2020 Atomic Saildrone Cruise Report, version 1
6 July 2020

NASA Physical Oceanography, NOAA PMEL, and Saildrone

NASA grant #80NSSC20K0768

17 January to 2 March 2020

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 and SBE37 oxygen. 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. The SBE37 oxygen concentration has errors, the RBR oxygen values appear to be more accurate for this cruise. Please see the vehicle description for more information. 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 Barbados. Image credit: Saildrone, Inc.

Figure 1. Saildrone vehicles in Barbados.

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Saildrone ATOMIC 2020 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
Cesar Rocha	Collaborator	eddies	crocha@whoi.edu

Saildrone ATOMIC 2020 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	kim@saildrone.com
Dalton Nonweiler	Mission Management Lead	Vehicle Operations / Client Relations	dalton@saildrone.com

Cruise Narrative

The Saildrone vehicles collected data on a 45-day cruise from Barbados as part of the field program (Figure 2). During a 6-week period in January-February 2020, U.S. and European scientists will come together to participate in the field campaign of ATOMIC and Elucidating the role of clouds- circulation coupling in climate (EUREC4A-OA) in the northwest tropical Atlantic east of Barbados, Eurec4a/ATOMIC. The goal is to understand the Ocean-Atmosphere interaction particularly over the mesoscale ocean eddies. In situ and remote sensing observations will be made from several research vessels, as well as airplanes, in the Atlantic waters offshore of Barbados. In addition to forming an array of observing networks over the ocean to provide the large-scale context of detailed cloud observation from the Barbados Cloud Observatory (BCO) and research flights, research vessels will also conduct eddy profiling to characterize the ocean eddies and their impact on air-sea interaction. While the eddy kinetic energy is elevated near Barbados with 30% of time occupied by an anticyclonic eddy, the ocean to the east has much reduced eddy activity. Even near Barbados, only a fraction of the 6-week observation will likely to be in the ocean eddies. In support of the ATOMIC campaign, we deployed three (3) Saildrone USVs for a period of 45 days to enhance the ATOMIC observation array days, specifically to measure the air-sea interaction processes associated with ocean eddies.

This cruise consisted of three NASA funded Saildrones (sd-1026, sd-1060, and sd-1061; the GTS WMO header is IOBX03 KWNB for all three Saildrones, and their IDs are:4803908, 1801580, 1801581). Saildrones are autonomous remote vehicles powered by solar and wind (Figure 3). A joint effort between NASA, NOAA's Pacific Marine Environmental Laboratory (PMEL), and the NOAA/University of Washington Joint Institute for the Study of the Ocean and Atmosphere (JISAO) coordinated these three saildrones with two others funded by NOAA on a longer duration mission. This report only covers the three 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 and search for data at the PMEL data site.

Vehicle description

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 (Figure 4). Four cameras aboard each vehicle imaged up, down, port and starboard of the wing. Vehicles measured near surface currents with 300 kHz acoustic Doppler current profilers (ADCP). All the data collected, sampling intervals, and instrument details are given in Table 3,4, and 5.

Other supporting measurements were made during this mission as part of the Eurec4a/ATOMIC campaign, including research vessels, aircraft, gliders, and drifters.

General Timeline for Saildrones, 15 January - 2 March 2020

Jan 15: Data collection begins at 55.8 W, 10.6 N, sampling eddy
Jan 22: Arrival eddy at 53 W, 8 N
Feb 2: Head towards R/V Ron Brown
Feb 5: Met up with R/V Atalante
Feb 10: Under Halo flight area
Feb 21: Head towards eddy 52 W 9 N, break off and sample eddy edges

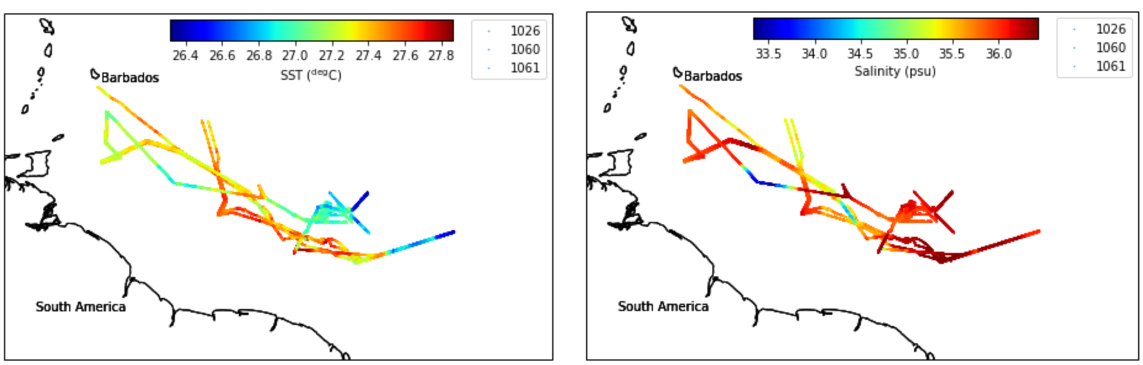

Figure 2. Overall cruise tracks for the 2020 Atomic Saildrone deployments, top image shows salinity and bottom image shows SSTs measured by vehicles.

