NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

# DATA ACQUISITION AND PROCESSING REPORT FOR PA013

| | |
|---|---|
| *Site Name:* | Ocean Station Papa |
| ***Deployment Number:*** | **PA013** |
| *Year Established:* | 2007 |
| *Nominal Location:* | 50.1°N 144.9°W |
| *Anchor Position:* | 50° 07.592’ N, 144° 50.418’ W (anchor drop) |
| *Deployment Date:* | June 12, 2019 |
| *Recovery Date:* | August 17, 2020 |
| *Project P.I.:* | Dr. Meghan F. Cronin |
| *Report Authors:* | N.D. Anderson, P. Berk, and M.F. Cronin |
| *Data Processors:* | N.D. Anderson |
| *Date of Report:* | March 14, 2022 |
| *Revision History:* | |

*Special Notes:*

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# Data Acquisition and Processing Report for OCS Mooring PA013

## 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. PA013 was the thirteenth deployment at this site.

The PA013 mooring was deployed on June 12th, 2019 from the Canadian Coast Guard Ship (CCGS) JOHN P. TULLY. Recovery was performed on August 17th, 2020 by the NOAA ship OSCAR DYSON. The Ocean Climate Stations group would like to thank the captain and crew of both ships, as well as the supporting scientists, for their contributions to the success and maintenance of the Papa mooring.

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.

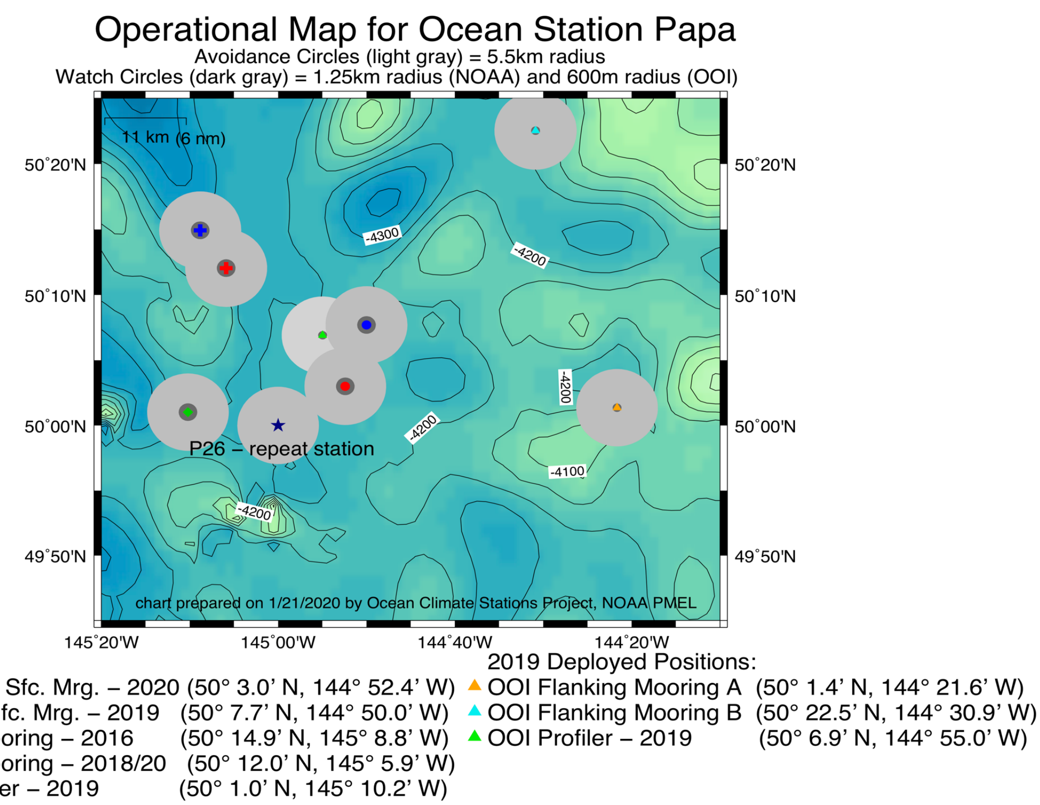


Figure 1: Overview of Station P deployments, at the time of PA013's deployment.

## 1.1 Mooring Description

The PA013 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 3. 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. OCS is not responsible for the acquisition or processing of these data. No further discussion of these systems is included in this report.

