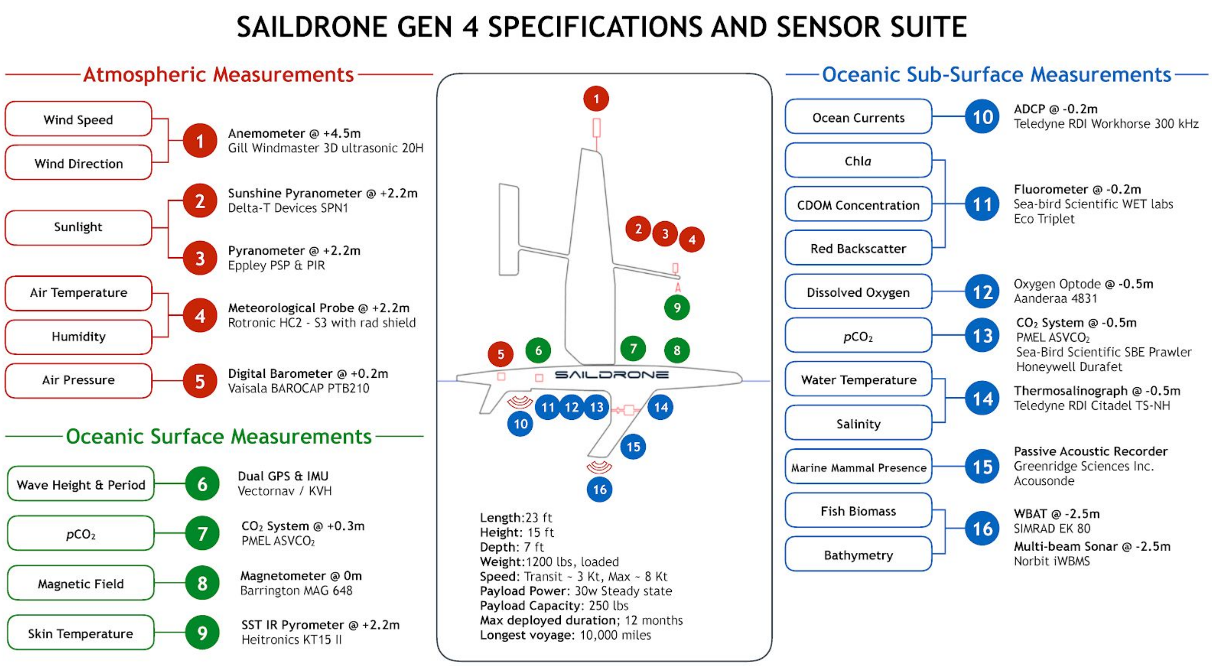

Figure 4. Saildrone vehicle instrumentation placement. Not all instruments in the figure were installed for these cruises; additional IR Hitronics radiometers were installed on the aft deck, as shown in Figure 1.

Table 4. Information on the Saildrone vehicle in situ dataset. This table is meant to accompany the Saildrone data description. See the report for more details on each dataset. This table describes the data from the standard vehicle payload.

Variable Name	Variable	Sensor Description	Model Name	Installed Height (m)	Sampling Schedule
BARO_PRES_MEAN	air_pressure	Vaisala Barometer	Vaisala : PTB210	0.3	60s on, 240s off, centered at :00
BARO_PRES_STDDEV	air_pressure	Vaisala Barometer	Vaisala : PTB210	0.3	60s on, 240s off, centered at :00
CHLOR_WETLABS_MEAN	Chlorophyll concentration	WET Labs	WET Labs Fluorometer	-0.5	12s on, 48s off, centered at :00
CHLOR_WETLABS_STDDEV	Chlorophyll concentration	WET Labs	WET Labs Fluorometer	-0.5	12s on, 48s off, centered at :00
CHLOR_RBR_MEAN	mass_concentration_of_chlorophyll_in_sea_water	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
CHLOR_RBR_STDDEV	mass_concentration_of_chlorophyll_in_sea_water	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
COG	platform_course				
COND_SBE37_MEAN	Seawater conductivity	Sea-Bird	SBE37-SMP-ODO Microcat	-0.5	12s on, 588s off, centered at :00
COND_SBE37_STDDEV	Seawater conductivity	Sea_bird	SBE37-SMP-ODO Microcat	-0.5	12s on, 588s off, centered at :00
COND_RBR_MEAN	Seawater conductivity	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
COND__RBR_STDDEV	Seawater conductivity	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
GUST_WND_MEAN	wind_speed_of_gust	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
GUST_WND_STDDEV	wind_speed_of_gust	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00

HDG	platform_yaw_angle				
HDG_WING					
O2_CONC_SBE37_MEAN	Oxygen concentration	Sea-Bird	SBE37-SMP-ODO Microcat	-0.5	12s on, 588s off, centered at :00
O2_CONC_SBE37_MEAN	Oxygen concentration			-0.5	12s on, 588s off, centered at :00
O2_SAT_SBE37_MEAN	Oxygen concentration	Sea-Bird	SBE37-SMP-ODO Microcat	-0.5	12s on, 588s off, centered at :00
O2_SAT_SBE37_STDDEV	Oxygen concentration	Sea-Bird	SBE37-SMP-ODO Microcat	-0.5	12s on, 588s off, centered at :00
O2_CONC_RBR_MEAN	Oxygen concentration	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
O2_CONC_RBR_STDEV	Oxygen concentration	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
O2_SAT_RBR_MEAN	Oxygen concentration	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
O2_SAT_RBR_STDEV	Oxygen concentration	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
PITCH	platform_pitch_angle				
PAR_AIR_MEAN	Photosynthetically active radiation in air	LI-COR	LI-192SA		Always On
PAR_AIR_STD	Photosynthetically active radiation in air	LI-COR	LI-192SA		Always On
RH_MEAN	relative_humidity	Rotronic AT/RH	Rotronic : HC2-S3	2.4	60s on, 240s off, centered at :00
RH_STDDEV	relative_humidity	Rotronic AT/RH	Rotronic : HC2-S3	2.4	60s on, 240s off, centered at :00
ROLL	platform_roll_angle				
SAL_RBR_MEAN	Seawater salinity	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00

