NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

DATA ACQUISITION AND PROCESSING REPORT FOR PA011

Site Name:	Ocean Station Papa
Deployment Number:	**PA011**
Year Established:	2007
Nominal Location:	50.1°N 144.9°W
Anchor Position:	50° 07.65' N, 144° 49.55' W (buoy flyby)
Deployment Date:	June 14, 2017
Recovery Date:	July 29, 2018
Project P.I.:	Dr. Meghan F. Cronin
Report Authors:	N.D. Anderson, J.A. Keene, P. Berk, and M.F. Cronin
Data Processors:	N.D. Anderson
Date of Report:	January 8, 2021
Revision History:	

Special Notes: The 20m instrument flooded, so real-time data were included in the final data files at that depth.

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Data Acquisition and Processing Report for OCS Mooring PA011

1.0 Mooring Summary

As the site of a former ocean weather ship, Station Papa (50°N, 145°W) is one of the oldest oceanic time series and a critical site in the global network of OceanSITES time series reference stations. Through initial 3-year support from the National Science Foundation (NSF) and sustained funding from NOAA, and in collaboration with the Canadian Department of Fisheries and Oceans (DFO) Line P Program, a surface mooring was deployed in June 2007 at Ocean Station Papa to monitor ocean-atmosphere interactions, carbon uptake, and ocean acidification. PA011 was the eleventh deployment at this site.

The PA011 mooring was deployed on June 14th, 2017 during a collaborative research cruise between the NOAA Ocean Climate Stations (OCS) group and the Canadian Institute of Ocean Sciences (IOS) aboard the Canadian Coast Guard Ship JOHN P. TULLY. The mooring was recovered on July 29th 2018 by OCS during a Woods Hole Oceanographic Institute (WHOI)/NOAA cruise aboard the R/V SALLY RIDE. The Ocean Climate Stations group would like to thank the crew of both ships and the other scientists on board for crucial help during all mooring work.

The Papa mooring site is nominally at 50.1°N, 144.9°W. The actual anchor position is different for each year, but deployments alternate between two target locations.

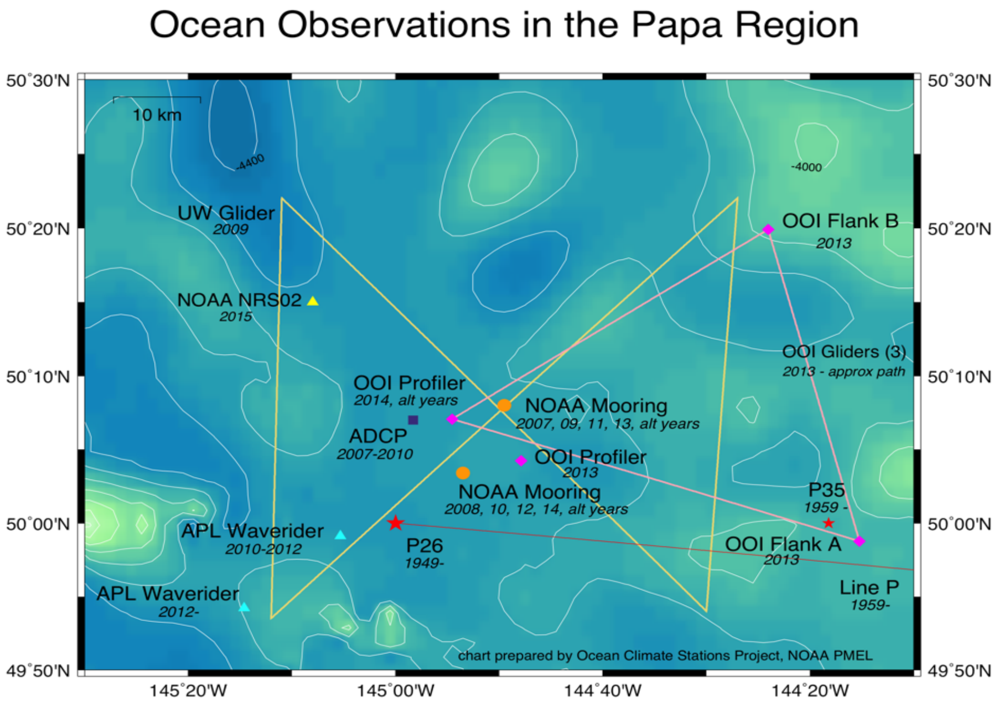

Figure 1: Ocean observations near OCS Station Papa mooring (labeled "NOAA Mooring").

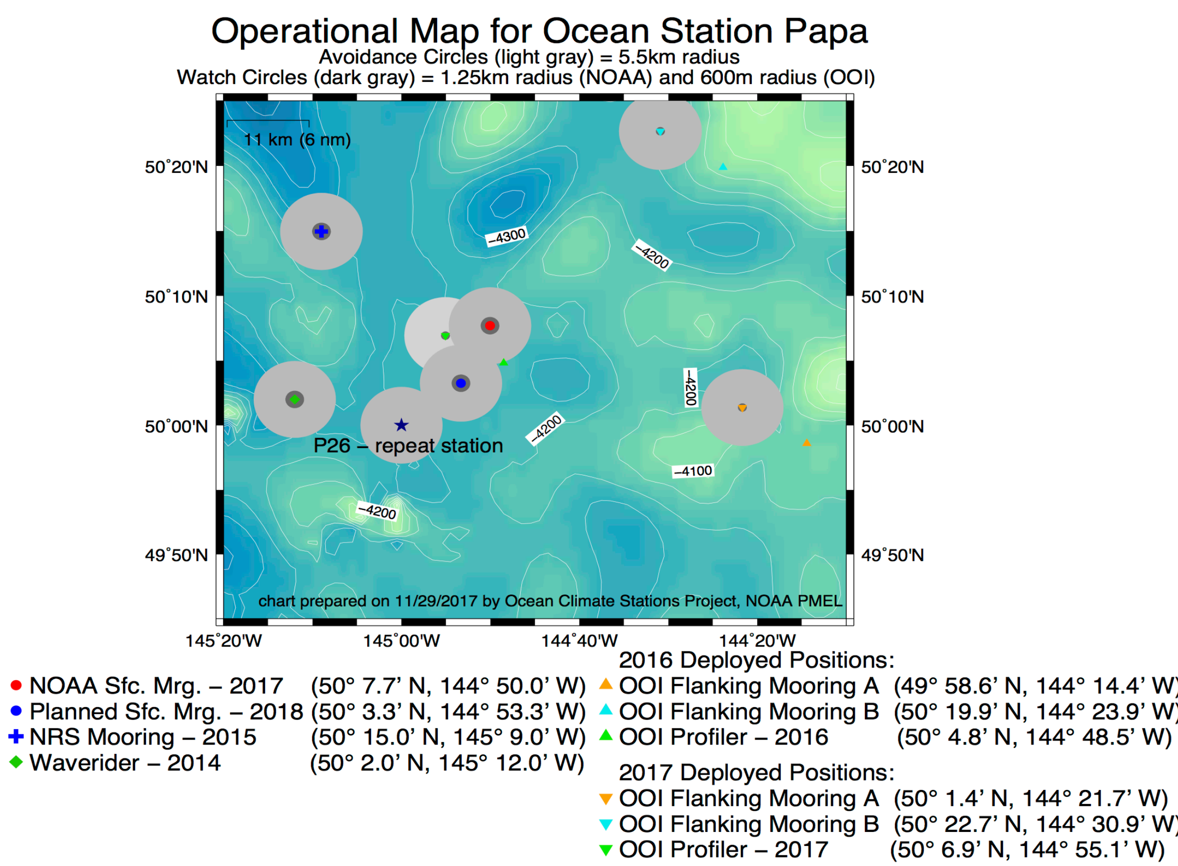

Figure 2: Overview of Station P deployments, at the time of PA011's deployment.

1.1 Mooring Description

The PA011 mooring was a taut-line mooring, with a scope of 0.965. Non-rotating 7/16” (1.11cm) diameter wire rope, jacketed to 1/2" (1.27cm), was used in the upper 325m of the mooring line. The remainder consisted of plaited 8-strand nylon line to the acoustic release in line above the anchor, as shown in Figure 4. The 6,850lb (3,107kg) anchor was fabricated from scrap railroad wheels.

The surface buoy was a 2.6m fiberglass-over-foam discus buoy, with a central instrument well. It had an aluminum tower and a stainless steel bridle.

OCS partner groups also provided mooring instrumentation. The University of Washington contributed a seabird, gas tension device, and oxygen level monitoring equipment, while the PMEL carbon group attached a fluorometer and a SAMI pH sensor, along with their primary CO_2 flux monitoring system housed in the well. The SBE16 pump connector was found corroded upon recovery, but partner sensors otherwise appeared intact. OCS is not responsible for the acquisition or processing of these data. No further discussion of these systems is included in this report.

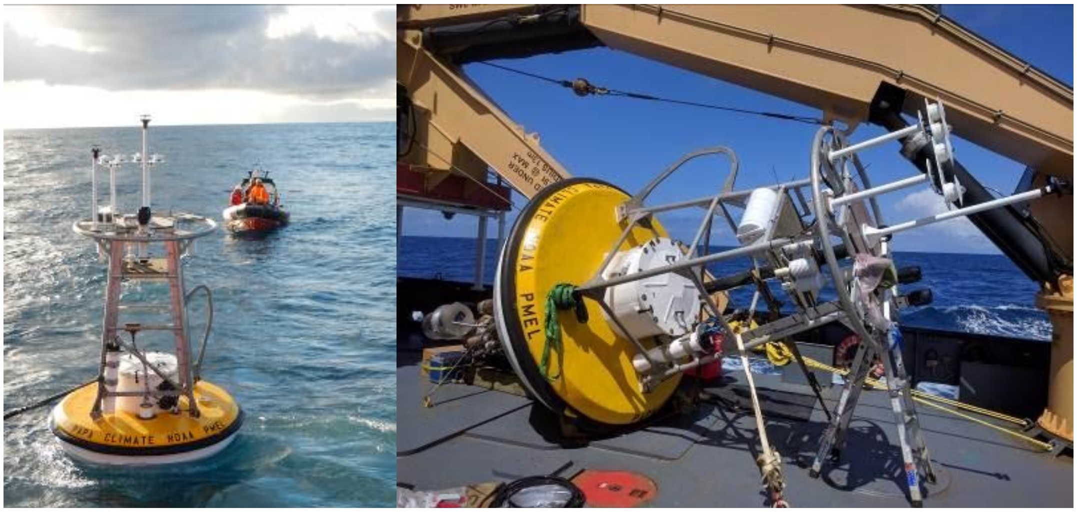

Figure 3: PA011 as deployed.

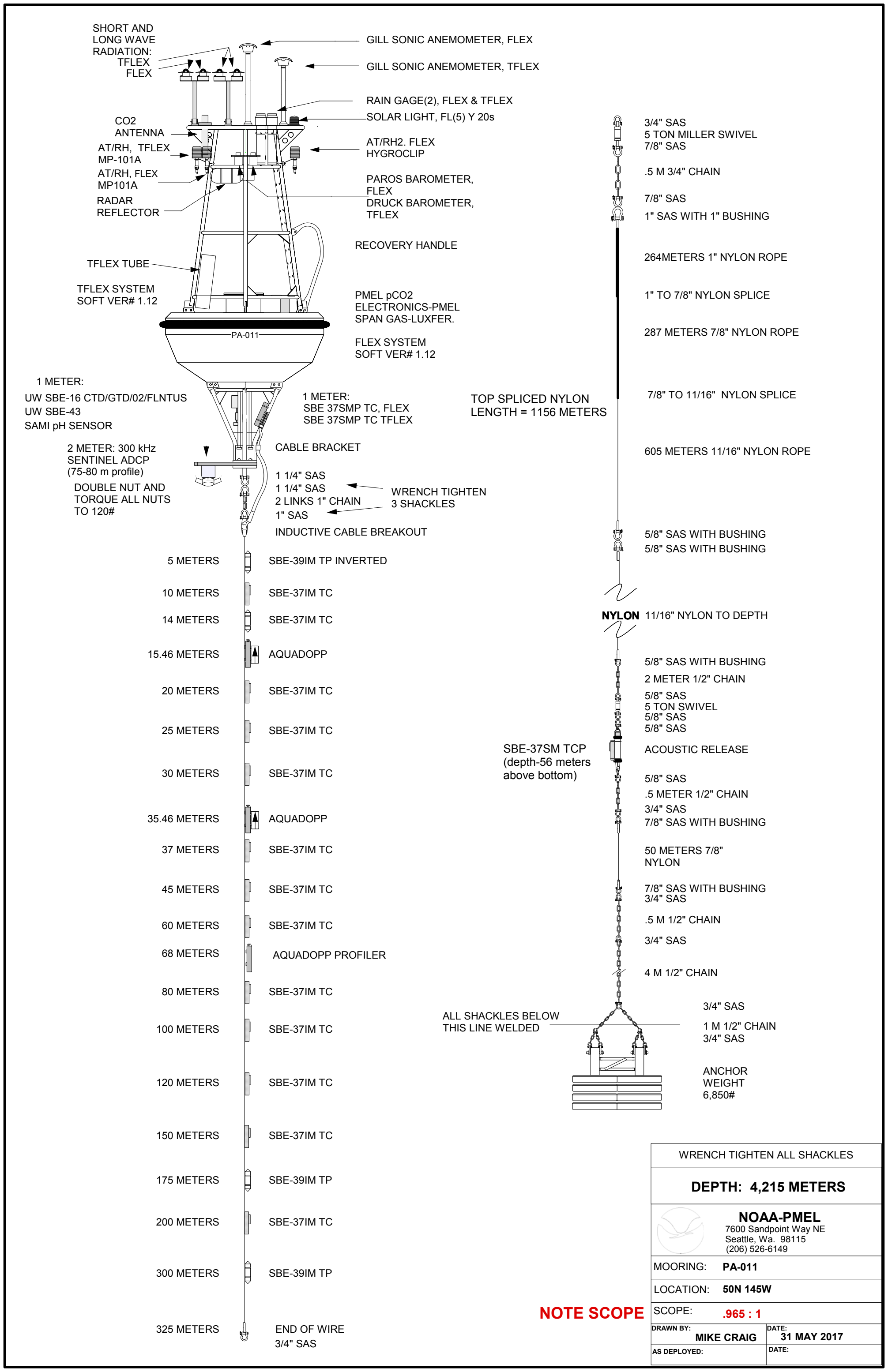

Figure 4: PA011 mooring diagram.

1.2 Instrumentation on PA011

The following instrumentation was deployed on PA011. Redundant data acquisition systems were used, Flex and TFlex. Flex meteorological sensors are generally considered primary. Any substitutions are noted in the relevant section of this report.