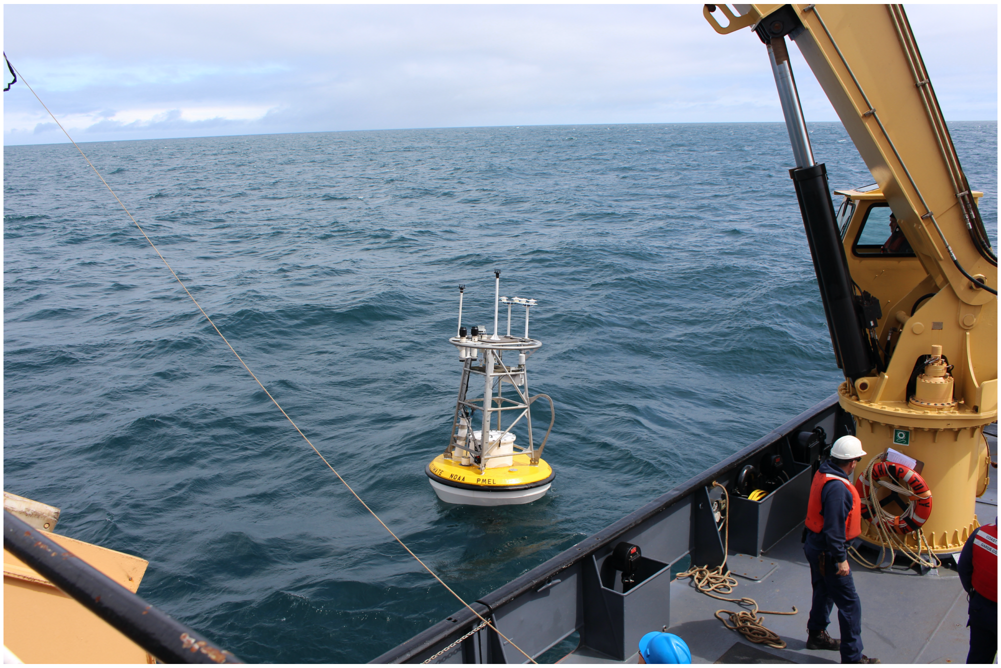

**Figure 2: PA013 mooring as deployed (photo credit: Jade Shiller, UBC).**

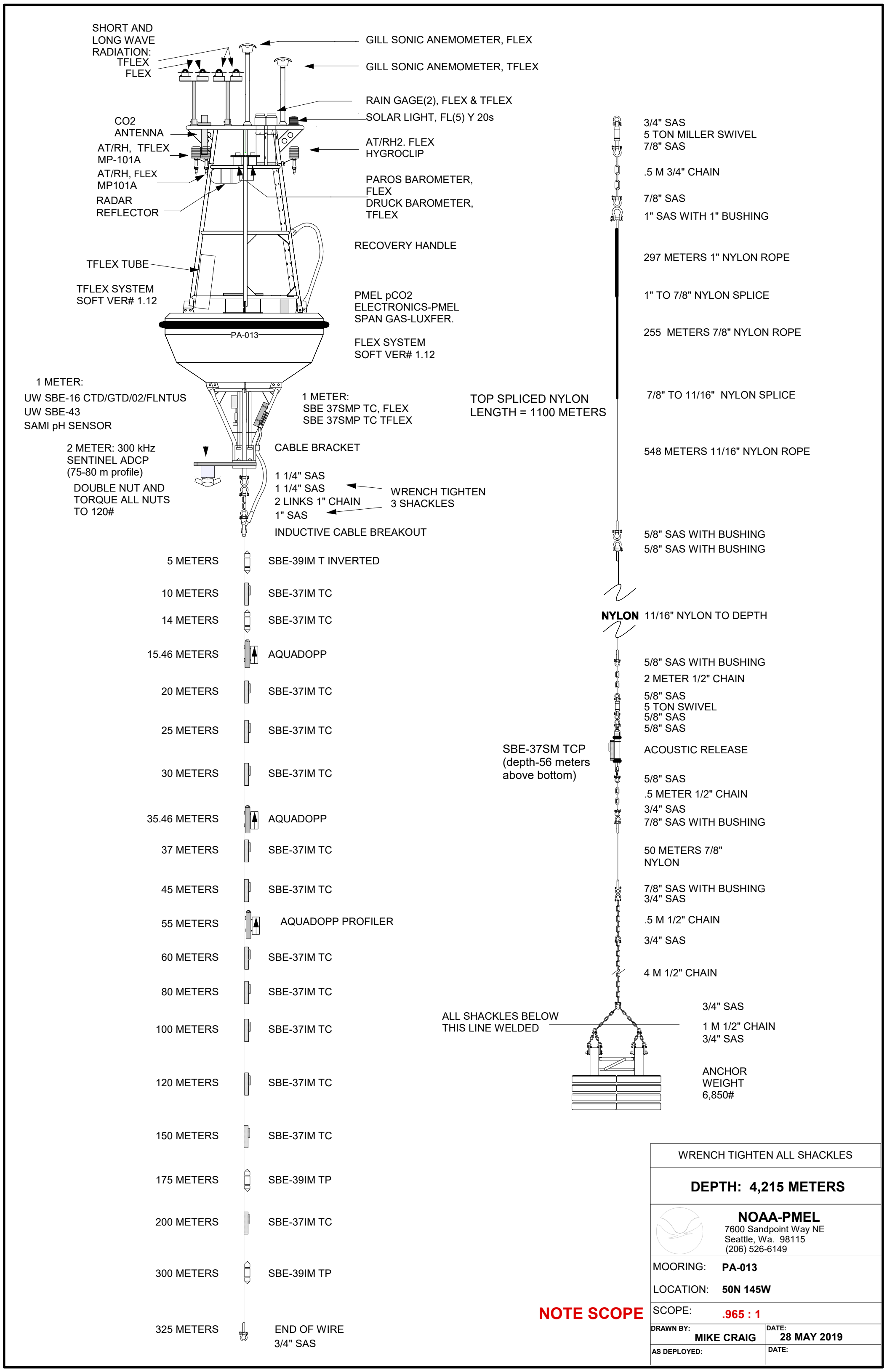


**Figure 3: PA013 mooring diagram.**

## 1.2 Instrumentation on PA013

The following instrumentation was deployed on PA013. 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:** | | **PA013** | | | |
|---|---|---|---|---|---|
| **Met Sensors** | | **Model** | **Serial #** | | **Notes** |
| **Height** | Acquisition | **FLEX** | 4 | | |
| 2.6m | ATRH | Rotronics MP-101A | 51042 | | |
| 2.6m | ATRH2 | Rotronics HygroClip | 61222482 | | |
| 4.2m | Wind | Gill | 10510081 | | |
| 2.5m | BP | Paros | 127685 | | |
| 3.1m | Rain | RM Young | 1639 | | |
| 3.6m | SWR | Eppley PSP | 38433 | | |
| 3.6m | LWR | Eppley PIR | 38437 | | |
| | | | | | |
| | Acquisition | **TFLEX** | 2005 | | |
| 2.6m | ATRH | Rotronics MP-101A | 460994 | | |
| 3.8m | Wind | Gill | 70229 | | |
| 2.4m | BP | Druck | 2153676 | | |
| 3.1m | Rain | RM Young | 1677 | | |
| 3.6m | SWR | Eppley PSP | 38475 | | |
| 3.6m | LWR | Eppley PIR | 38438 | | |
| | | | | | |
| **CO2** | Electronics | PMEL | 207 | | |
| | Span Gas | Luxfer | JB03032 | | |
| | | | | | |
| **Subsurface Instrumentation** | | | | | |
| **Bridle** | | **Model** | **Serial #** | | **Notes** |
| 1m | SST/C | SBE37SMP - TC | 7088 | | Flex, AA batteries (2015) |
| 1m | SST/C | SBE37SMP - TC | 7090 | | TFLEX, AA batteries |
| 1m | pH | SAMI | P212 | | |
| 1m | SST/C | SBE16 | 6618 | | Supplied by UW |
| 1m | Oxygen | Optode | 487 | | Supplied by UW |
| 1m | Oxygen | SBE43 | 430333 | | Supplied by UW |
| 1m | Fluorescence | ECO FLNTUS | 2341 5T 054617 | | Supplied by CO2 - Self Powered |
| 1m | Gas Tension | GTD | 22-018-RD13 | | Supplied by UW |
| 2m | ADCP | Workhorse Sentinel | 14605 | | |
| | | | | | |
| **Wire Depth** | | **Model** | **Serial #** | **ID** | **Notes** |
| 5m | T | SBE39IM - T | 4380 | 01 | Inverted (Use TP for titanium housing) |
| 10m | TC | SBE37IM - TC | 8419 | 02 | |
| 14m | TC | SBE37IM - TC | 7788 | 03 | |
| 15.46m | ADCP | AquaDopp | 9819 | 04 | |
| 20m | TC | SBE37IM - TC | 8420 | 05 | |
| 25m | TC | SBE37IM - TC | 8421 | 06 | |
| 30m | TC | SBE37IM - TC | 8422 | 07 | |
| 35.46m | ADCP | AquaDopp | 13499 | 08 | |
| 37m | TC | SBE37IM - TC | 8423 | 09 | |
| 45m | TC | SBE37IM - TC | 8424 | 10 | |
| 55m | ADCP | AquaDopp Profiler | 13890 | | Non-inductive; Upward Looking |
| 60m | TC | SBE37IM - TC | 13248 | 11 | |
| 80m | TC | SBE37IM - TC | 6072 | 12 | |
| 100m | TC | SBE37IM - TC | 6073 | 13 | |
| 120m | TC | SBE37IM - TC | 6074 | 14 | |
| 150m | TC | SBE37IM - TC | 6075 | 15 | |
| 175m | TP | SBE39IM - TP | 4863 | 16 | |
| 200m | TC | SBE37IM - TC | 20087 | 17 | |
| 300m | TP | SBE39IM - TP | 4865 | 18 | |
| 325m | End of Wire | | | | |
| Release | TCP | SBE37SM - TCP | 10503 | - | |
| Acoustic | Release | | 33946 | | |

Table 1: Instruments deployed on PA013.

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.

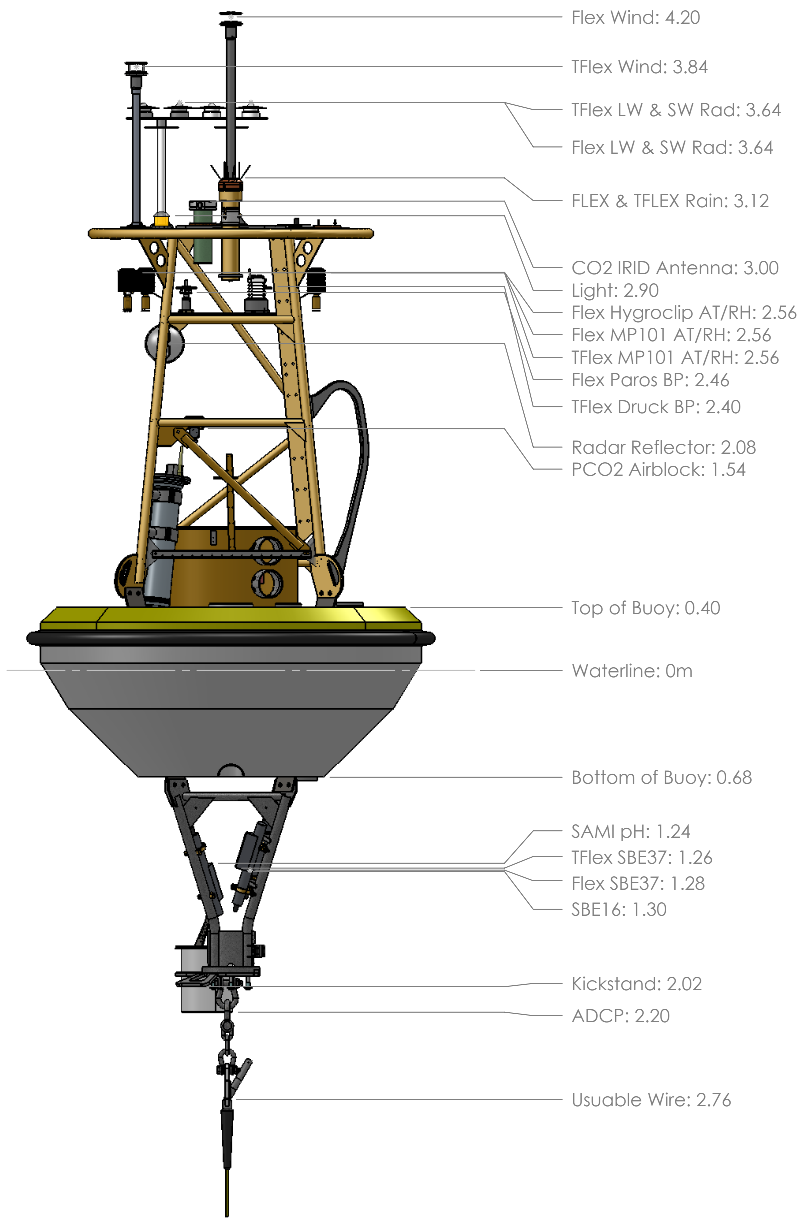


**Figure 4: Buoy diagram showing bridle arrangement. The SBE16 package contains a suite of sensors.**

# 2.0 Data Acquisition

Two independent data acquisition systems were deployed on PA013, 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 PA013 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 | FLEX |
| 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 | FLEX |
| Longwave Radiation (Thermopile, Case & Dome Temperatures) | 1 Hz | 1 min | 0000-0001, 0001-0002… | 1 min | FLEX |
| 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 | 2334-2336, 0004-0006… | 30 min | Internal |
| Ocean Currents (AQDPRO) | 1 Hz | 2 min | 2359-0001, 0029-0031… | 30 min | Internal |
| GPS Positions | 1 per hr | Instant. | ~0000, 0100… | 1 hr | FLEX |

Table 2: Sampling parameters of the primary sensors on PA013.

**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 | TFLEX |
| 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 | TFLEX |
| Longwave Radiation (Thermopile, Case & Dome Temperatures) | 1 Hz | 1 min | 0000-0001, 0001-0002… | 1 min | TFLEX |
| 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 PA013.**

## 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 0004:**

```
Data Return Summary
2019-06-13 01:19:00 to 2020-08-17 20:00:00

Sensor      Deployed      Obs    Return
=======================================
AT1            62177    44318     71.3%
AT2            62177    62009     99.7%
RH1            62177    44318     71.3%
RH2            62177    62009     99.7%
WIND1          62177    61804     99.4%
BP1            62177    62009     99.7%
RAIN1         621762   616576     99.2%
SWR1          621762   616602     99.2%
LWR1          621762   616604     99.2%

Subsurface Temperature Profile
     1m        62177    46446     74.7%
     5m        62177    62176    100.0%
    10m        62177        0      0.0% * Instruments involved in
    14m        62177    31044     49.9% * cascade or lost at sea.
    20m        62177        0      0.0% * Reduced data returns,
    25m        62177        0      0.0% * with some realtime data
    30m        62177    36420     58.6% * available.
    37m        62177    62176    100.0%
    45m        62177    62176    100.0%
    60m        62177    62176    100.0%
    80m        62177    62176    100.0%
   100m        62177    62176    100.0%
   120m        62177    62176    100.0%
   150m        62177    62176    100.0%
   175m        62177    62176    100.0%
   200m        62177    62176    100.0%
   300m        62177    59591     95.8%
  4159m        62177    62176    100.0%
  Total      1119186   857437     76.6%

Subsurface Pressure Profile
     5m        62177    62176    100.0%
   175m        62177    62176    100.0%
   300m        62177    59591     95.8%
  4159m        62177    62176    100.0%
  Total       248708   246119     99.0%
```

Subsurface Salinity Profile

| | | | | |
|---|---|---|---|---|
| 1m | 62177 | 42851 | 68.9% | |
| 10m | 62177 | 0 | 0.0% | * |
| 14m | 62177 | 31044 | 49.9% | * |
| 20m | 62177 | 0 | 0.0% | * |
| 25m | 62177 | 0 | 0.0% | * |
| 30m | 62177 | 36420 | 58.6% | * |
| 37m | 62177 | 62176 | 100.0% | |
| 45m | 62177 | 62176 | 100.0% | |
| 60m | 62177 | 62176 | 100.0% | |
| 80m | 62177 | 62176 | 100.0% | |
| 100m | 62177 | 62176 | 100.0% | |
| 120m | 62177 | 62176 | 100.0% | |
| 150m | 62177 | 62176 | 100.0% | |
| 200m | 62177 | 62176 | 100.0% | |
| 4159m | 62177 | 62176 | 100.0% | |
| Total | 932655 | 669899 | 71.8% | |

AQD Current Velocity

| | | | |
|---|---|---|---|
| 35m | 62177 | 62176 | 100.0% |
| Total | 62177 | 62176 | 100.0% |

**TFlex 2005:**

Data Return Summary
2019-06-13 01:19:00 to 2020-08-17 20:00:00

| Sensor | Deployed | Obs | Return |
|---|---|---|---|
| AT1 | 62177 | 62039 | 99.8% |
| RH1 | 62177 | 62039 | 99.8% |
| WIND1 | 62177 | 62039 | 99.8% |
| BP1 | 62177 | 62039 | 99.8% |
| RAIN1 | 621762 | 608030 | 97.8% |
| SWR1 | 621762 | 609498 | 98.0% |
| LWR1 | 621762 | 610306 | 98.2% |
| SST1 | 62177 | 46935 | 75.5% |
| SSC1 | 62177 | 46935 | 75.5% |
| SSS1 | 62177 | 46935 | 75.5% |

## 2.3 Known Sensor Issues

Air temperature and relative humidity sensors diverged by the end of the PA013 deployment. The Flex AT failed its post-cal, so the TFlex ATRH was classified primary. This decision was confirmed by comparing PA013 data with PA014 realtime data, with the TFlex record showing continuity with the 3 sensors on the new mooring.

Conversely, the TFlex RH failed its postcal and the Flex RH had no postcal due to terminal corrosion. The TFlex RH was flagged Q4 from 6/24/2020 to the end of the record, having drifted away from the hygroclip, and being 5-10% higher than the start of all 3 sensor records on the PA014 mooring. The hygroclip maxed out at 100% toward the end of the record, and as a tertiary sensor, its data are not distributed.

While testing in recent years, it was discovered that Flex and TFlex systems do not apply their given calibration coefficients to the Druck BP sensors. The application of calibration coefficients are therefore applied in post-processing, and brought the mean difference between the two barometers to within 0.1mb.

The TFlex SWR daily average was higher by 1.0%, equal to the threshold for selecting TFlex radiation data as primary. However, this was weighed against a more complete Flex record (TFlex had a data gap from 10/24/2019 to 10/31/2019 due to a system timing error where no data recorded to memory), so Flex remained primary. Prior to the gap, the TFlex daily averages were 0.4% higher than Flex, compared to 1.4% higher after the gap. This could point to degraded (biased high) TFlex performance after the measurement gap. Since the only period between PA013's deployment and PA012's recovery was overnight, no meaningful SWR intercomparison was possible. However, overlap between PA013 and PA014 realtime data suggest that choosing Flex SWR as primary on PA013 improved cross-deployment continuity. Hourly realtime data from PA014's Flex SWR averaged 0.065 $W/m^2$ higher than hourly PA013 Flex SWR and 1.994 $W/m^2$ lower than hourly PA013 TFlex SWR, again suggesting the PA013 TFlex was biased high by the deployment's end.

The 15m Aquadopp point current meter was involved in an instrument cascade down the mooring line. The final realtime transmission on 2/26/2020 showed that the instrument had come to rest at 30m, indicating that the 20m and 25m instruments had also come to rest on the 30m instrument. The Aquadopp was returned with a busted fin and had cracked/flooded, resulting in no delayed-mode data being recovered. Seabird data (mostly TC on Papa) were flagged Q4 in instances where the Aquadopp pressure data indicated a displacement past a Seabird sensor's nominal depth.

The 10m, 20m and 25m instruments were lost, so only realtime data exists and is distributed at those depths. Data were recovered from 30m, but the instrument stopped recording on 2/20/2020, likely a consequence of the 15m, 20m, and 25m instruments having cascaded against it. Both SSTCs also had records ending early (Flex 4/30/2020 and TFlex 5/4/2020), as well as the 300m sensor (7/30/2020), the 14m sensor (1/14/2020).