SAL_RBR_STDDEV	Seawater salinity	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
SAL_SBE37_MEAN	sea_water_practical_salinity	SBE37-SMP-ODO Microca	Sea Bird CTD	-0.6	12s on, 48s off, centered at :00
SAL_SBE37_STDDEV	sea_water_practical_salinity	SBE37-SMP-ODO Microca	Sea Bird CTD	-0.6	12s on, 48s off, centered at :00
SOG	platform_speed_wrt_ground				
TEMP_AIR_MEAN	air_temperature	Rotronic AT/RH	Rotronic : HC2-S3	2.4	60s on, 240s off, centered at :00
TEMP_AIR_STDDEV	air_temperature	Rotronic AT/RH	Rotronic : HC2-S3	2.4	60s on, 240s off, centered at :00
TEMP_CTD_RBR_MEAN	Seawater temperature	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
TEMP_CTD_RBR_STDDEV	Seawater temperature	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
TEMP_IR_SKY_HULL_MEAN	Hull Sky IR Temperature	Heitronics Wing IR Pyrometer	Heitronics:ct+09 series	0.6	30s on, 270s off, centered at :00
TEMP_IR_SKY_HUL_STDDEV	Hull Sky IR Temperature	Heitronics Wing IR Pyrometer	Heitronics : CT09 series	0.6	30s on, 270s off, centered at :00
TEMP_IR_SEA_HULL_UNCOMP_MEAN	Hull Sea IR Temperature	Heitronics Hull IR Pyrometer	Heitronics CT15.10	0.6	30s on, 270s off, centered at :00
TEMP_IR_SEA_HULL_UNCOMP_STDDEV	Hull Sea IR Temperature	Heitronics Hull IR Pyrometer	Heitronics CT15.10	0.6	30s on, 270s off, centered at :00
TEMP_IR_SEA_WING_UNCOMP_MEAN	Wing Sea IR Temperature	Heitronics Wing IR Pyrometer	Heitronics CT15.10	2.25	30s on, 270s off, centered at :00
TEMP_IR_SEA_WING_UNCOMP_STDDEV	Wing Sea IR Temperature	Heitronics Wing IR Pyrometer	Heitronics CT15.10	2.25	30s on, 270s off, centered at :00
TEMP_O2_RBR_MEAN	sea_water_temperature	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
TEMP_O2_RBR_STDDEV	sea_water_temperature	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00

TEMP_SBE37_MEAN	sea_water_temperature	SBE37-SMP-ODO Microcat	Sea Bird CTD	-0.6	12s on, 48s off, centered at :00
TEMP_SBE37_STDDEV	sea_water_temperature	SBE37-SMP-ODO Microcat	Sea Bird CTD	0.6	12s on, 48s off, centered at :00
UWND_MEAN	eastward_wind	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
UWND_STDDEV	eastward_wind	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
VWND_MEAN	northward_wind	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
VWND_STDDEV	northward_wind	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
WAVE_DOMINANT_PERIOD	Dominant wave period	VectorNav	VectorNav Hull IMU	0.34	Always On
WAVE_SIGNIFICANT_HEIGHT	Significant wave height	VectorNav	VectorNav Hull IMU	0.34	Always On
WING_ANGLE					
WWND_MEAN	downward_air_velocity	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
WWND_STDDEV	downward_air_velocity	Gill Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
latitude	latitude	VectorNav IMU	VectorNav : VN-200 Wing		Always On
longitude	longitude	VectorNav IMU	VectorNav : VN-200 Wing		Always On
time	time UTC				
trajectory	Saildrone assigned identification number				

Table 5. Information on the Saildrone ADCP in situ dataset. This table is meant to accompany the Saildrone data description. Instrument website: www.teledynemarine.com/workhorse-monitor-adcp

Variable Name	Variable
vel_east	east velocity
vel_north	north velocity
vel_up	vertical velocity
roll	platform roll angle
pitch	platform pitch angle
nav_start_time	navigation start time
nav_start_longitude	longitude of ensemble start
nav_start_latitude	latitude of ensemble start
nav_end_time	navigation end time
nav_end_longitude	longitude of ensemble end
nav_end_latitude	latitude of ensemble start
heading	vehicle heading
error_vel	error velocity
cell_depth	depth of bin center
bt_range	bottom track range
bt_amp	bottom track echo amplitude
bt_cor	bottom track correlation
bt_percent_good	percent of good bottom track pings
bt_vel_east	east velocity of bottom track
bt_vel_north	north velocity of bottom track
bt_vel_up	up velocity of bottom track
correlation	correlation
echo_intensity	echo amplitude

percent_good	percent good using 3 or 4 beam solutions
percent_good_3_beam	percent good using 3 beam solution
percent_good_4_beam	percent good using 4 beam solution
avg_true_vel_east	east velocity of the vehicle
avg_true_vel_north	north velocity of the vehicle
avg_true_vel_up	up velocity of the vehicle
latitude	latitude
longitude	longitude
time	time UTC
trajectory	Saildrone vehicle identification number

Table 6. Information on the Saildrone SB56 temperature logger in situ dataset. This table is meant to accompany the Saildrone data description. See the report for more details on each dataset.

Variable Name	**Variable**	**Sensor Description**	**Model Name**	**Link to Product Webpage**	**Installed Height (m)**	**Sampling Schedule**
sea_water_temperature_1	temperature	temperature logger	SB56	http://www.seabird.com/sbe56-temperature-logger	-0.295	2 sec
sea_water_temperature_2	temperature	temperature logger	SB56	http://www.seabird.com/sbe56-temperature-logger	-0.985	2 sec
sea_water_temperature_3	temperature	temperature logger	SB56	http://www.seabird.co	-1.420	2 sec

				m/sbe56-temperature-logger		
sea_water_temperature_4	temperature	temperature logger	SB56	http://www.seabird.com/sbe56-temperature-logger	-1.785	2 sec
time	time UTC					

Seawater Temperature

Saildrone carries several instruments for measuring seawater temperature. These include two CTDs that measure sea water temperature at approximately 0.5 meters depth, and two pyrometers to measure infrared (IR) radiance from which the skin sea-surface temperatures can be derived. Two pyrometers were mounted on a support on the aft deck, one directed at the sea surface and the other directed at the atmosphere, and one on the wing. All pyrometers are made by Heitronics with a model number of CT15.10. These measured temperatures should be considered as experimental and used with caution.