Deployment:		**PA011**			
Met Sensors		**Model**	**Serial #**		**Notes**
Height	Acquisition	**FLEX**	0002	3/1	
2.6m	ATRH	Rotronics MP-101A	104889		
2.6m	ATRH2	Rotronics HygroClip	61222482		
4.2m	Wind	Gill	11520107		
2.5m	BP	Paros	127686		
3.1m	Rain	RM Young	1564		
3.6m	SWR	Eppley PSP	38427		
3.6m	LWR	Eppley PIR	38437		
	Acquisition	**TFLEX**	2001		
2.6m	ATRH	Rotronics MP-101A	91589		
3.8m	Wind	Gill	070229		
2.4m	BP	Druck	1749053		
3.1m	Rain	RM Young	854		
3.6m	SWR	Eppley PSP	38428		
3.6m	LWR	Eppley PIR	38438		
CO2	Electronics	PMEL			
	Span Gas	Luxfer			
Subsurface Instrumentation					
Bridle		**Model**	**Serial #**		**Notes**
1m	SST/C	SBE37SMP - TC	7090		Flex, AA
1m	SST/C	SBE37SMP - TC	7089		TFLEX
1m	pH	SAMI			Supplied by UW
1m	SST/C	SBE16			Supplied by UW
1m	Oxygen	Optode			Supplied by UW
1m	Oxygen	SBE43			Supplied by UW
1m	Fluorescence	ECO FLNTUS			Supplied by CO2 - Self Powered
1m	Gas Tension	GTD			Supplied by UW
2m	ADCP	Workhorse Sentinel	14605		
Depth		**Model**	**Serial #**	**IM ID**	**Notes**
5m	TP	SBE39IM - TP	4380	01	Inverted (Use TP for titanium housing)
10m	TC	SBE37IM - TC	6075	02	
14m	TC	SBE37IM - TC	13248	03	AA
15.46m	ADCM	AquaDopp	13499	04	
20m	TC	SBE37IM - TC	12550	05	AA
25m	TC	SBE37IM - TC	8419	06	
30m	TC	SBE37IM - TC	8420	07	
35.46m	ADCM	AquaDopp	9819	08	
37m	TC	SBE37IM - TC	6140	09	
45m	TC	SBE37IM - TC	8422	10	
60m	TC	SBE37IM - TC	8423	11	
68m	ADCP	Aquadopp Profiler	13314		New Profiler. Logging internally.
80m	TC	SBE37IM - TC	8424	12	
100m	TC	SBE37IM - TC	6072	13	
120m	TC	SBE37IM - TC	6073	14	
150m	TC	SBE37IM - TC	6074	15	
175m	TP	SBE39IM - TP	4863	16	
200m	TC	SBE37IM - TC	7788	17	
300m	TP	SBE39IM - TP	4864	18	
325m	End of Wire				
Release	TCP	SBE37SM - TCP	10503	-	AA

Table 1: Instruments deployed on PA011.

Since 2007, the measurement point for SST/C is known to have varied between 1.0 - 1.3m depth. Uncertainties in actual measurement depth are introduced by changes in buoy waterlines, variation between instrument mounting locations, and alteration of measurement points with different instrument versions. For these reasons, the nominal depth for the SST/C measurement is stated as 1m.

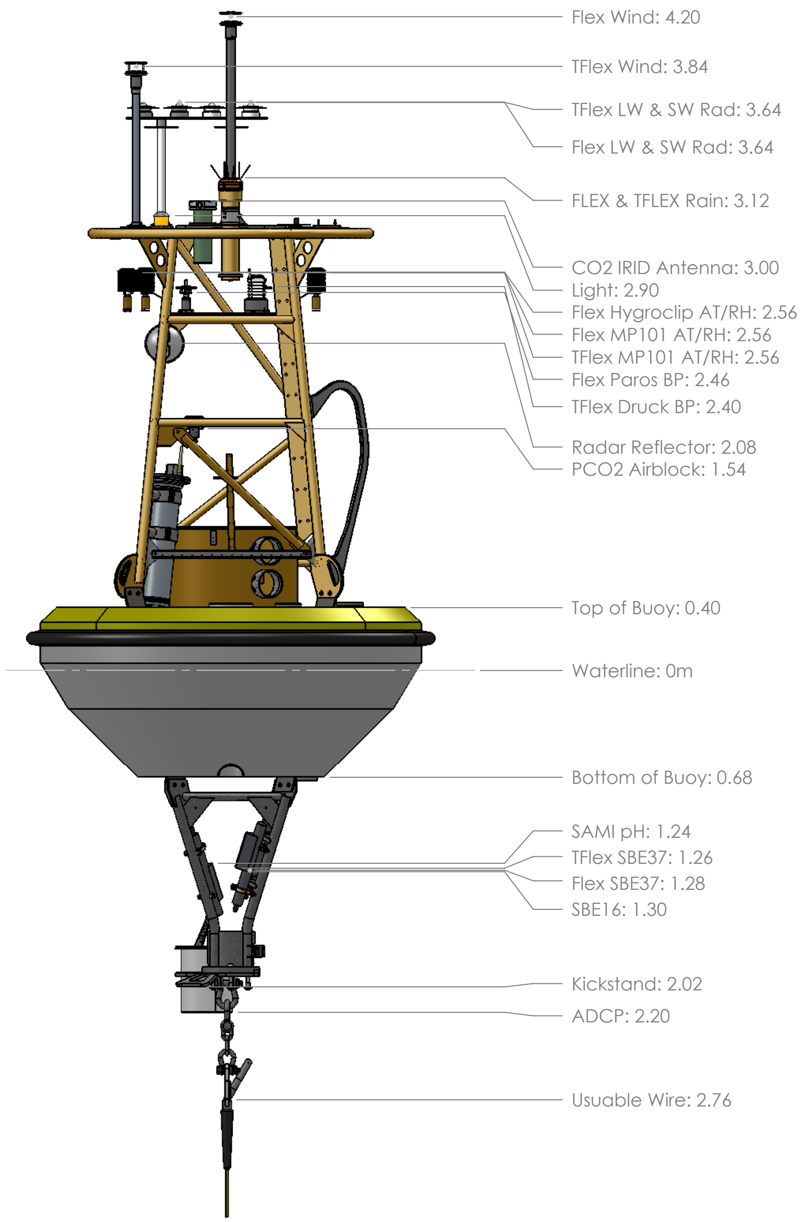

Figure 5: Buoy diagram showing bridle arrangement. The SBE16 package contains a suite of sensors.

2.0 Data Acquisition

Two independent data acquisition systems were deployed on PA011, Flex and TFlex. Both systems telemetered hourly averaged surface data via Iridium satellite, with Flex also transmitting hourly data from the subsurface instruments. High-resolution data are logged internally throughout the deployment in subsurface instruments, and downloaded upon recovery of the mooring.

Position information associated with real-time data comes through the Iridium satellite network. Buoy latitude and longitude are transmitted to shore via three GPS devices on the Flex, TFlex, and CO_2 systems. The Flex GPS measurements are hourly, and TFlex GPS measurements occur every six hours. Occasional position errors were spotted and removed during quality control operations.

2.1 Sampling Specifications

The following tables describe the high-resolution sampling schemes for the PA011 mooring, for both the primary and secondary systems. Observation times in data files are assigned to the center of the averaging interval. Flex sensors are generally considered primary. Any substitutions are noted in the relevant section of this report.

PRIMARY SENSORS

Measurement	Sample Rate	Sample Period	Sample Times	Recorded Resolution	Acquisition System
Wind Speed/Direction	2 Hz	2 min	2359-0001, 0009-0011…	10 min	TFLEX
Air Temperature + Relative Humidity	1 Hz	2 min	2359-0001, 0009-0011…	10 min	TFLEX
Barometric Pressure	1 Hz	2 min	2359-0001, 0009-0011…	10 min	FLEX
Rain Rate	1 Hz	1 min	0000-0001, 0001-0002…	1 min	FLEX
Shortwave Radiation	1 Hz	1 min	0000-0001, 0001-0002…	1 min	TFLEX
Longwave Radiation (Thermopile, Case & Dome Temperatures)	1 Hz	1 min	0000-0001, 0001-0002…	1 min	TFLEX
Seawater Temperature, Pressure & Conductivity	1 per 10 min	Instant.	0000, 0010,…	10 min	Internal
Ocean Currents (Point)	1 Hz	2 min	2359-0001, 0009-0011…	10 min	Internal
Ocean Currents (Sentinel)	1 Hz	2 min	2359-0001, 0029-0031…	30 min	Internal
Ocean Currents (AQDPRO)	1 Hz	2 min	2354-2356, 0054-0056…	1 hr	Internal
GPS Positions	1 per hr	Instant.	~0000, 0100…	1 hr	FLEX

Table 2: Sampling parameters of the primary sensors on PA011.

SECONDARY SENSORS

Measurement	Sample Rate	Sample Period	Sample Times	Recorded Resolution	Acquisition System
Wind Speed/Direction	2 Hz	2 min	2359-0001, 0009-0011…	10 min	FLEX
Air Temperature + Relative Humidity	1 Hz	2 min	2359-0001, 0009-0011…	10 min	FLEX
Barometric Pressure	1 Hz	2 min	2359-0001, 0009-0011…	10 min	TFLEX
Rain Rate	1 Hz	1 min	0000-0001, 0001-0002…	1 min	TFLEX
Shortwave Radiation	1 Hz	1 min	0000-0001, 0001-0002…	1 min	FLEX
Longwave Radiation (Thermopile, Case & Dome Temperatures)	1 Hz	1 min	0000-0001, 0001-0002…	1 min	FLEX
SSTC	1 per 10 min	Instant.	0000, 0010,…	10 min	Internal
GPS Positions	1 per 6hrs	Instant.	~0000, 0600, …	6 hrs	TFLEX

Table 3: Sampling parameters of the secondary sensors on PA011.

2.2 Data Return

Data returns are calculated from the highest-resolution data, comparing the number of records available to the total amount of records expected for the period. The following list shows the data returns from the surface and subsurface measurements from both acquisition systems.

Flex 0002:

```
Data Return Summary
2017-06-15 01:25:00 to 2018-07-29 16:15:00

Sensor      Deployed      Obs    Return
=======================================
AT1            58985    58846     99.8%
AT2            58985    58948     99.9%
RH1            58985    58846     99.8%
RH2            58985    58948     99.9%
WIND1          58985    33189     56.3%
BP1            58985    58948     99.9%
RAIN1         589850   585888     99.3%
SWR1          589850   585923     99.3%
LWR1          589850   585948     99.3%

Subsurface Temperature Profile
     1m        58985    57590     97.6% ** Started late
     1m(TFlex)58985     58985    100.0%
     5m        58985    58985    100.0%
    10m        58985    58985    100.0%
    14m        58985    58985    100.0%
    20m        58985        0      0.0% ** Flooded; RT present
    25m        58985    58985    100.0%
    30m        58985    58985    100.0%
    37m        58985    58985    100.0%
    45m        58985    58985    100.0%
    60m        58985    58985    100.0%
    80m        58985    58985    100.0%
   100m        58985    58985    100.0%
   120m        58985    58985    100.0%
   150m        58985    58985    100.0%
   175m        58985    58985    100.0%
   200m        58985    58985    100.0%
   300m        58985    58985    100.0%
  4165m        58985    58985    100.0%

Subsurface Pressure Profile
     5m        58985    58985    100.0%
   175m        58985    58985    100.0%
   300m        58985    58985    100.0%
  4165m        58985    58985    100.0%
```

Subsurface Salinity Profile

1m	58985	35429	60.1%	** Mid-deployment gap
1m(TFlex)	58985	58985	100.0%	
10m	58985	58985	100.0%	
14m	58985	58985	100.0%	
20m	58985	0	0.0%	** Flooded; RT present
25m	58985	58985	100.0%	
30m	58985	58985	100.0%	
37m	58985	58985	100.0%	
45m	58985	58985	100.0%	
60m	58985	58985	100.0%	
80m	58985	58985	100.0%	
100m	58985	58985	100.0%	
120m	58985	58985	100.0%	
150m	58985	58985	100.0%	
200m	58985	58985	100.0%	
4165m	58985	58985	100.0%	

AQD Current Velocity

15m	58985	58985	100.0%
35m	58985	58985	100.0%

TFlex 2001*:

Data Return Summary
2017-06-15 01:25:00 to 2018-07-29 16:15:00

Sensor	Deployed	Obs	Return
AT1	58985	58805	99.7%
RH1	58985	58805	99.7%
WIND1	58985	58805	99.7%
BP1	58985	58805	99.7%
RAIN1	589850	585429	99.3%
SWR1	589850	586348	99.4%
LWR1	589850	586921	99.5%

* TFlex had a gap of 1 day + 1:10:00 (data failed to write to RAM)

2.3 Known Sensor Issues

The inductive line used to obtain real-time data from subsurface instruments was intermittent throughout the deployment and deteriorated with time. On recovery, the cable that connects the underwater inductive cable to the FLEX faceplate had come free of its bridle clamp and has hanging with strain on the cable, potentially causing the poor inductive communication. Delayed-mode data were downloaded from subsurface instruments, recovering a majority of the records that were missing in real-time.

Surface meteorological delayed-mode data from the TFlex system had a 1-day gap from 8:00 UTC 9/25/2017 to 9:00 UTC 9/26/2017. The cause is unknown, and the flash card was re-dumped to confirm that no data was written to memory during this period.

The 20m SBE37 (S/N 12550) stopped reporting real-time data on February 4th, 2018 at 08:00 UTC. Upon recovery, the 15m Aquadopp was found to have slid down to rest on the 20m sensor (occurred 1/5/2018 at 2:50 UTC, having settled by 3:00 UTC). The 20m conductivity shield's pump tube was broken off, and all housing screws were missing. The instrument body was twisted 90°, causing catastrophic flooding and circuit board damage. No repair or data recovery was possible, so the 20m realtime data is distributed as the best available data at that depth. The quality of the Aquadopp data was reduced after it slid down the wire, to indicate the change from its nominal position.

Incorrect setup of the Flex SSTC instrument resulted in the instrument starting 10 days into the deployment. This was unknown during deployment, as a constant, seasonal value was being transmitted, and the error was not discovered until noticed at PMEL. The Flex SSTC (S/N 7090) also reported unrealistically low values from October 2017 through March 2018, when conductivity and salinity noise increased and values frequently approached 0. The data temporarily flatten at around 1.5 S/m (15 PSU) by mid-March, and proceed to recover by the end of March. Air bubbles in the conductivity cell could be responsible (the air-bleed holes of near-surface SBEs can be clogged by biofouling), and the regions of bad data were flagged Q5.

