NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

DATA ACQUISITION AND PROCESSING REPORT FOR KE014

Site Name:	Kuroshio Extension Observatory (KEO)
Deployment Number:	**KE014**
Year Established:	2004
Nominal Location:	32.3°N 144.6°E
Anchor Position:	32.29°N 144.61°E (triangulated)
Deployment Date:	July 31st, 2016
Recovery Date:	July 16th, 2017
Project P.I.:	Dr. Meghan F. Cronin
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Data Processors:	N.D. Anderson
Date of Report:	February 4, 2021
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Special Notes:
Severe Tropical Storm Omais (Aug 7, 2016) & Typhoon Lionrock (Aug 29, 2016) passed close to KE014. Lionrock contributed notably to sensor damage.

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Data Acquisition and Processing Report for OCS Mooring KE014

1.0 Mooring Summary

The NOAA Ocean Climate Stations reference mooring at the Kuroshio Extension Observatory (KEO) site was established with the deployment of the KE001 mooring in June 2004. The 2004 deployment was part of the first year of the two-year Kuroshio Extension System Study (KESS). At the conclusion of KESS, a partnership with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) was formed.

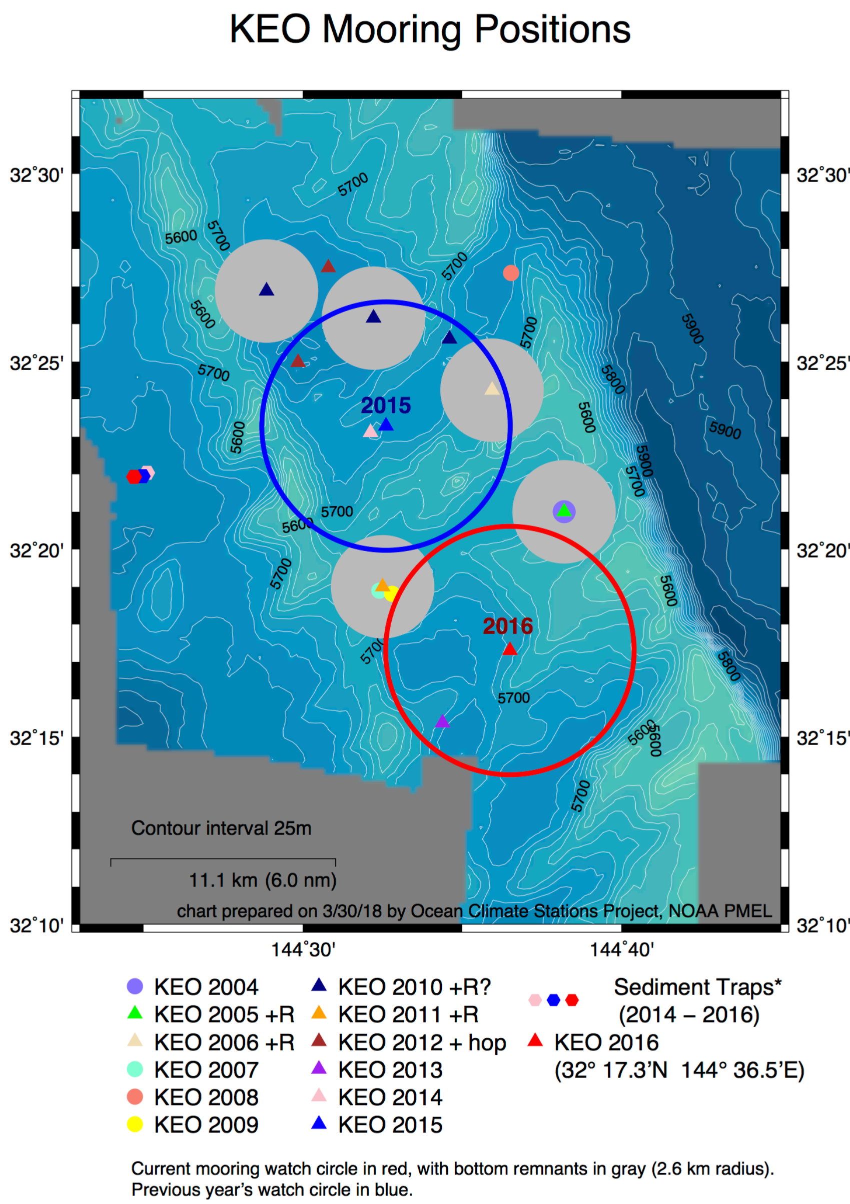

Figure 1: KEO regional map, with the KE014 (red triangle) and JAMSTEC sediment trap (red hexagon).

KE014 experienced close passes by severe tropical storm Omais and Typhoon Lionrock. Redundancy kept data streams mostly operational, but many sensors were destroyed.

KE014 was the 13th deployment at the KEO site (the KE004 name was given to a buoy deployed at the nearby JKEO site, maintained by JAMSTEC). With funding from NOAA's Climate Observation Division of its Climate Program Office, KE014 was deployed on July 31, 2016 and recovered on July 16, 2017 by the M/V BLUEFIN. The captain and crew of the BLUEFIN are gratefully acknowledged.

1.1 Mooring Description

The KE014 mooring was a slack-line mooring, with a nominal scope of 1.4. Non-rotating 7/16" (1.11cm) diameter wire rope, jacketed to 1/2" (1.27cm), was used in the upper 700m of the mooring line. Plastic fairings were installed on the wire rope from 1m – 150m and 240m – 350m. The remainder of the mooring line consisted of plaited 8-strand nylon line, spliced to buoyant polyolefin, as shown in Figure 3. There were 18 glass balls in line above the acoustic release. The 8,240lb (3,738kg) anchor was fabricated from scrap railroad wheels.

The upper portion of the mooring was kept fairly vertical by using a reverse catenary design, but less so than with taut-line moorings. Since instrument depths change on a slack line mooring, most KEO instruments measure pressure. Interpolated pressures are used in salinity calculations where no pressure measurements exist.

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.

A CO_2 flux monitoring system was also deployed on the KE014 mooring, in collaboration with the PMEL Carbon Group. KE014 also included a University of Washington Passive Acoustic Listening (PAL) device at 200m, which again fell from its mount during the yearlong deployment. OCS is not responsible for the acquisition or processing of these data, and no further discussion of these systems are included in this report.

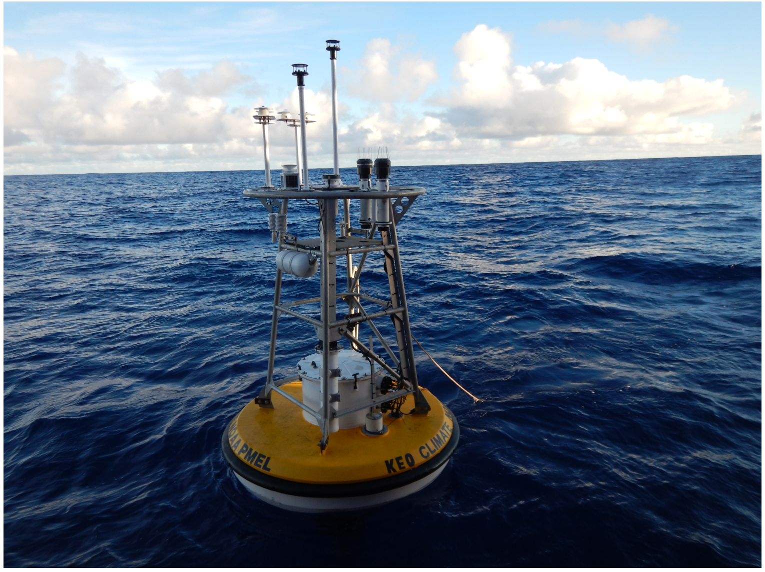

Figure 2: KE014 as deployed.

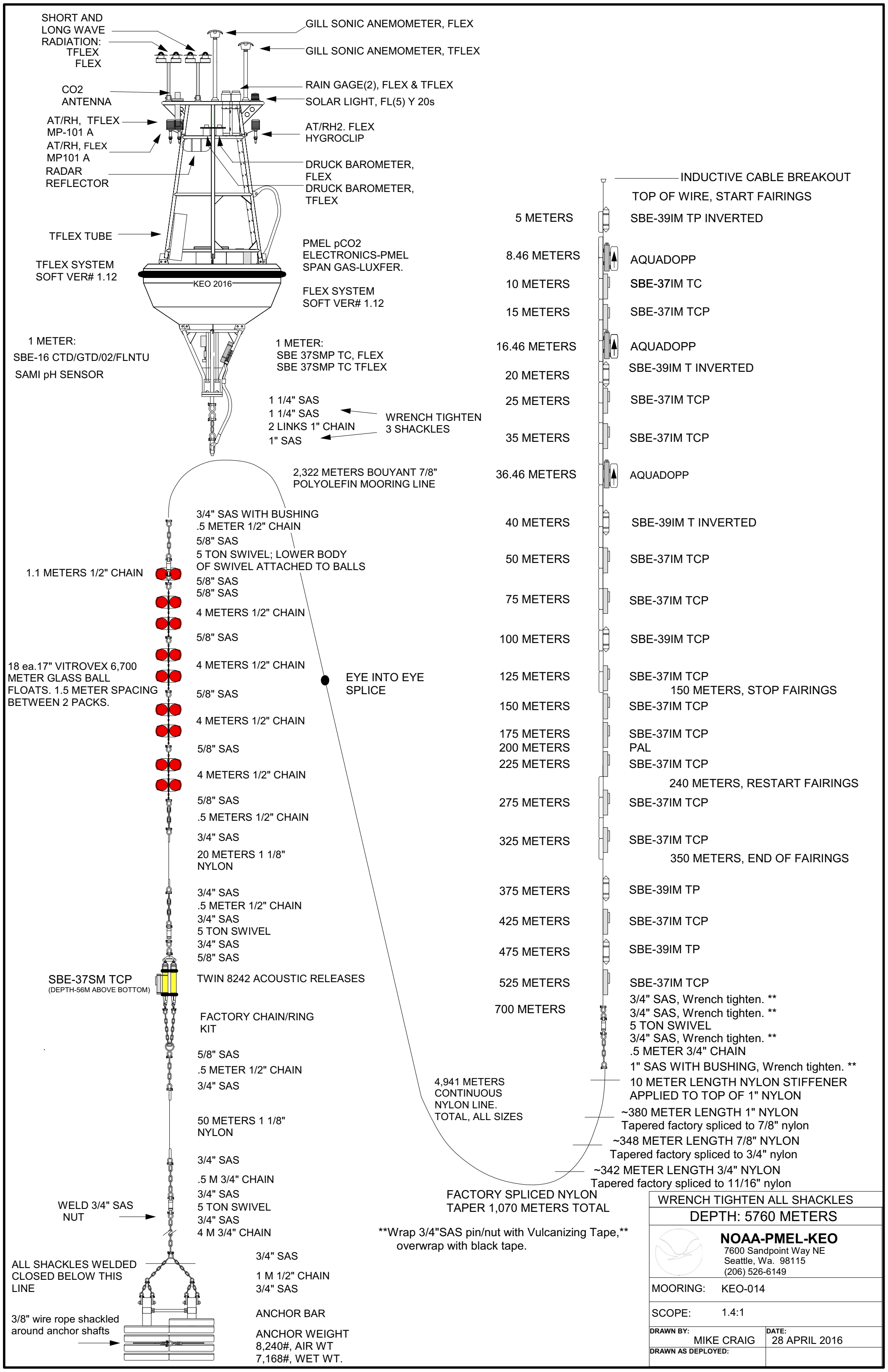

Figure 3: KE014 mooring diagram.

1.2 Instrumentation on KE014

The following instrumentation was deployed on KE014. 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:		**KE014**			
Met Sensors		**Model**	**Serial #**		**Notes**
Height	Acquisition	**FLEX**	0006	4/7	
2.6m	ATRH	Rotronics MP-101A	58365		
2.6m	ATRH2	Rotronics HygroClip	61365505		
4.2m	Wind	Gill	051414		
2.4m	BP	Druck	2153585		
3.1m	Rain	RM Young	1628		
3.6m	SWR	Eppley PSP	35777		
3.6m	LWR	Eppley PIR	37075		
	Acquisition	**TFLEX**	2006		
2.6m	ATRH	Rotronics MP-101A	133374		
3.8m	Wind	Gill	08170010		
2.4m	BP	Druck	4252470		
3.1m	Rain	RM Young	749		
3.6m	SWR	Eppley PSP	35978		
3.6m	LWR	Eppley PIR	37080		
CO2	Electronics	PMEL	0029		
	Span Gas	Luxfer	JB03202		Spare Deployed
Subsurface Instrumentation					
Bridle		**Model**	**Serial #**		**Notes**
1m	SST/C	SBE37SMP - TC	4562		Flex
1m	SST/C	SBE37SMP - TC	11552		TFLEX, AA batteries
1m	pH	Sami	P0016		CO2
1m	SST/C	SBE16+V2	6885		CO2
1m	Oxygen	Optode	1544		Attached to CO2 SBE16+
1m	Fluorescence	ECO FLNTUS	2093		Attached to CO2 SBE16+
1m	Gas Tension	GTD	122464		Attached to CO2 SBE16+ (owned by UW)
Depth		**Model**	**Serial #**	**IM ID**	**Notes**
5m	TP	SBE39IM-TP	4861	01	Inverted
8.46m	ADCM	AquaDopp	12241	02	
10m	TC	SBE37IM - TC	7793	03	
15m	TCP	SBE37IM - TCP	7102	04	
16.46m	ADCM	AquaDopp	6290	05	
20m	T	SBE39IM-T	3285	06	Inverted, New Batteries @ deployment
25m	TCP	SBE37IM - TCP	7103	07	
35m	TCP	SBE37IM - TCP	7104	08	
36.46m	ADCM	AquaDopp	6808	09	
40m	T	SBE39IM-T	4857	10	Inverted, Spare Deployed
50m	TCP	SBE37IM - TCP	7105	11	
75m	TCP	SBE37IM - TCP	7106	12	
100m	TCP	SBE37IM - TCP	7107	13	
125m	TCP	SBE37IM - TCP	7108	14	
150m	TCP	SBE37IM - TCP	9413	15	AA batteries
175m	TCP	SBE37IM - TCP	7781	16	
200m		PAL	DUNLIN		UW APL
225m	TCP	SBE37IM - TCP	7782	17	
275m	TCP	SBE37IM - TCP	7783	18	
325m	TCP	SBE37IM - TCP	7784	19	
375m	TP	SBE39IM-TP	4360	20	
425m	TCP	SBE37IM - TCP	7091	21	
475m	TP	SBE39IM-TP	4378	22	
525m	TCP	SBE37IM - TCP	7092	23	
700m	End of Wire				
Release	TCP	SBE37SM - TCP	11926	-	AA batteries

Table 1: Instruments deployed on KE014.