The Seabird SBE56 CTD measures seawater temperature to high accuracy and with fast sampling. The highly stable instrument makes it possible to preserve the initial calibration in rapid sampling. For Saildrone seawater temperature was recorded at a depth of 0.5 meters.

Another CTD by RBR measures temperature at a depth of 0.6 meters. The RBR is a temperature logger specifically designed for one minute sampling.

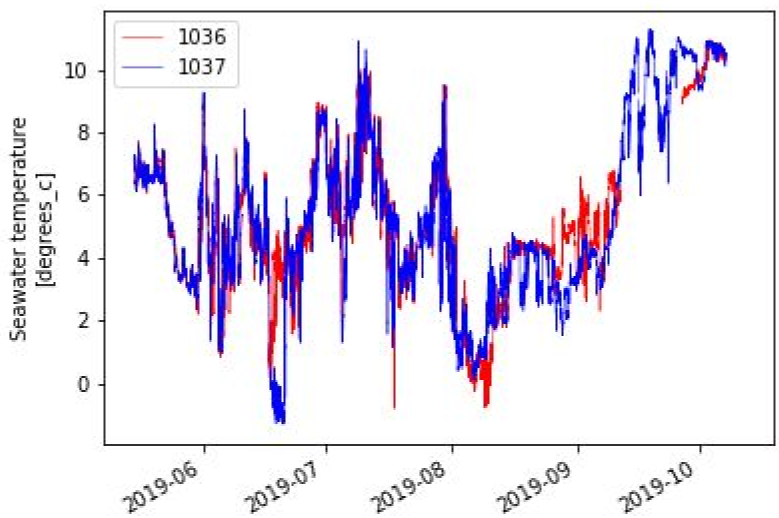

Figure 4. 0.6m seawater temperatures measured by the RBR instruments during the cruises.

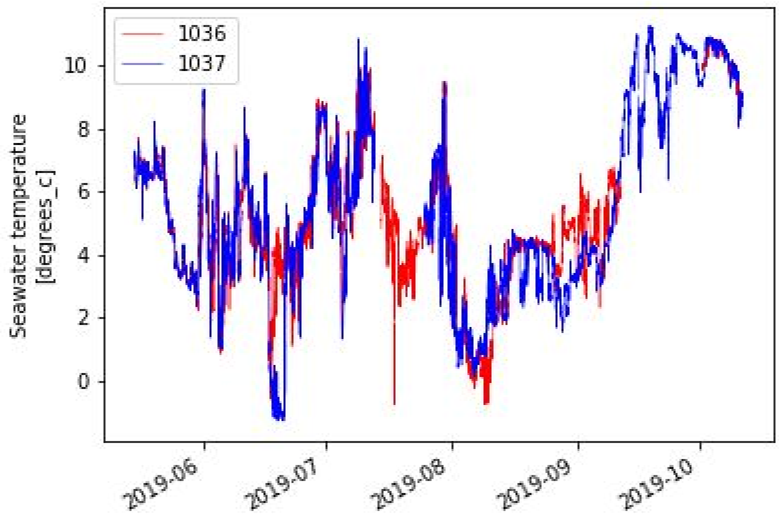

Figure 5. 0.6 m seawater temperatures measured by SBE37 instruments during the cruises.

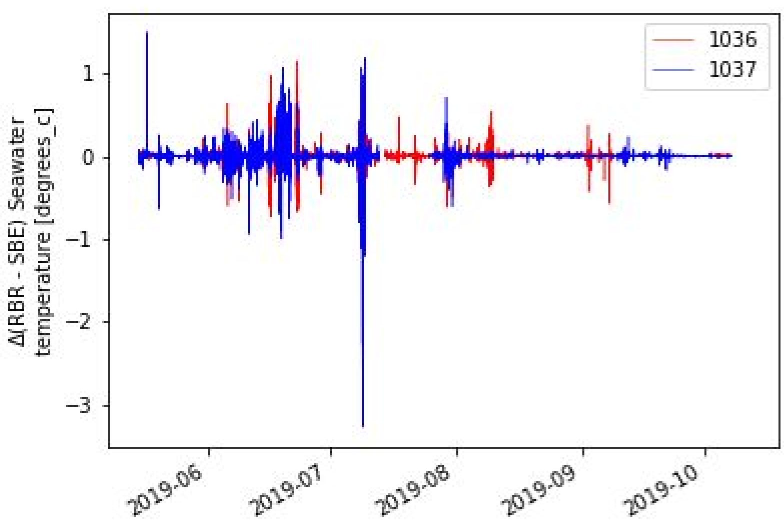

Figure 6. RBR minus SBE37 0.6 m seawater temperature.

Skin SST

Infrared (IR) sea surface brightness temperature, i.e. the temperature derived from a measurement of spectral radiance, was provided by a Heitronics IR Pyrometer CT15.10 installed on the aft deck (FIgure 1) at a height of 0.6m in addition to the standard CT15.10 on the wing at 2.25 m above the waterline. The measurement of the sea-surface brightness temperature by the CT15.10 pyrometer includes a component that is reflected by sky radiation. For these deployments an additional

CT15.10 was installed pointing upwards at the same angle to zenith as the sea-viewing sensor is to nadir to measure the sky spectral radiance to correct for the reflection present in the sea measurement. The sky temperature is very cold for clear skies, and close to the sea temperature when low clouds are present, and is thus very variable and strongly dependent on cloud cover. A problem with the sky measurements is the presence of rain or ice on the instrument window as the sensor then measures the temperature of the rain water or ice. The effectiveness of the sky radiance correction in these measurements has yet to be assessed and so the accuracy of the skin SST retrievals has not yet been determined. Consequently, these measurements should be used with caution.