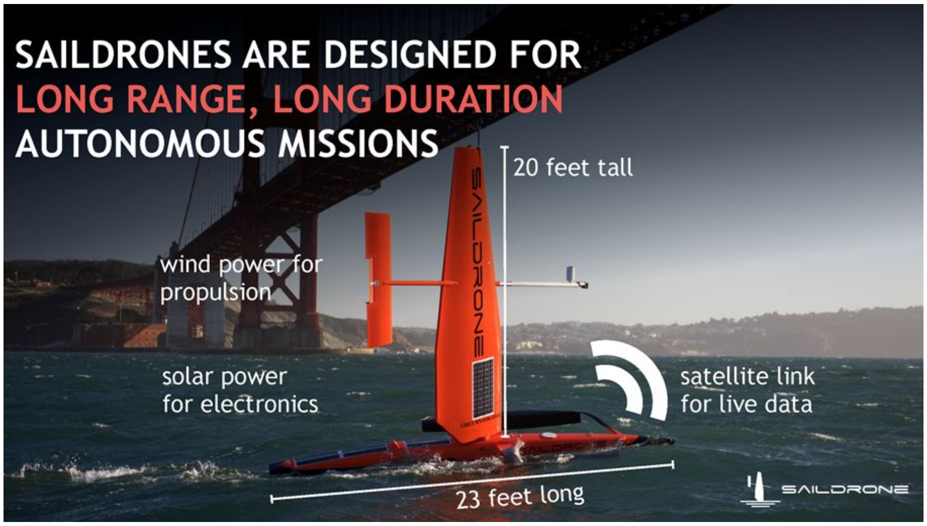

Figure 3. Dimensions of the vehicle. Figure credit Saildrone, Inc.

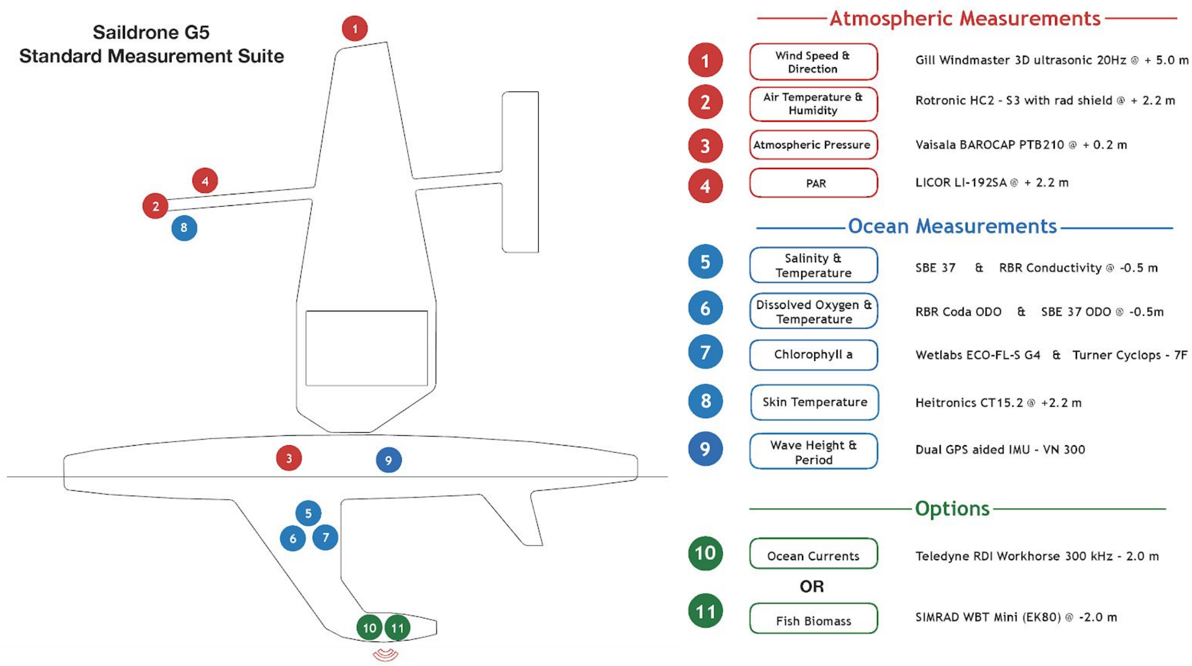

Figure 4. Saildrone vehicle instrumentation placement. Not all instruments in the figure were installed for this cruise; additional self-logging thermistors were installed along the hull, as shown in Figure 3.

Table 3. 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 Heigh	Sampling Schedule

				t (m)	
BARO_PRES_MEAN	air_pressure	Vaisala Barometer	Vaisala : PTB210	0.2	60s on, 240s off, centered at :00
BARO_PRES_STDDEV	air_pressure	Vaisala Barometer	Vaisala : PTB210	0.2	60s on, 240s off, centered at :00
CHLOR_RBR_MEAN	Chlorophyll concentration	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
CHLOR_RBR_STDDEV	Chlorophyll concentration	RBR	Saildrone^3	-0.53	12s on, 48s 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
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	Anemometer	Gill : 1590-PK-020	5.2	60s on, 240s off, centered at :00
GUST_WND_STDDEV	wind_speed_of_gust	Anemometer	Gill : 1590-PK-020	5.2	60s on, 240s off, centered at :00
O2_CONC_SBE37_MEAN	Oxygen concentration	Sea-Bird	SBE37-SMP-ODO Microcat	-0.5	12s on, 588s off, centered at :00
O2_CONC_SBE37_STDDEV	Oxygen concentration	Sea-Bird	SBE37-SMP-ODO Microcat	-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 saturation	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00