# 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, spectral plots, and histograms 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 PA013 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 PA013 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

Automated gross error checks 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 wind 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 Flex winds, where unrealistically high speeds and gusts occurred (i.e. outside of the presence of a storm or contextually inconsistent) and were not confirmed by the secondary sensor. Aside from these few flags, the Flex wind record was more complete and was considered primary.

### 3.2.2 Air Temperature

The TFlex air temperature sensor was selected as primary due to the Flex air temperature sensor's failed post-calibration, along with persistent upward drift after 2/23/2020 (see Appendix, C6). The secondary sensor was flagged Q5 (removed) at the onset of drift, and Figure 5 shows nearly +1°C bias by the deployment's end, using data shown prior to the application of quality control flagging. The tertiary Hygroclip sensor drifted in the opposite direction, and is discontinuous with the beginning records of PA014.

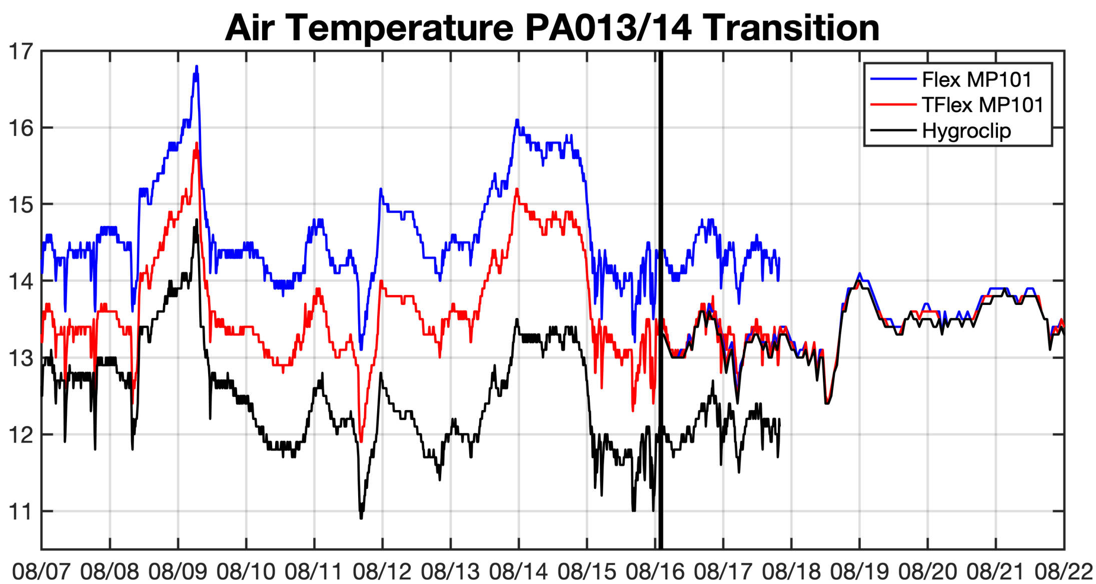


**Figure 5: Air Temperature intercomparison between deployments. The vertical black line indicates the start of the next deployment.**

### 3.2.3 Relative Humidity

The TFlex relative humidity sensor was selected as primary to match the selection for air temperature sensor. The Flex RH was returned with corrosion on it's terminal, so no post-cal was possible. Although the TFlex RH failed its post-cal, it was the only full record available (the tertiary hygroclip had saturated at 100%, and Flex RH dropped to <50%). The TFlex RH was flagged Q4 from 6/24/2020 forward, the estimated start of the drift toward higher values. The secondary sensor was flagged Q5 from 2/23/2020 to the end of the record, matching the Flex air temperature flagging. Final sensor failure was indicated by a significant discontinuity in April 2020, where values dropped outside of climatological bounds and persisted at RH<50% and off the y-axis of Figure 6. The hygroclip also failed during this deployment, becoming saturated more frequently as time elapsed.

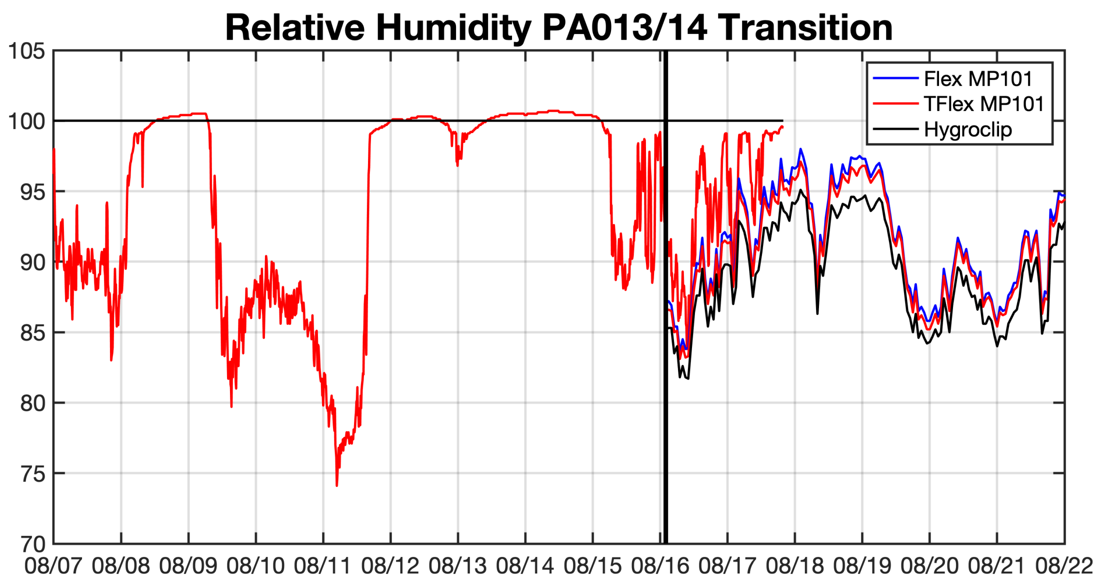


**Figure 6: Relative Humidity intercomparison between deployments. The Hygroclip frequently became saturated and the Flex RH dropped outside of climatological norms. TFlex RH was the best available record, but the later data required lower quality flags (see discontinuity against PA014 RH sensors).**

### 3.2.4 Barometric Pressure

Discovered in past years of testing, the aging mooring acquisition systems are known to fail at applying BP calibrations to Druck sensors. While the primary Flex sensor was a Paros and gets no calibration applied (after verifying it's within limits against a reference sensor), the coefficients obtained for the TFlex barometric pressure sensor had to be applied in post-processing. No other issues presented in the barometric pressure records.

### 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 1.0%. 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 PA013 Flex SWR was primary.

An October TFlex data gap caused no data to be recorded to memory during a narrow window of time. Interestingly, TFlex SWR data prior to this gap were just 0.4% higher than Flex (within specifications), while TFlex data after the gap were 1.4% higher. Combined with the continuity of the Flex SWR with surrounding deployments (not shown), higher confidence is placed in the Flex SWR.

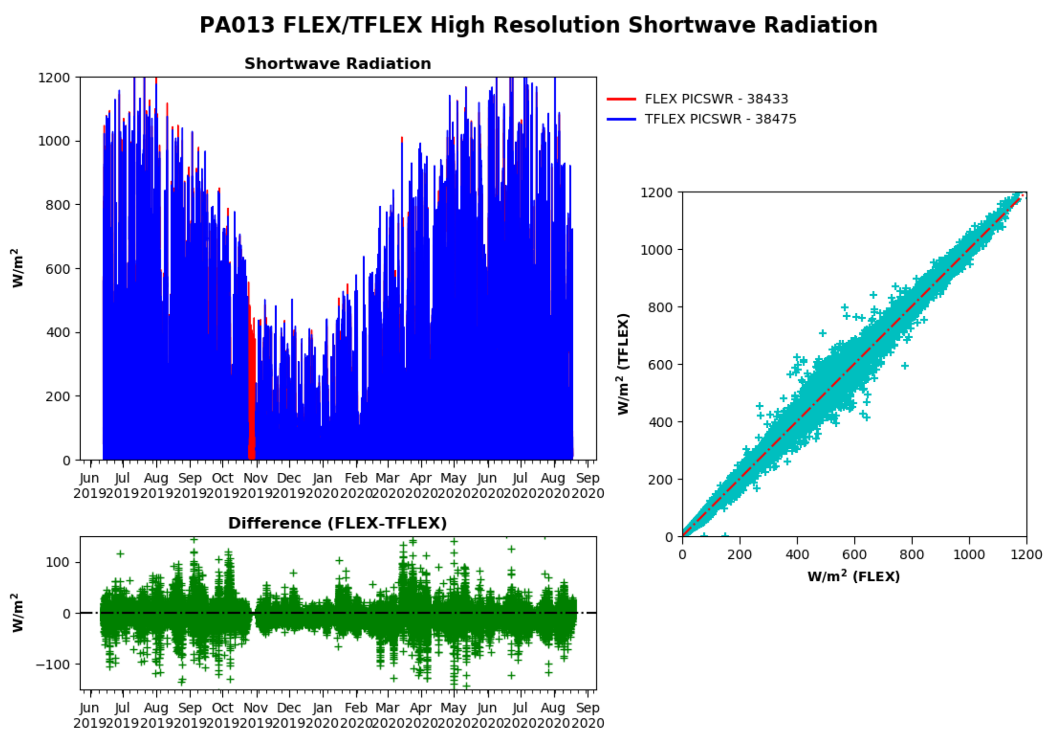


**Figure 7: PA013 SWR sensor data, differences, and property-property plot.**

### 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 PA013 Flex LWR was primary.

LWR and SWR measurements were occasionally interrupted by realtime 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 a minor impact on total data returns.

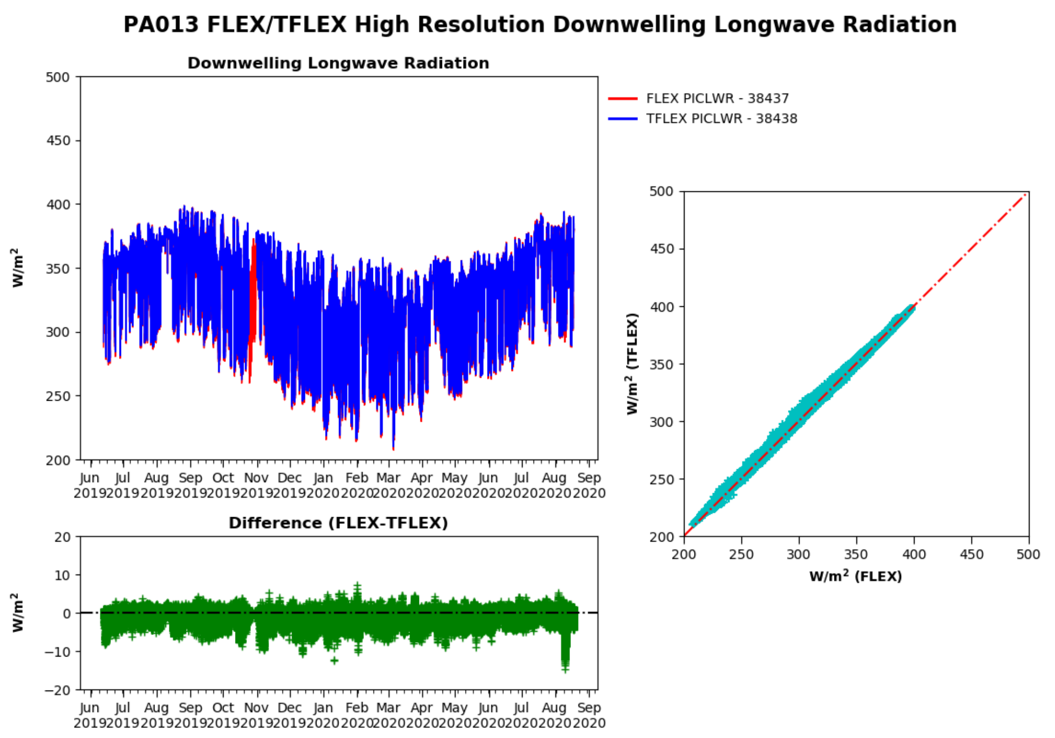


Figure 8: PA013 LWR sensor data, differences, and property-property plot.