Since 2007, the measurement point for bridle sensors, including the 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 all bridle sensors is stated as 1m.

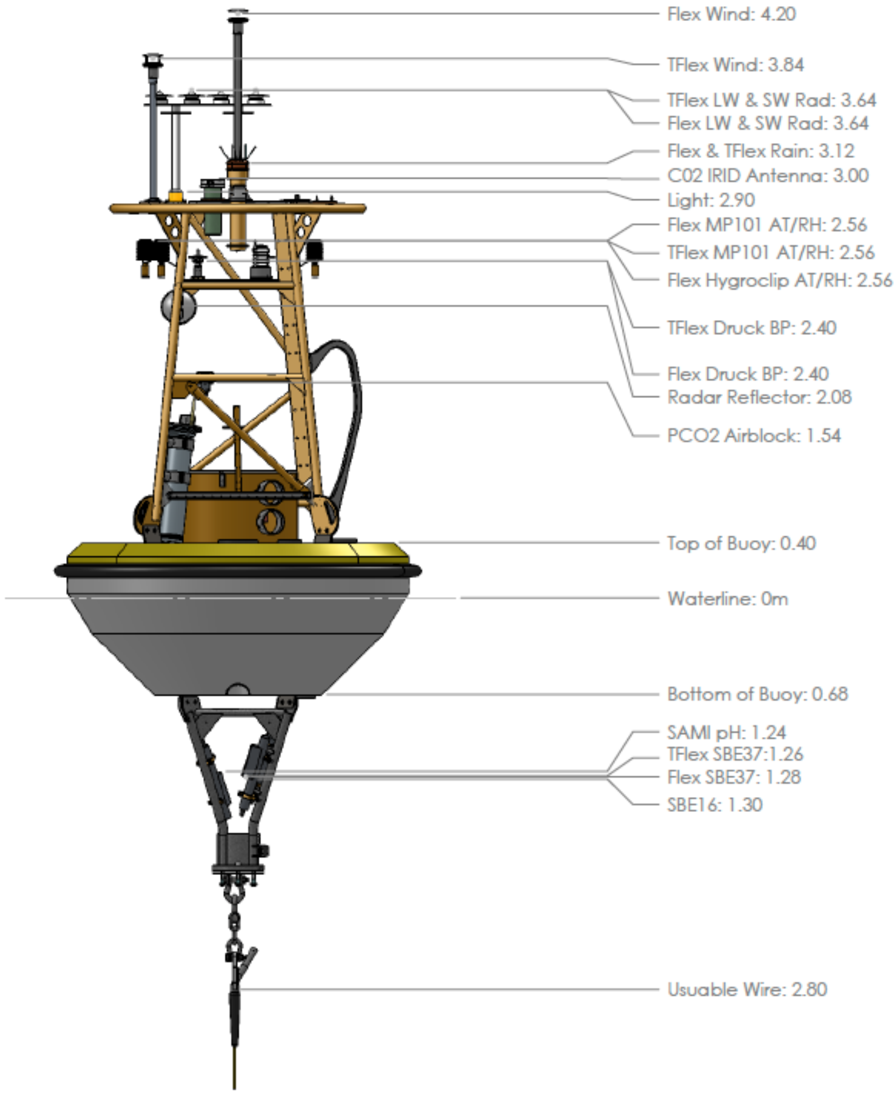

Figure 4: Buoy diagram showing bridle arrangement. The SBE16 package contains a suite of sensors.

2.0 Data Acquisition

Two independent data acquisition systems were deployed on KE014, 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. KE014 was the third KEO mooring to have phased out the ATLAS system and implemented the newer TFlex.

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.

The KEO mooring site is nominally at 32.3°N, 144.6°E. The actual anchor position is different for each deployment, and the slack line mooring has a watch circle radius greater than 5km. For users performing intercomparisons, it may be important to use the actual position of the buoy from the Flex GPS data. Also, depths of the subsurface measurements will change over time on the slack mooring. Depths shown in the delivered KEO files represent the location of the sensor on the mooring line. To determine the true depth of the measurement, use the accompanying pressure time series data.

2.1 Sampling Specifications

The following tables describe the high-resolution sampling schemes for the KE014 mooring, for both the primary and secondary systems. Observation times in data files are assigned to the center of the averaging interval. The Flex system sensors are usually considered primary, but reasoning for any substitutions are described in the relevant sections that follow.

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	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
GPS Position	1 per hr	Instant.	0000, 0100, …	1 hr	FLEX

Table 2: Sampling parameters of the primary sensors on KE014.

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	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 Position	1 per 6 hrs	Instant.	0000, 0600, …	6 hr	TFLEX

Table 3: Sampling parameters for the secondary sensors on KE014.

2.2 Data Returns

Delayed-mode data are returned to the lab post-recovery. These data are evaluated based on the amount of data available against the total amount of data possible for the period.

Data Return Summary (Flex)
2016-07-31 05:46:00 to 2017-07-16 05:27:00

Sensor	Deployed	Obs	Return	
AT1	50398	50054	99.3%	
AT2	50398	4189	8.3%	
RH1	50398	50054	99.3%	
RH2	50398	4189	8.3%	
WIND1	50398	12381	24.6%	
BP1	50398	50054	99.3%	
RAIN1	503981	474216	94.1%	
SWR1	503981	474904	94.2%	
LWR1	503981	475877	94.4%	
Subsurface Temperature Profile				
1m	50398	50398	100.0%	
5m	50398	50398	100.0%	
10m	50398	0	0.0%	* Some Realtime Available.
15m	50398	50398	100.0%	
20m	50398	1185	2.4%	
25m	50398	27849	55.3%	
35m	50398	50398	100.0%	
40m	50398	50398	100.0%	
50m	50398	50398	100.0%	
75m	50398	14844	29.5%	
100m	50398	17319	34.4%	
125m	50398	24607	48.8%	
150m	50398	50398	100.0%	
175m	50398	50398	100.0%	
225m	50398	27492	54.5%	
275m	50398	18263	36.2%	
325m	50398	4217	8.4%	
375m	50398	50398	100.0%	
425m	50398	0	0.0%	** Lost, with no realtime.
475m	50398	50398	100.0%	
525m	50398	50398	100.0%	
5487m	50398	50398	100.0%	
Total	1108756	740552	66.8%	

Subsurface Pressure Profile

5m	50398	50398	100.0%	
25m	50398	27849	55.3%	
35m	50398	40840	81.0%	
40m	50398	50398	100.0%	
50m	50398	50398	100.0%	
75m	50398	14844	29.5%	
100m	50398	17319	34.4%	
125m	50398	24607	48.8%	
150m	50398	50398	100.0%	
175m	50398	50398	100.0%	
225m	50398	27492	54.5%	
275m	50398	18263	36.2%	
325m	50398	4217	8.4%	
375m	50398	50398	100.0%	
425m	50398	0	0.0%	**
475m	50398	50398	100.0%	
525m	50398	50398	100.0%	
5487m	50398	50398	100.0%	
Total	907164	629013	69.3%	

Subsurface Salinity Profile

1m	50398	50398	100.0%	
10m	50398	0	0.0%	*
15m	50398	50398	100.0%	
25m	50398	27831	55.2%	
35m	50398	50356	99.9%	
50m	50398	50398	100.0%	
75m	50398	14844	29.5%	
100m	50398	17319	34.4%	
125m	50398	24607	48.8%	
150m	50398	50398	100.0%	
175m	50398	50398	100.0%	
225m	50398	27492	54.5%	
275m	50398	18263	36.2%	
325m	50398	4217	8.4%	
425m	50398	0	0.0%	**
525m	50398	50398	100.0%	
5487m	50398	50398	100.0%	
Total	856766	537715	62.8%	

AQD Current Velocity

8m	50398	28248	56.0%
16m	50398	35148	69.7%
36m	50398	50398	100.0%
Total	151194	113794	75.3%

Data Return Summary (TFlex)
2016-07-31 05:46:00 to 2017-07-16 05:27:00

Sensor	Deployed	Obs	Return
AT1	50398	50376	100.0%
RH1	50398	50376	100.0%
WIND1	50398	6789	13.5%
BP1	50398	26464	52.5%
RAIN1	503981	499001	99.0%
SWR1	503981	499724	99.2%
LWR1	503981	500343	99.3%
SST1	50398	50398	100.0%
SSC1	50398	50398	100.0%
SSS1	50398	50398	100.0%

2.3 Known Sensor Issues

Relative humidity sensors both failed post-calibrations at PMEL. Lower quality flags were assigned. Air temperatures were unaffected, and both passed their post-calibrations.

Wind sensors both failed at different times, and resulted in a long gap from October 2016 until the KE015 buoy was deployed in July 2017. Repair operations had been considered, but no viable options presented. Further details about the wind sensors appear in Section 3.2.1.

The shelf holding the barometric pressure sensors in the middle of the buoy was found forced up against the top shelf. Typhoon Lionrock is likely responsible for this damage. Both barometers continued to report data, but drifted apart. The Flex sensor was designated primary after comparing with model data, observing noise in the TFlex time-series, and water damage in the recovered TFlex sensor.

The Aquadopps had moderate returns on KE014. The 8m instrument slid to 10m, and had the lowest current meter data return at 56%. Pressures indicate the instrument dislodged on January 29th, 2017, and lower quality flags (Q4) are assigned after this point. External surfaces were not damaged, so it is unclear if the descent contributed to the early battery depletion. Dead batteries were also found in the 16m instrument, which had a data return of 69.7%. The 36m instrument functioned throughout the deployment.

The 425m instrument was missing, and no realtime data was received. While longline was noted at 200 - 400 m, the lack of realtime data hints that the instrument could have dislodged shortly after deployment.

Dead batteries were found on several Seabird instruments. Data from instruments at 20m, 25m, 75m, 100m, 125m, 225m, 275m and 325m all ended early. S/N 7793, deployed at 10m, had 0% data return despite having recorded 29,032 samples. When examined, the entire hex record contained 0's, and Seabird could not recover any data. Realtime data at 10m exist until February 12, 2017, so these data will remain posted on the OCS webpage and in OceanSITES. The 225m instrument had timestamp offsets of just under 2 minutes, and was handled by aligning data to the standard 10-minute grid.

The 35m instrument's pressure record ended early compared to temperature and conductivity. Pressures were interpolated from surrounding depths, so that the salinity calculations could proceed.

A University of Washington passive acoustic listening device (PAL) was deployed on KE014 at 200m. It broke free from its frame, which was still attached to the wire upon recovery. This is the second PAL lost at KEO, and a redesigned frame is recommended if deployed again.

3.0 Data Processing

Processing of data from OCS moorings is performed after the data are returned to PMEL. 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 of 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 instrument 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 KEO is a slack-line mooring with a long scope, the buoy has a watch circle radius of more than 5km. When using KEO data in scientific analyses, it may be appropriate to consider the actual GPS position of the buoy rather than its nominal position. Gross error checking was performed to eliminate values outside the watch circle. The positions were used to determine buoy velocities for processing current meter data, as described in Section 3.3.5.

3.2 Meteorological Data

Most primary meteorological sensors on KE014 remained functional at or near 100% throughout the deployment. Some TFlex instruments were considered primary in this deployment due to higher data returns or failed Flex instrument post-calibrations.

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: http://dods.ndbc.noaa.gov/thredds/catalog/oceansites/DATA/KEO/catalog.html

The KE014 buoy had secondary air temperature, relative humidity, wind, rain, air pressure, and radiation sensors. The only tertiary sensor deployed was a Rotronic HygroClip attached to the Flex system, measuring air temperature and relative humidity. These tertiary data were not distributed in any format.

3.2.1 Winds

Both wind sensors failed early on KE014, and no repair cruise was possible. The TFlex wind failed in mid-October, but was flagged Q5 after September 17, 2016, due to visibly apparent noise. Severe water intrusion was present, and no repairs were possible, so the instrument was retired. The Flex wind failed the following month on October 25, 2016, presumably when the top plate on the Flex wind sensor broke off. No post-calibrations were performed due to the damage sustained on both wind sensors.

In rare instances where the wind speeds exceeded the gust speed (the highest 3 second sustained wind speed), Q5 flags were applied, as this indicates that either the gust or the speed is incorrect. No separate flag exists for wind gust measurements, so to prevent poor gust measurements from being distributed, a gross error threshold of 5 m/s (between the Flex and TFlex winds) was used to eliminate bad data.