O2_SAT_RBR_STDEV	Oxygen saturation	RBR	Saildrone^3	-0.53	12s on, 48s off, centered at :00
PAR_AIR_MEAN	Photosynthetically active radiation in air	LI-COR	LI-192SA	2.6	Always On
PAR_AIR_STD	Photosynthetically active radiation in air	LI-COR	LI-192SA	2.6	Always On
RH_MEAN	relative_humidity	Rotronic AT/RH	Rotronic : HC2-S3	2.3	60s on, 240s off, centered at :00
RH_STDDEV	relative_humidity	Rotronic AT/RH	Rotronic : HC2-S3	2.3	60s on, 240s off, centered at :00
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 Microcat	Sea Bird CTD	-0.5	12s on, 588s off, centered at :00
SAL_SBE37_STDDEV	sea_water_practical_salinity	SBE37-SMP-ODO Microcat	Sea Bird CTD	-0.5	12s on, 588s off, centered at :00
TEMP_AIR_MEAN	air_temperature	Rotronic AT/RH	Rotronic : HC2-S3	2.3	60s on, 240s off, centered at :00
TEMP_AIR_STDDEV	air_temperature	Rotronic AT/RH	Rotronic : HC2-S3	2.3	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_SEA_WING_UNCOMP_MEAN	Wing Sea IR Temperature	IR Pyrometer	Heitronics CT15.10	2.25	30s on, 270s off, centered at :00
TEMP_IR_SEA_WING_UNCOMP_STDDEV	Wing Sea IR Temperature	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	-0.5	12s on, 588s off, centered at :00
TEMP_SBE37_STDDEV	sea_water_temperature	SBE37-SMP-ODO Microcat	Sea Bird CTD	-0.	12s on, 588s off, centered at :00
UWND_MEAN	eastward_wind	Gill Anemometer	Gill : 1590-PK-020	5.2	60s on, 240s off, centered at :00

UWND_STDDEV	eastward_wind	Anemometer	Gill : 1590-PK-020	5.2	60s on, 240s off, centered at :00
VWND_MEAN	northward_wind	Anemometer	Gill : 1590-PK-020	5.2	60s on, 240s off, centered at :00
VWND_STDDEV	northward_wind	Anemometer	Gill : 1590-PK-020	5.2	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
WWND_MEAN	downward_air_velocity	Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00
WWND_STDDEV	downward_air_velocity	Anemometer	Gill : 1590-PK-020	5	60s on, 240s off, centered at :00

Table 4. 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 5. 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**	**Installed Height (m)**	**Sampling Schedule**
sea_water_temperature_1	temperature	temperature logger	RBR solo_t	-0.400	1 sec
sea_water_temperature_2	temperature	temperature logger	RBR solo_t	-0.850	1 sec
sea_water_temperature_3	temperature	temperature logger	RBR solo_t	-1.300	1 sec
sea_water_temperature_4	temperature	temperature logger	RBR solo_t	-1.800	1 sec
time	time UTC				

Data

Comparison of data taken by independent sensors

On the Saildrone vehicle there are several parameters collected by more than one instrument. To better understand the accuracy of the data, Table 6 shows the comparison for these data, for each vehicle. This is a simple way to assess instrument accuracy. The CTD measurements of temperature and salinity agree very well with each other but the oxygen concentration and chlorophyll measurements have both biases and large differences in variability.

Table 6. The variables listed below are collected by at least 2 sensors on the same vehicle. The difference (mean and standard deviation) between those 2 sensors is shown in the table below.

Variable	**Vehicle**	**difference**		
		mean	**stdev**	**num. obs.**
0.5 m seawater temperature (degrees C)	1026	0.05	0.00	66183
	1060	0.06	0.01	66183
	1061	0.06	0.01	66183
0.5 m salinity (psu)	1026	0.00	0.00	66183
	1060	0.01	0.01	66183
	1061	0.00	0.01	66183
O2 Conc	1026	4.63	0.91	66183
	1060	3.84	2.43	66183
	1061	-2.60	8.30	66183
Chlor	1026	-0.17	2.44	66183
	1060	-0.26	1.18	66183
	1061	-0.26	0.24	66183

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 a pyrometer to measure infrared (IR) radiance from which the skin sea-surface temperatures can be derived. The 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 m.

Another CTD by RBR measures temperature at a depth of 0.5 m. The RBR is a temperature logger specifically designed for one minute sampling.

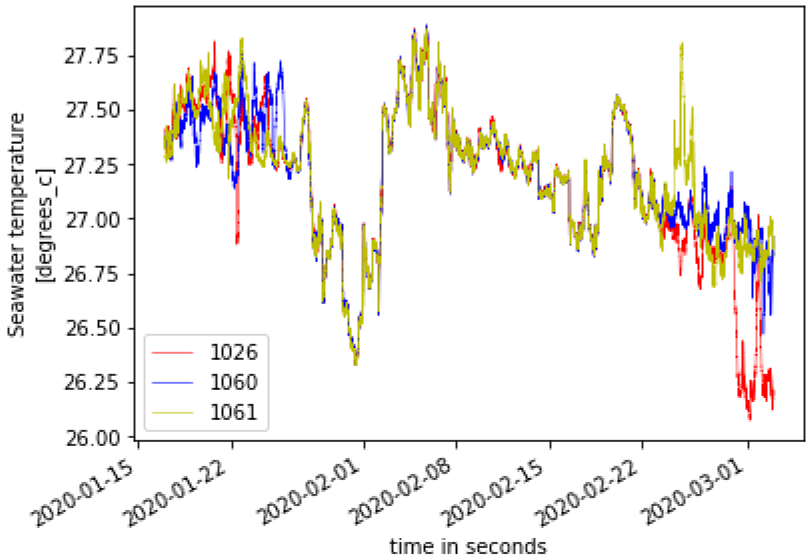

Figure 4. 0.5 m seawater temperatures measured by the RBR instruments during the cruises.