The Flex and Hygroclip RH both failed their post-calibration procedures and were flagged as lower quality (Q4). The hygroclip is considered a test sensor, and data are not distributed. Both time-series drifted relative to the TFlex RH, which passed its post-calibration and was distributed as primary. Rare RH outliers were flagged Q5.

A mean offset of 0.4 mb was noted between the barometric pressure sensors, with the TFlex instrument reporting higher values. The Paros sensor attached to the Flex system is considered a superior sensor and was primary. Details of testing, calibrations, and data comparisons appear in the barometric pressure section of this report.

The Flex wind sensor failed its compass post-calibration. Along with other minor issues described in the wind section below, manual flagging was required, and the TFlex winds were considered primary.

3.0 Data Processing

Processing of data from OCS moorings is performed with the assistance of the PMEL Global Tropical Moored Buoy Array (GTMBA) project group. There are some differences between OCS data and data from GTMBA moorings, but standard methods described below are applied whenever possible. The process includes assignment of quality flags for each observation, which are described in Appendix A. Any issues or deviations from standard methods are noted in processing logs, and in this report.

Raw data recovered from the internal memory of the data acquisition system are first processed using computer programs. Instrumentation recovered in working condition is returned to PMEL for post-recovery calibration before being reused on future deployments. These post-recovery calibration coefficients are compared to the pre-deployment coefficients. If the comparison indicates a drift larger than the expected instrumental accuracy, the quality flag is lowered for the measurement. If post-recovery calibrations indicate that sensor drift was within expected limits, the quality flag is raised. Post-recovery calibrations are not generally applied to the data, except for seawater salinity, or as otherwise noted in this report. Failed post-recovery calibrations are noted, along with mode of failure, and quality flags are left unchanged to indicate that pre-deployment calibrations were applied and sensor drift was not estimated.

The automated programs also search for missing data, and perform gross error checks for data that fall outside physically realistic ranges. A computer log of potential data problems is automatically generated as a result of these procedures.

Time series plots, difference plots, and comparison plots are generated for all data. Plots of differences between adjacent subsurface temperature measurements are also generated. Statistics, including the mean, median, standard deviation, variance, minimum and maximum are calculated for each time series.

Trained analysts examine individual time series and statistical summaries. Data that have passed gross error checks, but which are unusual relative to neighboring data in the time series, or which are statistical outliers, are examined on a case-by-case basis. Mooring deployment and recovery logs are searched for corroborating information such as battery failures, vandalism, damaged sensors, or incorrect clocks. Consistency with other variables is also checked. Data points that are ultimately judged to be erroneous are flagged, and in some cases, values are replaced with “out of range” markers. For a full description of quality flags, refer to Appendix A.

For some variables, additional post-processing after recovery is required to ensure maximum quality. These variable-specific procedures are described below.

3.1 Buoy Positions

Since Papa is a taut-line mooring with a short scope, the buoy has a watch circle radius of 1.25km. When using Papa data in scientific analyses, the nominal position is usually adequate. For users wanting additional accuracy, the more accurate positions from the GPS are also provided at their native resolution. Gross error checking was performed to eliminate values outside the watch circle, but no further processing was performed.

At Papa, the acquired positions were used to determine buoy velocities. These velocities are not applied, but are provided alongside the current meter data at hourly and higher resolutions.

3.2 Meteorological Data

All primary meteorological sensors on PA011 remained functional at or near 100% throughout the deployment.

No data from secondary sensors are included in the final data files, except when included in OceanSITES files as secondary data. The OceanSITES data repository can be found here: https://dods.ndbc.noaa.gov/thredds/catalog/oceansites/DATA/PAPA/catalog.html

The PA011 buoy had secondary air temperature, relative humidity, wind, rain, air pressure, and radiation sensors. A Rotronic HygroClip measuring air temperature and relative humidity provided the mooring's only tertiary data, which were not distributed in any format.

3.2.1 Winds

A combination of noise, intermittent delayed-mode and real-time data, and offsets between sensors brought the Flex wind data quality into question. Flex wind speed data averaged 0.41 m/s higher than the TFlex wind speeds. The latter half of the real-time data frequently missed the 240th sample within each 2-minute sampling interval, and reported gust as 0 m/s (Figure 6). The Flex wind compass check failed its post-calibration with a maximum 6.7 degree error at 300 degrees, so the delayed-mode data quality was downgraded to Q4. Additionally, the delayed-mode Flex data became highly intermittent in February 2018, as shown in the secondary wind plot in appendix C.

A gross error check of wind speed (agreement to within 5 m/s of the other sensor) resulted in several Q5 flags in the Flex record prior to the period of intermittent data. On both systems, a few instances where speed exceeded the recorded gust value required Q5 flags, as this indicates that at least one measurement was incorrect.

A few Q5 flags were needed in the TFlex winds, where unrealistically high speeds and gusts occurred out of context (absent a storm) and were not confirmed by the secondary sensor. An example of one prominent outlier can be seen early in the raw gust record in the lowest panel of Figure 6. Aside from these few flags, the TFlex wind record was more complete and was considered primary.

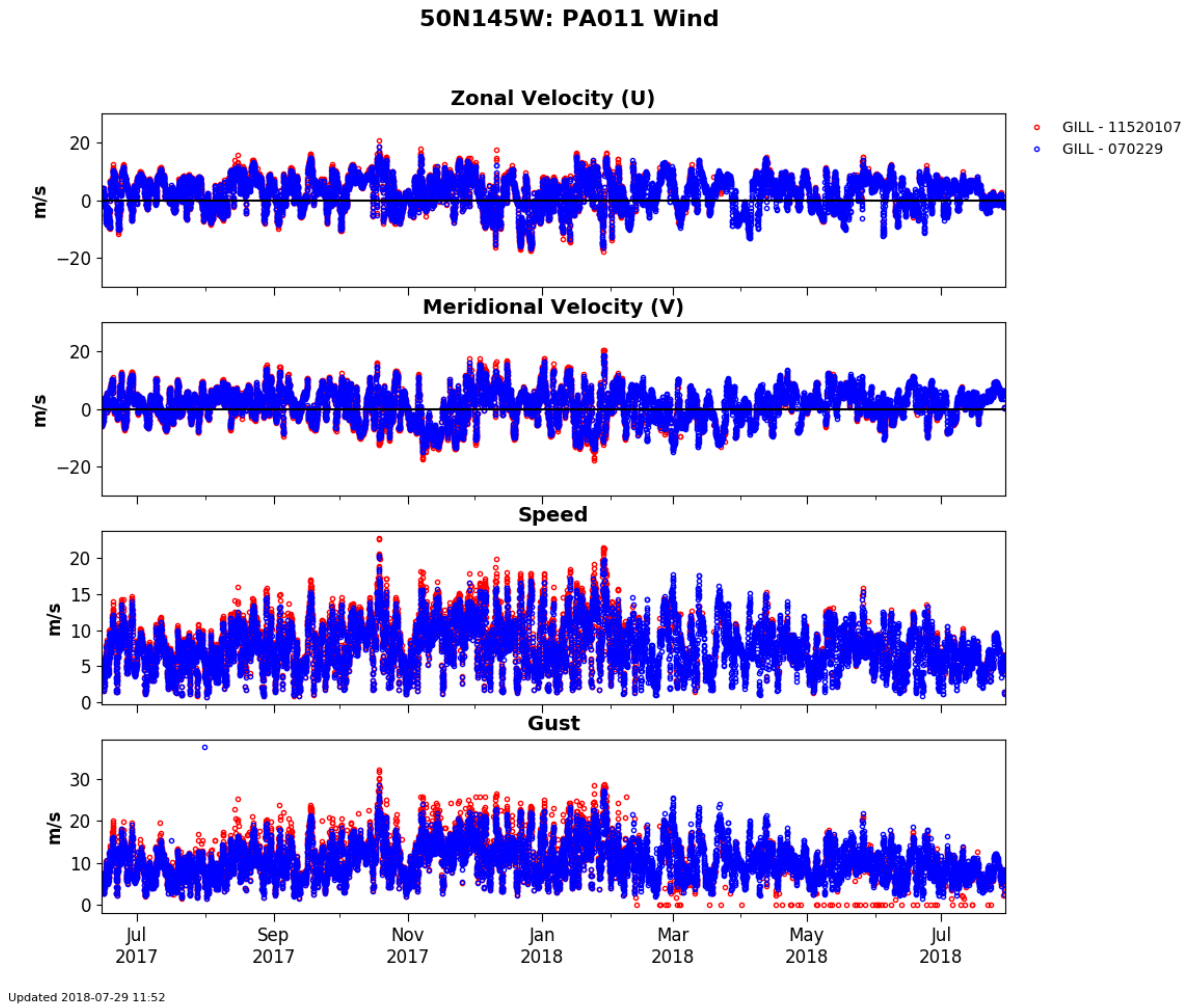

Figure 6: PA011 realtime (raw) winds, showing poor performance by the Flex Gill.

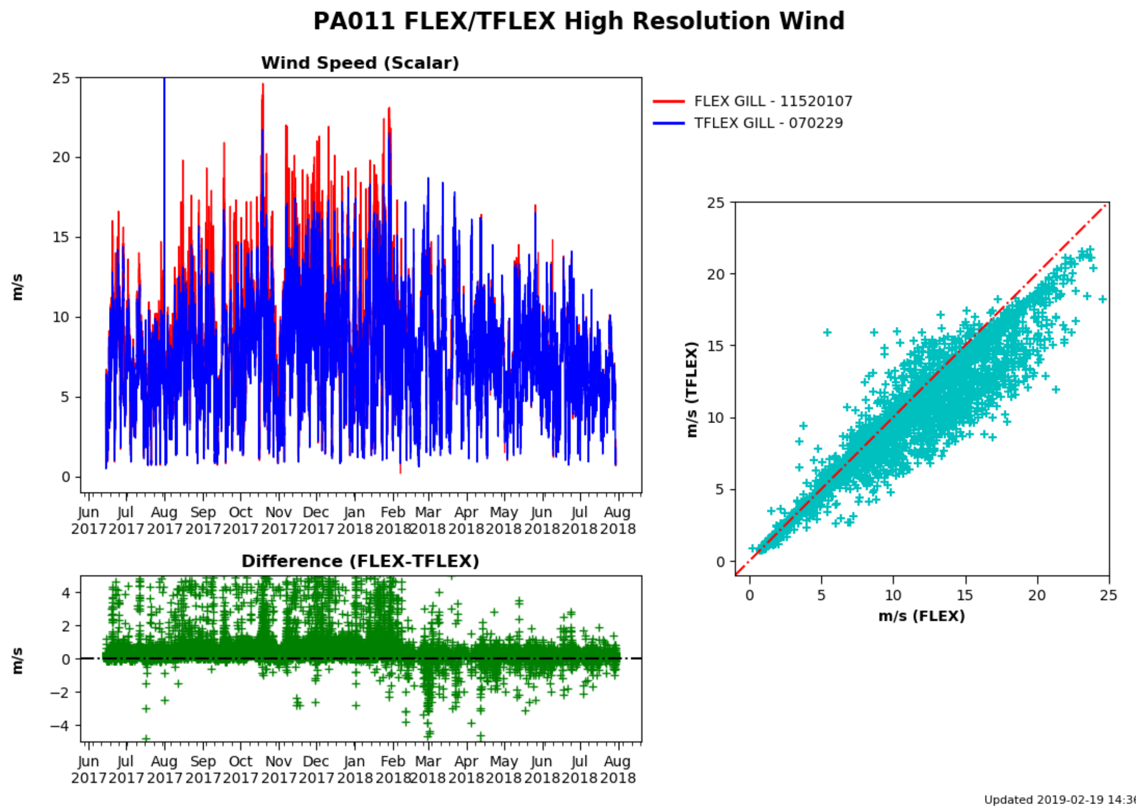

Figure 7: PA011 delayed-mode wind speed (before QC application), highlighting the Flex sensor bias.

3.2.2 Air Temperature

The TFlex air temperature sensor was selected as primary due to the Flex relative humidity calibration failing its post-calibration. The air temperature sensors otherwise performed well during throughout this deployment.

3.2.3 Relative Humidity

The only relative humidity sensor to pass post-calibration procedures was the TFlex RH, which was distributed as the primary sensor. The other sensors were flagged Q4 due to failed calibrations, drift (see difference plot in Figure 9), and more frequent saturation seen in the Flex sensor. Typically, values over 100% are allowed, as the sensors are calibrated for maximum accuracy in the 45-95% RH range. In this deployment, all RH remained below 100% aside from a few spikes shown in the raw data of Figures 8 and 9. The spikes are removed with Q5 flagging in post-processing, and do not appear in the final product. It is possible that water temporarily saturated the sensor at these times, causing unrealistic measurements.

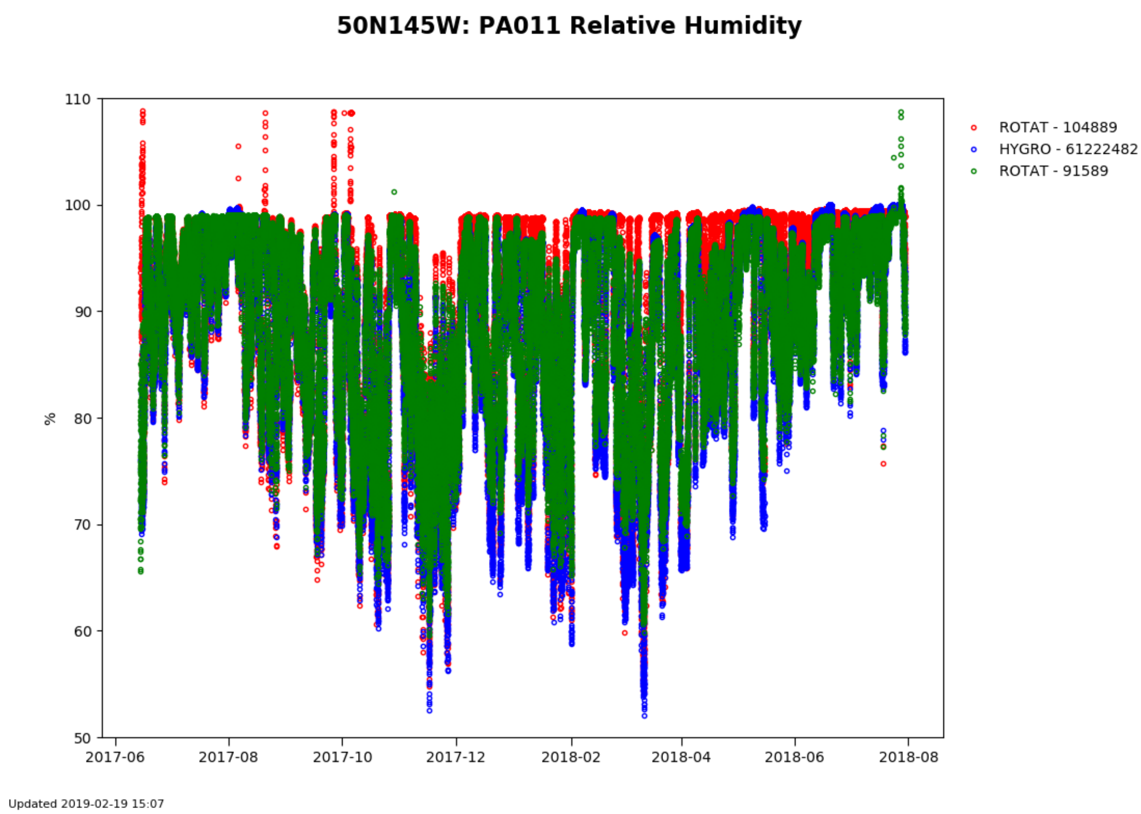

Figure 8: PA011 relative humidity (before post-processing QC).