## 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 below (Figure 9). 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 in the rare case where clock error drifted beyond half the measurement interval.

A moderate number of instrument clock errors were not reported from PA013 due to a combination of damage from the instrument cascade and battery depletion. Without OCS personnel aboard during the recovery mission, post-recovery troubleshooting was performed at PMEL, where battery swapping and other in-lab diagnostics enabled the reactivation of a few failed sensors and allowed additional clock error retrievals.

| Type | Serial | Real Time | Inst Time | Clock Error |
|---|---|---|---|---|
| SBE37-TC-SMP | 7088 | 17:48:45 | 17:48:30 | -0:00:15 |
| SBE37-TC-SMP | 7090 | 20:48:40 | 20:48:54 | 0:00:14 |
| SBE37-TC-IMP | 4380 | 21:28:35 | 21:30:14 | 0:01:39 |
| SBE37-TC-IMP | 7788 | 20:37:00 | 20:37:47 | 0:00:47 |
| SBE37-TC-IMP | 8423 | 15:37:45 | 15:38:08 | 0:00:23 |
| SBE37-TC-IMP | 8424 | 15:26:05 | 15:26:48 | 0:00:43 |
| SBE37-TC-IMP | 13248 | 15:03:40 | 15:03:21 | -0:00:19 |
| SBE37-TC-IMP | 6072 | 15:19:20 | 15:19:38 | 0:00:18 |
| SBE37-TC-IMP | 6073 | 15:10:00 | 15:10:15 | 0:00:15 |
| SBE37-TC-IMP | 6074 | 15:50:15 | 15:50:25 | 0:00:10 |
| SBE37-TC-IMP | 6075 | 16:01:45 | 16:02:02 | 0:00:17 |
| SBE37-TC-IMP | 4863 | 21:30:05 | 21:31:01 | 0:00:56 |
| SBE37-TC-IMP | 20087 | 16:27:15 | 16:37:39 | 0:10:24 |
| SBE39-TP-IM | 4865 | 18:33:35 | 18:34:55 | 0:01:20 |

**Figure 9: Reported clock errors (from instruments reporting upon recovery)**

### 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.

The instrument cascade was a notable event on PA013 that displaced several instruments from their nominal depths. Because the 3 pressure sensors at 5m, 175m and 300m were not involved in the cascade, the speed and timing of instrument displacements were only estimated based on pressures from the Aquadopp point current meters. If an instrument is displaced from its nominal depth, using the nominal pressure within the salinity calculation can introduce a small error. Therefore, data from the Seabird sensors were flagged Q4 wherever the aquadopp current meter first indicated displacement beyond a neighboring instrument's nominal pressure. Based on this criteria, any 20m data after 1/5/2020 at 7:00 UTC and any 25m data after 1/29/2020 at 5:00 UTC were flagged. An improvement to the aquadopp mounting system (clamps with teeth to better grip the nilspin wire) will be used on future deployments to mitigate instrument cascades.

### 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. Notably on PA013, the TFlex SSTC was primary instead of the Flex SSTC because the latter had noisy data, with conductivity values near 1.5 S/m in the first month requiring Q5 flags.

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.

<u>Salinity Drifts in PSU (post-pre):</u>

| **Depth:** | **Drift:** |
|---|---|
| 1m (TFlex) | -0.0046 |
| 1m (Flex) | -0.0004 |
| 10m | N/A (sensor not recovered) |
| 14m | -0.0027 |
| 20m | N/A (instrument cascade; sensor not recovered) |
| 25m | N/A (instrument cascade; sensor not recovered) |
| 30m | -0.0056 |
| 37m | -0.0033 |
| 45m | -0.0028 |
| 60m | -0.0186 |
| 80m | -0.0031 |
| 100m | 0.0023 |
| 120m | -0.0041 |
| 150m | -0.0035 |
| 200m | 0.0122 |

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 beyond the adjustments required during density intercomparisons.

### Manual Salinity Adjustments

The drift-corrected salinities were checked for continuity across deployments. Instrument ranges and magnitudes of variation matched well with the prior and subsequent deployment. The instrument accuracy specifications were not strictly applied for cross-deployment comparisons, 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).

Additional linear corrections are applied to the salinity data in time segments based on density comparisons with surrounding instruments. These *in situ* calibration procedures are described by Freitag et al. (1999).

Based on manual review of the data against neighboring instruments, the following adjustments were made:

2019-07-06 15:45:15 to 2019-10-28 14:40:49 at 1m (Flex) adjusted 0.0000 to 0.0022
2019-10-28 14:40:49 to 2020-01-16 10:29:37 at 1m (Flex) adjusted 0.0022 to 0.0055
2020-01-16 10:29:37 to 2020-09-08 02:28:32 at 1m (Flex) adjusted 0.0055 to 0.0055
2019-06-11 06:11:52 to 2019-08-15 02:30:43 at 1m (TFlex) adjusted 0.0000 to -0.0006
2019-08-15 02:30:43 to 2020-01-06 14:05:19 at 1m (TFlex) adjusted -0.0006 to -0.0094
2020-01-06 14:05:19 to 2020-01-21 03:34:36 at 1m (TFlex) adjusted -0.0094 to -0.0072
2020-01-21 03:34:36 to 2020-09-08 02:28:32 at 1m (TFlex) adjusted -0.0072 to -0.0100
2019-05-16 11:53:22 to 2020-09-08 02:28:32 at 60 m adjusted -0.0200 to -0.0200

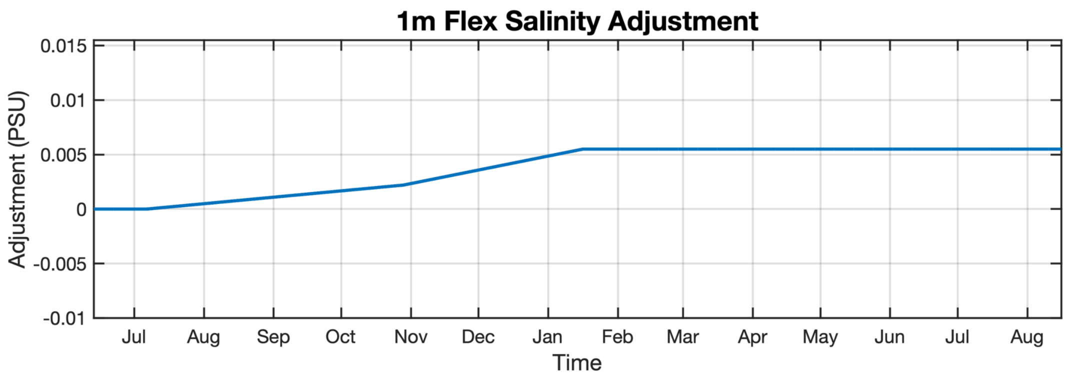


**Figure 10: Minor salinity adjustments to the secondary Flex SSTC.**

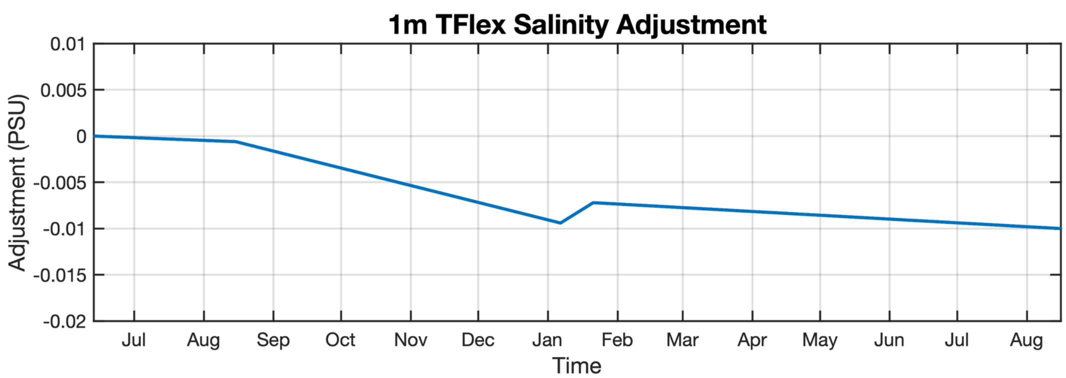


**Figure 11: Minor salinity adjustments to the primary TFlex SSTC.**

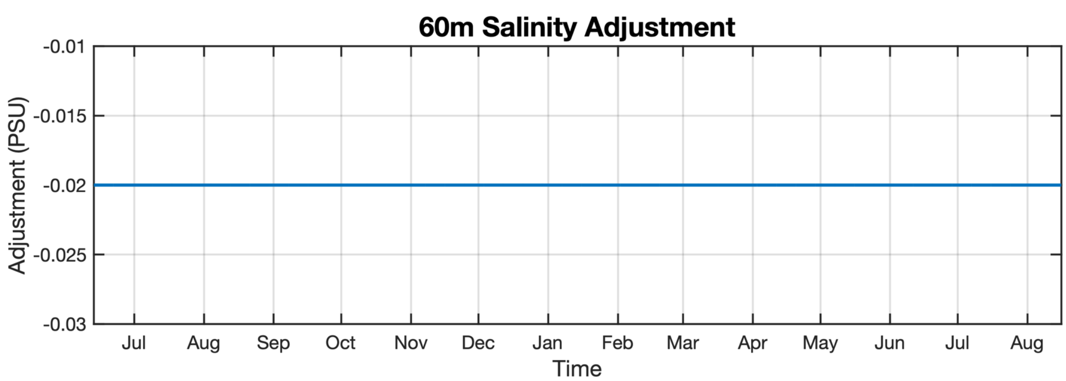


**Figure 12: Salinity adjustment on the 60m instrument. The constant adjustment was applied to prevent inversions against neighboring instruments in the mixed layer.**

### 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.

Temperature and pressure, along with 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.

The deep T/S data are shown in appendix plot B5. The slight increase in pressure with time is hypothesized to be real, as the anchor settles slightly over time. Note that the salinity range on the y-axis is narrow, but the small decreases in salinity over time are aligned with the general multi-year trend at Papa.

### 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 is applied, and data are smoothed to hourly resolution using a thirteen-point Hanning filter.

Since PA013 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.

A magnetic declination correction of +15 degrees is added to the current meters in post-processing. The 15m Aquadopp slid down the line on this deployment, affecting several Seabird sensors on the line before finally coming to rest at ~30m. The instrument itself flooded, and only realtime data are available. The 35m Aquadopp was processed as usual (with delayed-mode data available).

### 3.3.6 Acoustic Doppler Current Profiler (Aquadopp Profiler)

An upward-looking Aquadopp Profiler was deployed for the third time on the PA013 mooring. This was the first deployment to raise the profiler to a nominal depth of 55m to obtain data closer to the surface, and the first deployment to have 30-minute sampling from the profiler. To process the data, 3 corrections were applied: declination (+15 degrees), tilt correction, and head depth adjustment. Aquadopps do not have an internal setting for declination, so this correction to true heading is applied first 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 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 is 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 was set to 30-minutes starting with PA013 and going forward.

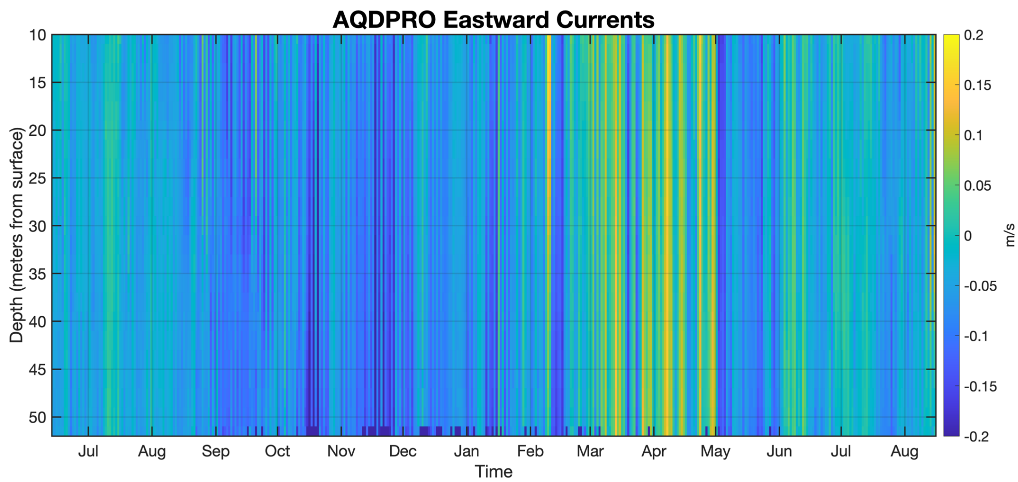


**Figure 13: Aquadopp Profiler eastward velocities.**

### 3.3.7 Acoustic Doppler Current Profiler (Sentinel ADCP)

A downward looking Sentinel ADCP was deployed for the final time on PA013, as this instrument is being phased out. 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.