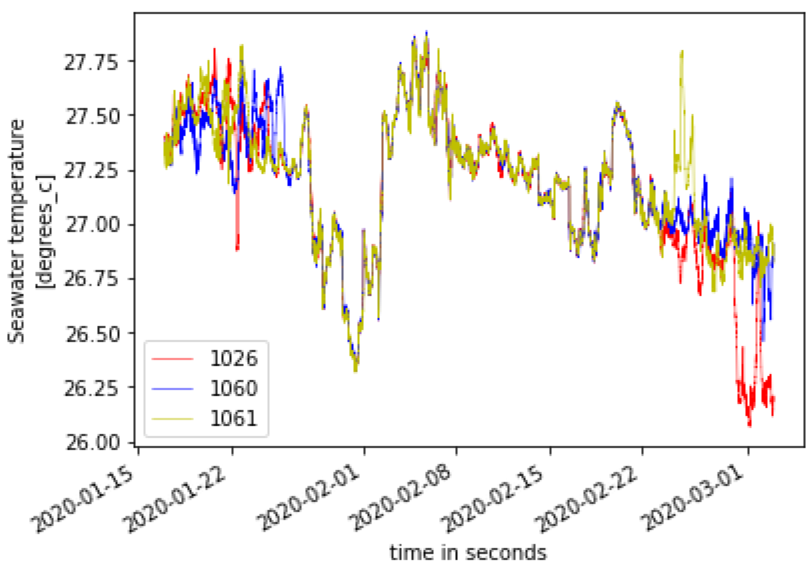

Figure 5. 0.5 m seawater temperatures measured by SBE37 instruments during the cruises.

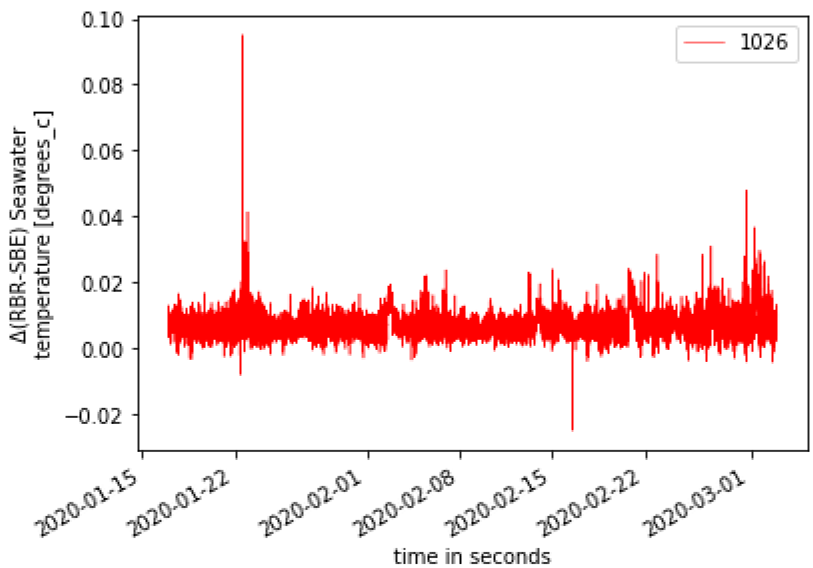

Figure 6. RBR minus SBE37 0.5 m seawater temperature.

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 2.25m 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.

Dissolved Oxygen

The vehicles measure 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 these sensors- there is no pumping. Saildrone designed the flow-thru so that "fresh" water would always be flowing past dissolved oxygen sensors due to motion of the vehicle, the drone's motion is essentially providing pumping. Figure 9, 10, and 11 show time series for the different oxygen sensors on each vehicle. Figure 9 shows the RBR oxygen concentration, with small offsets, which are expected, between the different vehicles. Figure 10 shows the SBE37 Oxygen data having unexpected drops in Oxygen concentration that appear to be noise and vehicle 1061 has a clear erroneous drift in the data after about 2/15/2020. Figure 11 compares the two instruments, again revealing problems. Based on these data, for oxygen concentration we recommend using the RBR data for this cruise.