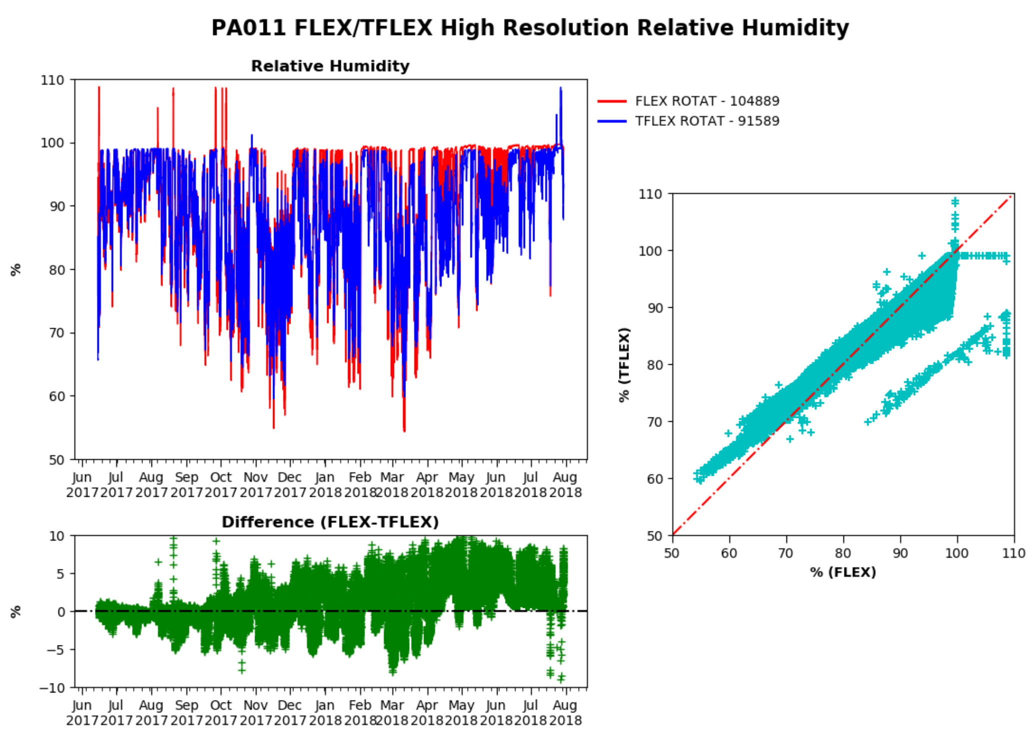

Figure 9: PA011 relative humidity and difference plot (before post-processing QC).

3.2.4 Barometric Pressure

A mean 0.4mb offset between the Flex and TFlex barometer was observed in the real-time and delayed-mode data. Calibration coefficients were revisited, and the TFlex barometric pressure data were corrected in post-processing. Continuity with adjacent deployments and testing at PMEL suggested the Flex instrument had better data quality.

Post-recovery testing at PMEL revealed that the TFlex BP sensor averaged 0.357 mb higher than the standard (reference) Paros, and the Flex BP averaged 0.082 mb lower than the standard Paros. With biases on opposite sides of the reference instrument, the cumulative bias was near the 0.4 mb offset seen in the field.

Pre-deployment testing had shown the Flex BP averaged 0.062 mb below the standard Paros, similar to the equivalent post-recovery test mentioned (0.082 mb lower than the standard). Both were considered acceptable, being within the 0.1 mb calibration threshold, so the Flex Paros BP was primary and assigned standard Q2 quality flags. Pre-deployment testing had shown the TFlex BP as slightly high (0.173mb RMSE) compared to the Flex BP, but when pre-deployment calibration coefficients were applied to the TFlex BP data, the RMSE between the two instruments fell to an acceptable 0.045mb. Either the range of pressures observed in testing was not adequate to produce a good fit for field conditions, or the TFlex failed to apply the initial calibration internally. By instead applying the post-calibration coefficients to the TFlex BP data and flagging Q3 (adjusted) throughout, the two BP time series were brought to within specifications (Figure 10).

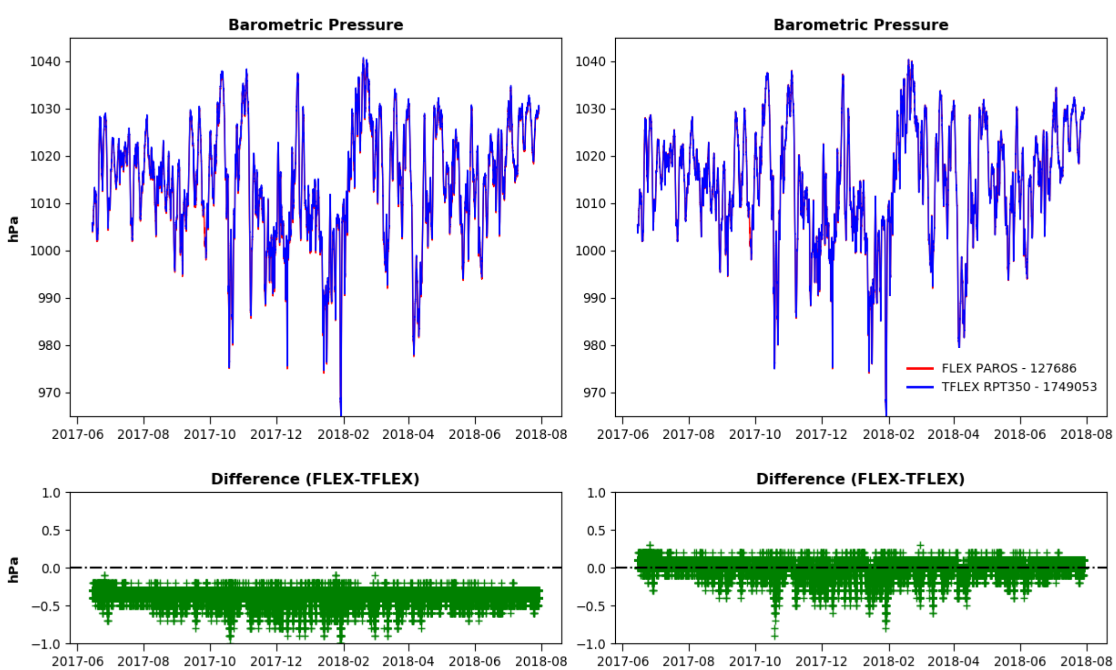

Figure 10: Flex and TFlex barometric pressure data. The application of pre-deployment calibration coefficients to the TFlex BP (left) resulted in a 0.4 mb offset, while the application of post-recovery calibration coefficients to the TFlex BP (right) brought the sensors within specifications.

3.2.5 Rain

Rain data are acquired as accumulation values, and then converted to rain rates during processing. Rainfall data are collected using a RM Young rain gauge, and recorded internally at a 1-min sample rate. The gauge consists of a 500mL catchment cylinder which, when full, empties automatically via a siphon tube. Data from a three-minute period centered near siphon events are ignored. Occasional random spikes in the accumulation data, which typically occur during periods of rapid rain accumulation, or immediately preceding or following siphon events, are eliminated manually.

To reduce instrumental noise, internally recorded 1-minute rain accumulation values are smoothed with a 16-minute Hanning filter upon recovery. These smoothed data are then differenced at 10-minute intervals and converted to rain rates in mm/hr. The resultant rain rate values are centered at times coincident with other 10-minute data (0000, 0010, 0020...).

Residual noise in the filtered data may include occasional false negative rain rates, but these rarely exceed a few mm/hr. No wind correction is applied, as this is expected to be done by the user. The wind effect can be large. According to the Serra, et al. (2001) correction scheme, at wind speeds of 5 m/s the rain rates should be multiplied by a factor of 1.09, while at wind speeds of 10 m/s, the factor is 1.3. As winds are high at Papa, the user is strongly encouraged to apply an appropriate wind correction.

Rain data processing uses scripts to detect siphons and other events. The TFlex rain gauge accumulations were noisier than usual, requiring occasional interpolation, adjustments, and flagging near siphons to extract true rain rates. The noise may be electronic in nature, as spikes in accumulation occurred semi-regularly at HH:M6:32.

3.2.6 Shortwave Radiation

Kelly Balmes established the selection criteria for primary and secondary radiation sensors. Mean daily Flex and TFlex SWR values were compared, and found to differ by 1.8%. When the difference is over 1%, the higher of the two instruments is considered primary, since lower values could indicate a bent radiation mast. If the difference is less than 1%, the sensor that maximizes the available data is primary, and if all else is equal, the Flex system is primary. Based on these criteria, the PA011 TFlex SWR was made primary.

3.2.7 Longwave Radiation

The downwelling longwave radiation is computed from thermopile voltage, dome temperature, and instrument case temperature measurements, using the method described by Fairall et al. (1998). Lower longwave radiation values are associated with clearer, colder skies, whereas larger values are associated with more water in the air column (e.g. cloudy, humid conditions).

The primary longwave sensor is chosen to be consistent with the SWR decision, unless the data are unavailable. This is based on the fact that SWR and LWR are on the same mast and mast tilt is determined by the SWR decision. Using the same acquisition system also keeps the high-resolution radiation data on the same time base. Although LWR is less sensitive to orientation, a bent mast could impact the data. Based on these criteria, the PA011 TFlex LWR was primary.

LWR and SWR measurements were occasionally interrupted by real-time transmissions. At around 6 hour intervals, a single minute of radiation data typically came back as a missing value in the delayed-mode data. The firmware issue has been observed before, and has negligible impacts on data return.

A few Flex LWR points that passed gross error checking were flagged as seasonal outliers, confirmed by their large differences when compared to the data from the more seasonally consistent records from the TFlex sensor. The Flex LWR had a slightly higher spread (higher highs + lower lows) than the TFlex LWR, but the mean difference between the two time-series was less than 1 W/m^2.

3.3 Subsurface Data

All OCS subsurface instrumentation was connected inductively to the Flex system, except for the instrument attached to the acoustic release. General comments and clock errors from each recovered subsurface instrument are summarized in a snapshot of the FileMaker log (Figure 11). Positive clock errors were most common, meaning the instrument drifted ahead of the actual time. Measurements were mapped to the nearest 10-minute time increment where drift occurred (notably, in S/N 6073).

Clock Errors Are the clock dates all okay? (type yes/no or comment):

	Sensor Type	S/N	Actual Time (GMT)	Instr. Time	Clock Error	File Name	Bat. Voltage from Status	Comments	# of Records
0	SBE37-	7090	1:52:25	1:52:38	0:00:13		6.89		
1	SBE37-	7089	1:58:05	1:58:53	0:00:48		6.63		
2	MapCO2	146							
3	SBE16	6618							
4	ECO	4133							
5	Andera	4175/487							
6	GTD	22018-							
7	SAMI	p0032							
8	Sentinel		19:56:25	19:52:55	-0:03:30				
9	SBE39-	4380	19:15:00	19:16:34	0:01:34				
10	SBE37-	6075	1:33:25	1:33:50	0:00:25		6.65		
11	SBE37-	13248	1:27:15	1:27:09	-0:00:06		13.96		
12	Aquadop	13499							
13	SBE37-	12550	N/A	N/A	?			Water Damage	
14	SBE37-	8419	1:21:35	1:22:02	0:00:27		6.70		
15	SBE37-	8420	1:16:40	1:17:28	0:00:48		6.63		
16	Aquadop	9819							
17	SBE37-	6140	1:09:35	1:10:23	0:00:48		6.56		
18	SBE37-	8422	1:02:15	1:02:44	0:00:29		6.68		
19	SBE37-	8423	00:54:45	00:55:18	0:00:33		6.67		
20	SBE37-	8424	23:46:50	23:47:40	0:00:50		6.72		
21	SBE37-	6072	23:30:35	23:31:05	0:00:30		6.86		
22	SBE37-	6073	20:41:00	20:24:27	-0:16:33		6.69		
23	SBE37-	6074	20:29:00	20:29:21	0:00:21		6.66		
24	SBE39-	4863	19:23:10	19:24:08	0:00:58				
25	SBE37-	7788	20:17:10	20:18:04	0:00:54		6.71		
26	SBE39-	4864	19:36:40	19:37:50	0:01:10				
27	SBE37-	10503	18:41:35	18:41:35	0:00:00		6.92		
28									
29	Aquadop	13314							
30									
31									
32									
33									
34									
35									

Figure 11: Filemaker log displaying all instrument clock errors.

3.3.1 Temperature

High-resolution temperatures are provided at the original 10-minute sampling increment of the Seabird sensors, as well as at hourly and daily resolutions. Temperatures are rarely corrected based on post-calibrations, and there was no evidence of drifting temperature measurements.

3.3.2 Pressure

Since this was a taut mooring, the sensors can be assumed to have been recording measurements at their nominal depths. Pressure measurements were recorded by three subsurface instruments. In processing for salinity, actual pressures were used where available, and nominal pressures were used elsewhere, including where an instrument's pressure sensor failed. In the case of complete instrument failure, where no temperature or conductivity data exists, nominal pressures were truncated to the time of failure.

3.3.3 Salinity

Salinity values were calculated from measured conductivity and temperature data using the method of Fofonoff and Millard (1983). Conductivity values from all depths were adjusted for sensor calibration drift by linearly interpolating over time between values calculated from the pre-deployment calibration coefficients and those derived from the post-deployment calibration coefficients. Salinities were calculated from both the pre and post conductivity values, to determine the drift in the salinity measurement.