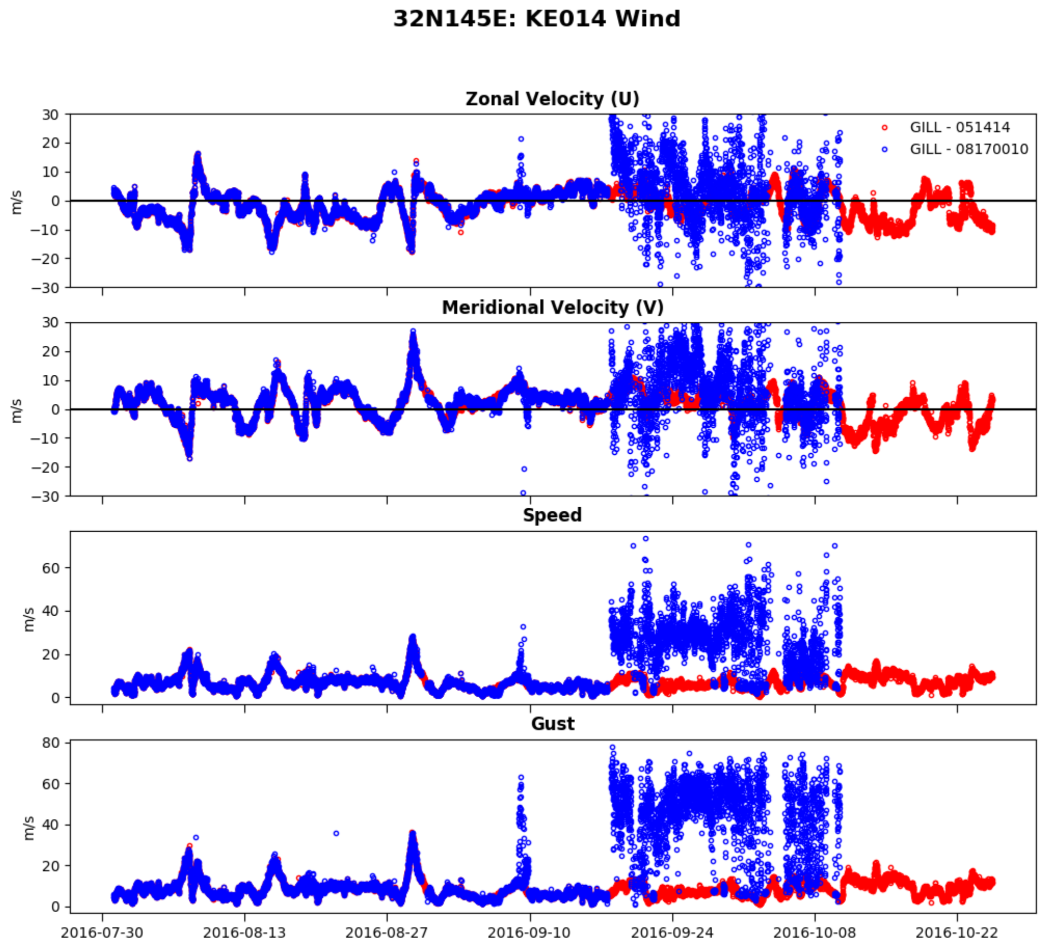

Figure 5: Raw delayed-mode wind data showing different modes of failure.

Figure 6: Flex wind sensor, with missing top plate.

3.2.2 Air Temperature

The primary and secondary air temperature sensors performed well (mean Flex – TFlex difference <0.05°C) throughout this deployment, and standard quality flags of Q2 were assigned. The Hygroclip test sensor was an exception, returning with a bent mount and missing shield. A 5-10 degree low bias in Hygroclip temperatures coincided with the passage of Typhoon Lionrock, and the drift became worse with time. These data are not distributed in any format, but Figure 7 shows the extensive damage to the sensor. The TFlex sensor was designated primary to match the primary relative humidity sensor.

Figure 7: Destroyed Hygroclip with a bent mount and missing shield.

3.2.3 Relative Humidity

Both relative humidity sensors failed their post-calibrations, so are distributed with Q4 (lower quality) flags. The TFlex RH was only slightly over the failing threshold during post-calibration. The values from the TFlex RH were also in closer agreement with the previous deployment, so the TFlex sensor was considered primary. Toward the deployment's end, both sensors drift slightly above 100%, but the TFlex sensor remained within specifications (±2.7% RH) and was considered acceptable, while the Flex sensor occasionally exceeded 103% (out of specification, even if RH was 100%).

Linear calibration coefficients are calculated at the lab and are programmed into the acquisition systems, which apply the coefficients during testing and throughout the deployment. As a test in post-processing, these calibrations were unapplied in an attempt to determine if the maximum values (or "saturation ceiling") would be reduced to 100% or less. This test only marginally reduced the saturation ceilings of the relative humidity sensors, and because the linear calibration is meant to maximize accuracy over the calibration points from 45 to 95%, the calibrations were left applied.

3.2.4 Barometric Pressure

Atmospheric pressure was measured using a Druck BP sensor on both Flex and TFlex. The TFlex sensor was damaged during Typhoon Lionrock on August 29th. The top portion of the TFlex sensor was smashed, with indications of water intrusion. The TFlex data became offset from the Flex sensor by approximately +4mb during typhoon Lionrock, and was flagged Q5 from that point forward, including throughout regions of severe noise in January and February. The secondary TFlex sensor unexpectedly self-corrected to within 0.1 mb of the Flex BP in the last week of the deployment, but the decision to leave the final records as Q5 was maintained due to the recovered condition of the sensor. No post-cruise analysis (e.g. post-cal or otherwise) was performed on the TFlex sensor due to the damage it sustained. When pre-calibration vs. post-calibration coefficients (calibrations in preparation for a different deployment) were applied to the Flex sensor, the mean difference was only 0.03mb, indicating calibration consistency.

Comparisons to the Global Forecast System (GFS) during Typhoon Lionrock also confirmed the quality of Flex sensor data, and the Flex BP was considered the primary sensor. No damage was noted to the Flex sensor, but the entire shelf that holds the Druck sensors had been forced up against the top plate of the buoy. Flex system data quality does not appear to have been affected, but the bent shelf could have had a minor effect on flow around the sensor.

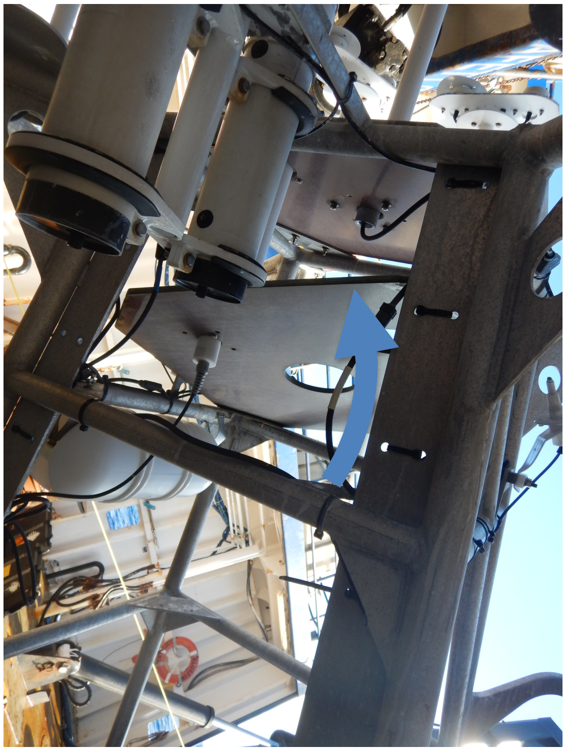

Figure 8: Barometric pressure sensors sit on the middle shelf, which was broken and forced upward.

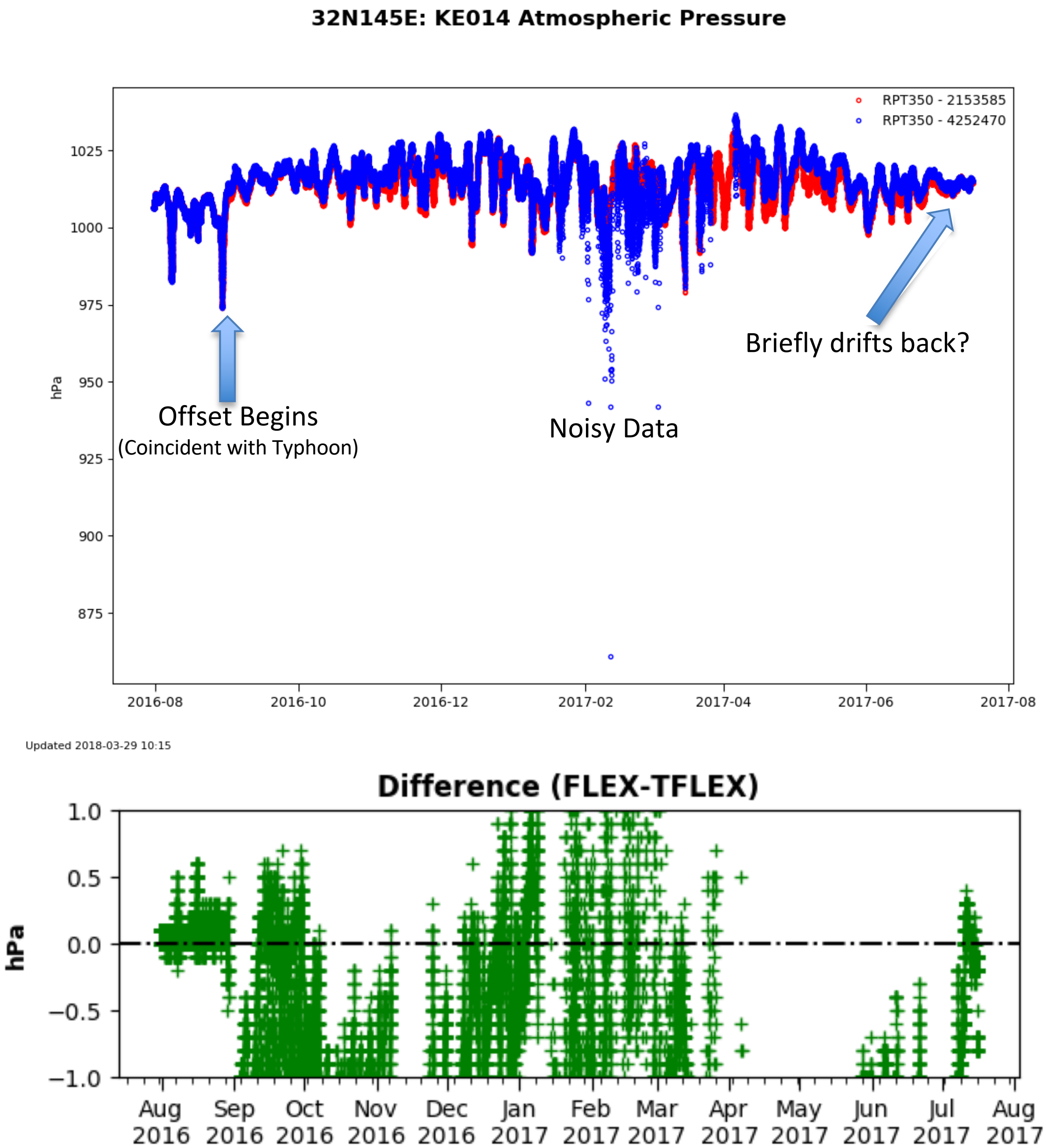

Figure 9: Unflagged barometric pressure time-series (top) and difference plot (bottom).

3.2.5 Rain

Rain data are acquired as accumulation values, and then converted to rain rates during processing. Rainfall data are collected using an 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 or as part of calculations for data products. For example, the wind correction is applied in the precipitation and evaporation minus precipitation "Flux" files served from the OCS flux display-and-delivery page: https://www.pmel.noaa.gov/oca/data/fluxdisdel/. 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 KEO, the user is strongly encouraged to apply an appropriate wind correction or access these data from the flux disdel page above.

The TFlex rain gauge (SN 749) passed its calibration on 1/4/2018, but bench tests showed instability, and the unit failed 4 subsequent calibrations before passing (presumably for redeployment). TFlex rain data were assigned Q5 (removed) starting October 4th, 2016, when accumulations remained flat while the Flex rain gauge indicated a rain event. The Flex rain gauge (SN 1628) passed a calibration on 1/4/2018, but subsequently failed two additional calibrations. It is unknown why redundant database entries appeared, but in the absence of a failure, and since the initial postcal passed, standard qualities were assigned to the primary Flex data.

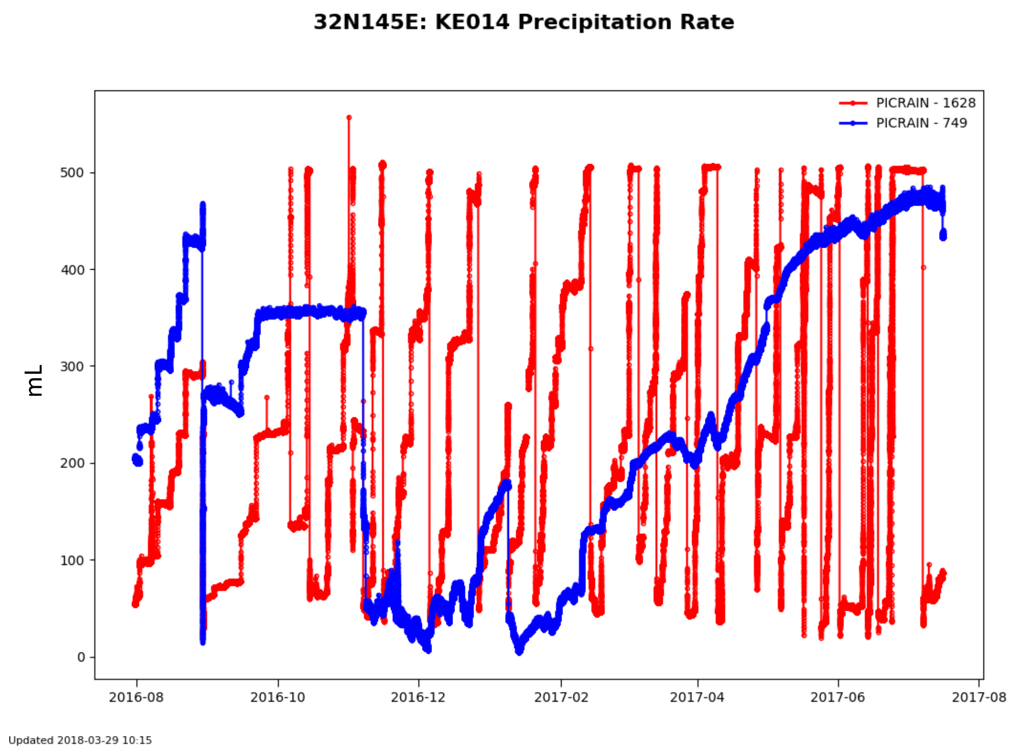

Figure 10: Unprocessed KE014 rain gauge accumulations. The TFlex rain failure was evident by October.

Heavy quality control was required for rain data, at least partially due to Typhoon Lionrock. Automated routines detected data anomalies that were reviewed and processed manually. Some uncertainty occurred during the typhoon, where accumulations were interrupted by siphons and discontinuous jumps (potentially sea-spray or water splashing out). An effort was made to smooth the chaotic accumulations into a continuous record, and some interpolation and adjustments to accumulation values were required.

In the figures below, raw accumulation records appear as yellow (Flex) and green (TFlex), with the flagged accumulations in red (Flex) and blue (TFlex). Spikes, gaps, and incomplete siphons are removed or corrected in the flagged records.

This mooring's rain data were processed using the same standard process as other deployments, but required more detailed attention to siphons and unrealistically large jumps in accumulation. GTMBA data processor C. Fey is acknowledged for providing feedback associated with the atypical accumulation events witnessed with this deployment.