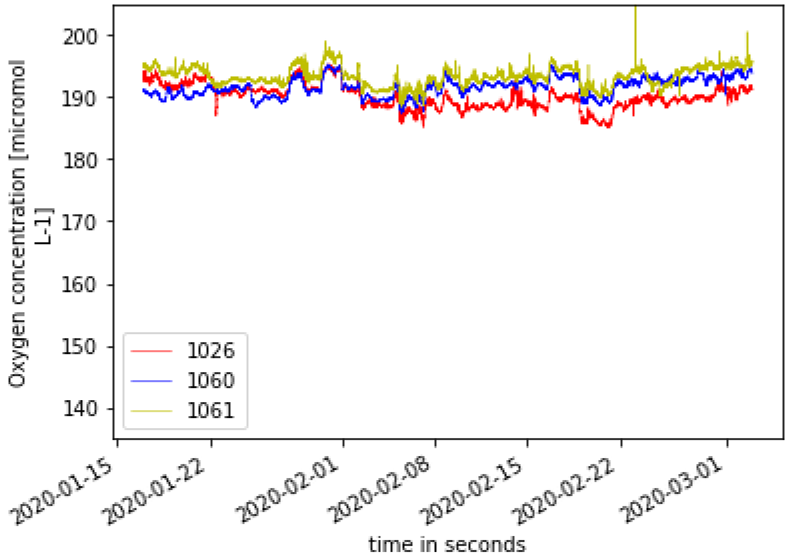

Figure 9. RBR O_2 concentrations measured by RBR instruments during the cruises.

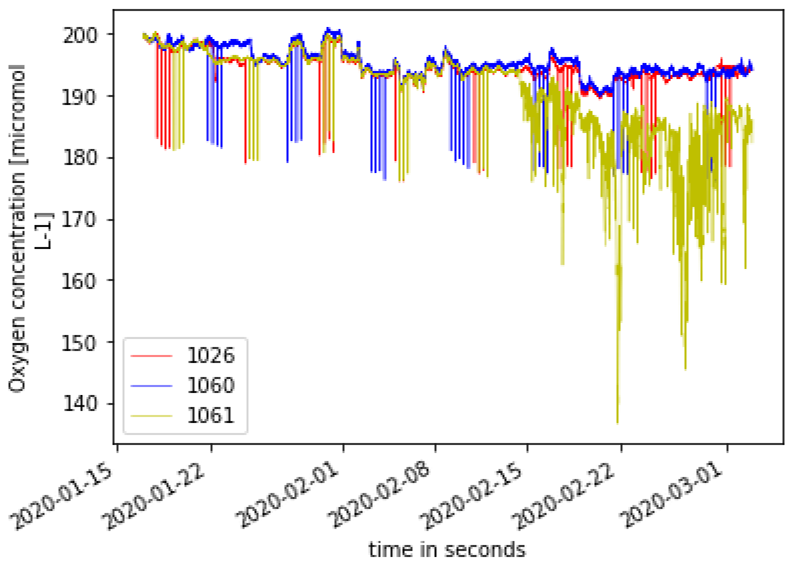

Figure 10. SBE37 O_2 concentrations measured during the cruises.

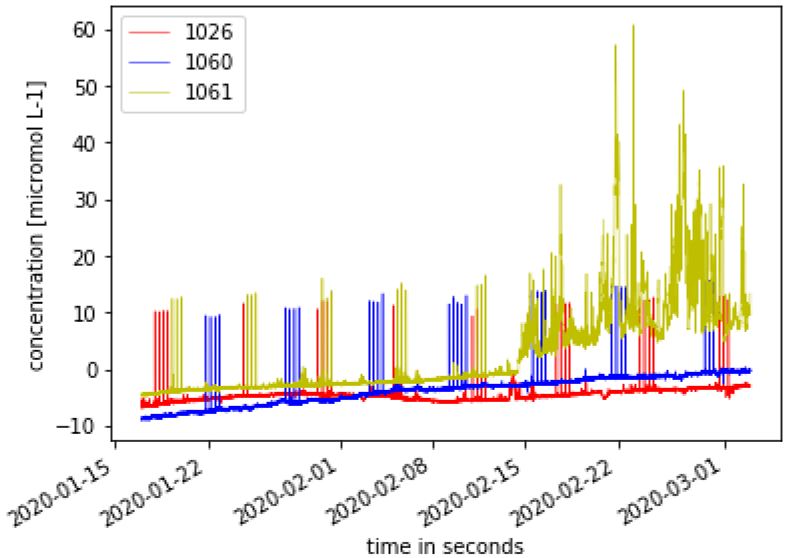

Figure 11. RBR minus SBE37 O_2 concentration differences.

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 5.2 m. Data sampled at 10Hz are averaged into 1 minute values centered at :00 every 5 minutes. Wind measurements are transformed and corrected with tangential and translational velocity every sample.

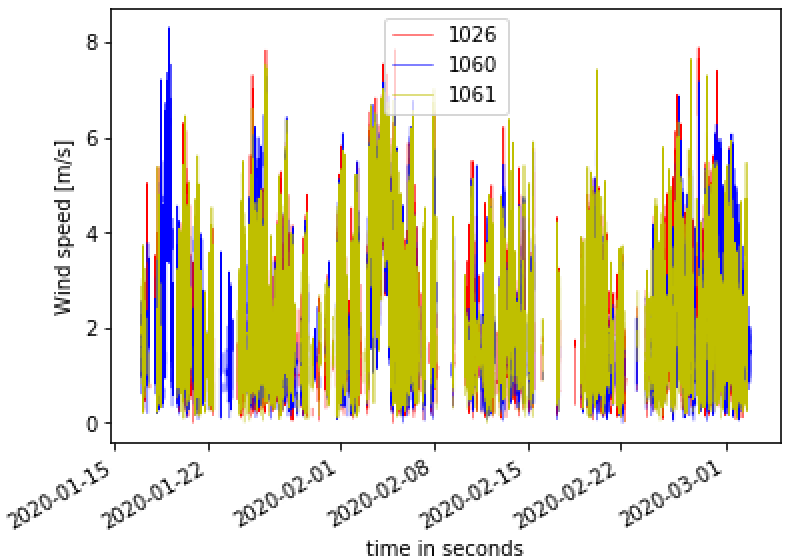

Figure 13. Wind speeds measured during the cruise.