The pre-deployment calibration coefficients were given a weight of one at the beginning of the deployment, and zero at the end, while the post-recovery calibration coefficients were weighted zero at the start of the deployment, and one at the end.

Salinity Drifts in PSU (post-pre):

Depth:	**Drift:**
1m (TFlex)	-0.0190
1m (Flex)	-0.0189
10m	-0.0078
14m	0.0051
20m	N/A *
25m	-0.0127
30m	-0.0093
37m	-0.0089
45m	-0.0095
60m	-0.0055
80m	-0.0074
100m	-0.0062
120m	-0.0046
150m	-0.0032
200m	-0.0052

* 20m SBE flooded; no post-calibration; real-time, pre-calibration data distributed.

The values above indicate the change in calculated salinity data values when post-recovery calibrations were applied to the conductivity measurements, versus when pre-deployment calibrations were applied. Negative differences suggest that the instrument drifted towards higher values while deployed, and indicate expansion of the conductivity cell effective cross-sectional area. This expansion is possibly due to scouring of the cell wall by abrasive material in the seawater. Positive values indicate decrease in the cell effective cross-sectional area, presumably due to fouling within the cell, and secondarily due to fouling or loss of material on the cell electrodes.

A thirteen-point Hanning filter was applied to the high-resolution (ten-minute interval) conductivity and temperature data. A filtered value was calculated at any point for which seven of the thirteen input points were available. The missing points were handled by dropping their weights from the calculation, rather than by adjusting the length of the filter. Salinity values were then recalculated from the filtered data.

CTD casts from the regular visits to station Papa (R/V TULLY), as well as casts taken after deployment and before recovery, indicated no need for data adjustments.

Manual Salinity Adjustments

The drift-corrected salinities were checked for continuity across deployments. Instrument ranges and magnitudes of variation matched well with prior and subsequent deployments. The instrument accuracy specifications were not strictly applied for this comparison, since Papa deployments are miles apart, and spatial differences can exceed instrument specifications (e.g. temperature accuracy is ±0.002°C–0.003°C, depending on instrument).

Typically, additional linear corrections are applied to the salinity data in time segments. These *in situ* calibration procedures are described by Freitag et al. (1999), but were not required for this deployment, based on the density intercomparisons between depths.

3.3.4 Deep SBE Data

Since 2012, an SBE37SM-TCP has been mounted on the acoustic release near the anchor. Several years of data are available at the time of this report.

At Papa, deep ocean measurements presented challenges, including calibration variability and small discontinuities between deployments. Calibration variability is the difference between data with pre-deployment calibrations applied and data with post-recovery calibrations applied. While calibration variability can indicate linear drift, interpolating between calibrations can also result in a false slope when the signal is small. Calibration variability was reduced by averaging conductivity and temperature calibrations. Many years of data were examined for continuity, to reduce the possibility of obscuring real changes captured by calibration differences.

Temperature and pressure, along with calibration-averaged conductivity, are used to calculate potential temperature (**θ**) and density (**ρ**) adjusted to the nearest 1000 dbar-reference pressure, which is 4000 dbar at Papa. Salinity is also calculated from these values, using the methods of Fofonoff and Millard, 1983. A standard 13-point Hanning filter was used to generate hourly data, and a boxcar filter created the daily averages.

3.3.5 Currents

The Nortek Aquadopp measures the speed of sound, and internally applies sound velocity corrections to current measurements. During post processing, a correction for magnetic declination (+16 degrees for this deployment) is applied, and data are smoothed to hourly resolution using a thirteen-point Hanning filter.

Since PA011 was a taut-line mooring, Aquadopp current meter data were not corrected for the buoy's negligible horizontal movement. However, buoy motions are provided alongside Aquadopp data for users wanting to add buoy motion to measured velocities. Quality flags of Q4 were assigned to the 15m Aquadopp when it slid down to rest on the 20m sensor, starting 1/5/2018 at 2:50 UTC.

An upward-looking Aquadopp Profiler was deployed at 68m for the first time on the PA011 mooring. To process the data, 3 corrections were applied: declination, tilt correction, and head depth adjustment. Aquadopps do not have an internal setting for declination, so this correction to true heading is applied in post-processing. Tilt correction, also called "bin-mapping," is then computed using a conversion between Earth and Beam coordinates, taking samples along each beam where it most nearly pierces defined horizontal slices of the water column. Tilts over 20 degrees are eliminated (Q5), as the manufacturer considers data beyond this threshold unusable. A head depth adjustment is needed for the profiler, as its vertical position varies slightly, unlike the downward-looking Sentinel ADCP. The data are then regridded onto Earth-relative depths using linear interpolation. Buoy-motion, which can be optionally added to U/V currents, is provided in the NetCDF file.

From PA011 forward (from 2017), the Aquadopp profiler will be distributed as the primary ADCP, replacing the Sentinel ADCP, which saw interference as its beams swept across instruments on the mooring line. The profiler's highest resolution was hourly on PA011 and PA012, but will be set to 30-minutes from PA013 onward. The utility of the profiler as a replacement for the Sentinel ADCP was still being assessed on PA011, so the profiler was set to perform its 2-minute burst sample 5 minutes before the hour, to avoid interference with the Sentinel. Interpolation was performed to center the data and corresponding timestamps on the hourly grid.

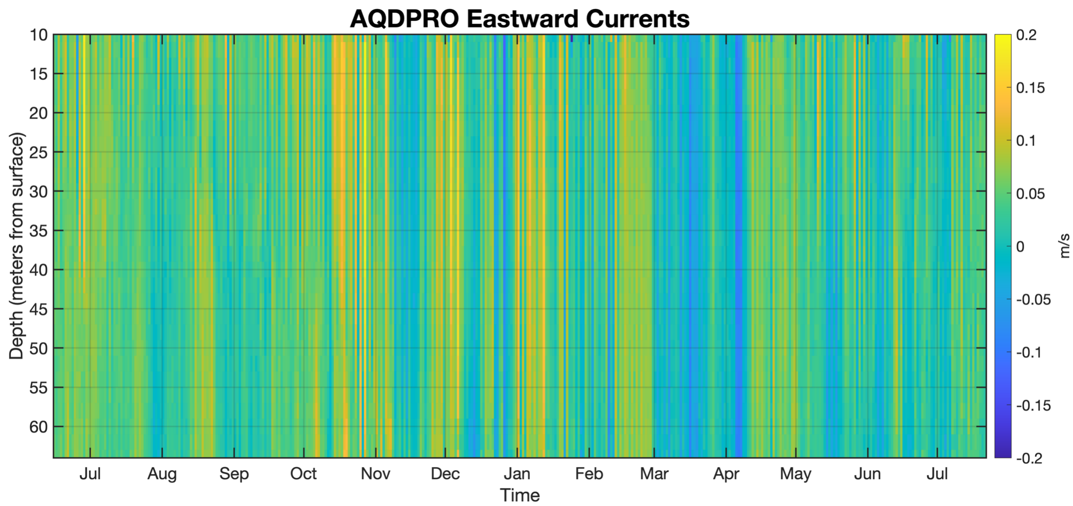

Figure 12: Aquadopp Profiler eastward velocities.

3.3.6 Acoustic Doppler Current Profiler (ADCP)

A downward looking Sentinel ADCP was deployed on PA011. Data were processed using established scripts that combine autonomous flagging with manual quality control. The ADCP collects various performance metrics that can be used to quality control recovered data. Standard thresholds are applied to echo amplitude ranges, percent good 3+ beam solutions, and error velocities. A clock check and orientation check are performed prior to releasing data.

The ADCP was set with a heading bias of +17. This will be changed on future deployments to match the time-variant declination correction. The magnetic declination at Papa changes slowly, currently at a rate of roughly 1 degree every 5 years.

Plots are used to visualize echo amplitudes and three-dimensional velocities collected from the four ADCP beams. Shear between bins is also examined to help detect bias.

Despite a 20 degree beam angle, all four ADCP beams appear to interact with other subsurface instruments. Data inspection confirms that echo amplitudes increase and velocities are biased toward zero when the beams encounter the solid, stationary instruments on the mooring line. Manual flagging was performed to flag the bins that experience consistent contamination. Engineering solutions to beam interference are being examined. While the ADCP is too heavy to mount on the line, a lighter, upward-looking Aquadopp profiler was deployed for the first time on PA011. This configuration appears to reduce interference. The downward-looking ADCP is cantilevered off the bridle, and pitches with the buoy, sweeping all beams across the mooring line with time.

The Sentinel ADCP will be considered secondary to the Aquadopp profiler from this deployment forward. The profiler, affixed to the mooring line, does not swing its beams across the mooring line, avoiding interference.

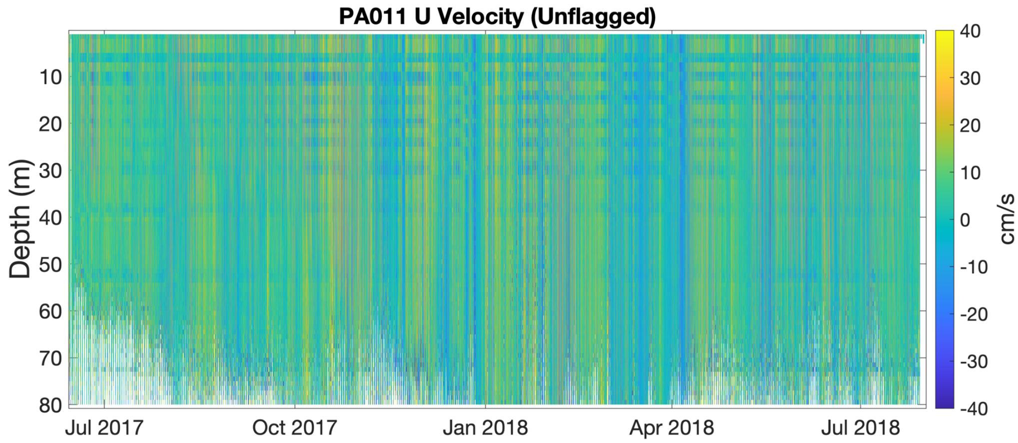

Figure 13: ADCP eastward velocities with autonomous flagging thresholds applied by the ADCP, but before manual flagging. All beams are affected by instruments on the line.

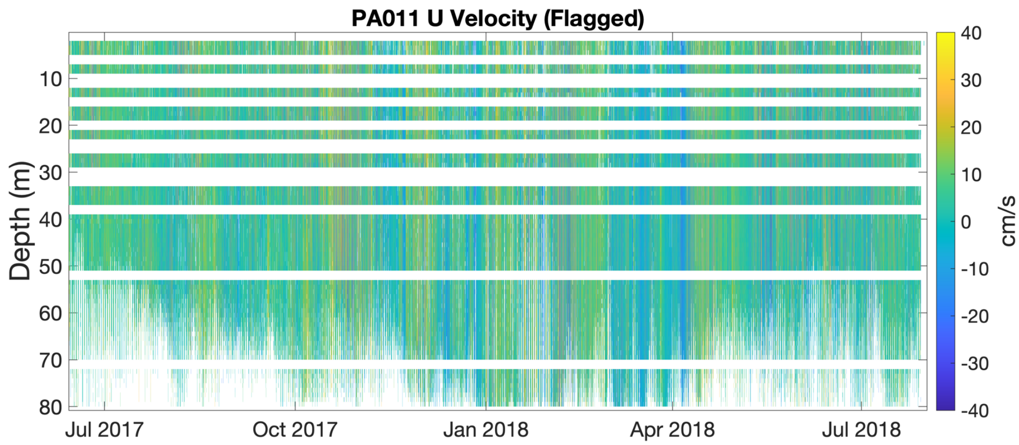

Figure 14: ADCP eastward velocities with manual flagging thresholds and bin-flagging applied, in addition to the autonomous flagging thresholds applied by the ADCP.

4.0 References

Freitag, H.P., M.E. McCarty, C. Nosse, R. Lukas, M.J. McPhaden, and M.F. Cronin, 1999: COARE Seacat data: Calibrations and quality control procedures. NOAA Tech. Memo. ERL PMEL-115, 89 pp.

Fairall, C.W., P.O.G. Persson, E.F. Bradley, R.E. Payne, and S.P. Anderson, 1998: A new look at calibration and use of Eppley Precision Infrared Radiometers. Part I: Theory and Application. J. Atmos. Ocean. Tech., 15, 1229-1242.

Fofonoff, P., and R. C. Millard Jr., 1983: Algorithms for computation of fundamental properties of seawater, Tech. Pap. Mar. Sci., 44, 53 pp., Unesco, Paris.

Serra, Y.L., P.A'Hearn, H.P. Freitag, and M.J. McPhaden, 2001: ATLAS self-siphoning rain gauge error estimates. J. Atmos. Ocean. Tech., 18, 1989-2002.

5.0 Acknowledgements

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6.0 Contact Information

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APPENDIX A: Description of Data Quality Flags

Instrumentation recovered in working condition is returned to PMEL for post-recovery calibration before being reused on future deployments. The resultant calibration coefficients are compared to the pre-deployment coefficients, and measurements are assigned quality indices based on drift, using the following criteria:

Q0 - No Sensor, or Datum Missing.

Q1 - Highest Quality. Pre/post-deployment calibrations agree to within sensor specifications. In most cases, only pre-deployment calibrations have been applied.

Q2 - Default Quality. Pre-deployment calibrations only or post-recovery calibrations only applied. Default value for sensors presently deployed and for sensors which were not recovered or not calibratable when recovered, or for which pre-deployment calibrations have been determined to be invalid.

Q3 - Adjusted Data. Pre/post calibrations differ, or original data do not agree with other data sources (e.g., other in situ data or climatology), or original data are noisy. Data have been adjusted in an attempt to reduce the error.

Q4 - Lower Quality. Pre/post calibrations differ, or data do not agree with other data sources (e.g., other in situ data or climatology), or data are noisy. Data could not be confidently adjusted to correct for error.

Q5 - Sensor, Instrument or Data System Failed.