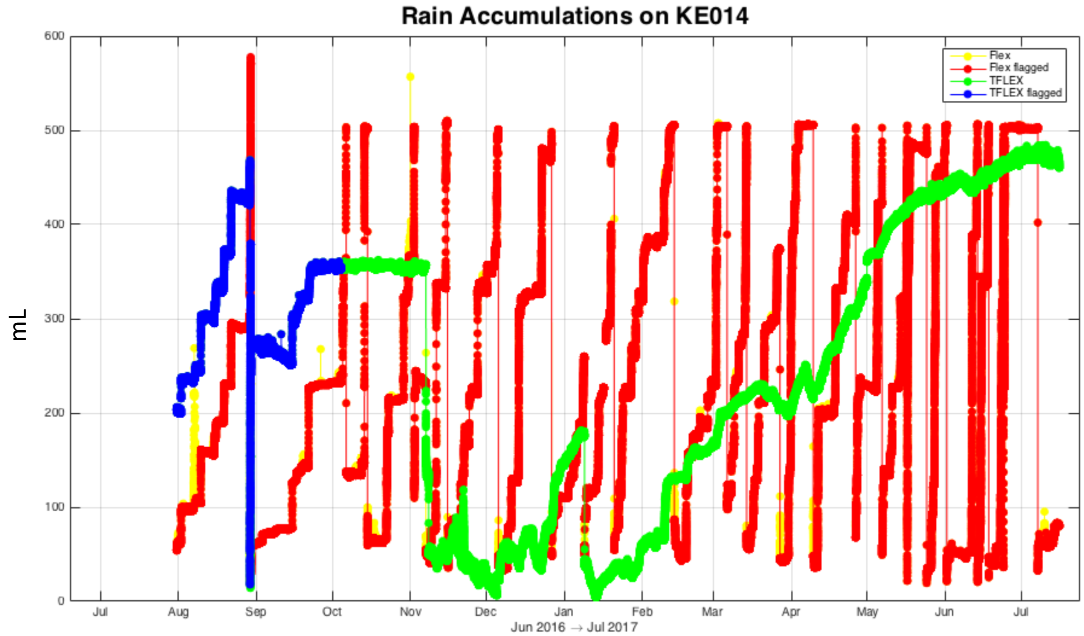

Figure 11: Flex and TFlex rain gauge accumulations from mid-processing. Typhoon Lionrock is a prominent feature, as well as the TFlex failure.

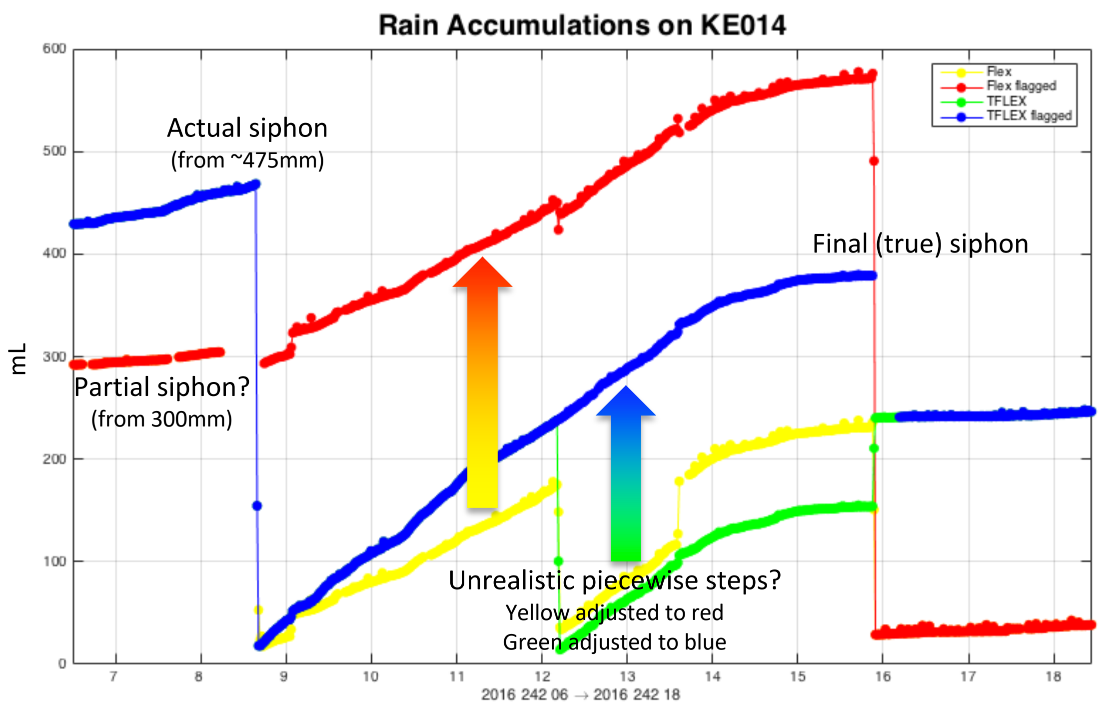

Figure 12: Rain gauge processing during Typhoon Lionrock. Data were adjusted to be more continuous, as immediate decreases and increases produce unrealistic spikes of single-minute negative and positive rain rates if left unadjusted.

3.2.6 Shortwave Radiation

The primary shortwave radiation sensor was chosen based on a system developed by Kelly Balmes during the summer of 2014, using the following criteria:

- Use the sensor with the higher shortwave daily average (if difference is > 1%)
- Use the FLEX system if all else is similar
- Use the sensor that maximizes the time period of available data

Based on these criteria, the KE014 TFlex shortwave radiometer, which also had the higher data return, was designated primary. Mean daily Flex and TFlex shortwave radiation values were compared, and found to differ by a large 10.3%, despite showing similar values in pre-deployment testing. Flex shortwave radiation was flagged Q4 due to its low bias. The TFlex radiometer measurements aligned with climatology, further justifying its primary classification.

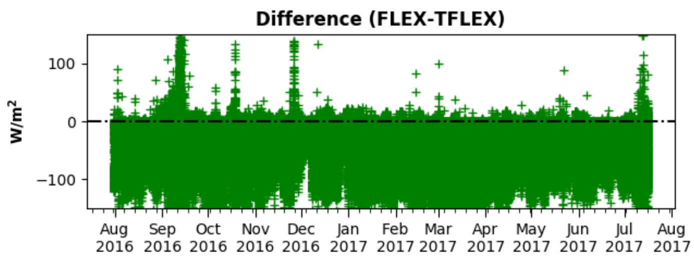

Figure 13: Difference plot comparing shortwave radiation sensors.

Shortwave radiation is processed into hourly and daily averaged values differently than other measurements. Because SWR goes to 0 at night, any substantial number of missing values during the night (day) will bias the data high (low). In keeping with GTMBA processing, the percentage of good high-resolution data for SWR must be at least 87.5% in order to generate an hourly or daily averaged data point. Most other instruments use a 50% threshold for high-resolution data needed to generate hourly and daily averages.

The TFlex shortwave radiation sensor (SN 35978) and the Flex LWR (SN 37075) sensors were missing their shields upon recovery, but a technical paper from WHOI revealed that modifications to the shield and other parts not critical to heat flow in the sensor were unlikely to affect performance (Payne, 1994).

Figure 14: TFlex (left) and Flex (right) radiation sensors on recovery.

The TFlex sensor had slightly clouded glass on closer inspection, so higher readings were somewhat unexpected, but could be attributed to a thermopile repainting prior to deployment. The manufacturer performs this maintenance as part of regular servicing when deemed necessary (usually at around 5 year intervals).

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).

Kelly Balmes also developed a set of criteria for determining the primary LWR sensor:

- Use the LWR data from the sensor on the data system that was chosen for SWR
- If LWR data from the first criteria is not available, use the remaining instrument

These criteria were created to maximize data returns and account for bent radiation masts, which are usually detectable by comparing SWR measurements. Although LWR is much less sensitive to orientation, a bent mast can affect either sensor. Clear sky conditions will have a lower LWR than clouds, which are warm due to water content (high LWR). With one LWR and one SWR sensor mounted to each mast, the goal of the criteria is to obtain data from the most vertical mast to avoid a mean tilt when samples are averaged over 1 minute.

Based on these criteria, the KE014 TFlex LWR, which also had the higher data return and an intact radiation shield, was designated primary. The secondary Flex LWR was recovered with a missing shield (Figure 14).

Regions of unrealistically high, noisy LWR data were seen during the hottest part of the year on KE014. This issue has been observed before, but no discernable pattern links it to a particular instrument or acquisition system. From as early as July to as late as September, LWR values on KE014 exceeded climatological norms. The Stefan Boltzman equation also suggests the data exceeded a downwelling LWR limit of 471.3 W/m^2, given the observed maximum air temperature of 28.8°C. The instrument manufacturer (Eppley) suggested the possibility of bad thermopile readings, stating that, in general, net LWR from the thermopile should not exceed 0 W/m^2 (indicating heat transfer from atmosphere to ocean), which is unlikely during mid-summer days. Both sensors frequently had net LWR greater than 0 in this summer window.

Backing up Eppley's hypothesis, SST exceeded air temperature during the anomaly, indicating sensible heat transfer from ocean to atmosphere. Unless other heat transfers (e.g. latent heat) are downward and of greater magnitude, this observation is inconsistent with a positive net LWR. However, it is difficult prove that net LWR is incorrect (aside from when the 2 instruments differ), because LWR is affected by the overlying atmosphere in addition to surface fluxes. Another theory is that the gain applied to the thermopile voltage before being interpreted by the acquisition system is incorrect, but this wouldn't explain why the data become noisy and inconsistent during a few weeks in the hotter months. Regardless of cause, Q5 flags (removed) were applied to downwelling LWR when net LWR was greater than 0, which eliminated the unrealistically high and noisy downwelling values. The remainder of the data were distributed with standard quality flags.

Average LWR values from raw data downloads over the past few deployments are presented below. The mean Flex LWR was lower than in previous years, yet the TFlex LWR was higher. However, data continuity with KE013 (Figure 16) provided additional evidence that supported the selection of the TFlex LWR as the primary sensor, noting that the KE014 TFlex LWR align with KE013 data (KE014 Flex LWR is biased lower).

More details on the summertime KEO LWR issue can be found in Technical Note 11, available at: https://www.pmel.noaa.gov/ocs/technical-notes

Deployment	**Flex Mean LWR Down**	**TFlex Mean LWR Down**
KE012	377.6	371.8
KE013	375.5	372.8
KE014	366.9	379.2

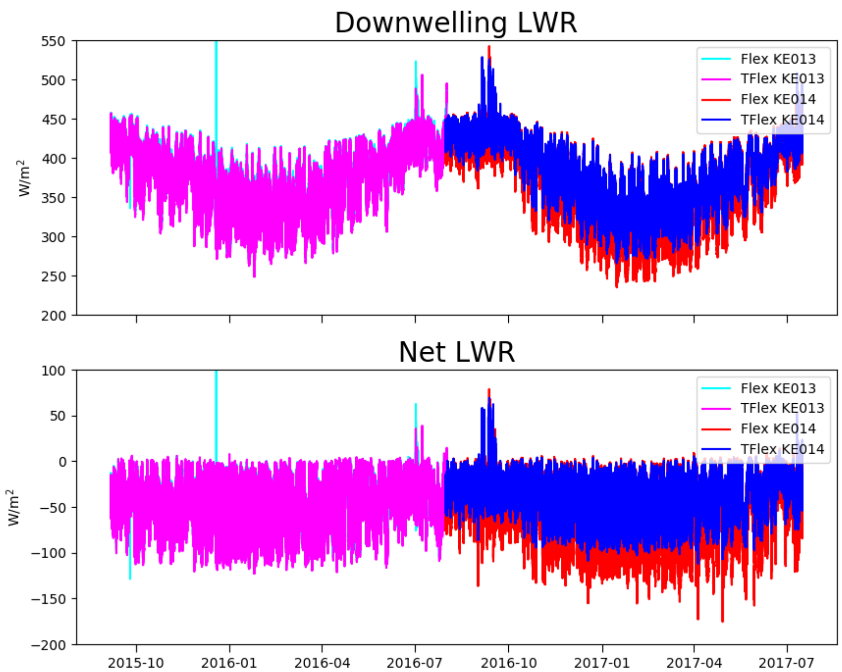

Figure 15: Raw (as downloaded) KE014 downwelling and net LWR compared with KE013. Summertime spikes are apparent in both time-series, with a concerning low bias in the Flex KE014 net LWR.

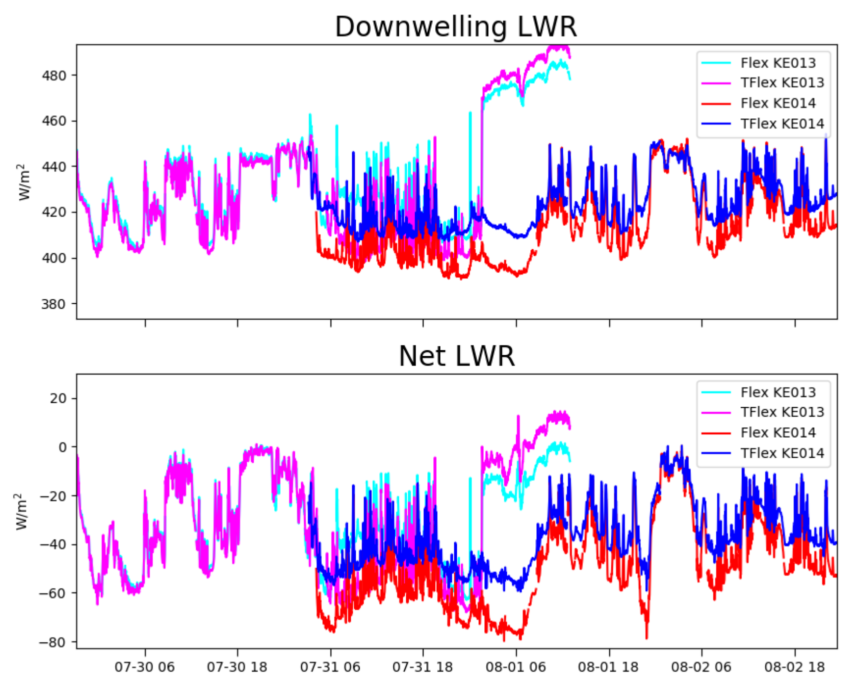

Figure 16: As in Figure 15, but zoomed on the deployment transition. The KE014 TFlex LWR record showed better continuity with the previous deployment.