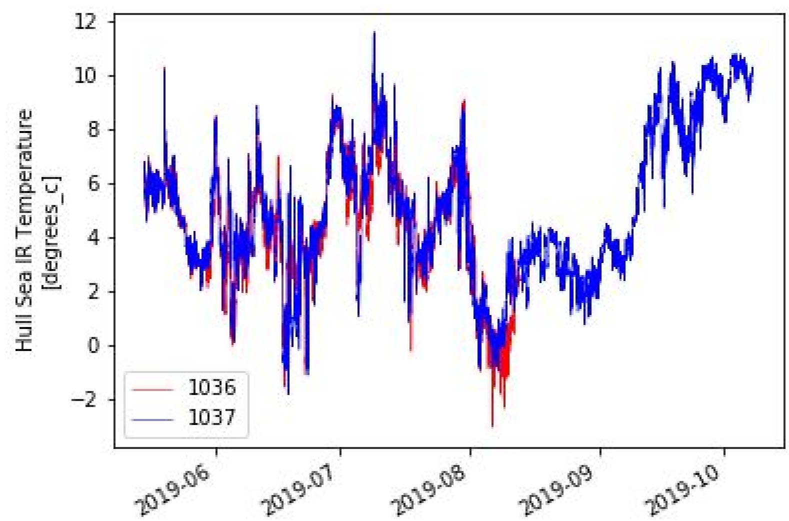

Figure 7. IR hull seawater temperature.

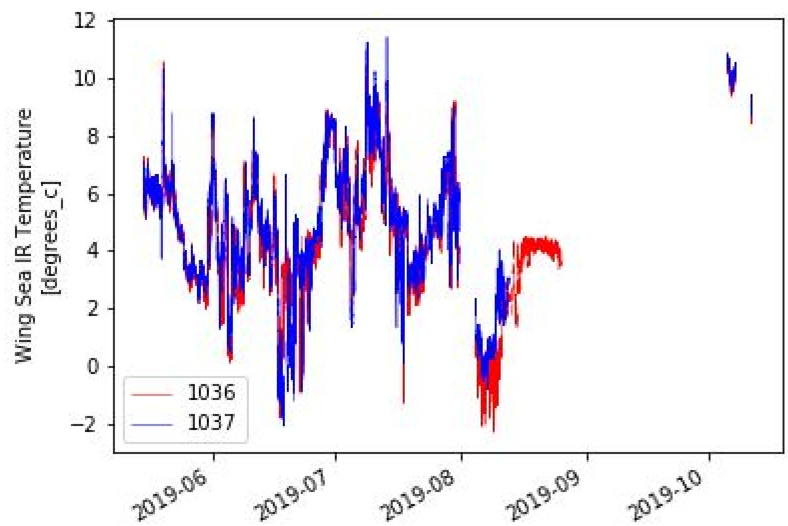

Figure X. IR wing seawater temperature.

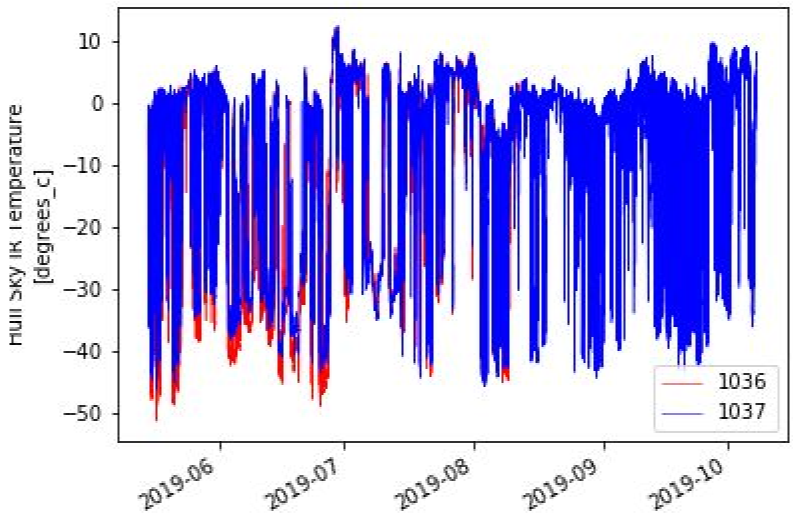

Figure 8. IR sky temperature.

Dissolved Oxygen

The vehicles measures oxygen concentration and saturation using both Sea-Bird and RBR instruments. Data are averaged into 1 minute means using 12 sec of 1Hz-sampled data centered at :00.   Seawater flows through this sensor, there is no pumping. Saildrone designed the flow-thru so that "fresh" water would always be flowing past dissolved oxygen sensor due to motion of the vehicle, the drone's motion is essentially providing pumping.

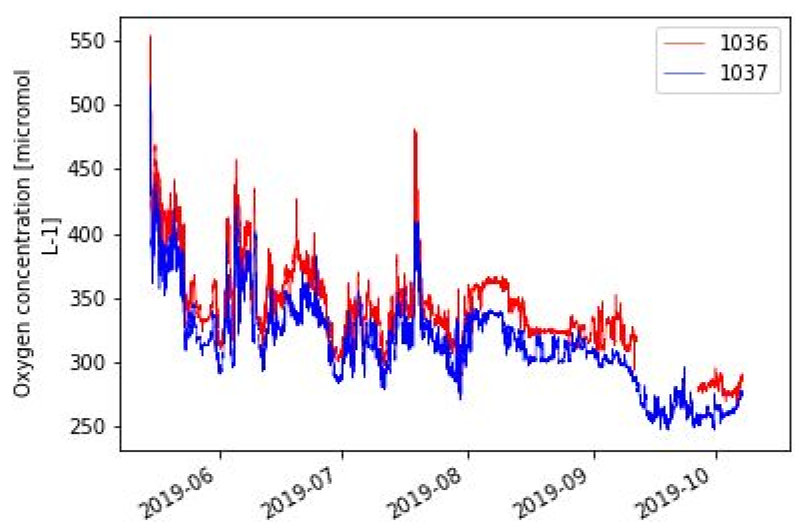

Figure 9. RBR O_2 concentrations measured during the cruises.