For data provided in OceanSITES v1.2 (or v1.3) format, the standard GTMBA quality flags described above are mapped to the different OceanSITES quality flags shown below:

Q0 -	No QC Performed.	
Q1 -	Good Data.	(GTMBA Q1, Q2)
Q2 -	Probably Good Data.	(GTMBA Q3, Q4)
Q3 -	Bad Data that are Potentially Correctable.	
Q4 -	Bad Data.	(GTMBA Q5)
Q5 -	Value Changed.	
Q6 -	Not Used.	
Q7 -	Nominal Value.	
Q8 -	Interpolated Value.	
Q9 -	Missing Value.	(GTMBA Q0)

APPENDIX B: Primary Instrument High Resolution Data Plots

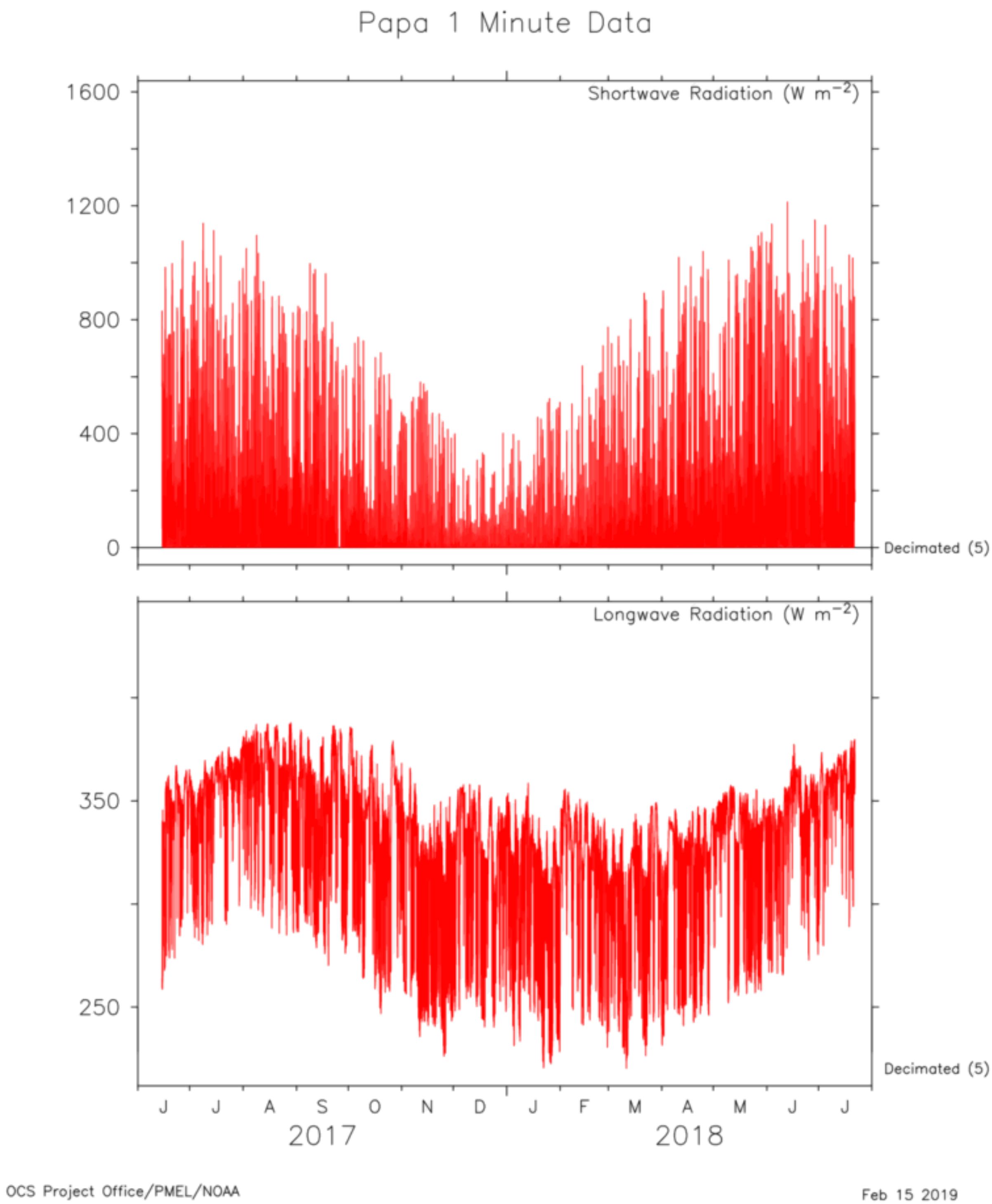

Figure B 1: PA011 primary shortwave and longwave radiation data at 1-min resolution (TFlex).

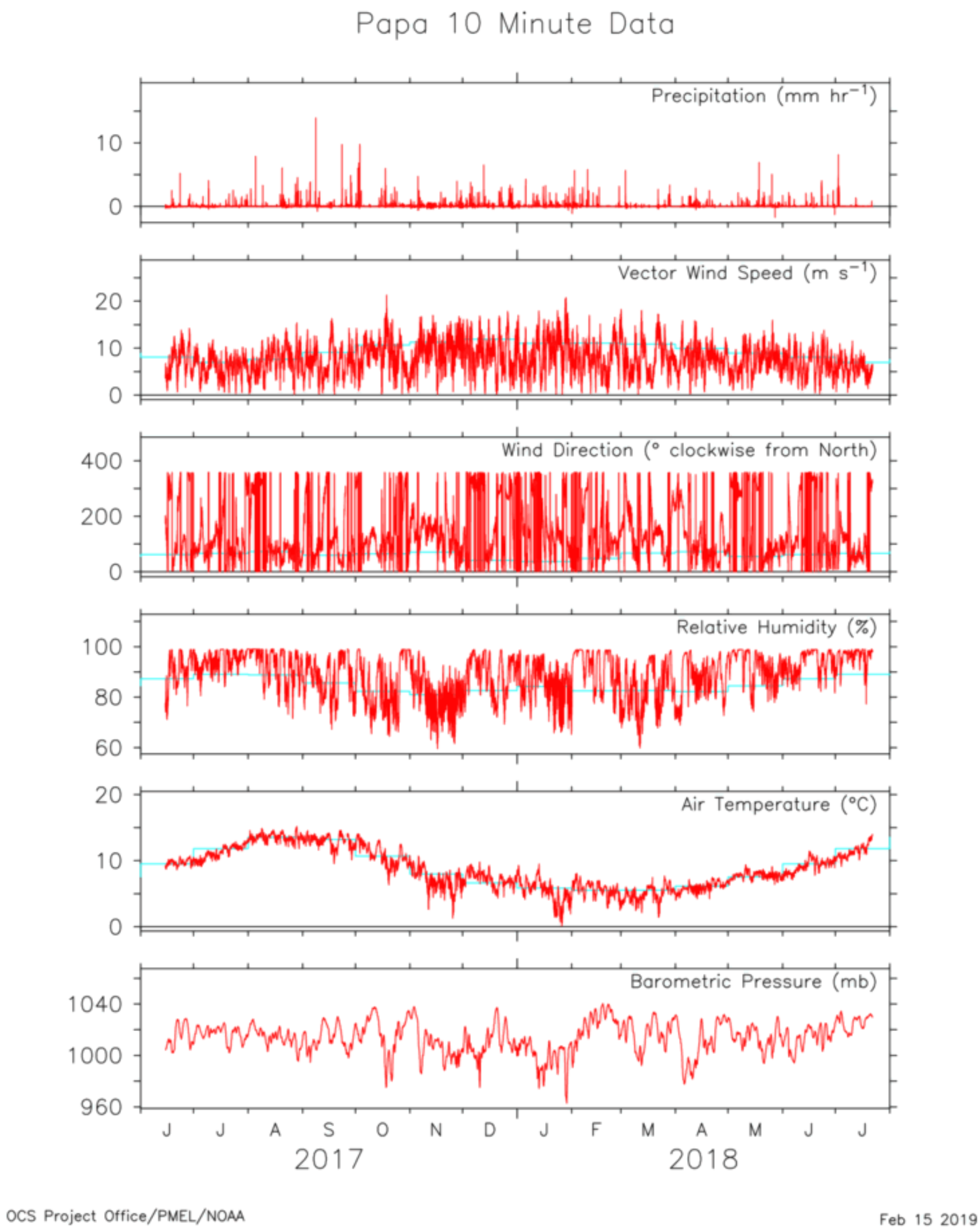

Figure B 2: PA011 meteorological data at 10-min resolution. Rain and BP are from the Flex system, and winds, AT, and RH are from the TFlex. While Flex is usually primary, a failed Flex RH post-calibration and a failed Flex compass post-calibration resulted in inferior wind and ATRH data quality compared to the TFlex.

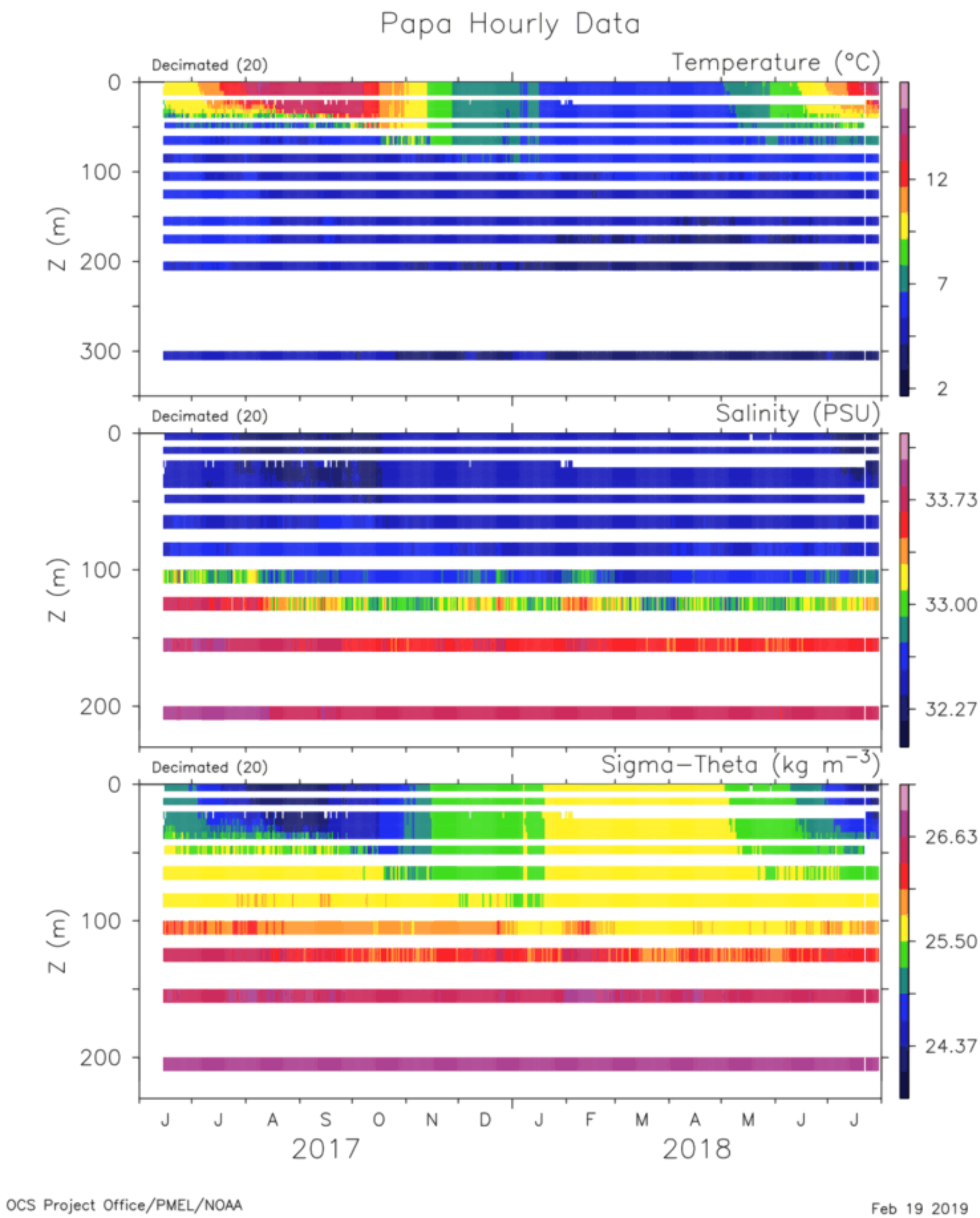

Figure B 3: PA011 subsurface temperature, salinity, and density at hourly resolution (decimated).

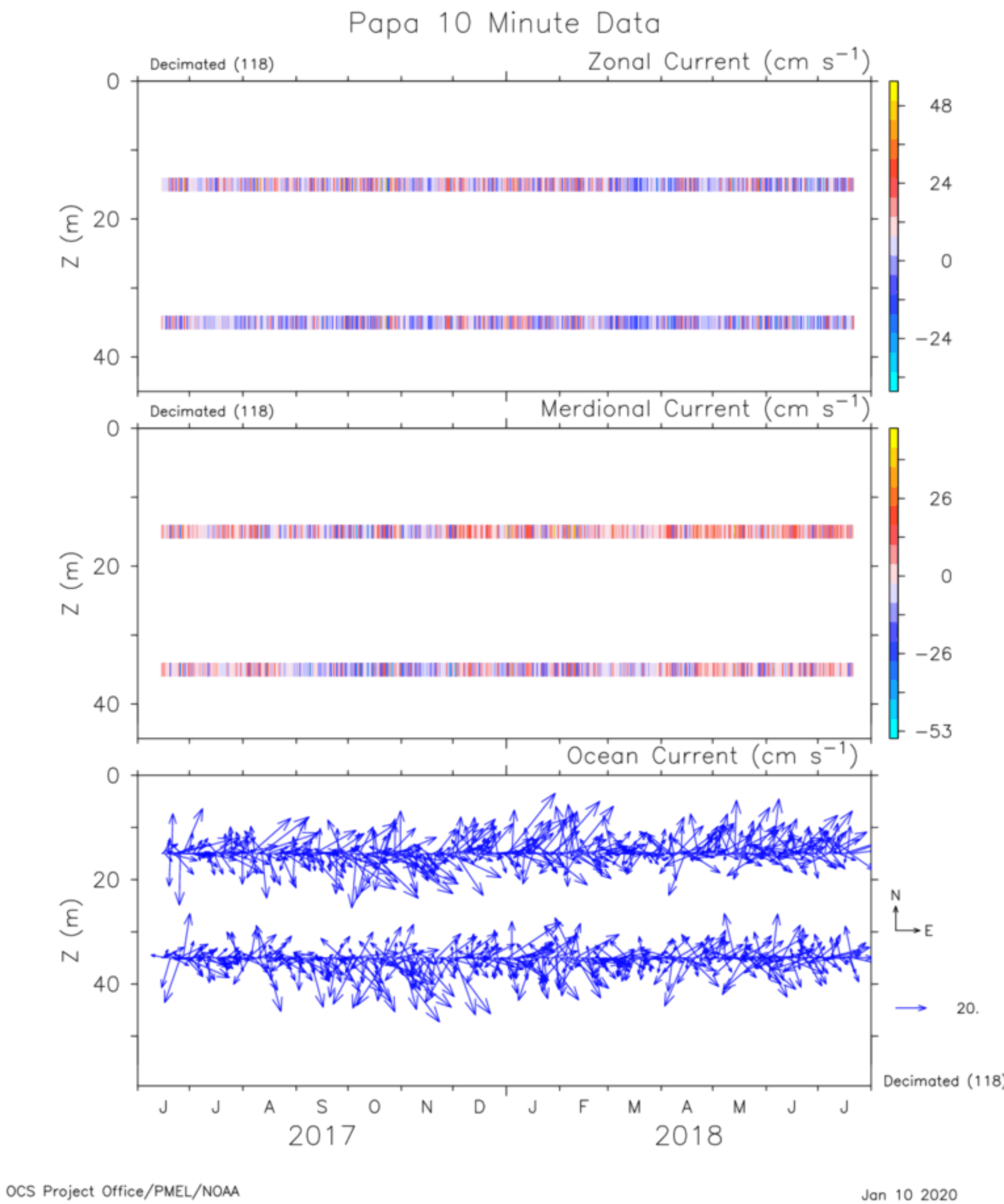

Figure B 4: Zonal and meridional current meter data from PA011.