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 were examined, but the ADCP is too heavy to mount on the line, and the lighter, upward-looking Aquadopp profiler is now considered the primary profiler. This upward-looking configuration appears to reduce interference, while the downward-looking Sentinel ADCP is cantilevered off the bridle, and pitches with the buoy, sweeping all beams across the mooring line with time. As a secondary ADCP on this deployment, the Sentinel was set to perform its 2-minute burst sample 5 minutes after the half hour, to avoid interference with the Aquadopp profiler, so timestamps are offset from the typical half-hourly grid (e.g. 1:05, 1:35, etc.).

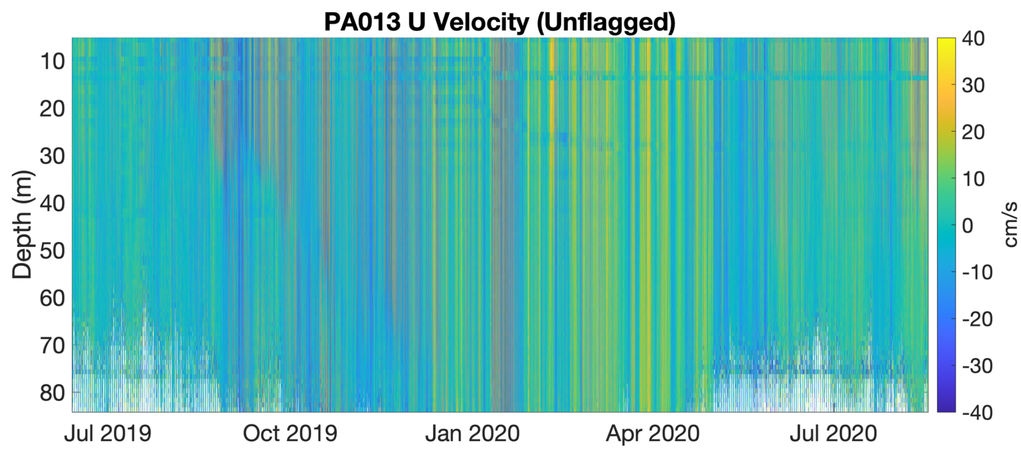


**Figure 14: ADCP eastward velocities with autonomous flagging thresholds applied by the ADCP, but before manual flagging. All beams are affected by instruments on the line.**

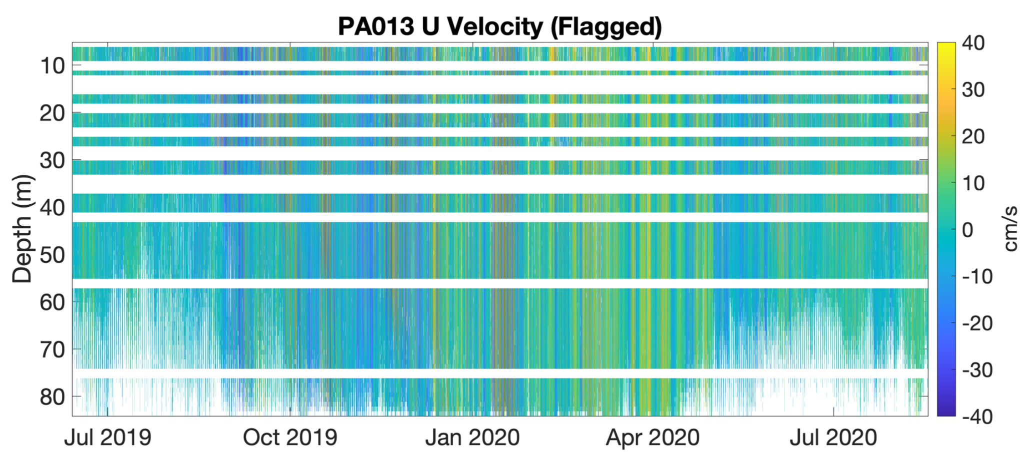


**Figure 15: ADCP eastward velocities with manual flagging thresholds and bin-flagging applied, in addition to the autonomous flagging thresholds applied by the ADCP.**

## 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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This work was supported by NOAA's Global Ocean Monitoring and Observing Program (FundRef number 100018302).

## 6.0 Contact Information

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Seattle, WA 98115

## 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 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

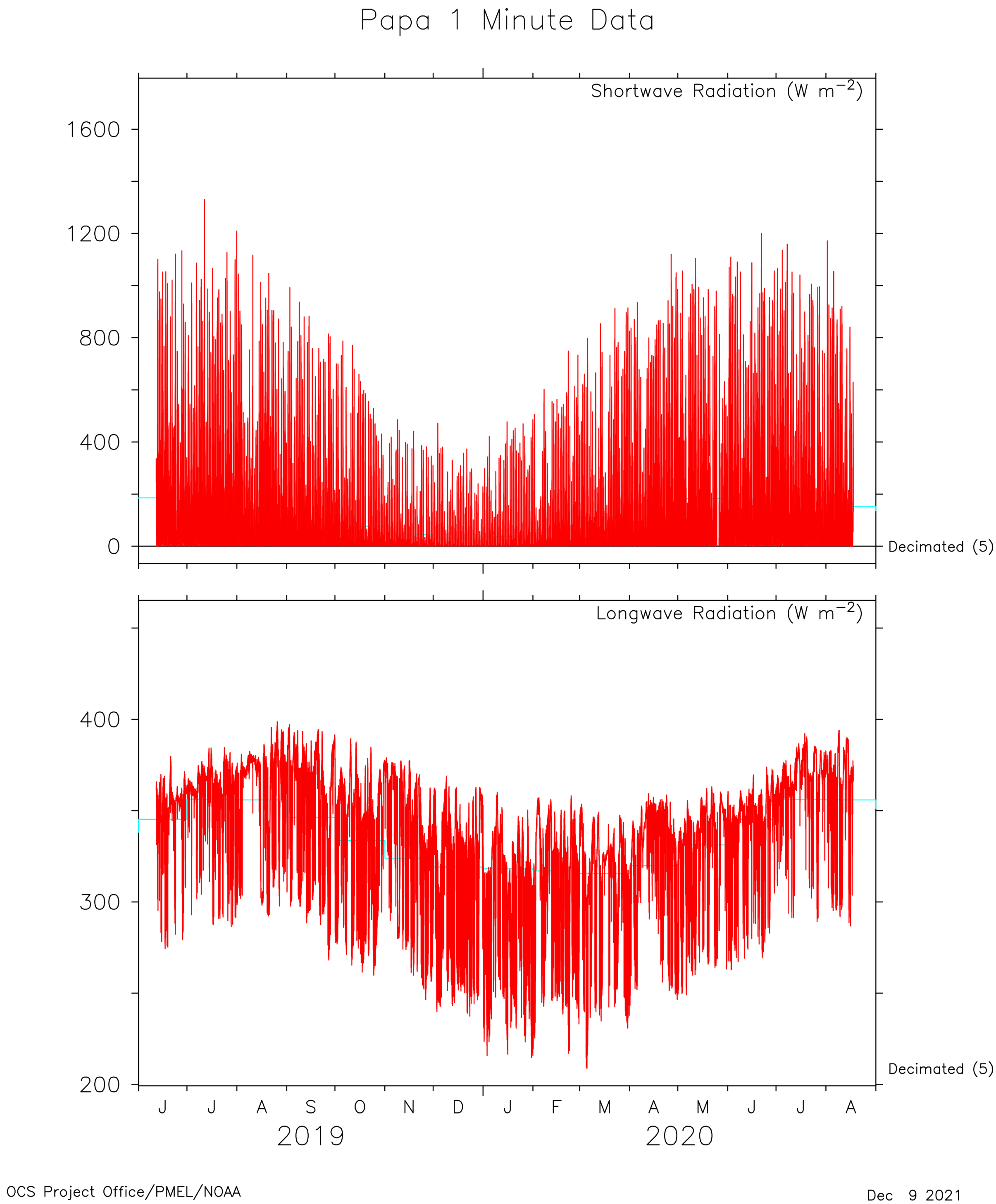


Figure B 1: PA013 primary shortwave and longwave radiation data at 1-min resolution (Flex).