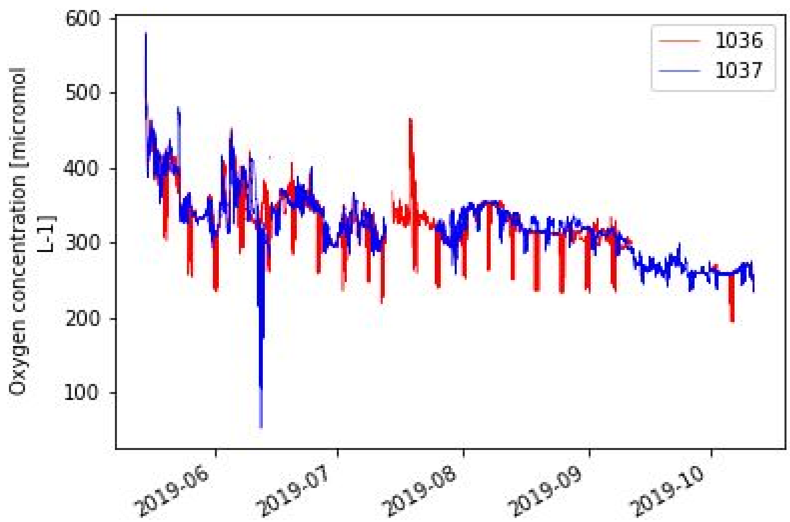

Figure 10. SBE37 O_2 concentrations measured during the cruises.

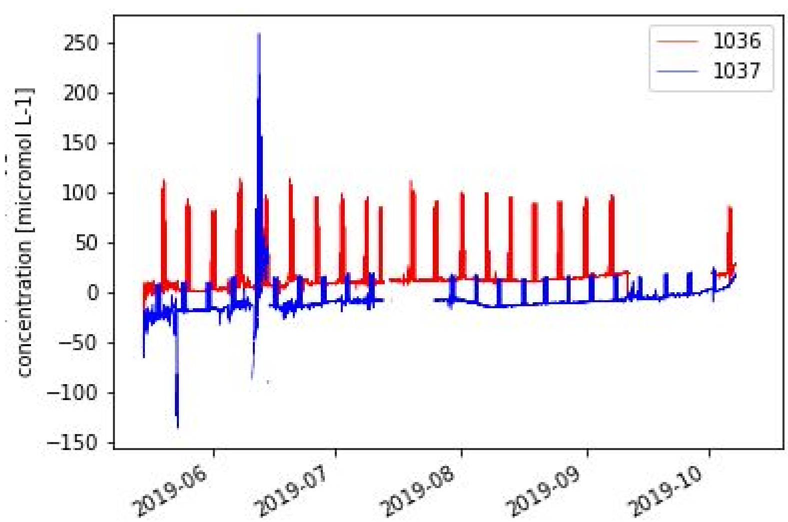

Figure 11. RBR minus SBE37 O_2 concentration differences.