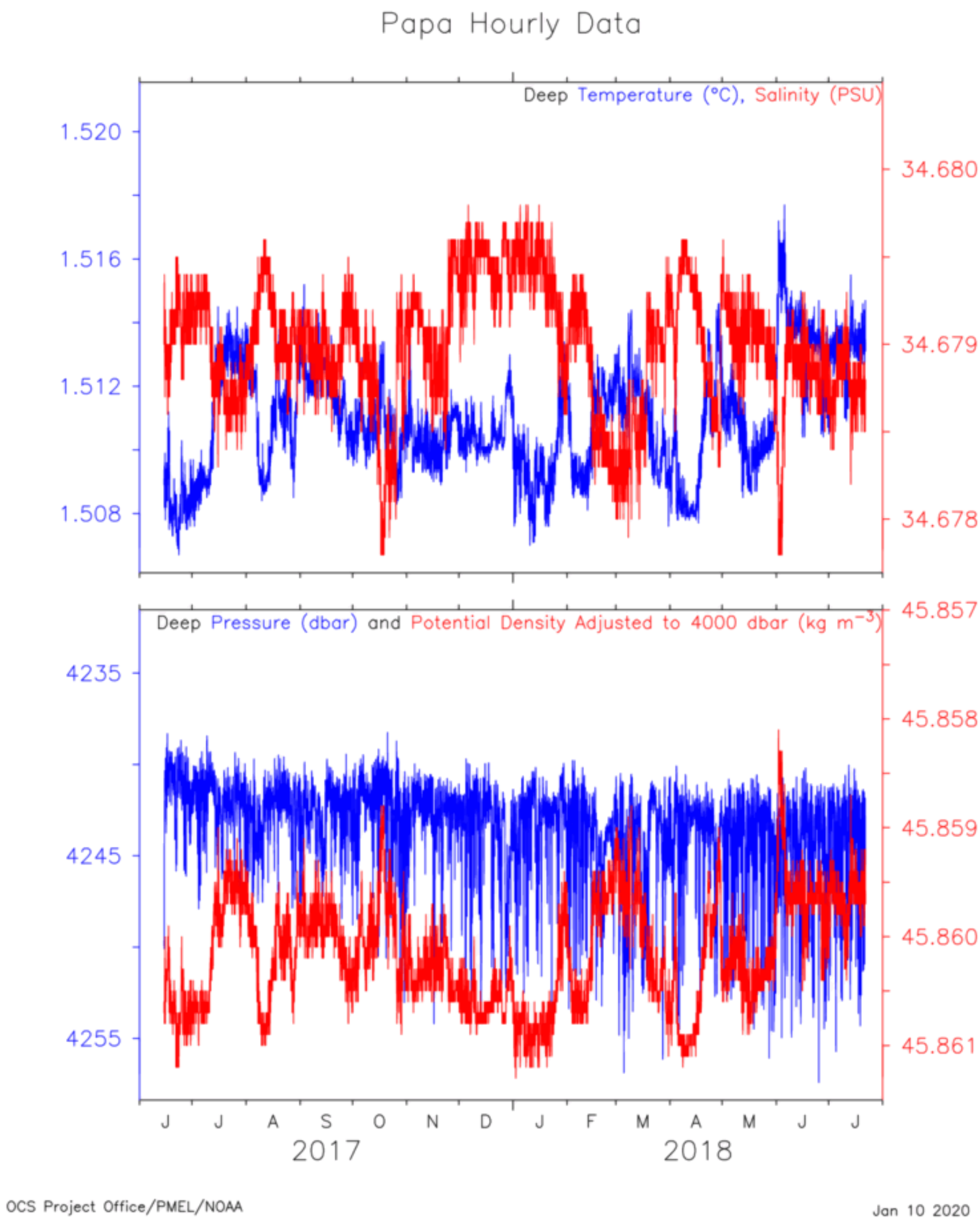

Figure B 5: Deep Seabird instrument temperature, pressure, salinity, and potential density.

APPENDIX C: Secondary Instrument High Resolution Data Plots

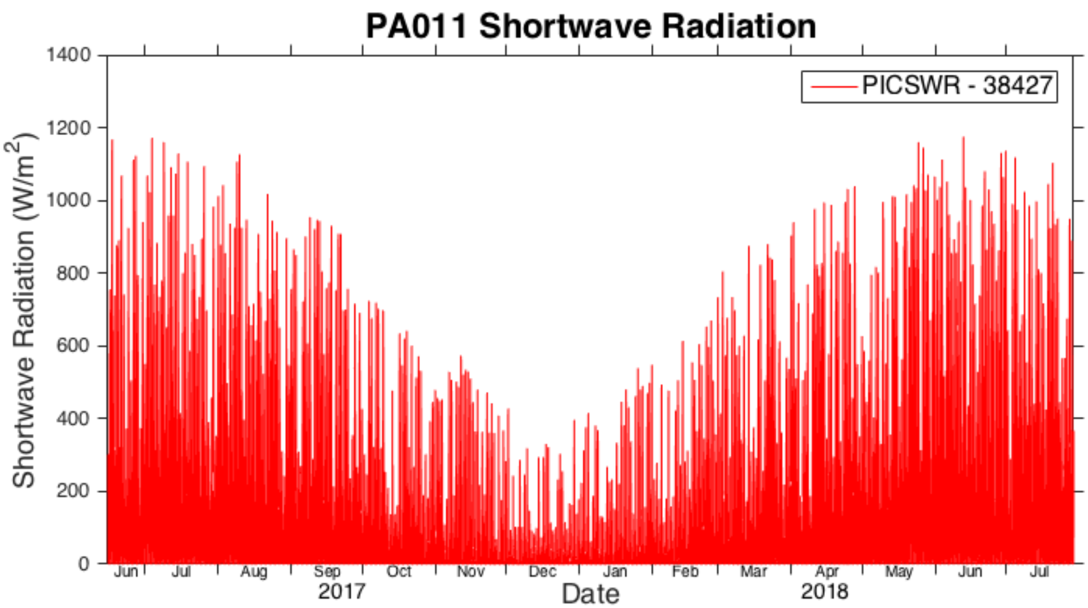

Figure C 1: Secondary (Flex Eppley PSP) shortwave radiation sensor.

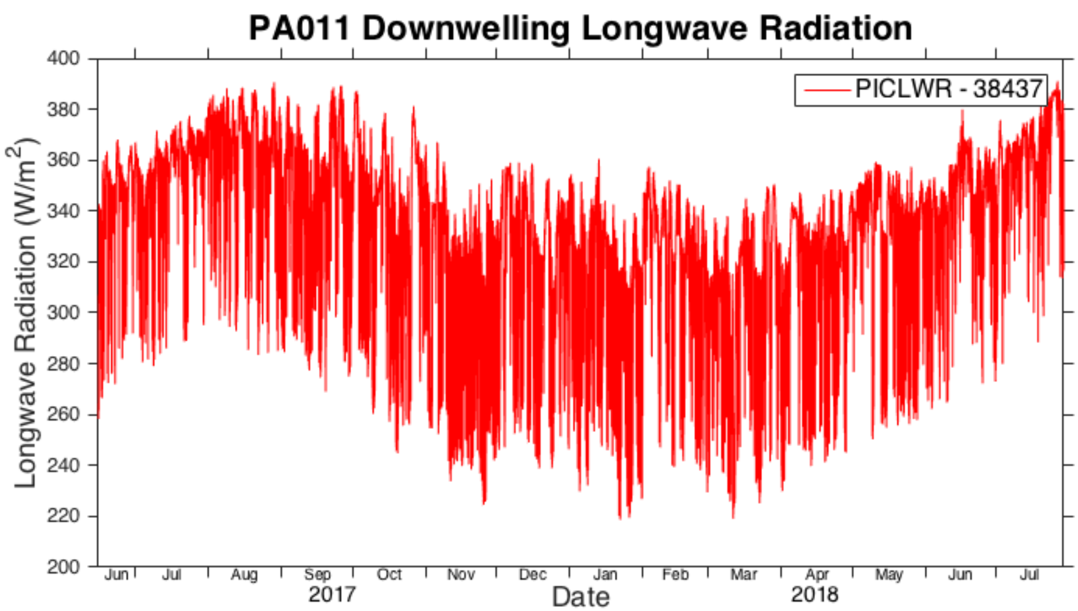

Figure C 2: Secondary (Flex Eppley PIR) longwave radiation sensor.

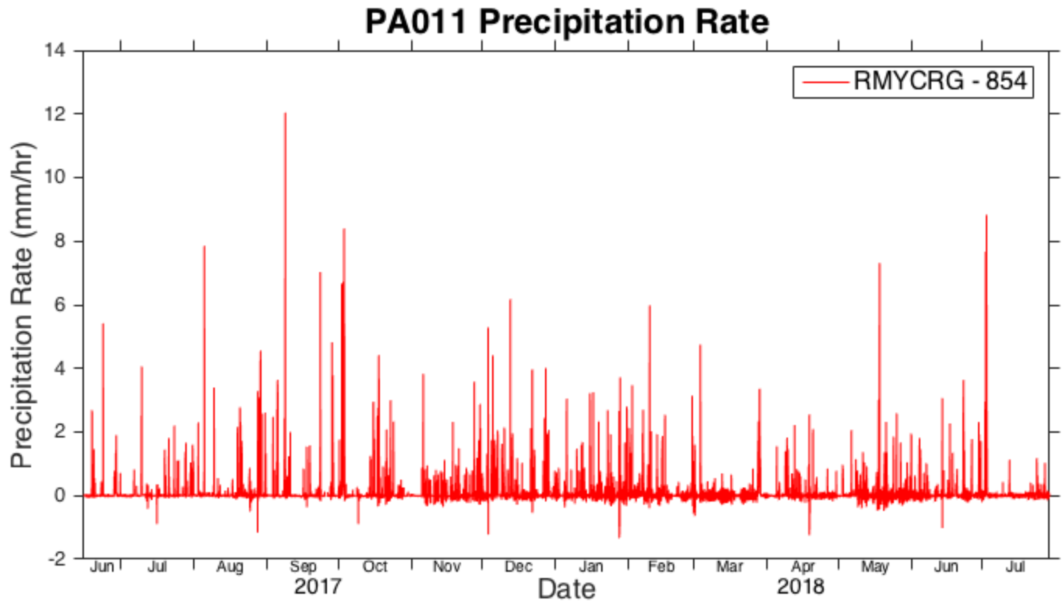

Figure C 3: Secondary (TFlex RM Young) rain sensor.

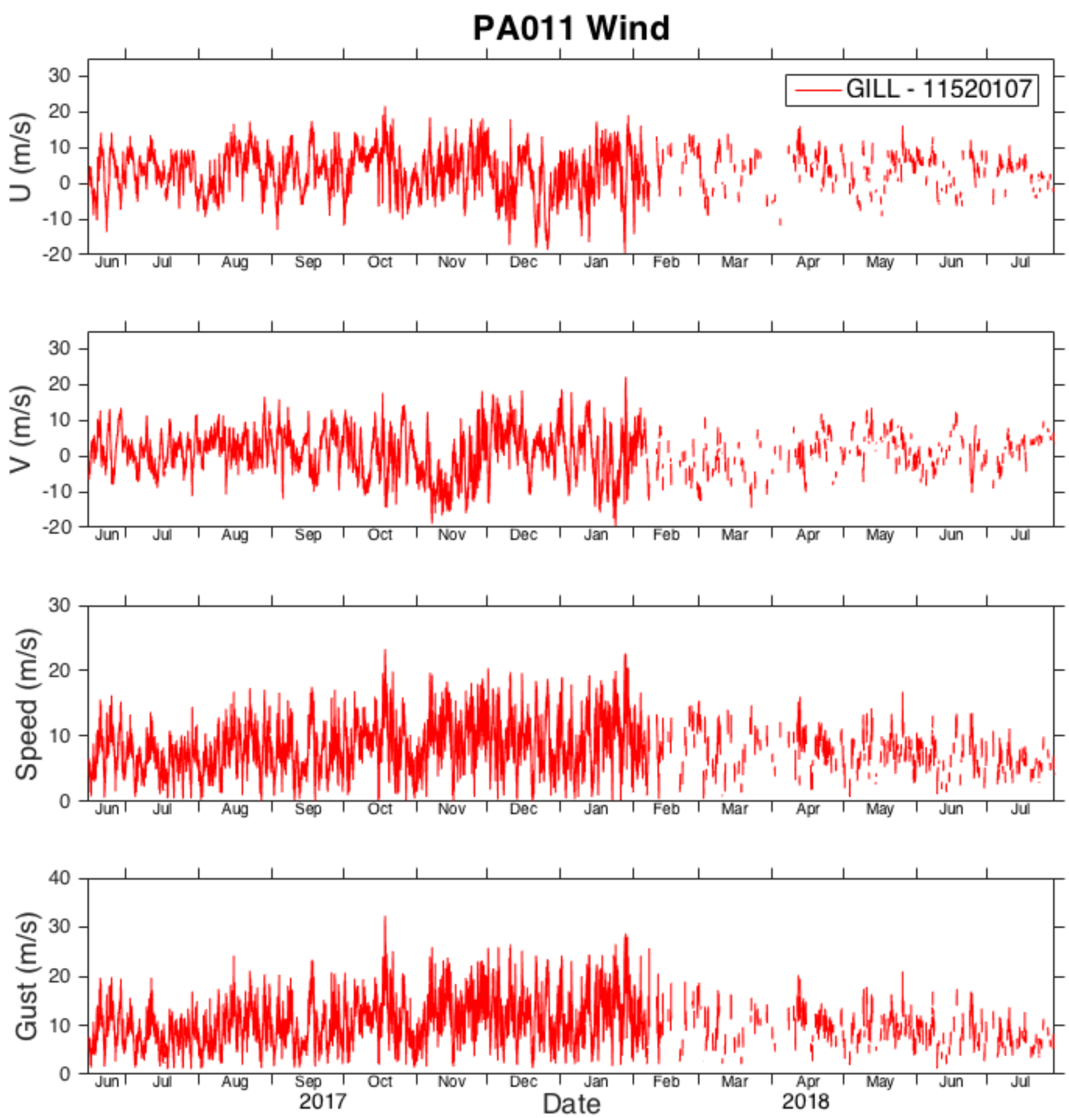

Figure C 4: Secondary (Flex Gill) wind sensor. Gaps in realtime and delayed-mode data occurred, especially in the latter half of the deployment, due to a combination of a failed compass post-calibration, large differences from the primary sensor (triggering gross error thresholds), and intermittency in the 240th sample. Data are flagged Q4 where present.