Air pressure
Barometric pressure is measured by a Vaisala Barometer PTB210 installed at a height of 0.2 m. Data sampled at 1Hz are averaged into 1 minute values centered at :00 every 5 minutes.

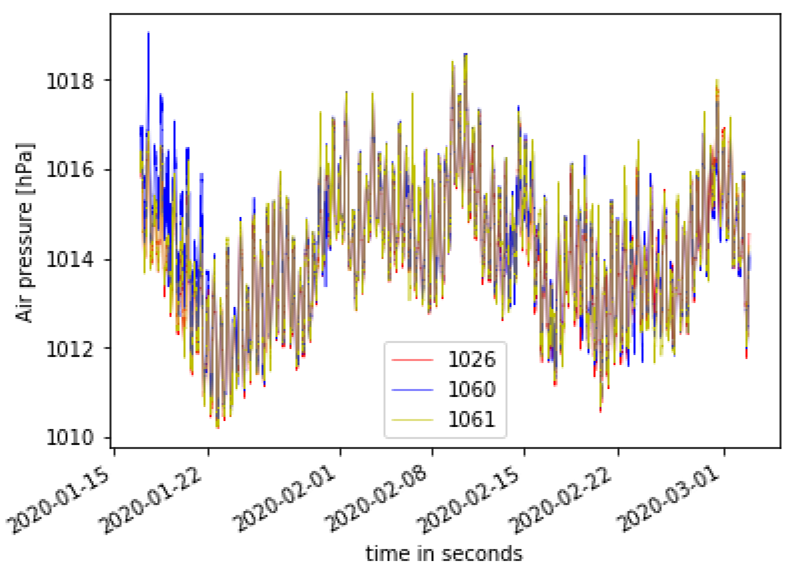

Figure 14. Time series of air pressures measured during the cruises.

Air temperature and humidity -

Air temperature and humidity were measured by Rotronic AT/RH HC2-S3 installed at a height of 2.3 m. Data sampled at 1Hz are averaged into 1 minute values centered at :00 every 5 minutes.

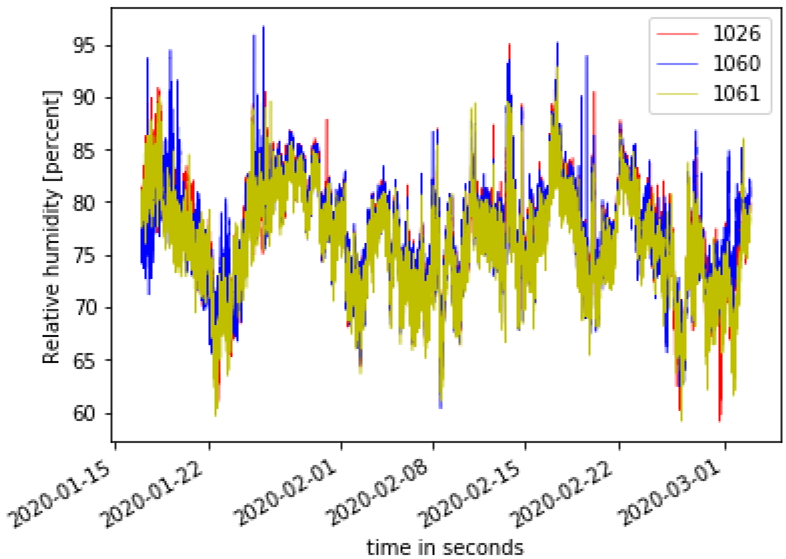

Figure 15. Relative humidity measured during the cruises.

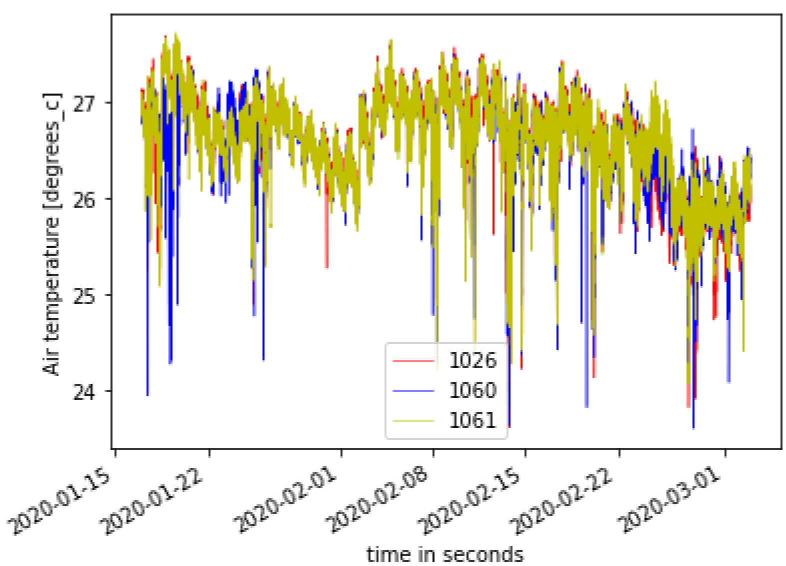

Figure 16. Air temperatures measured during the cruises.