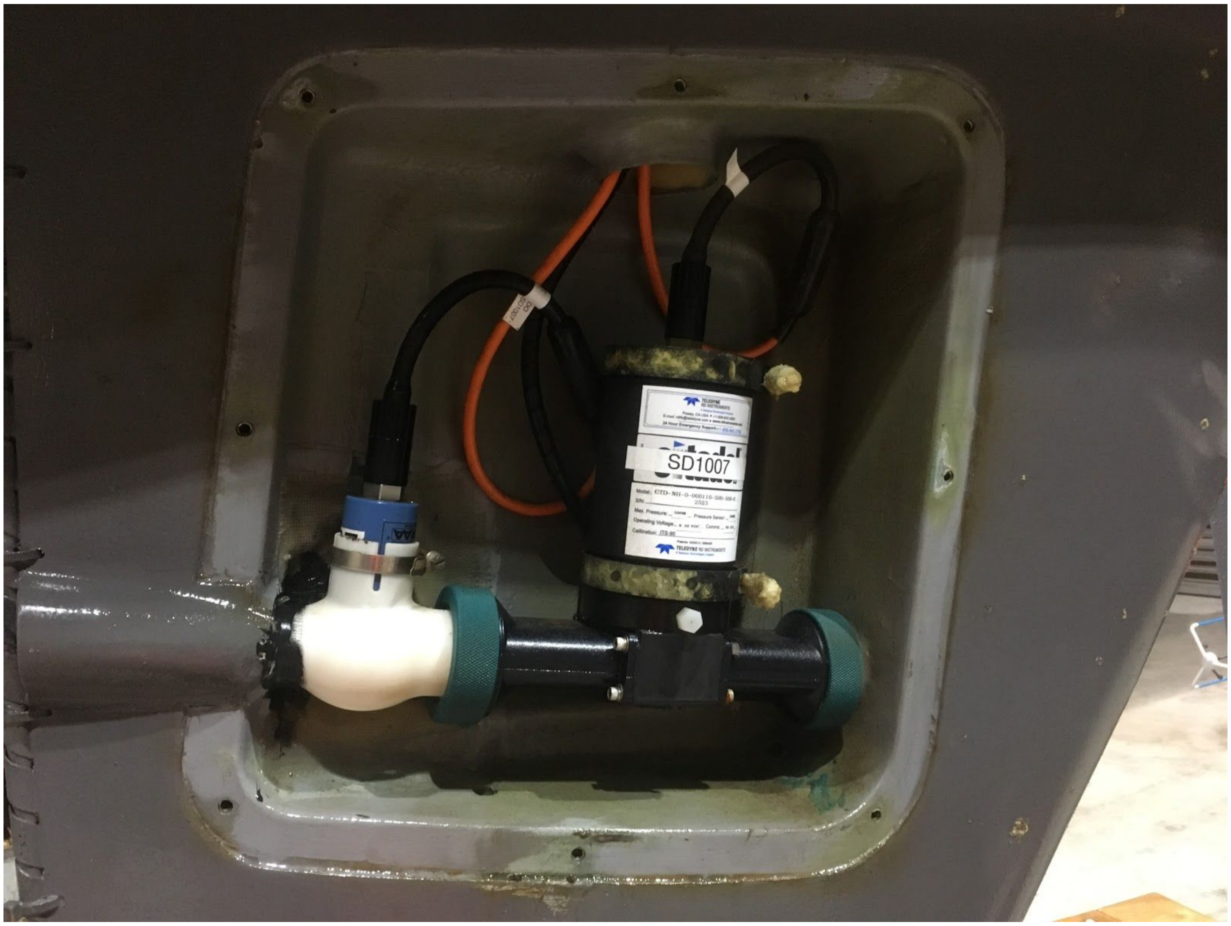

Figure 12. Dissolved Oxygen sensor installed on a Saildrone.

Wind speed

Three-dimensional wind vectors and gust values are collected by a Gill Anemometer 1590-PK-020. The anemometer is located at the top of the Saildrone mast at a height of 5 m. Data sampled at 10Hz are averaged into 1 minute values centered at :00 every 5 minutes. Wind measurements are transformed corrected with tangential and translational velocity every sample. During the cruise winds varied from 0.14 to 15.5 m/s.

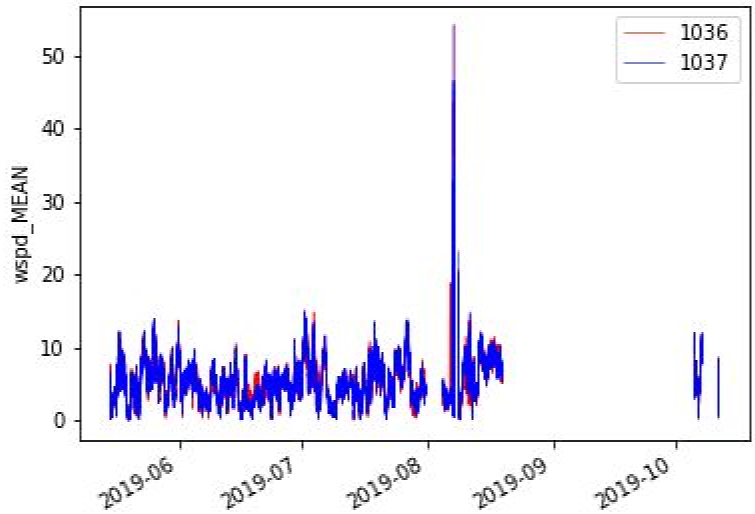

Figure 13. Wind speeds measured during the cruises (m/s).

Air pressure

Barometric pressure is measured by a Vaisala Barometer PTB210 installed at a height of 0.3 m. Data sampled at 1Hz are averaged into 1 minute values centered at :00 every 5 minutes.

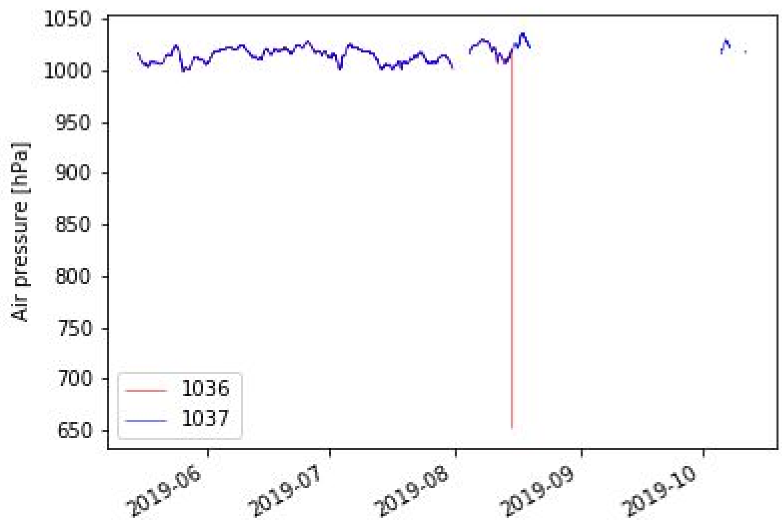

Figure 14. Time series of air pressures measured during the cruises.

Air temperature and humidity -

Air temperature and humidity were measured by Rotronic AT/RH HC2-S3 installed at a height of 2.4 m.   Data sampled at 1Hz are averaged into 1 minute values centered at :00 every 5 minutes.

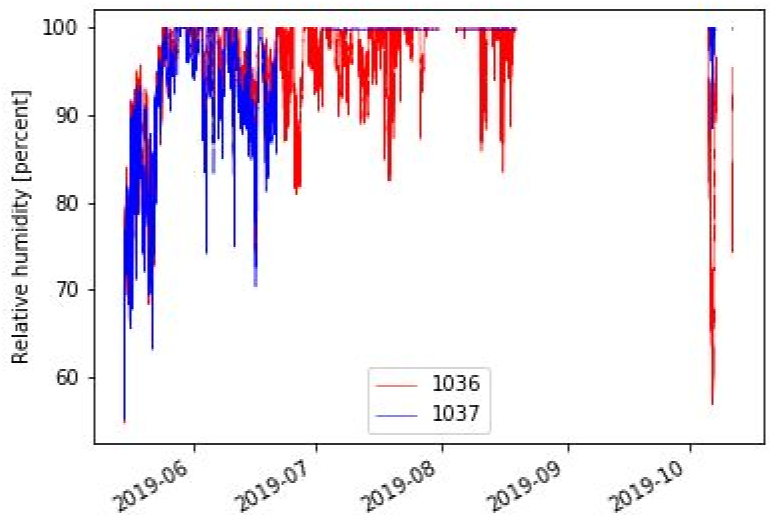

Figure 15. Relative humidity measured during the cruises.