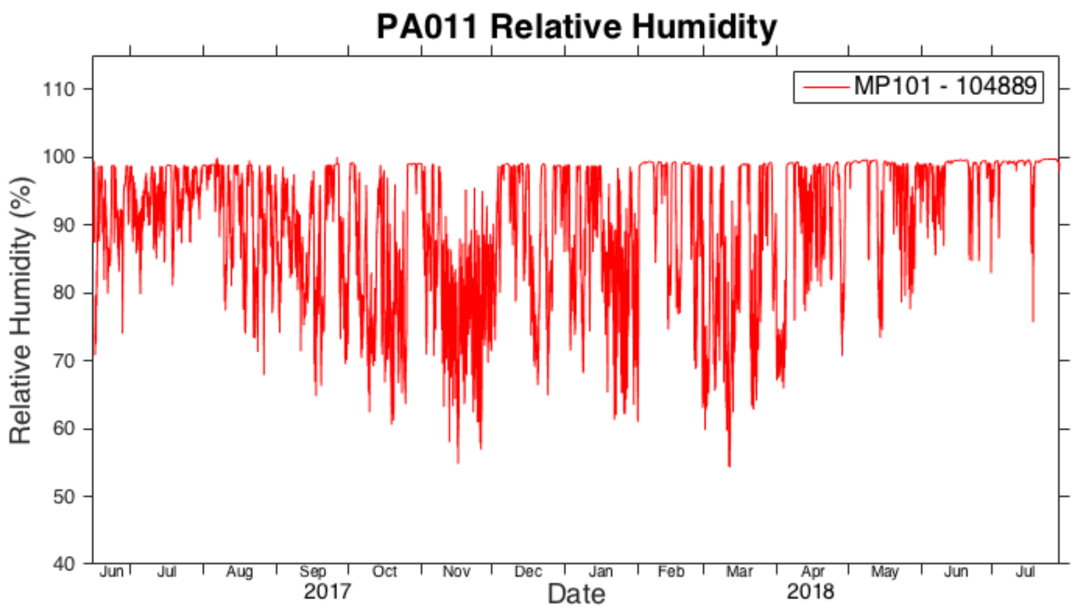

Figure C 5: Secondary (Flex MP101) relative humidity sensor. The instrument failed its post-calibration, so data were flagged as lower quality (Q4). The Hygroclip test sensor (not shown) failed its post-calibration as well, and both drifted with respect to the primary sensor.

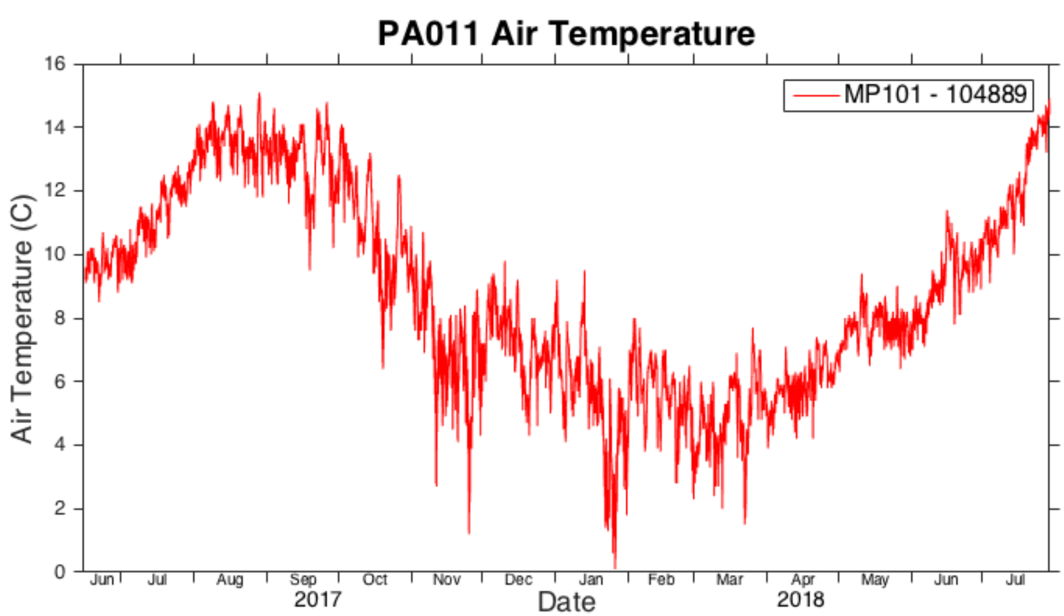

Figure C 6: Secondary (Flex MP101) air temperature sensor.

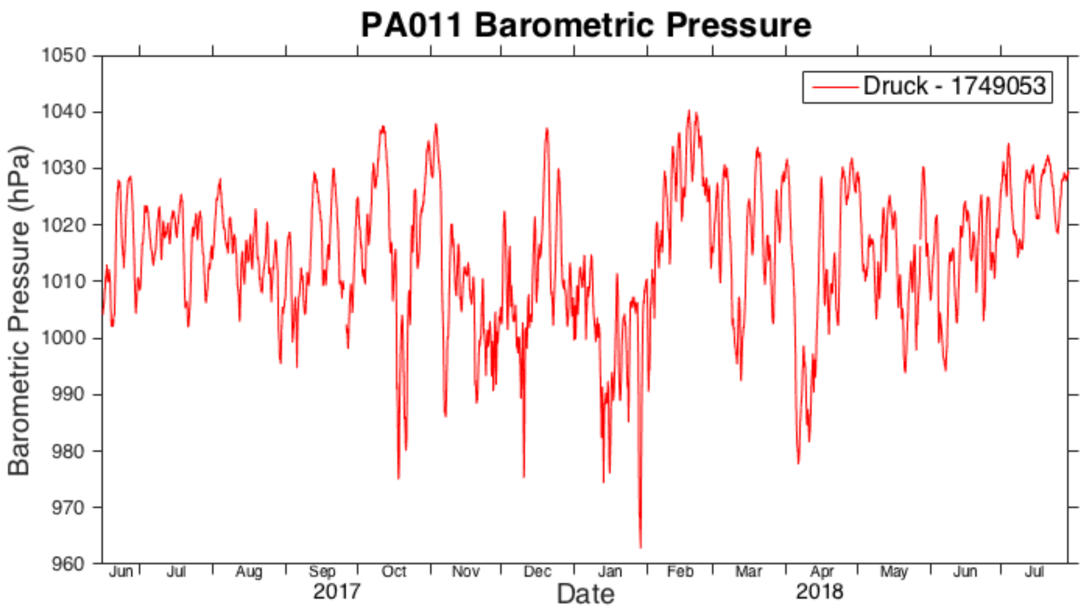

Figure C 7: Secondary (TFlex Druck) barometric pressure sensor. The data were biased high by about 0.4 mb compared to the Flex Paros. Field calibrations were unapplied, and new post-calibration coefficients were applied to the raw data to get this time-series. The adjustment aligned the data with the Paros to within accuracy specifications, and was flagged Q3 to indicate the adjustment.

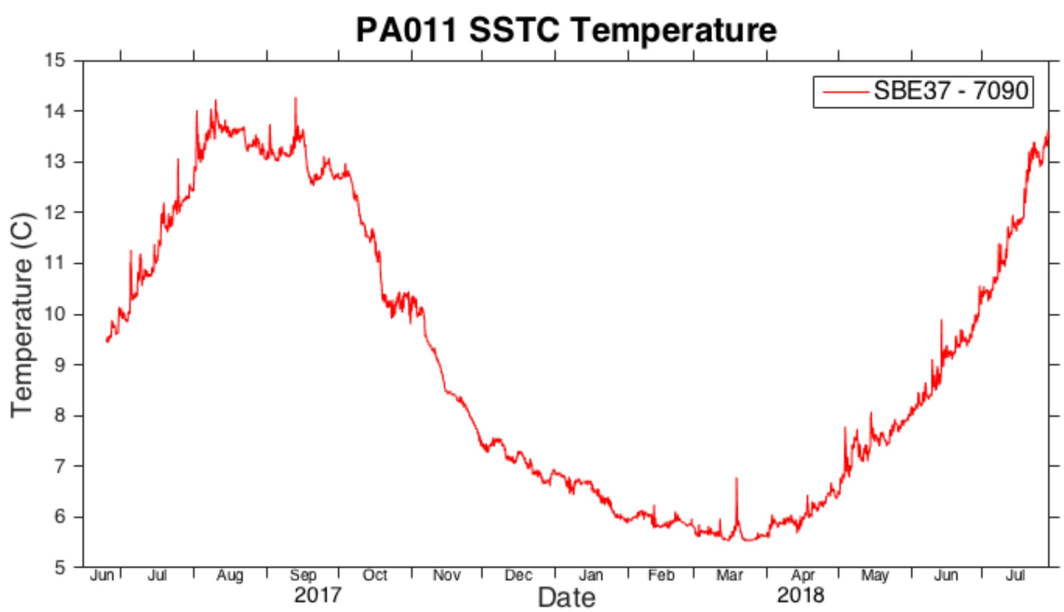

Figure C 8: Secondary (Flex) SSTC Temperature. This instrument turned on 10-days into the deployment, but data were otherwise unaffected.

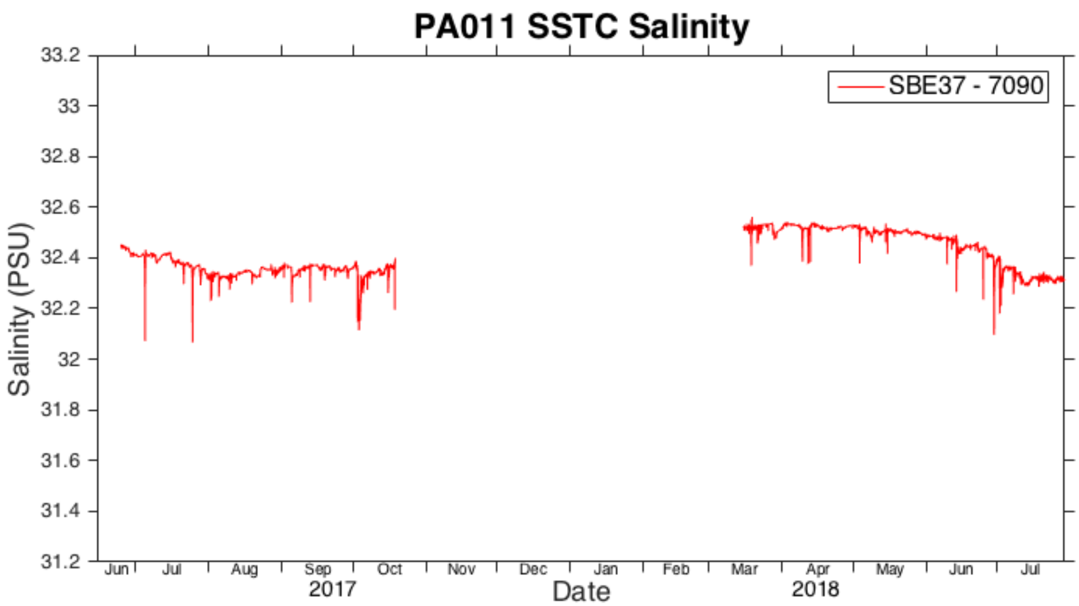

Figure C 9: Secondary (Flex) SSTC Salinity. Air bubbles likely infiltrated the SSTC, causing conductivity to drop close to 0 S/m mid-deployment. The erroneous conductivity, salinity, and density were flagged Q5 until the instrument recovered. If flagged data were shown here, values would quickly fall off the y-scale.

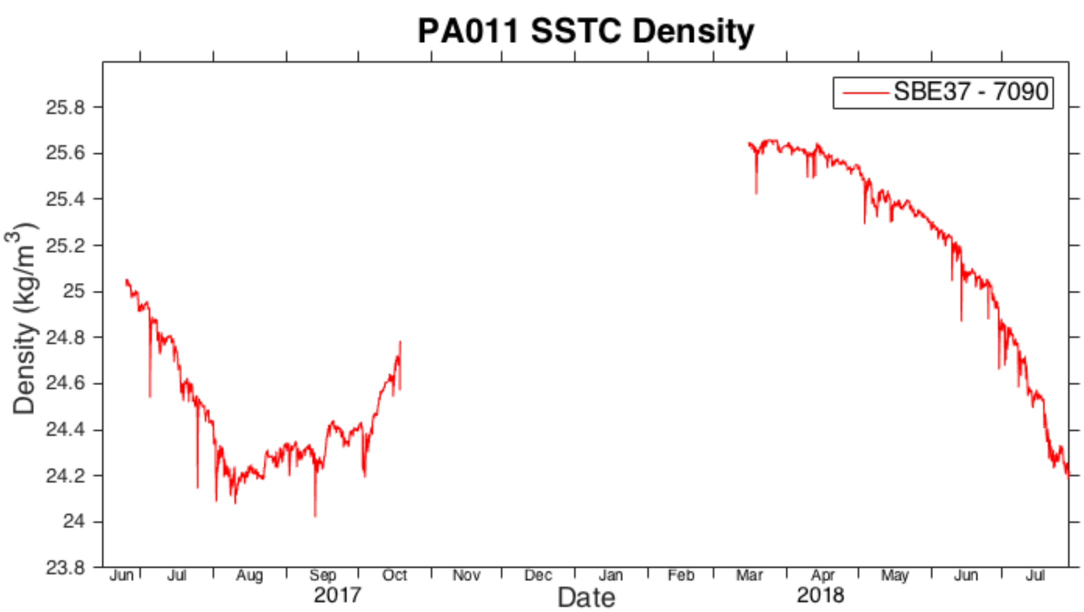

Figure C 10: Secondary (Flex) SSTC Density.