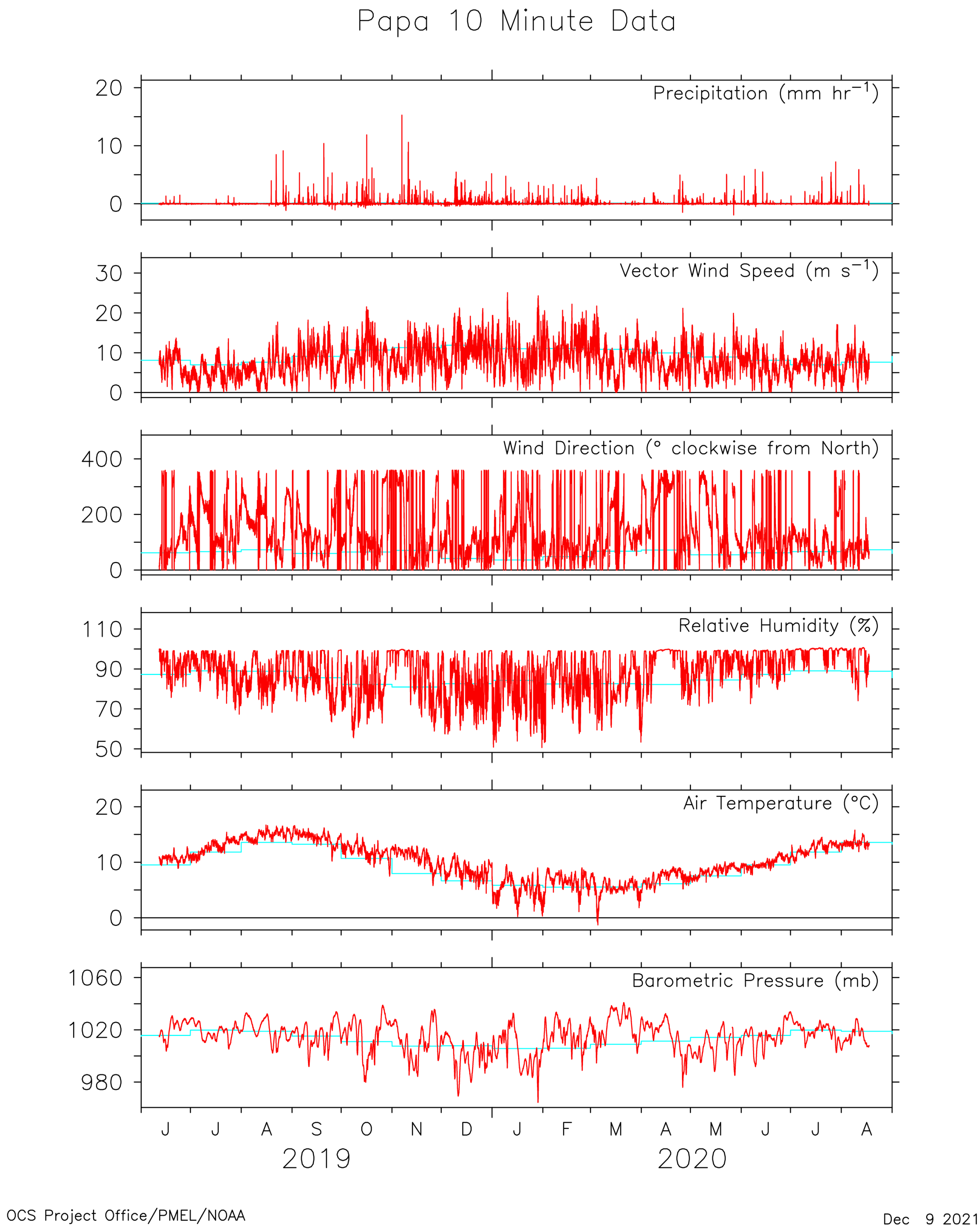


**Figure B 2: PA013 meteorological data at 10-min resolution (all Flex except AT/RH).**

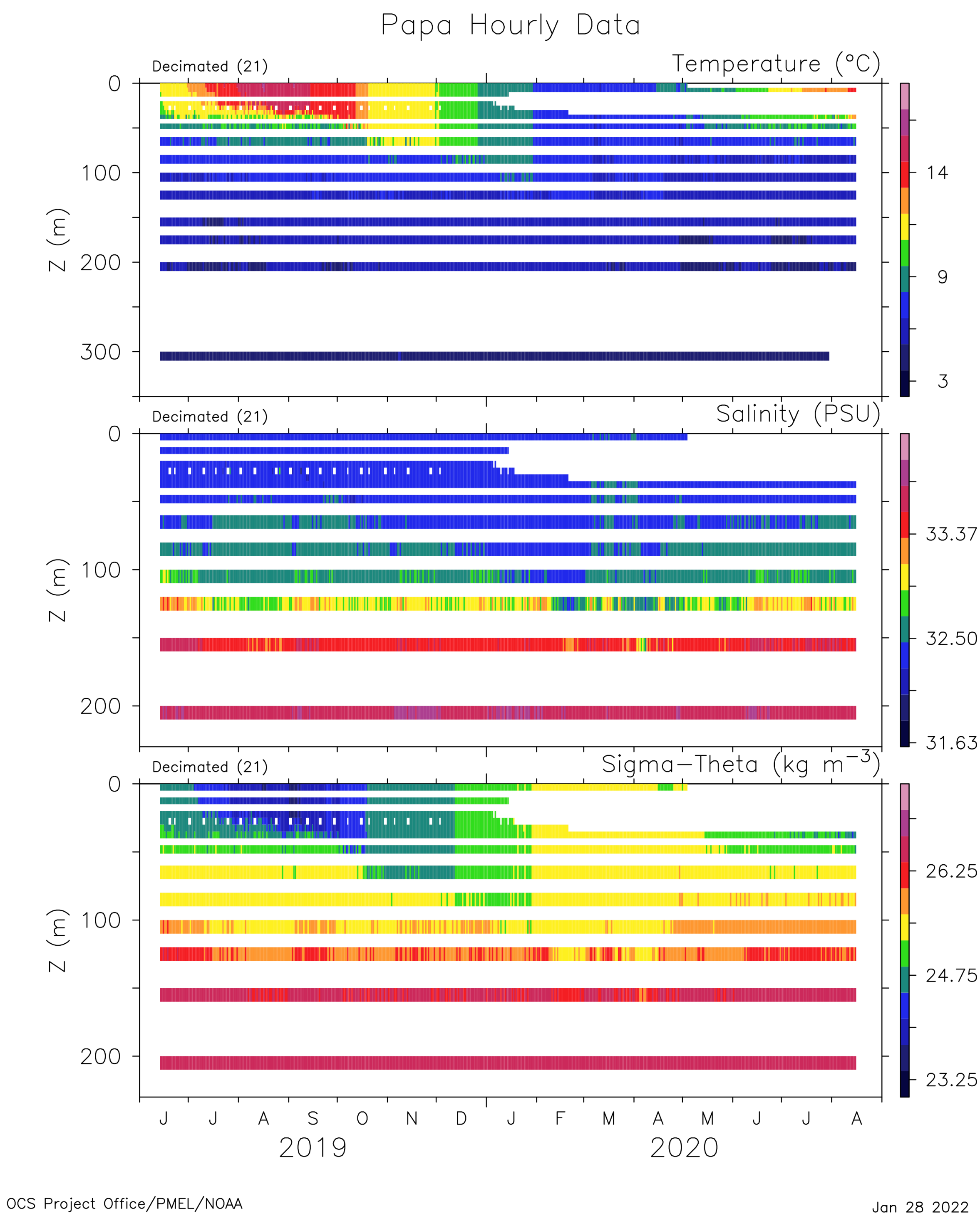


**Figure B 3: PA013 subsurface temperature, salinity, and density at hourly resolution (decimated).**

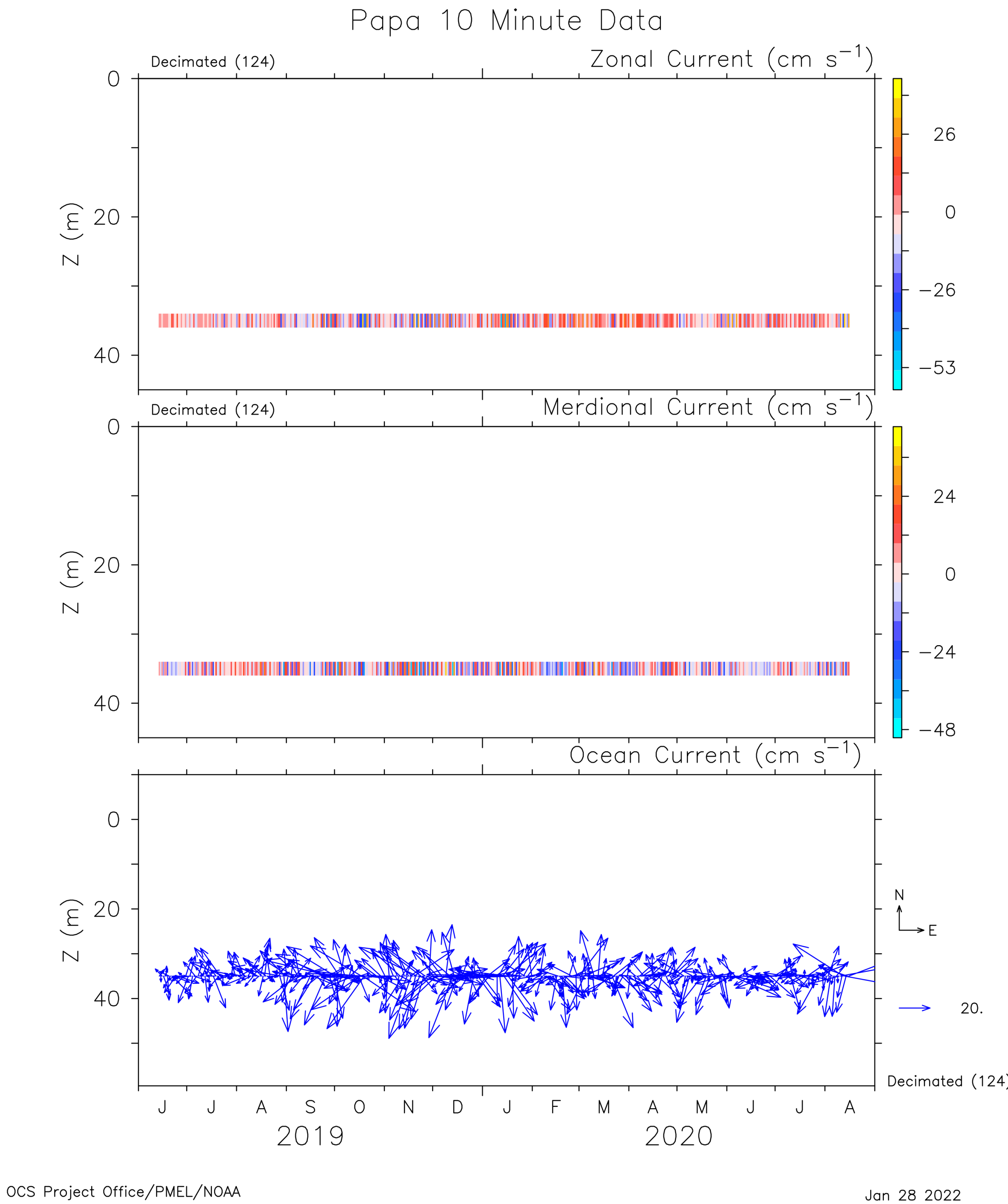


**Figure B 4: PA013 Aquadopp current meter data. Only realtime (hourly) data was available at 15m (not shown here), which was returned with a cracked/flooded housing.**