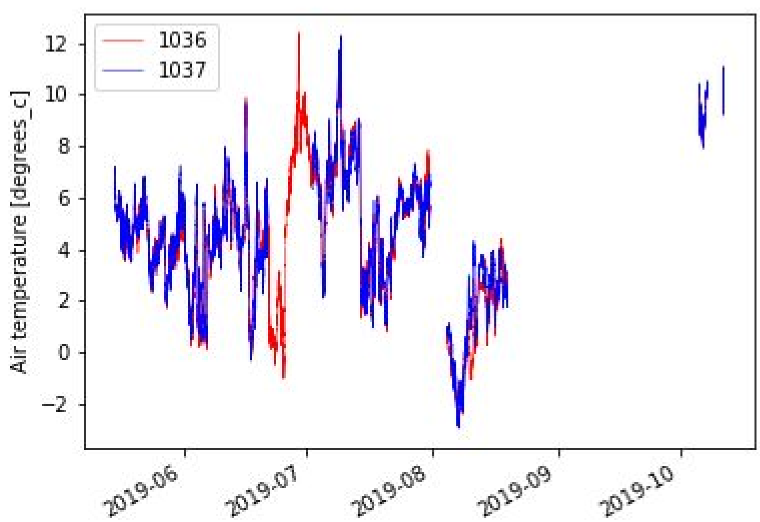

Figure 16. Air temperatures measured during the cruises.

Ocean color

Optical backscatter at 650 nm, CDOM concentration, and Chlorophyll concentration were measured by a WET Labs Fluorometer BBFL2W installed at a depth of 0.53 m. The instrument is mounted behind at the base of the hull behind the keel. in the hull of the Saildrone vehicle. Data are averaged into 1 minute averages using 12 sec of data centered at :00.

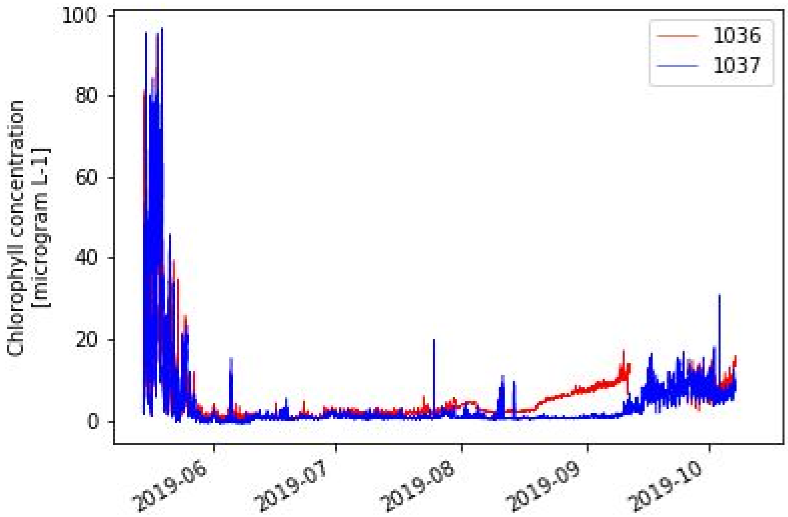

Figure 17. Chlorophyll concentrations measured by the RBR instruments.

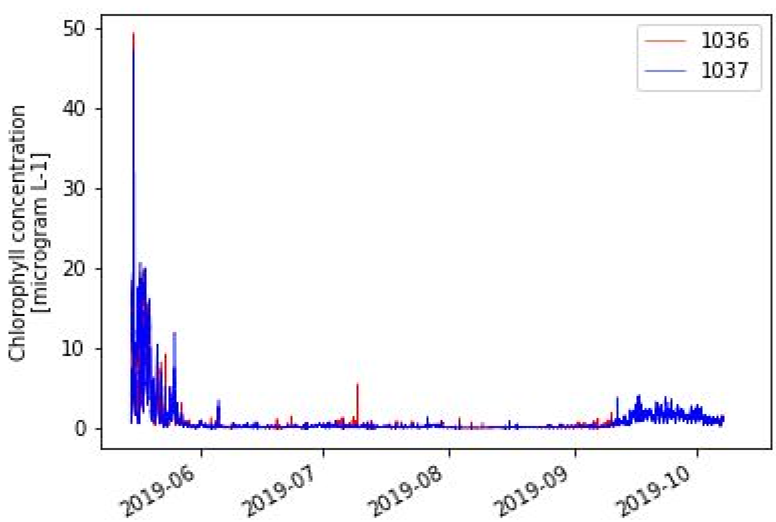

Figure 18. Chlorophyll concentrations measured by the Wetlabs instruments.

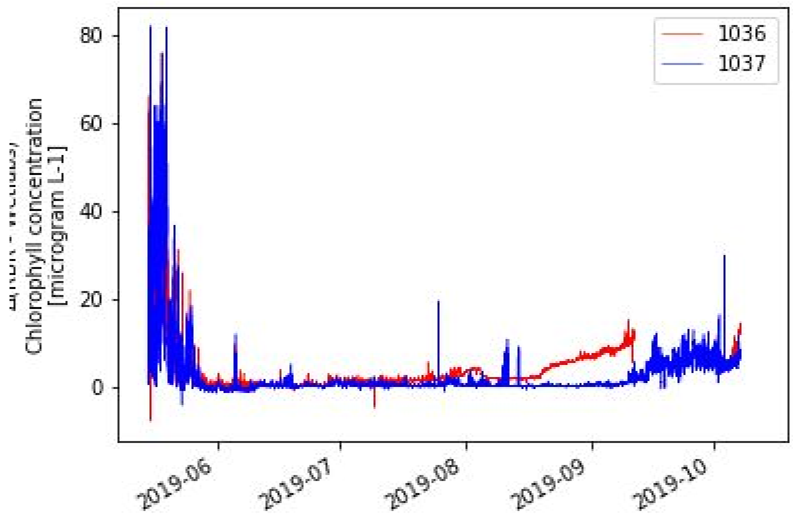

Figure 19. Differences of measured chlorophyll concentrations, RBR minus Wetlabs instruments.