3.3 Subsurface Data

There were two sea surface temperature and conductivity (SSTC) instruments deployed on the bridle (Table 1). One was wired to the Flex system, and the other to the TFlex system. Both also logged data internally.

All 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 recovery log (Figure 17). Since no clock errors exceeded half the sampling interval, measurements were mapped to the nearest 10-minute time increment.

The instrument at 225m presented a special case, where the batteries died mid-deployment, but the data were reported with timestamps of HH:M1:56. This offset was likely due to a setup error with the instrument's start time, and was verified in the data by comparing the timing of water-entry with surrounding instruments. As with other sensors, times were mapped to a 10-minute grid.

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

	Sensor Type	S/N	Actual Time (GMT)	Instr. Time	Clock Error	File Name	Bat. Voltage from Status	Comments	# of Records
0	SBE37-	4562	10:52:45	10:52:52	0:00:07		6.7/3.19		51307
1	SBE37-	11552	11:05:30	11:05:25	-0:00:05		13.6/3.12		51308
2	SAMI pH	P0016							
3	SBE16+v2	6885							
4	O2	1554							
5	ECO	2093							
6	GTD	122464							
7	SBE39-T-	4861	06:52:46	6:53:40	0:00:54		6.8		51288
8	Aquadopp	12241						Dead Batteries	
9	SBE37-TC	7793	time	lost	?			Dead Batteries -	1788
10	SBE37-	7102	6:53:32	6:53:58	0:00:26		6.57/3.21		51248
11	Aquadopp	6290						Dead Batteries	
12	SBE39-	3285	time	lost	?			Dead Batts	1788
13									
14	SBE37-	7103	time	lost	?			Dead Batteries -	28602
15	SBE37-	7104	6:54:50	6:55:11	0:00:21		6.68/3.19		51284
16	Aquadopp	6808							
17	SBE39-T-	4857	6:55:28	6:56:24	0:00:56		7.0		51280
18	SBE37-	7105	6:57:34	6:57:47	0:00:13		6.66/3.18		51283
19	SBE37-	7106	time	lost	?			Dead Batteries -	15752
20	SBE37-	7107	time	lost	?			Dead Batteries -	18283
21									
22	SBE37-	7108	time	lost	?			Dead Batteries -	25363
23	SBE37-	9413	6:59:05	6:59:13	0:00:08		14.04/3.19		51288
24	SBE37-	7781	6:59:23	6:59:47	0:00:24		6.59/3.19		51288
25	PAL	CURLEW						LOST	
26	SBE37-	7782	time	lost	?			Dead Batteries -	28238
27	SBE37-	7783	6:59:59	7:00:21	0:00:22		6.56/2.94	not logging, low	38608
28	SBE37-	7784	time	lost	?			Dead Batteries -	8738
29	SBE39-	4360	7:01:01	7:01:51	0:00:50		6.8		51284
30	SBE37-	7091						LOST	
31	SBE39-	4378	7:01:44	7:02:53	0:01:09		7.0		51284
32	SBE37-	7092	7:02:11	7:02:43	0:00:32		6.68/3.18		51284
33	SBE37-	11926	12:05:25	12:05:31	0:00:06		6.96/3.28		50621
34									
35									

Figure 17: Recovery log displaying all instrument clock errors, and dead battery reports.

Battery failure was an issue on KE014. Intermittent battery contact likely caused excess power drain, so the standard Seabird battery pack will be used in the future. Depleted batteries are summarized in the following table.

Instrument Depth	Serial Number	Final Sample Before Failure
20m	3285	08/08/2016 11:10 UTC
25m	7103	02/09/2017 15:10 UTC
75m	7106	11/11/2016 07:40 UTC
100m	7107	11/28/2016 12:20 UTC
125m	7108	01/18/2017 03:20 UTC
225m	7782	02/07/2017 03:40 UTC
275m	7783	12/05/2016 01:30 UTC
325m	7784	08/29/2016 12:30 UTC

Table 4: Timing of Battery Failures.

3.3.1 Temperature

Subsurface temperature instruments were set to 10-minute sampling increments. The data are also provided at hourly and daily resolutions. Temperatures are rarely corrected based on post-calibrations, and there was no evidence of drifting temperature measurements. Aside from several battery failures, the lost 425m instrument, and no delayed-mode data record from the 10m instrument, all temperature records were distributed.

3.3.2 Pressure

Since this was a slack mooring, none of the sensors can be assumed to have been recording measurements at their nominal depths. Users are reminded that the depths of subsurface sensors must be computed from the observed and interpolated pressures contained in the data files.

Pressure measurements were recorded by most of the subsurface instruments. In processing for salinity, interpolated pressures were used if an instrument's pressure sensor failed. In the case of complete instrument failure, where no temperature or conductivity data exists, interpolated pressures were truncated to the time of failure.

The 35m pressure sensor failed early, and interpolation was performed from surrounding depths from May 10, 2017 at 2:30 UTC until recovery.

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.

Salinity Drifts in PSU (post - pre):

Depth:	**Drift:**
1m (TFlex)	-0.0657*
1m (Flex)	-0.0614
10m	N/A **
15m	-0.0416
25m	-0.0242
35m	-0.0371
50m	-0.0573
75m	-0.0140
100m	-0.0139
125m	-0.0167
150m	-0.0178
175m	-0.0513
225m	-0.0183
275m	-0.0127
325m	-0.0018
425m	N/A ***
525m	-0.0058

* SSTCs had high pre-post differences, but they accurately corrected drift in the underlying data.

** 10m instrument had no delayed-mode data.

*** 425m instrument was lost.

The values above indicate the change in data values when post-recovery calibrations are applied vs. when pre-deployment calibrations are 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 sea water. Positive values indicate decrease in the cell effective cross-sectional area, presumably due to fouling, 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.

Manual Salinity Adjustments

The drift-corrected salinities were checked for continuity across deployments. The range and magnitude of variation matched well with prior and subsequent deployments.

Additional linear corrections were also applied to the salinity data in time segments, as noted below. These corrections were based on comparisons with neighboring sensors on the mooring line. If an unrealistic prolonged, unstable density inversion was found, an attempt was made to identify the sensor at fault and adjust its data based on differences with data from adjacent depths during unstratified conditions (e.g. within the mixed layer during nighttime). These *in situ* calibration procedures are described by Freitag et al. (1999).

Based on manual review of the data against neighboring instruments, a single adjustment was required to the TFlex SSTC (the secondary SSTC), which drifted later in the deployment with respect to neighboring instruments.

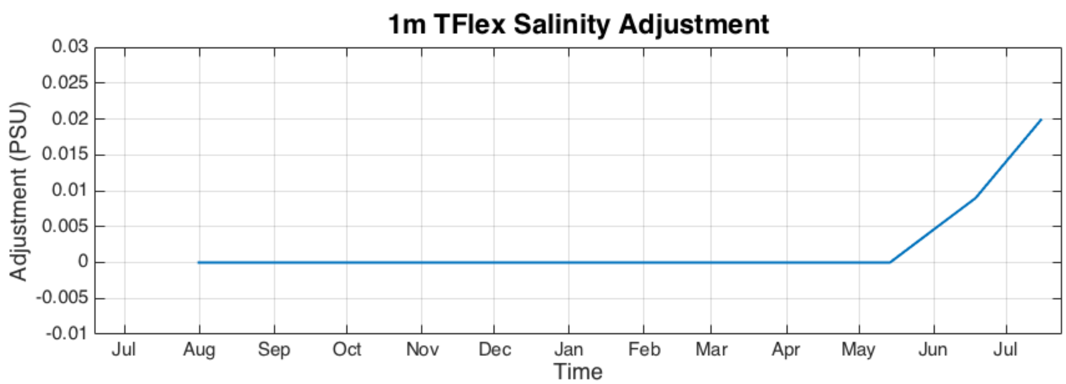

Figure 18: TFlex SSTC salinity adjustment based on density intercomparisons.

Post-deployment and pre-recovery CTDs were available for comparison. No adjustments were needed based on cast comparisons.

3.3.4 Deep SBE Data

Since 2013, 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.

A known issue at KEO is deep salinity drift (freshening) of 0.03 – 0.06 PSU per year. Early information about this drift can be found in Technical Note 9, with a more complete description in Anderson et al (2020). Despite pressure differences of 10-50m between mooring deployments (from terrain, line lengths, and mooring dynamics), potential temperature time-series have remained remarkably continuous, suggesting that temperature and pressure are measured correctly, with the root issue being sediment accumulation in the conductivity cell.

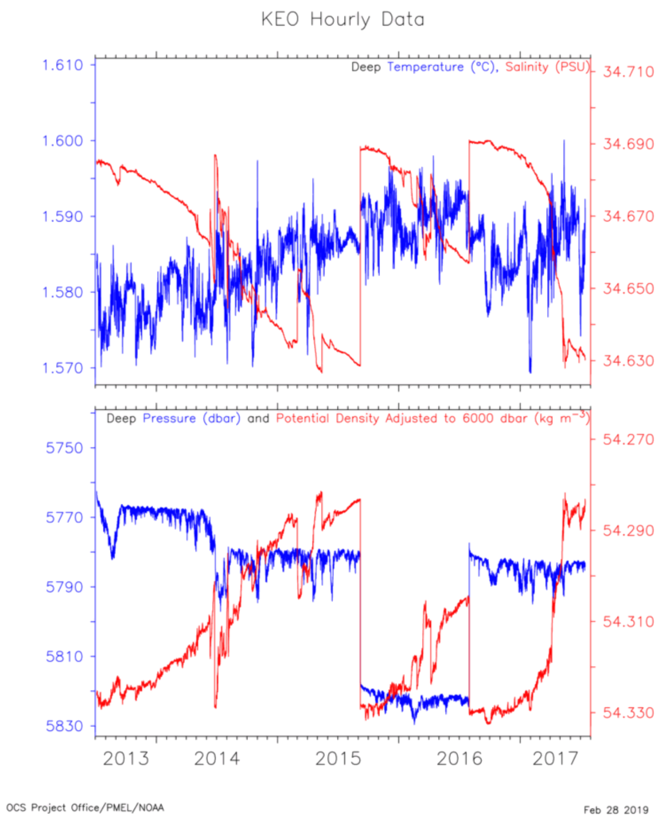

Figure 19: Deep SBE temperature, pressure, salinity and potential density time-series calculated using pre-calibration coefficients. The 2016 – 2017 data are shown in context with previous deployments.

Deep SBE data at KEO are distributed with pre-calibration coefficients applied (see Figure 19), as the sediment accumulated in the conductivity cell washes off upon ascent, and results in post-calibration coefficients that do not capture the salinity drift. 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 6000 dbar at KEO. 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

Point current meters were deployed at three depths on the KE014 mooring. The stated head depth differs from the actual current measurement depth, because the instruments require a blanking distance. Currents from the instruments deployed at 8.5, 16.5 and 36.5m measured velocities at 8, 16 and 36m, respectively. All current meters deployed on KE014 were upward-facing Nortek Aquadopps.

The current meters calculate the speed of sound, and internally apply sound velocity corrections to current measurements. During post processing, a correction for magnetic declination (-5.0°) is also applied to the delayed-mode data. A thirteen-point Hanning filter is passed over the 10-minute resolution data to get hourly data, and a boxcar filter produces daily averaged values.

Since the KEO buoy could move about its watch circle, the current meters did not measure true currents. Using time-stamped data from aggregated Flex+TFlex GPS system data, buoy velocity averages were generated. True currents were determined by adding calculated buoy motion to the measured current meter data.

Buoy motion was determined by first interpolating the acquired GPS positions onto a 10 minute grid (:05, :15, :25, etc.). Ten minute mooring velocities corresponding to current meter measurement intervals (:00, :10, :20, etc.) were then calculated using the haversine formula, to equate change in position over time to a mooring velocity. The calculated U and V mooring velocities are shown in Figure 20.

No flags were provided by the GPS systems, so data processors flagged the few acquired positions which placed the buoy outside the normal watch circle, but otherwise trusted the reasonable positions and calculated velocities.

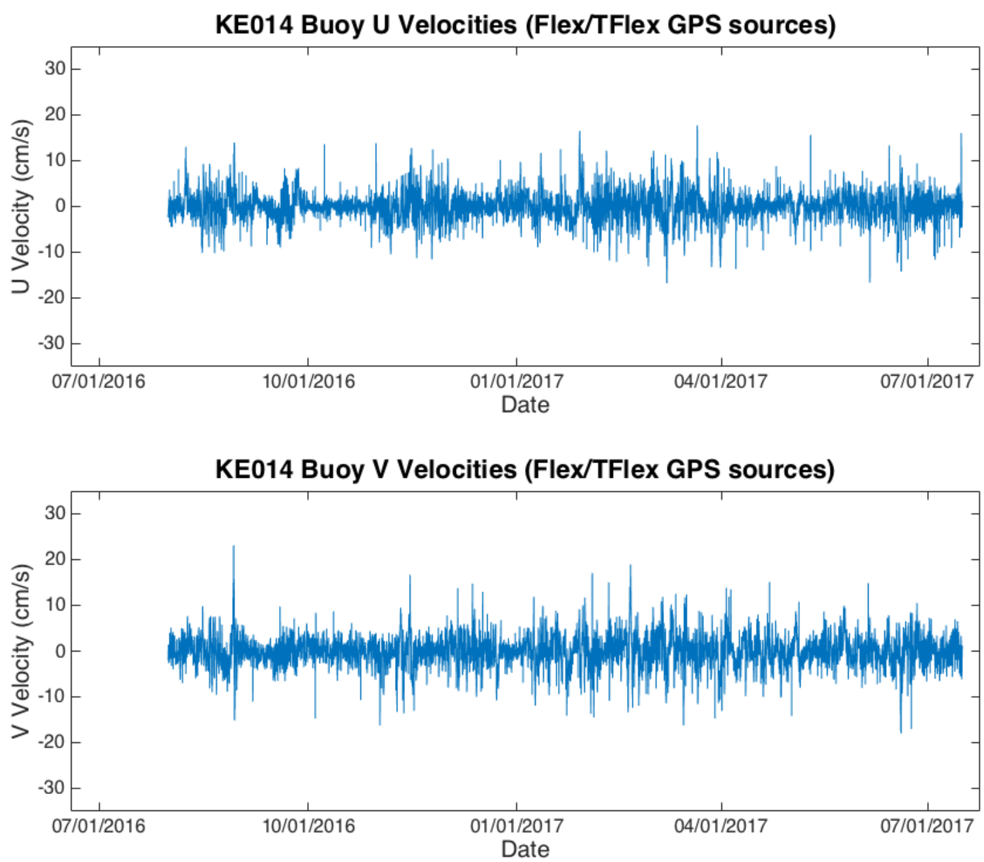

Figure 20: KE014 buoy velocities used to correct currents.