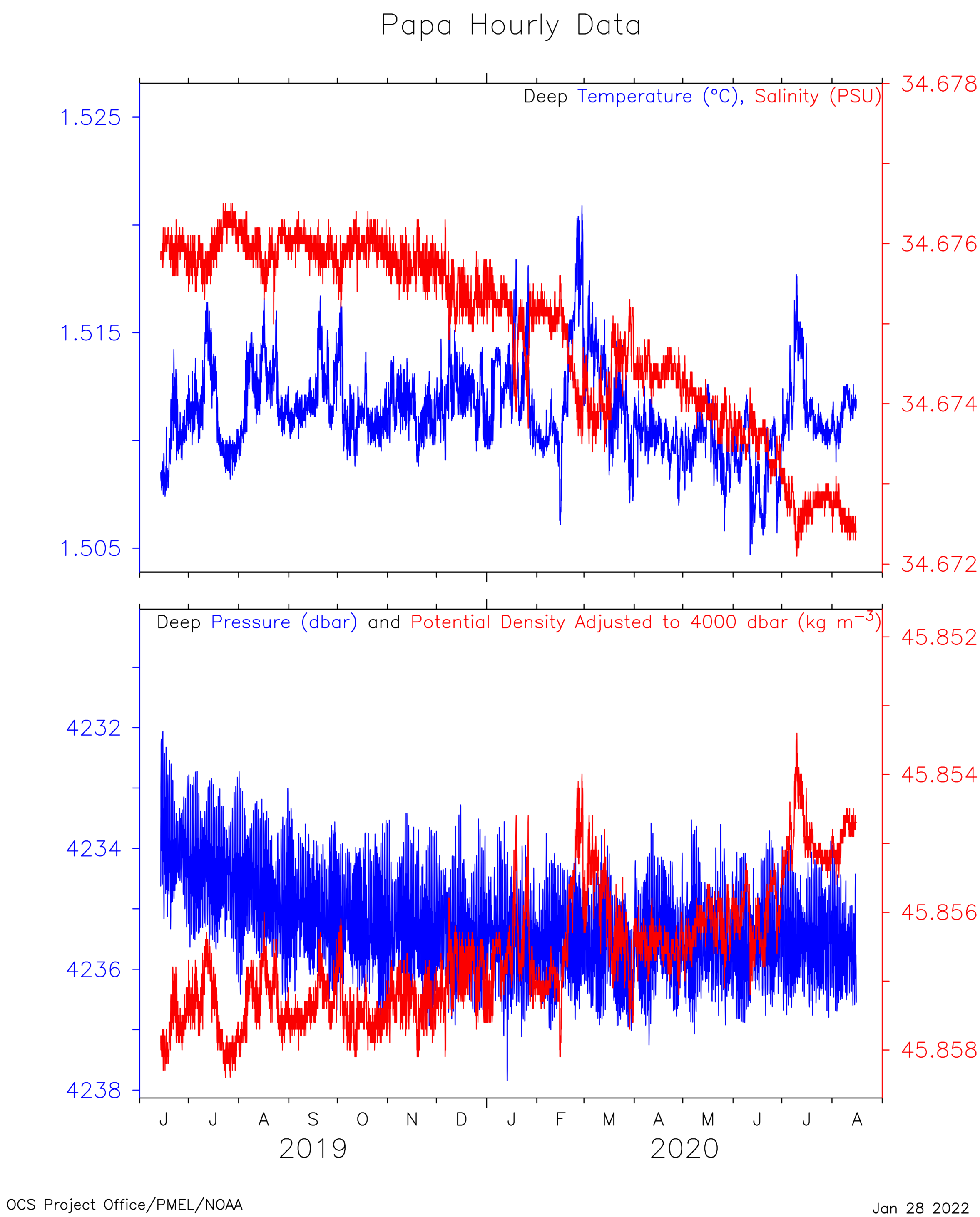


**Figure B 5: Deep Seabird temperature, salinity, pressure, and density.**

# APPENDIX C: Secondary Instrument High Resolution Data Plots

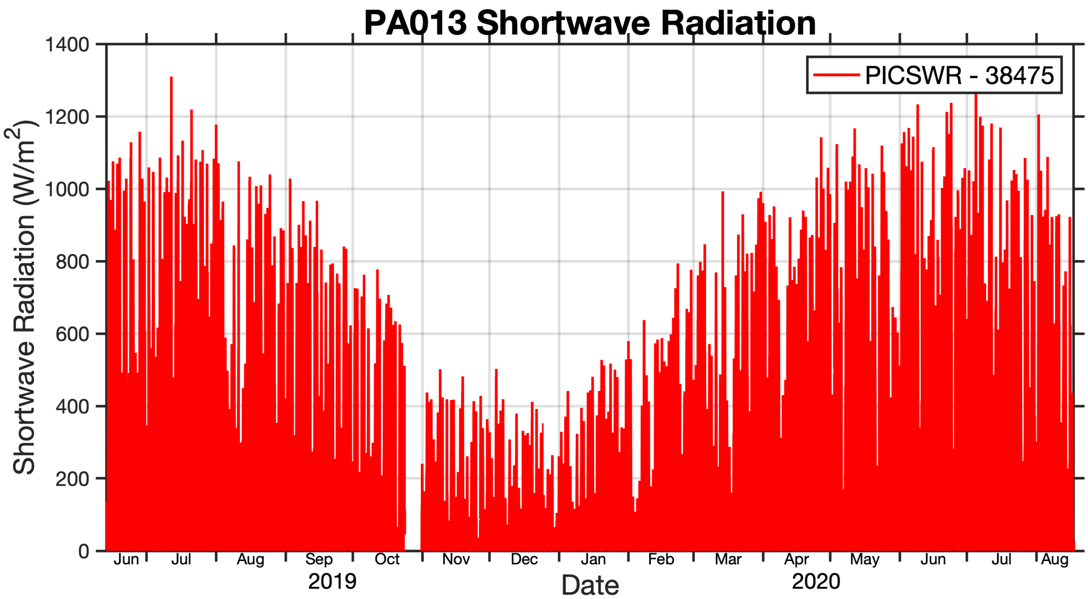


Figure C 1: Secondary (TFlex Eppley PSP) shortwave radiation sensor.

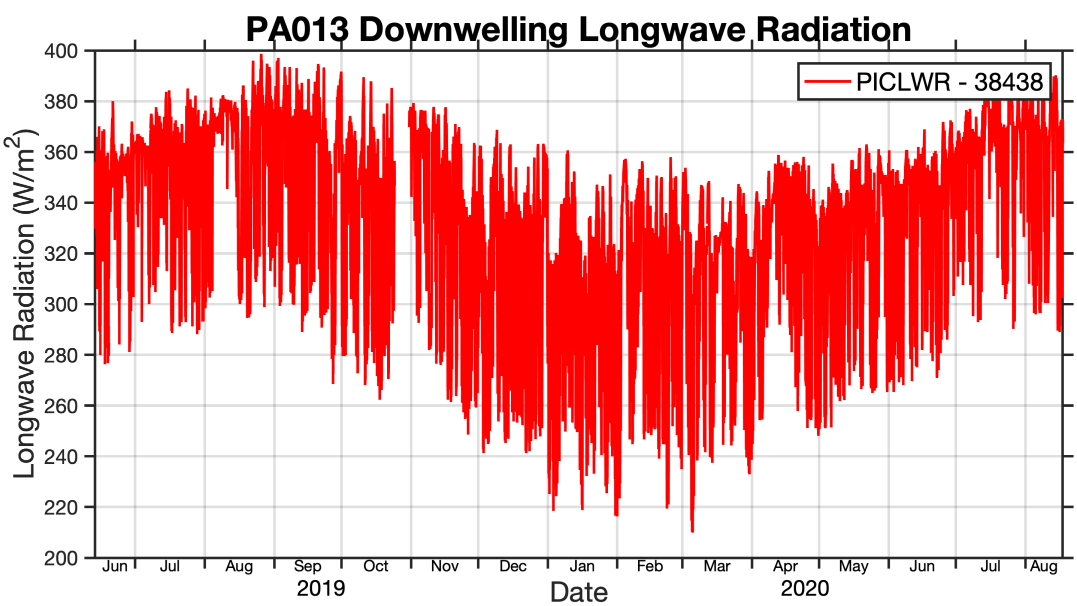


Figure C 2: Secondary (TFlex Eppley PIR) longwave radiation sensor.

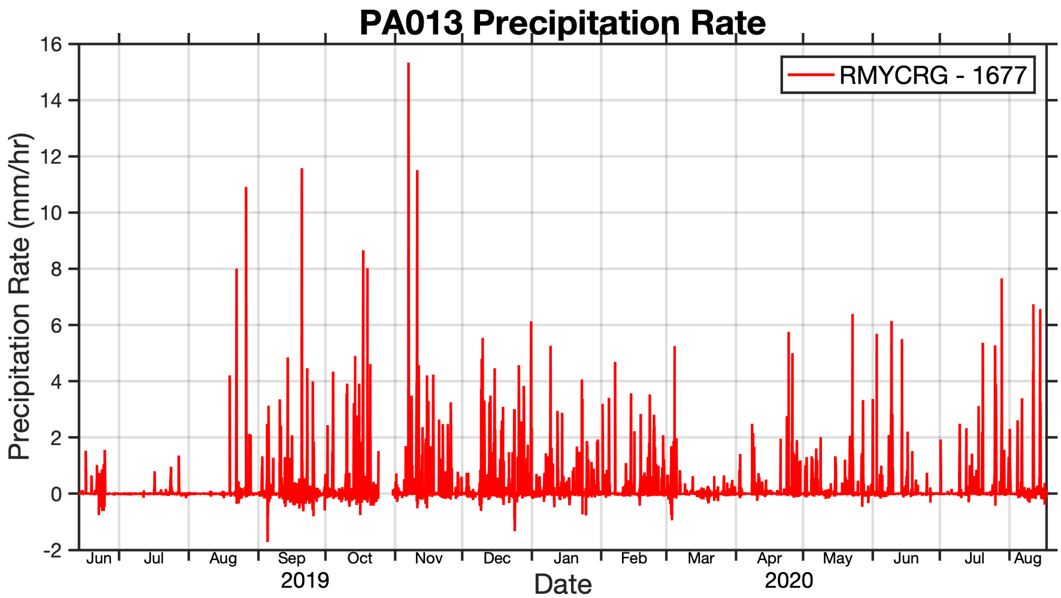


**Figure C 3: Secondary (TFlex RM Young) rain sensor.**

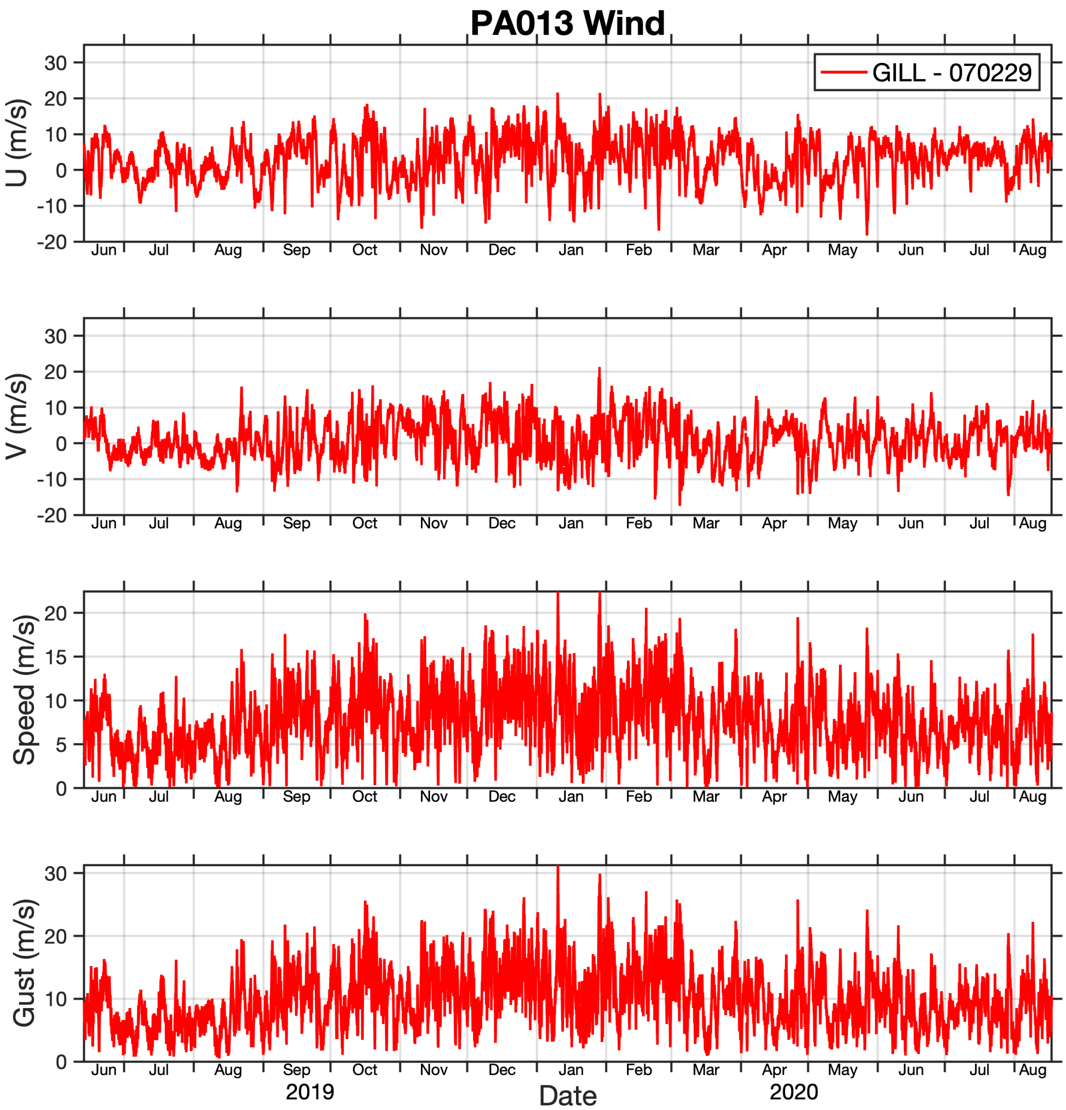


**Figure C 4: Secondary (TFlex Gill) wind sensor.**

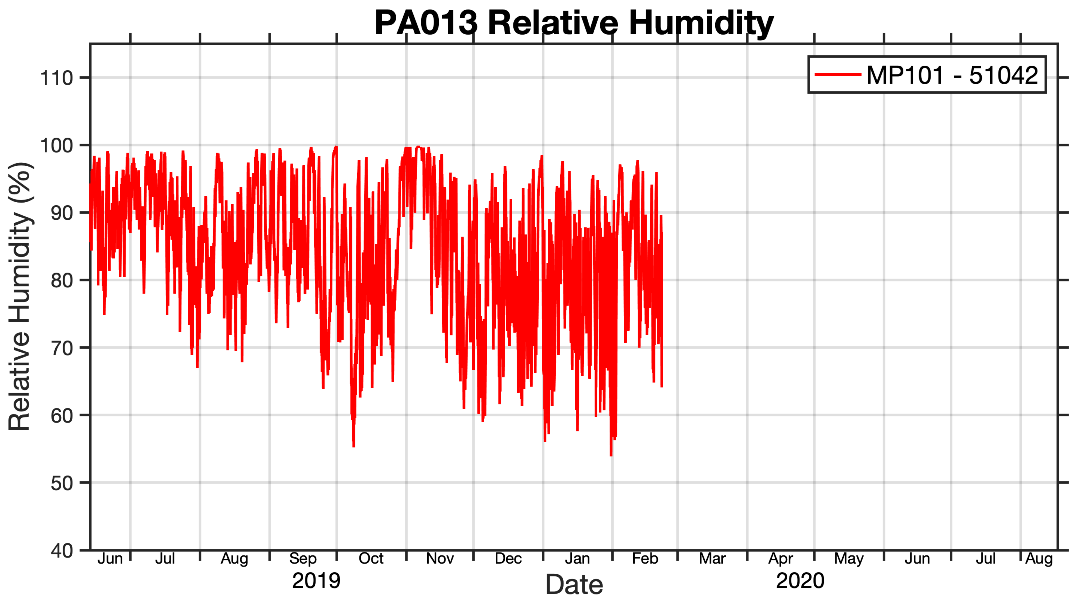


**Figure C 5: Secondary (Flex MP101) relative humidity sensor. The instrument did not have a post-cal due to terminal corrosion, drifted starting in late February (flagged Q5), and dropped precipitously toward 0% in April 2020.**