Figure 20. ADCP installed on a Saildrone vehicle.

Upper ocean velocities

The Saildrone ADCP is a 300kHz Teledyne Workhorse Monitor WHM300, configured with 2m bins, max depth of 93m, and 176cm blanking distance. The instrument is nominally sampled at 1Hz, 5 minutes out of 10, centered at :00. Per-ping radial beam data is transformed into world-space and corrected with vehicle velocity, and then averaged with a 5 minute period.

ADCP is located at the rear of the Saildrone vehicle, facing downwards (Figure X). It is at a depth of 0.25 m. The ADCP data was processed to netCDF files by Saildrone. The figures below show the horizontal and vertical velocities as a function of date and depth. Values with less than 60% good pings are not used in these figures and have a much higher rate of erroneous values and should be considered suspect.

Figure 21. ADCP installed on a Saildrone (vehicle rotated 90 degrees to present the bottom of the hull).

Temperature loggers

Four Seabird 56 Temperature Loggers were mounted to the keel at depths of

0.295, 0.985, 1.420, and 1.785 m. Sampling was set to 2 seconds on, 2 seconds off. At the end of the cruise, these data were resampled to the Saildrone 1 min sampling and integrated into the main file.

Salinity

Seawater salinity is derived from temperature and conductivity measured by Sea-Bird and RBR instruments.   Data sampled at 1Hz are averaged into 1 minute averages using 12 sec of data centered at :00 seconds.   The data generally agree but their is an offset, Saildrone recommends using the SBE37 data. Differences can occur in regions with high stratification or if something blocks the intake.

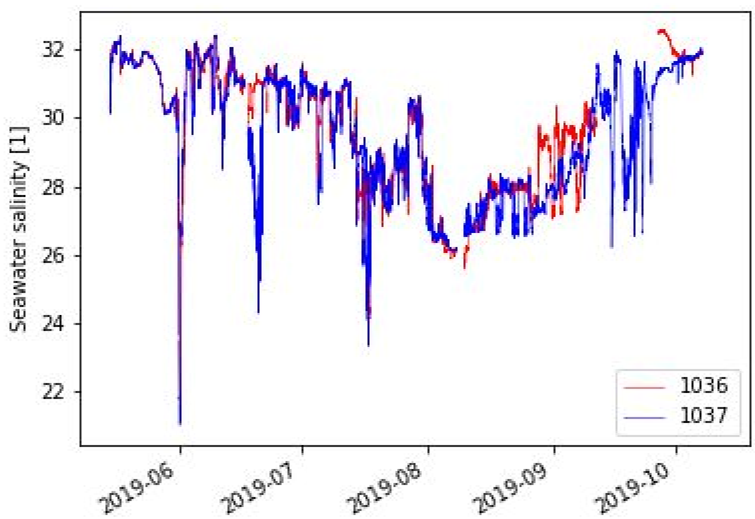

Figure 23. Salinity from RBR instrument.

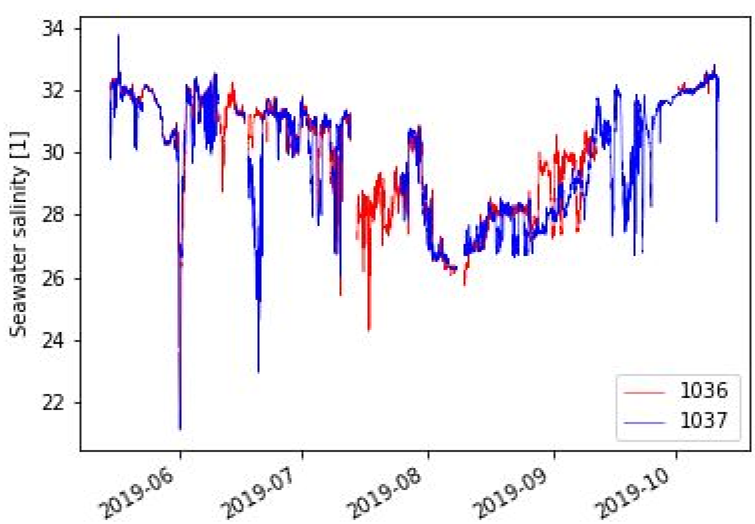

Figure 24. Salinity from SBE37 instrument.

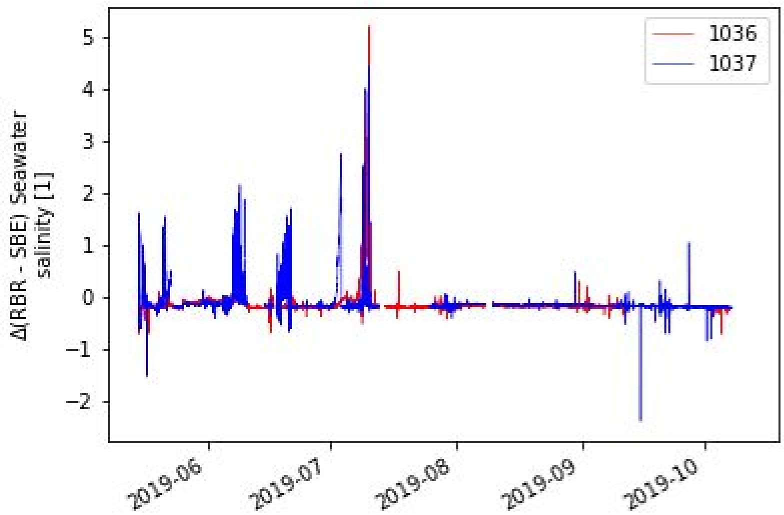

Figure 25. Difference in derived salinity, RBR minus SBE37.

Data Format and Access

All the data is in netcdf and CF/ACDD standards compliant and consistent with the NOAA/NCEI in-situ templated. Data for deployments SD1036 and SD1037 may be accessed through the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) via https://podaac.jpl.nasa.gov/dataset/SAILDRONE_ARCTIC.