The 8m instrument slid to 10m, and was flagged as lower quality (Q4) starting January 29th, 2017. Data returns were reduced by battery failures on the 8m and 16m Aquadopps.

4.0 References

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5.0 Acknowledgements

N. Anderson (UW JISAO) processed the Flex/TFlex data, with initial assistance from C. Fey (UW JISAO). D. Dougherty (UW JISAO) compiled data into initial python files, and quality controlled the real-time data.

The OCS project office is grateful to the captain and crew of the M/V BLUEFIN, who made the deployment and recovery operations possible. N. Anderson, D. Rivera, and P. Berk (all of UW JISAO) participated in the deployment cruise, and Mariela White (UW) assisted with sampling and operations. P. Berk and T. Nesseth participated in the recovery cruise, with Dr. Makio Honda acknowledged for assisting with mooring operations and water sampling.

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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 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

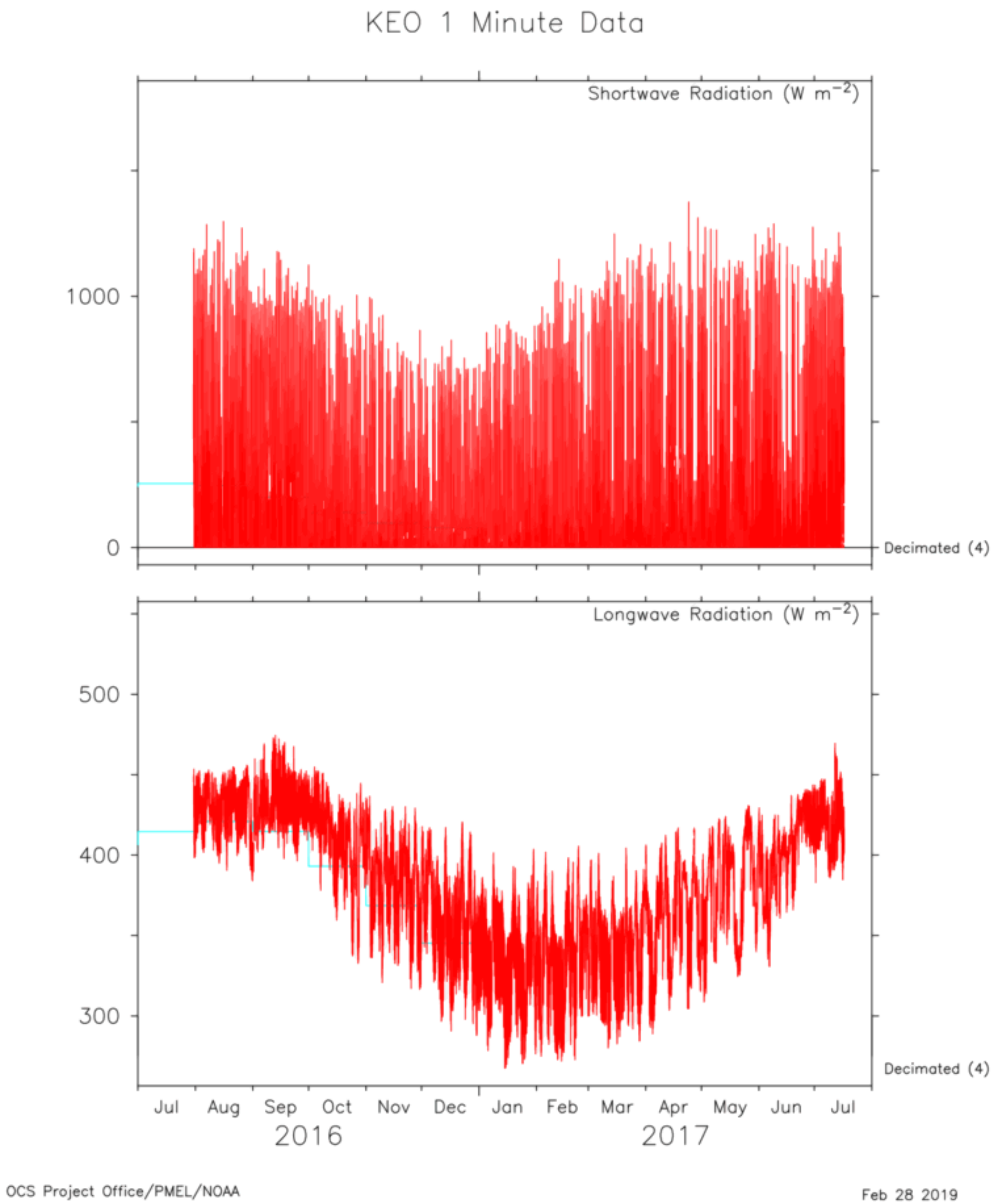

Figure B 1: KE014 primary shortwave and longwave radiation data at 1-min resolution (TFlex).

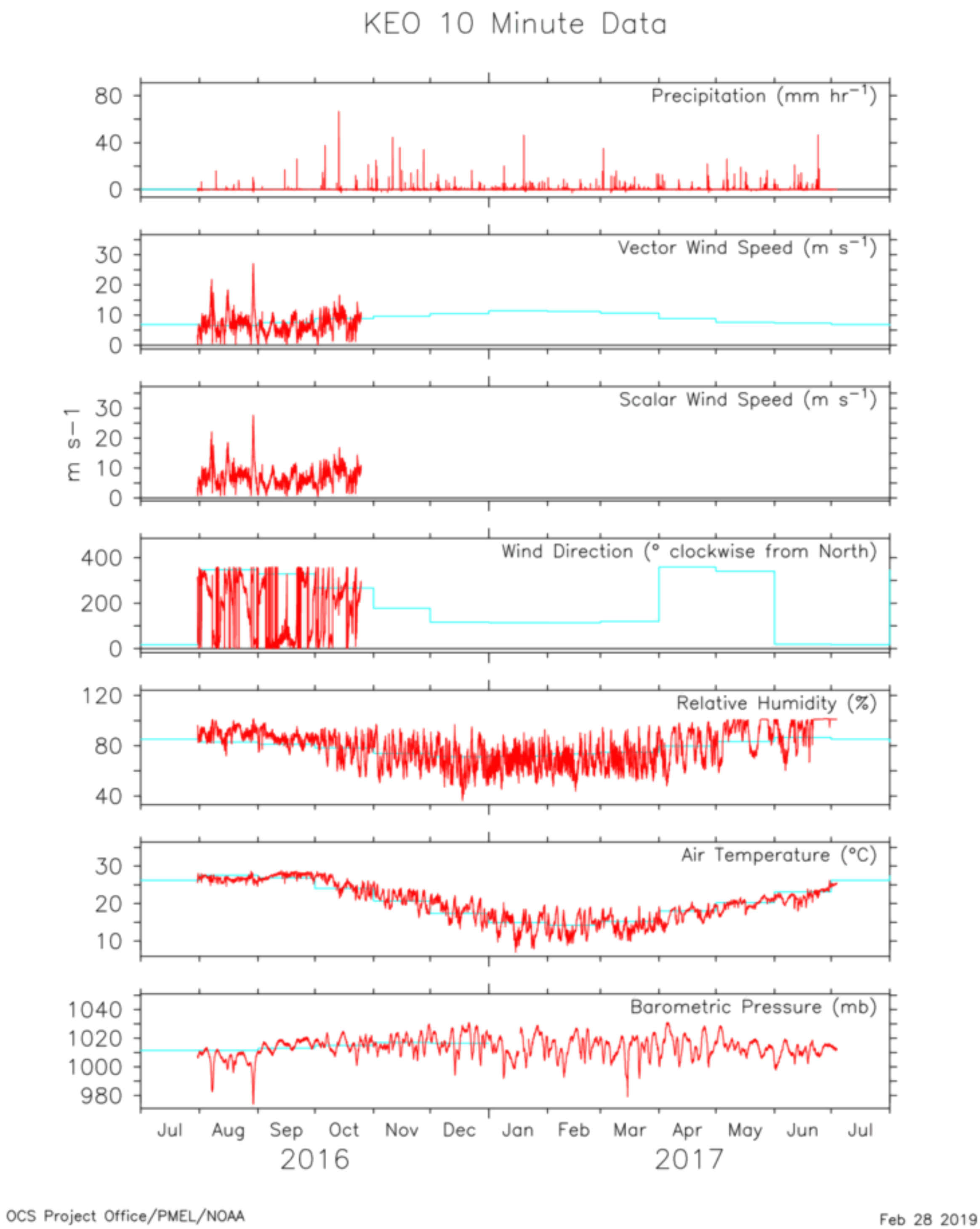

Figure B 2: KE014 primary meteorological data at 10-min resolution. AT/RH are from TFlex, and wind, BP, and rain are from Flex. Winds ended early on KE014 due to typhoon activity.

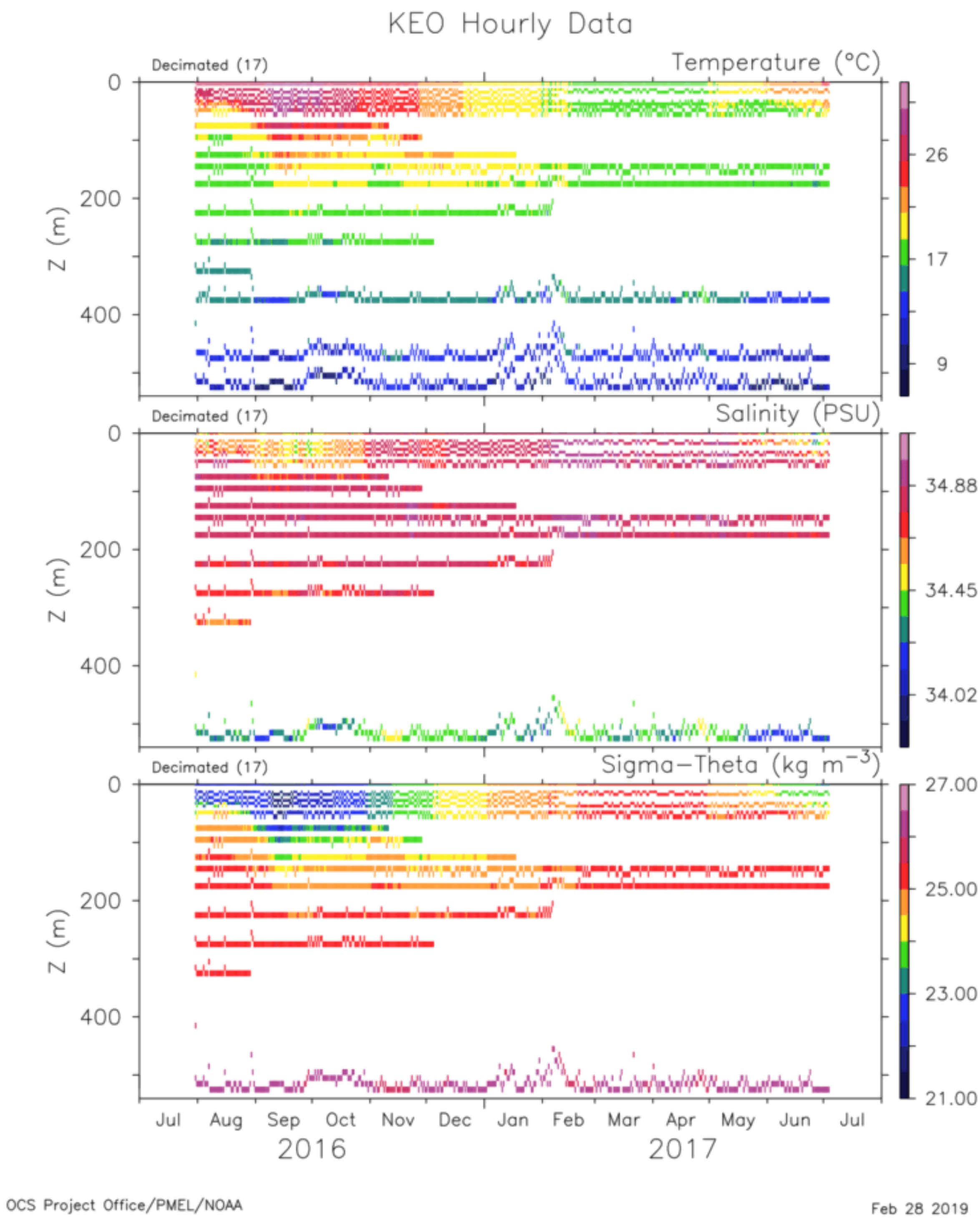

Figure B 3: KE014 subsurface temperature, salinity, and density at hourly resolution (decimated). Battery failures plagued this deployment.