Ocean color

Chlorophyll concentrations were measured by a WET Labs Fluorometer FLS installed at a depth of 0.5 m. The instrument is mounted behind at the base of the hull behind the keel, in the hull of the Saildrone vehicle. Additional measurements were performed by an RBR CTD/ODO/Chl-A Saildrone^3 installed at a depth of .53m. Data are averaged into 1 minute averages using 12 sec of data centered at :00.

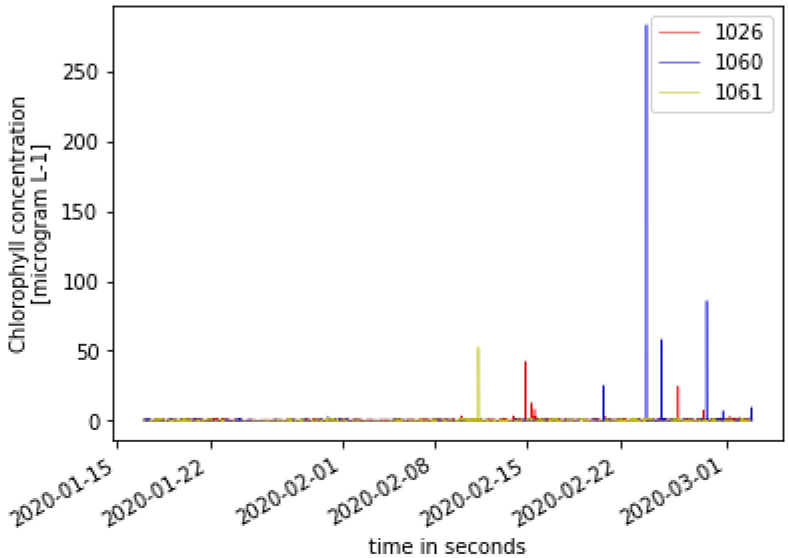

Figure 17. Chlorophyll concentrations measured by the RBR instruments.

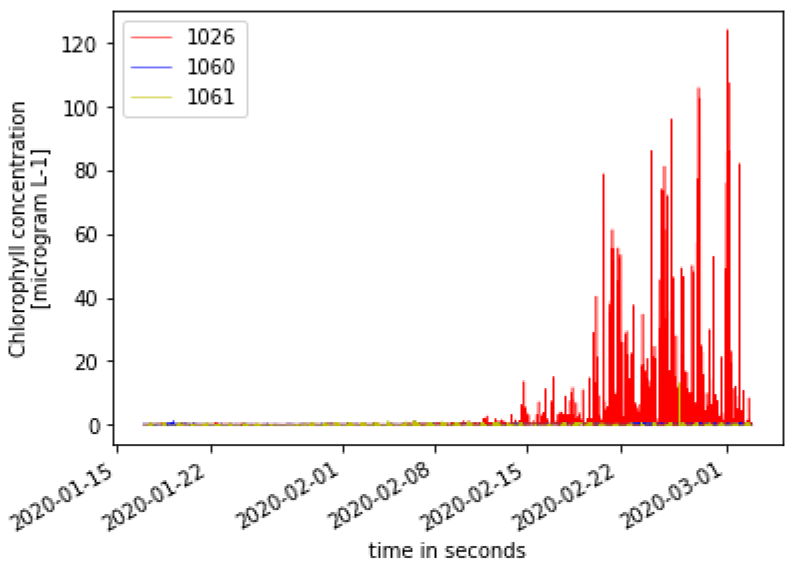

Figure 18. Chlorophyll concentrations measured by the Wetlabs instruments.

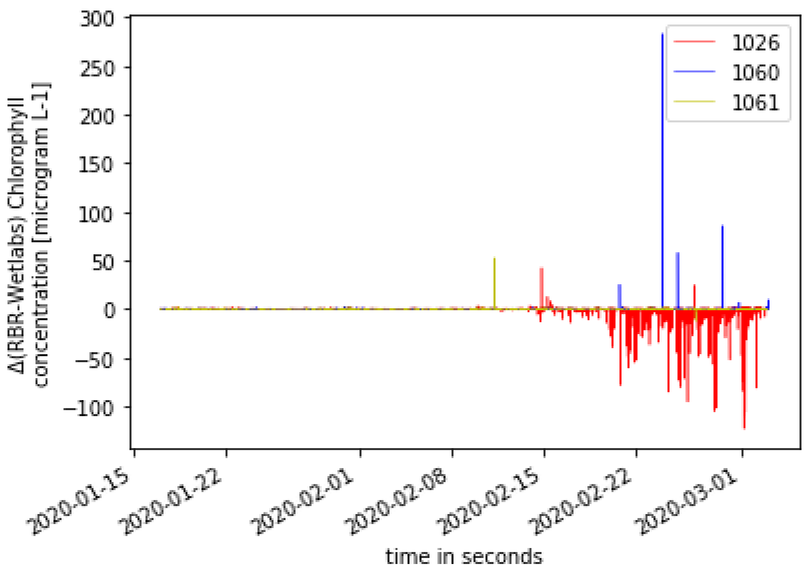

Figure 19. Differences of measured chlorophyll concentrations, RBR minus Wetlabs instruments.

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 bottom of the Saildrone vehicle's keel, facing downwards. It is at a depth of 1.8 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.

Temperature loggers

Four RBR solo_t Temperature Loggers were mounted to the keel at depths of 0.400, 0.850 1.300, and 1.800 m. Sampling was set to 1 second.