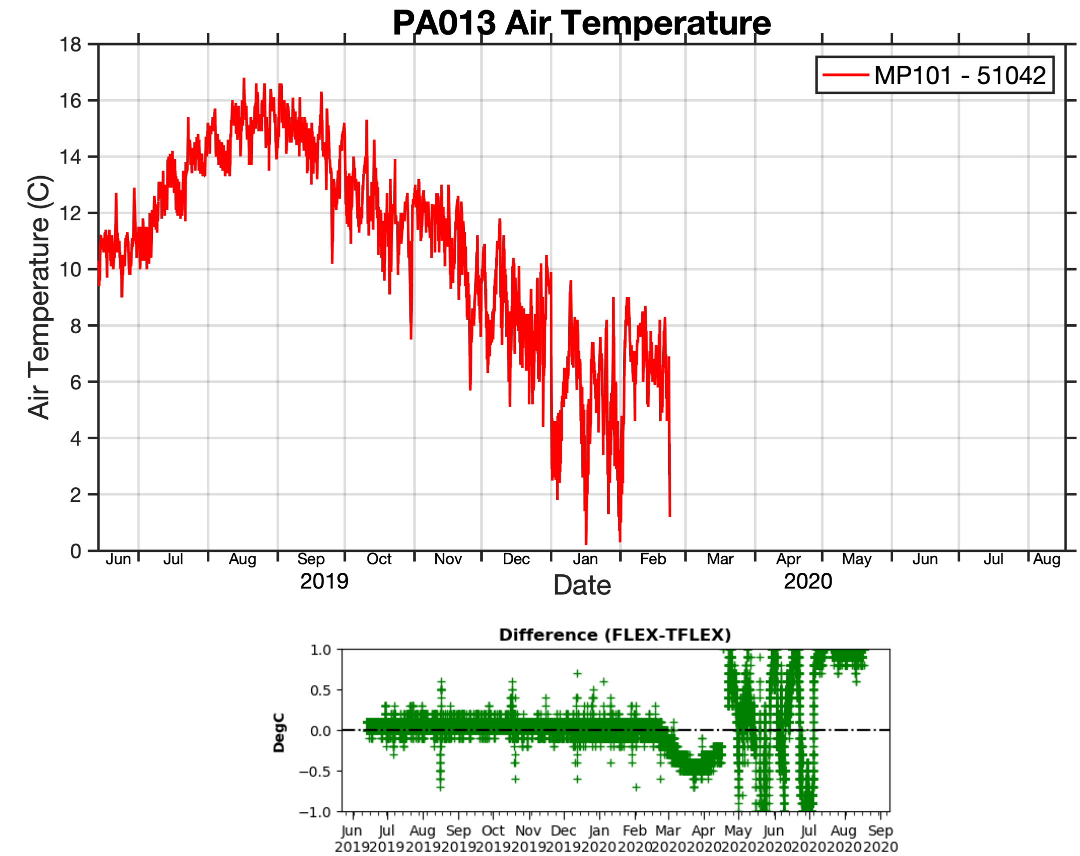


Figure C 6: Secondary (Flex MP101) air temperature sensor. The smaller difference plot below shows the onset of drift in late February and failure of the secondary sensor, which prompted Q5 flags.

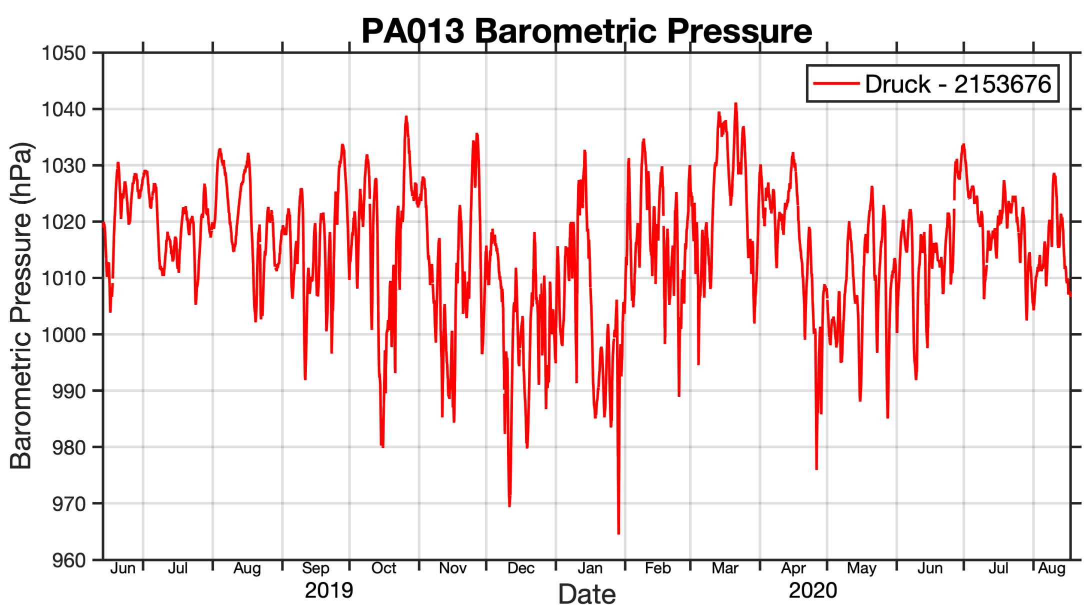


Figure C 7: Secondary (TFlex Druck) barometric pressure sensor. Since TFlex is suspected of not applying calibrations, the calibrations loaded into the TFlex were applied in post-processing.

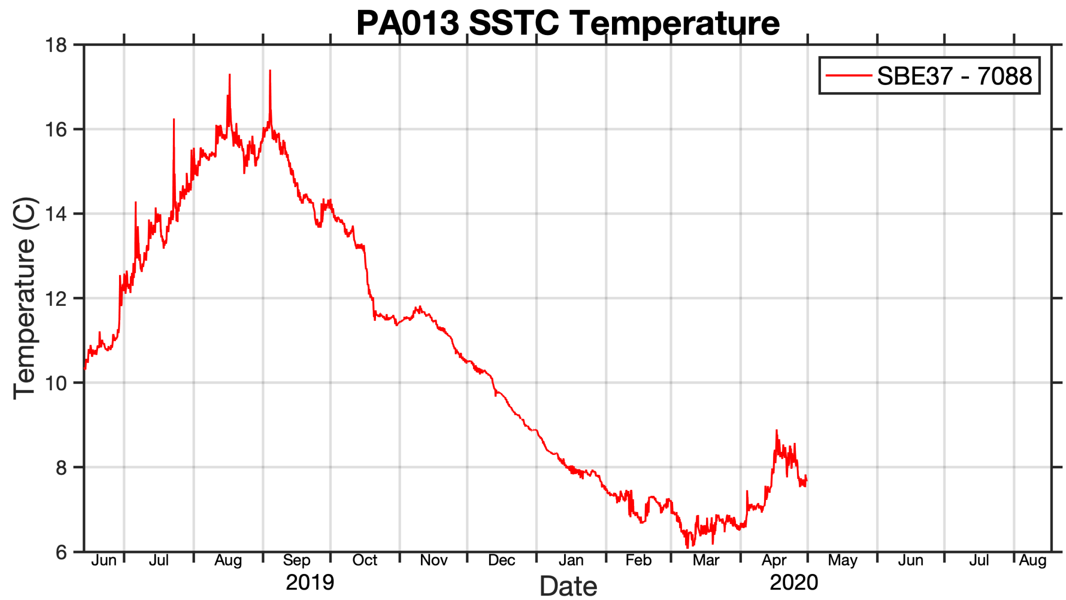


Figure C 8: Secondary (Flex) SSTC Temperature.

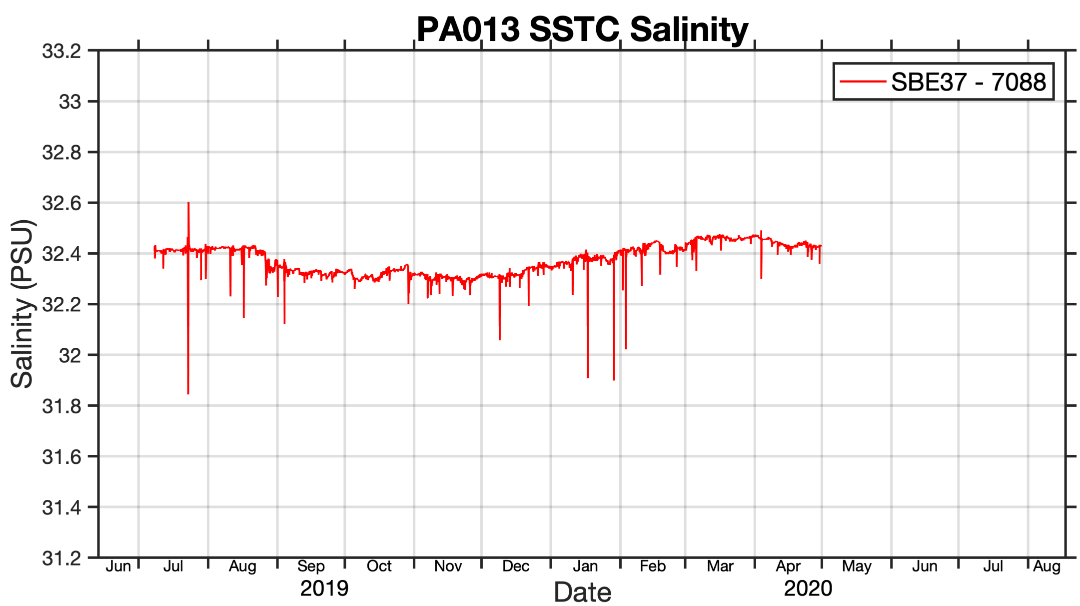


Figure C 9: Secondary (Flex) SSTC Salinity. Minor downward spikes were allowed to pass QC, since these could be brief freshwater lenses. The conductivity cell had issues during the first month, with spikes down to ~1.8 S/m.

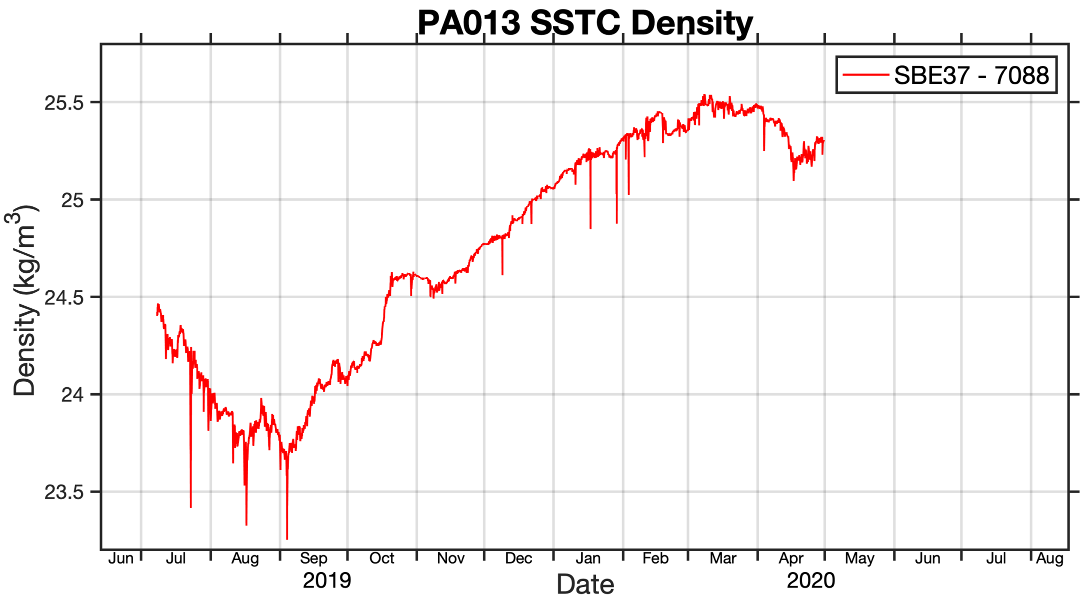


Figure C 10: Secondary (Flex) SSTC Density.