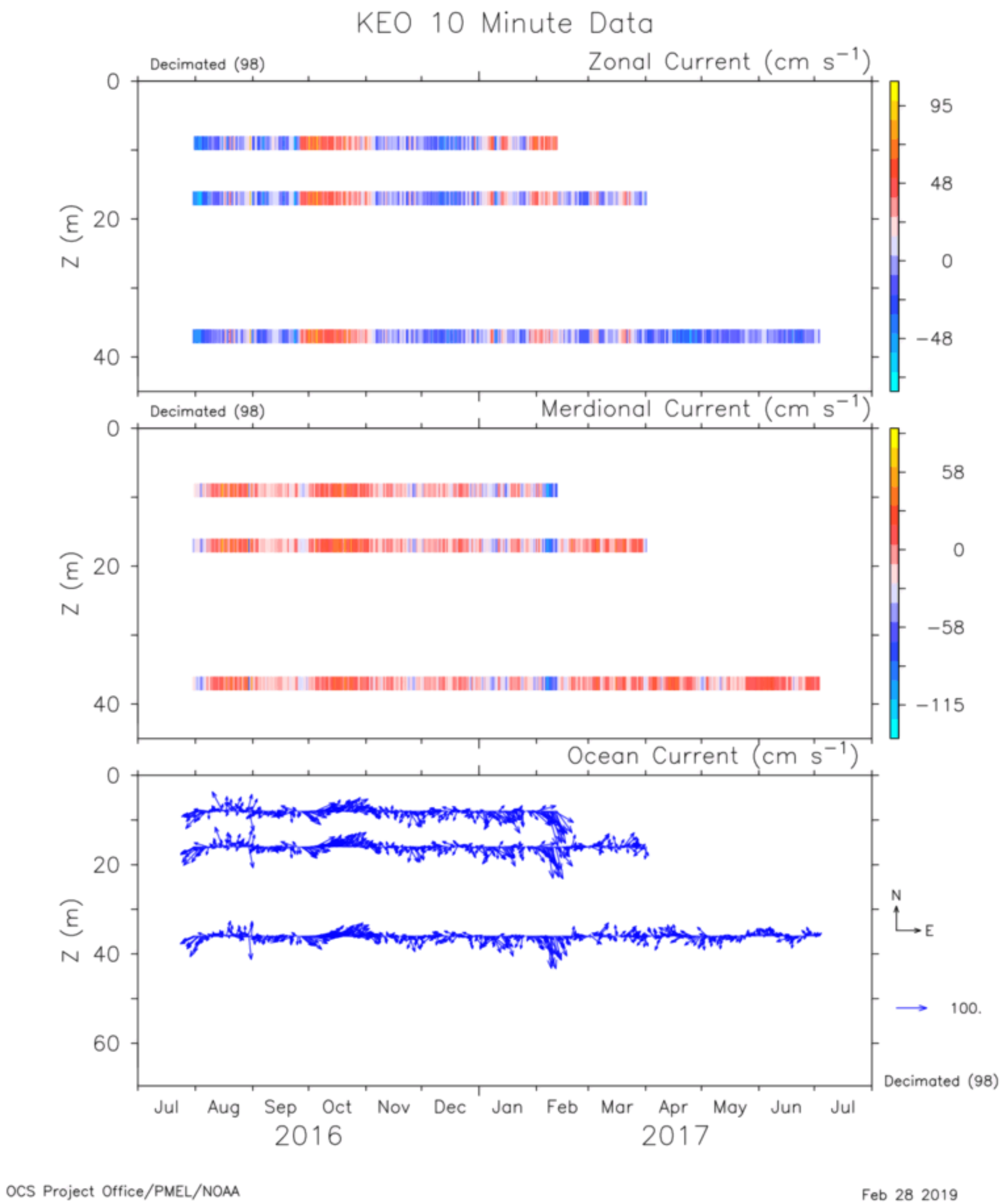

Figure B 4: Zonal and meridional current meter data (decimated) from KE014. Battery failures in the 8m and 16m instruments lowered data returns, and the 8m instrument was flagged Q4 after January 29th, 2017, when its clamp failed and came to rest on the 10m SeaBird instrument.

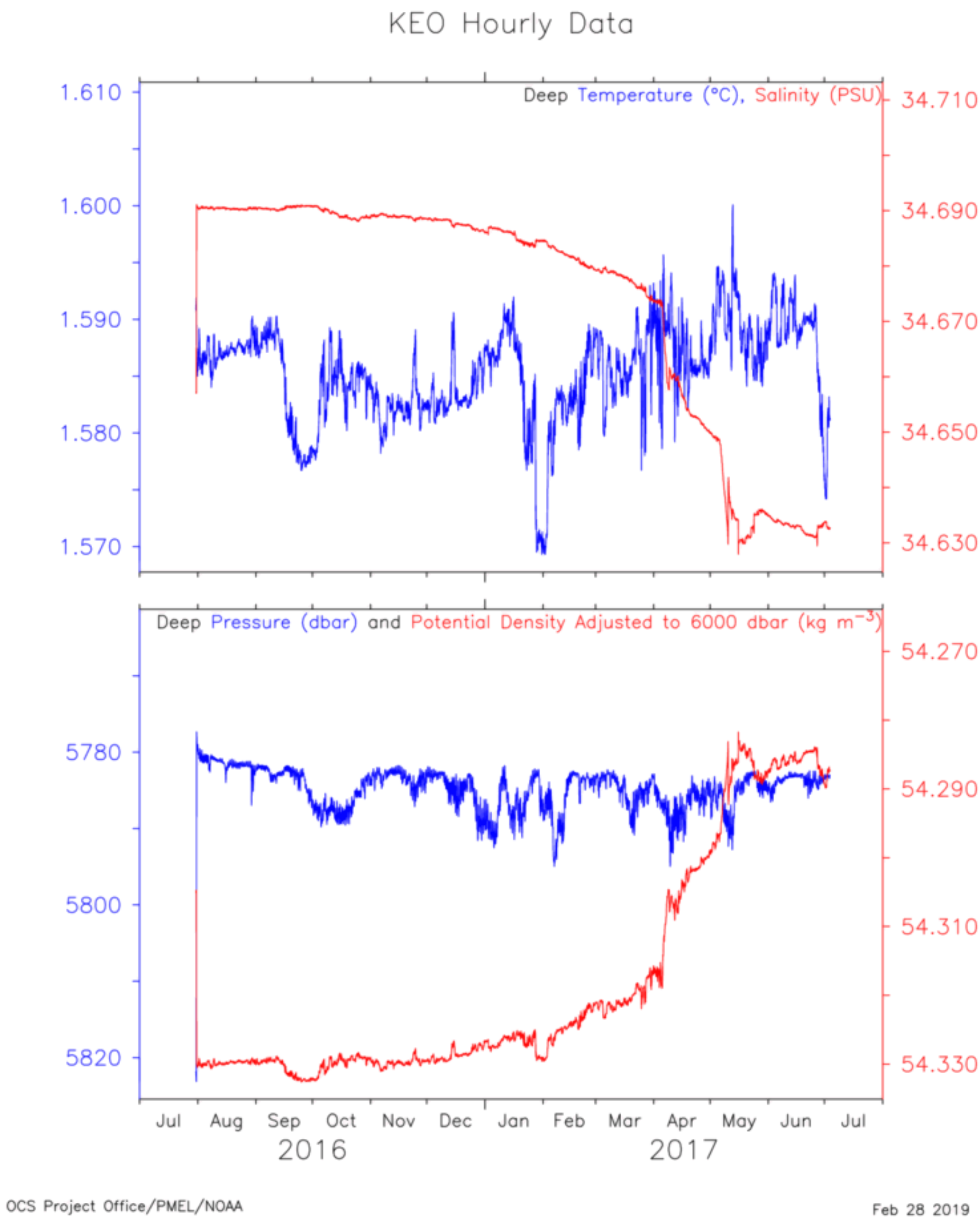

Figure B 5: Deep Seabird instrument temperature, pressure, salinity, and potential density. Pre-deployment calibration coefficients were applied. Salinity drift is apparent, but no known correction exists.

APPENDIX C: Secondary Instrument High Resolution Data Plots

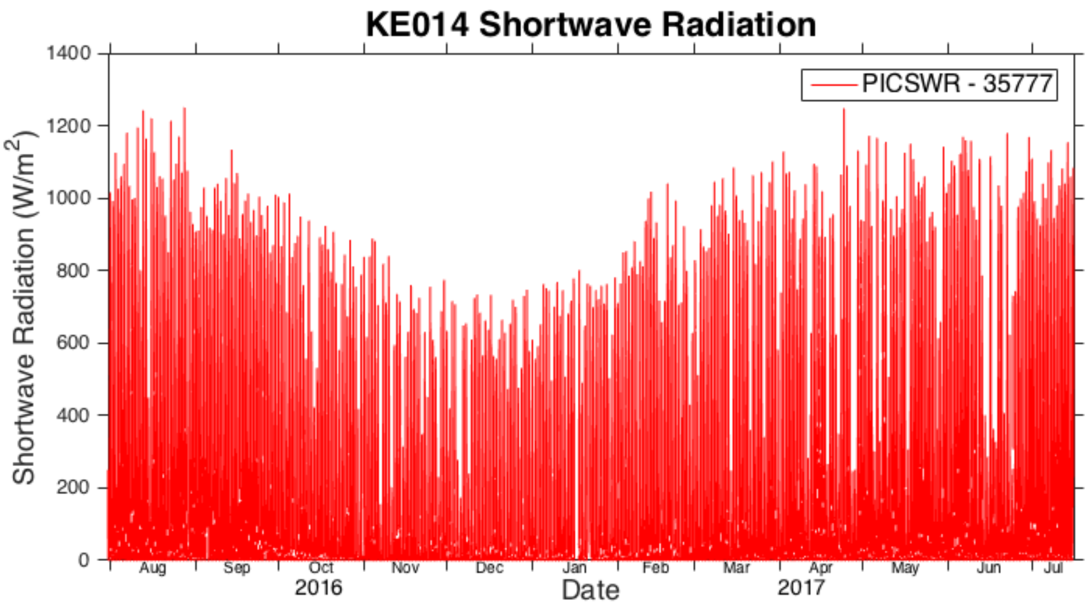

Figure C 1: Secondary (Flex Eppley PSP) shortwave radiation sensor.

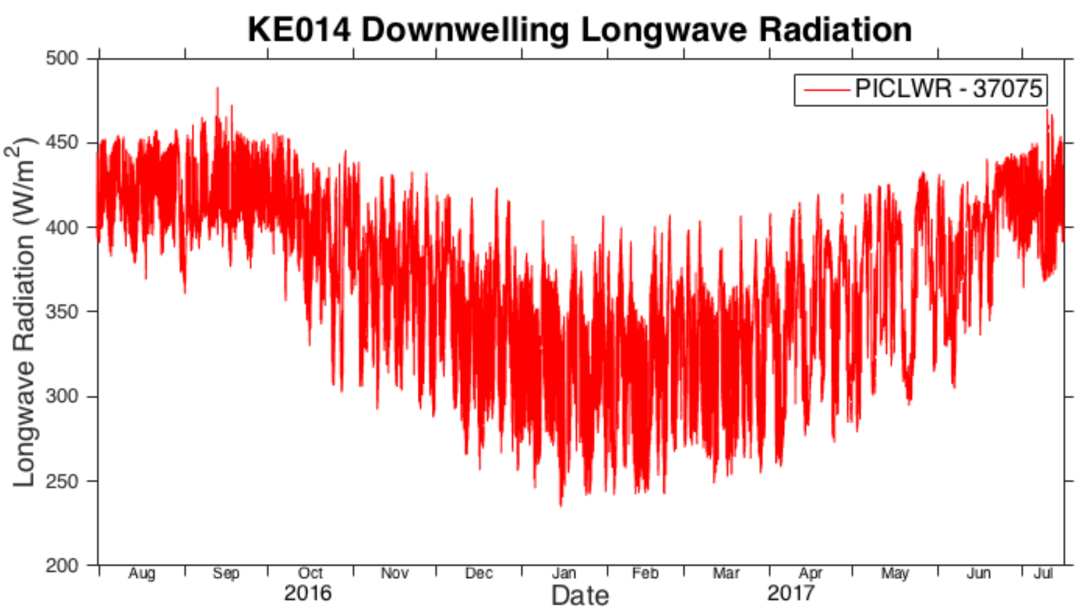

Figure C 2: Secondary (Flex Eppley PIR) longwave radiation sensor. Q5 (removed) flags were assigned where net LWR exceeded 0 W/m^2. This instrument was missing its shield upon recovery.

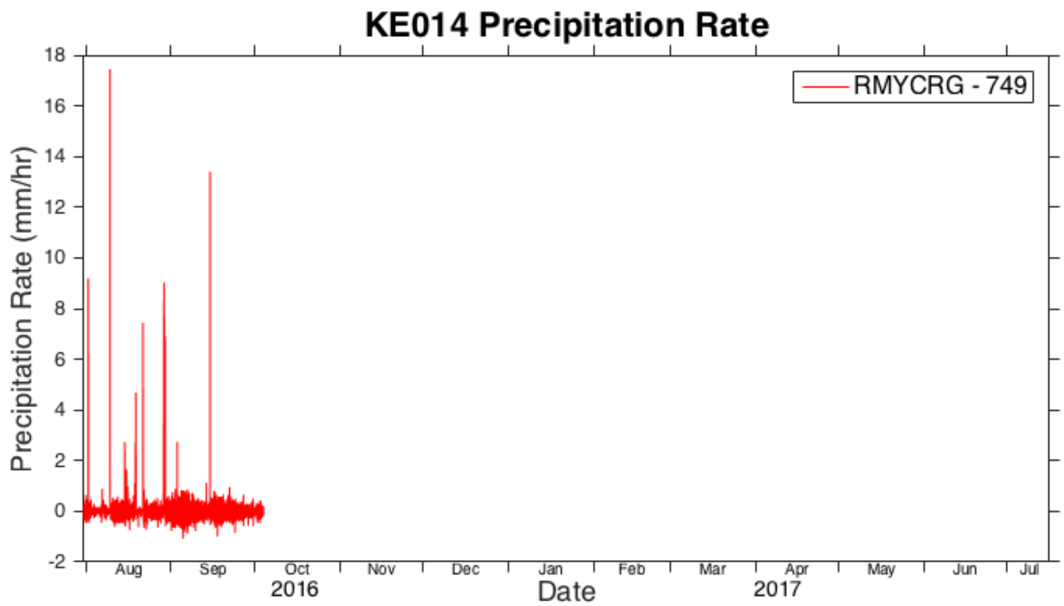

Figure C 3: Secondary (TFlex RM Young) rain sensor. The rain gauge failed to report positive accumulations after October 4, 2016.