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 there is an offset, Saildrone recommends using the SBE37 data. Differences can occur in regions with high stratification or if something blocks the intake.

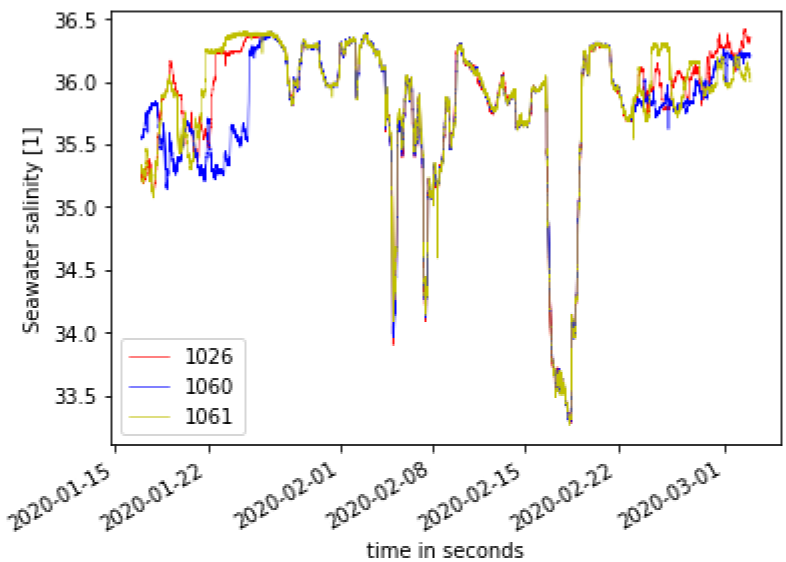

Figure 20. Salinity from RBR instrument.

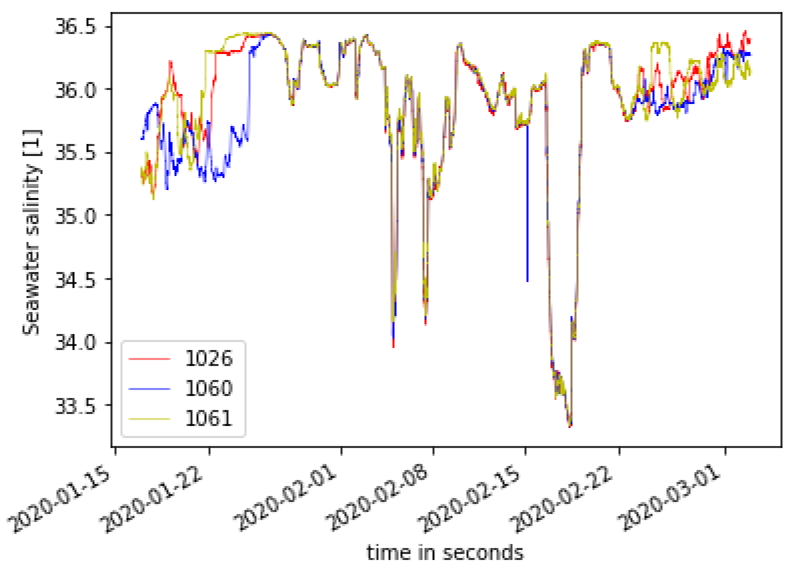

Figure 21. Salinity from SBE37 instrument.

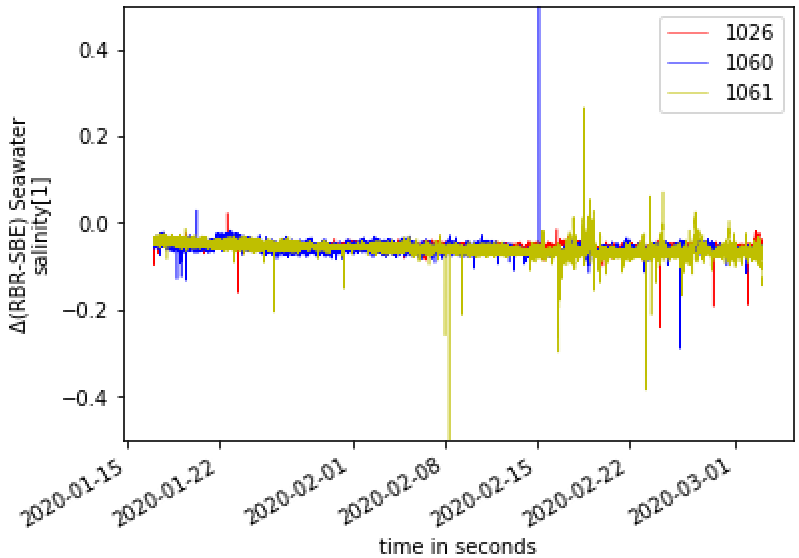

Figure 22. Difference in derived salinity, RBR minus SBE37.

Photosynthetically Active Radiation in Air

Photosynthetically active radiation in air is measured by a LI-COR PAR LI-192SA installed at a height of 2.6m. Data sampling was always on for these measurements and the data are averaged into 1 minute averages.

Dominant Wave Period and Significant Wave Height

Dominant wave period and significant wave height are measured by a VectorNav Hull IMU VN-300 installed at a height of .34m. Data sampling is always on for these measurements and the data are averaged into 1 minute averages.

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/Saildrone.