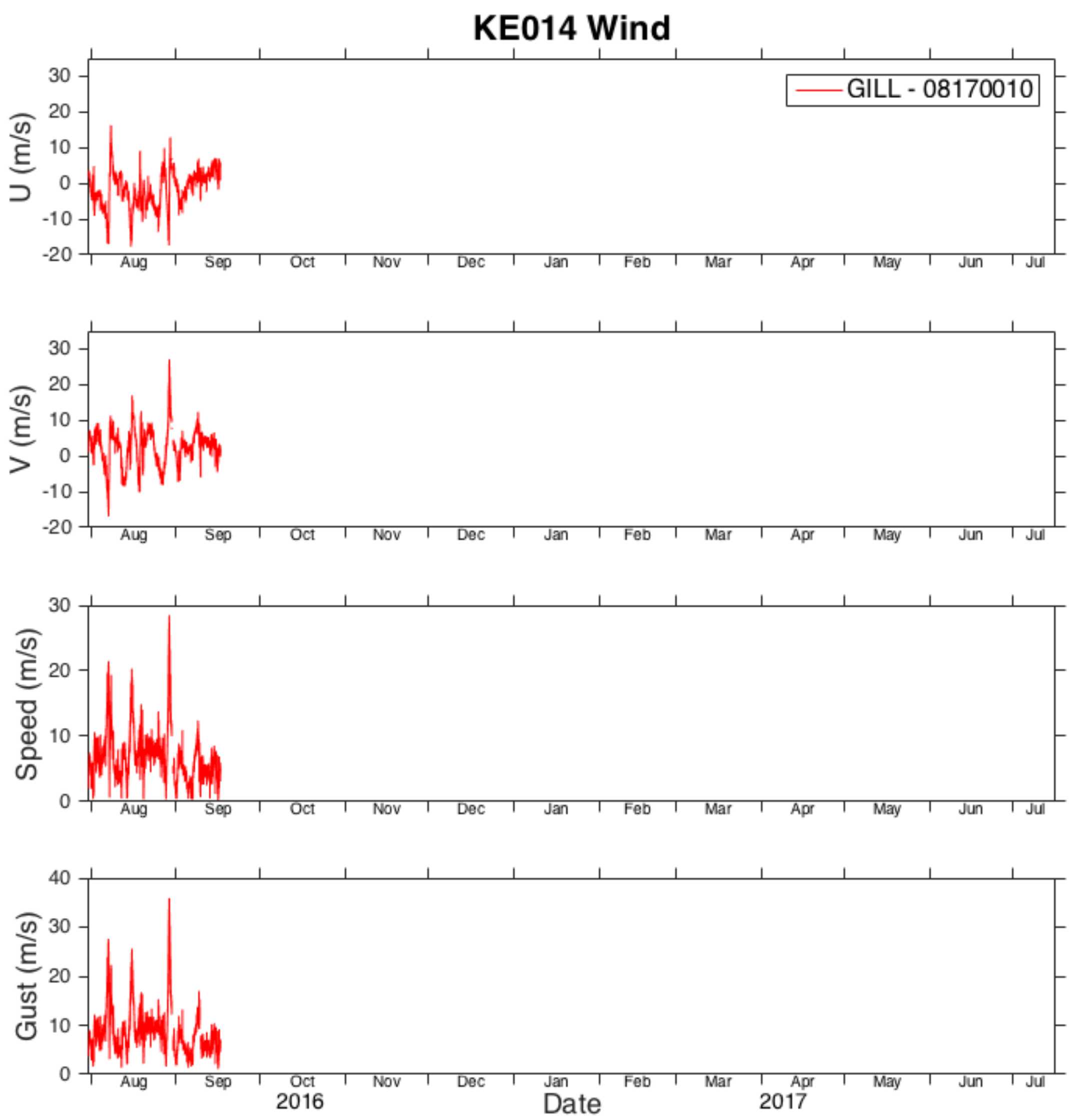

Figure C 4: Secondary (TFlex Gill) wind sensor. This instrument was found with water intrusion, and was retired.

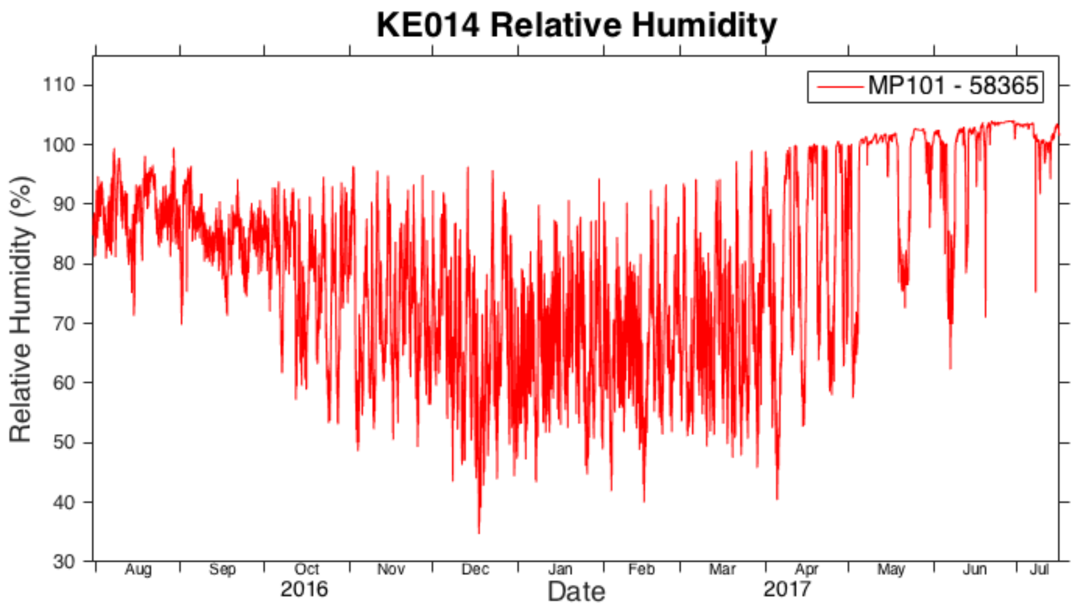

Figure C 5: Secondary (Flex MP101) relative humidity sensor. Both RH sensors failed their postcal and were assigned Q4 (lower quality). The Flex sensor shown here had larger max residuals, and went over 100% more frequently than the TFlex sensor toward the deployment's end.

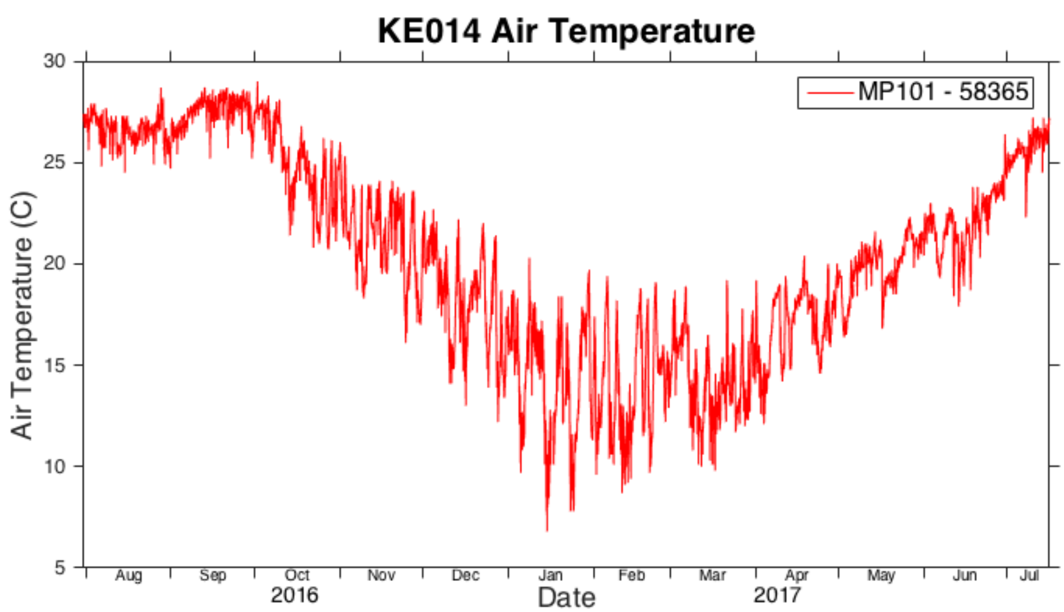

Figure C 6: Secondary (Flex MP101) air temperature sensor.

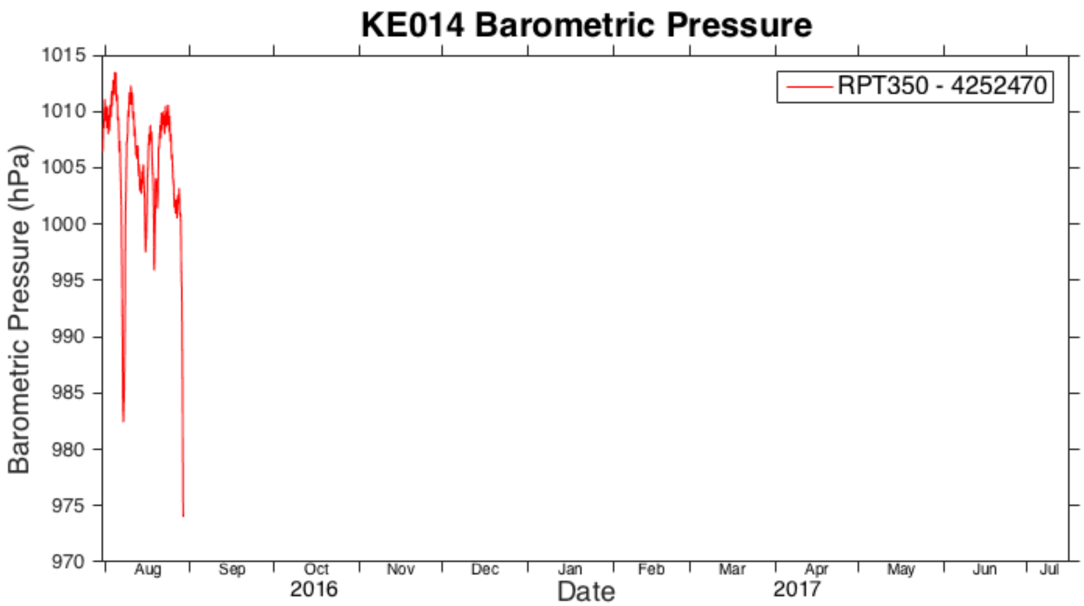

Figure C 7: Secondary (TFlex Druck) barometric pressure sensor. The sensor reported a full record of data, but was noisy and offset from the primary instrument after Typhoon Lionrock. This sensor also had evidence of water intrusion, and was cracked upon recovery. Standard quality was assigned until August 29, 2016, and no further data were distributed.

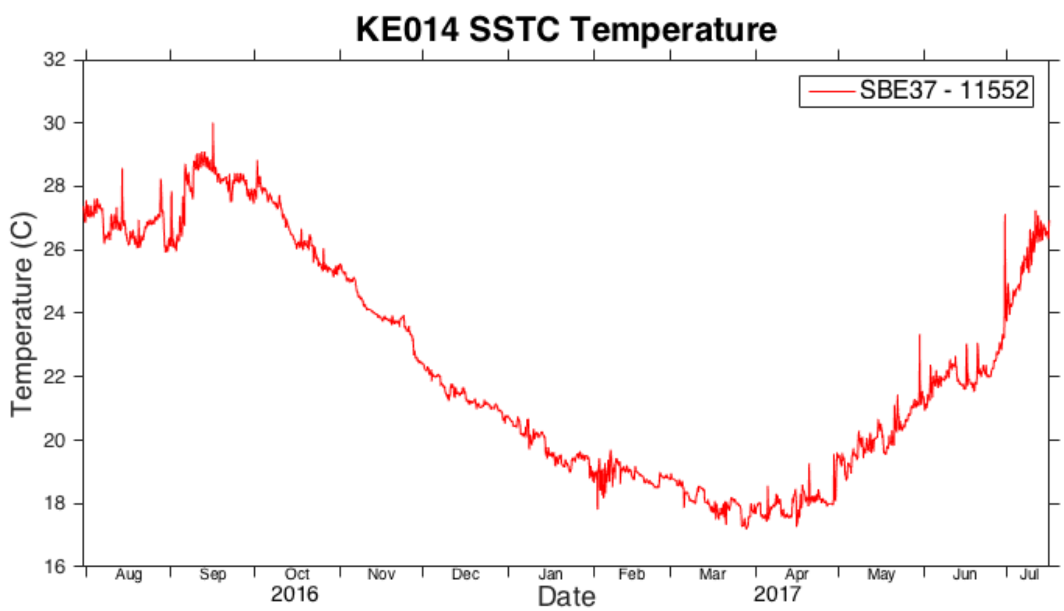

Figure C 8: Secondary (TFlex) SSTC Temperature.

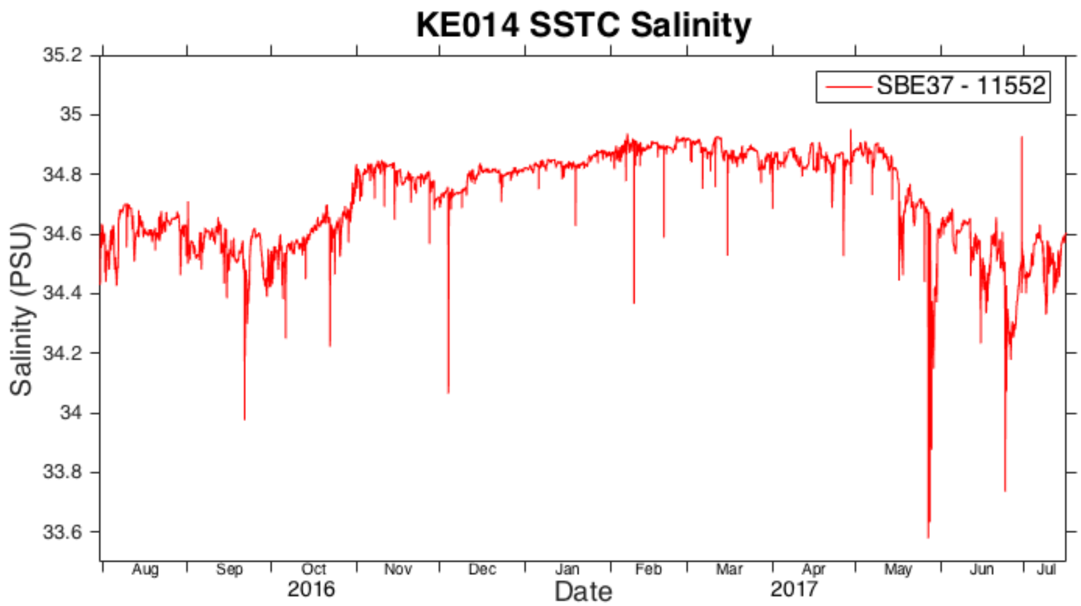

Figure C 9: Secondary (TFlex) SSTC Salinity.

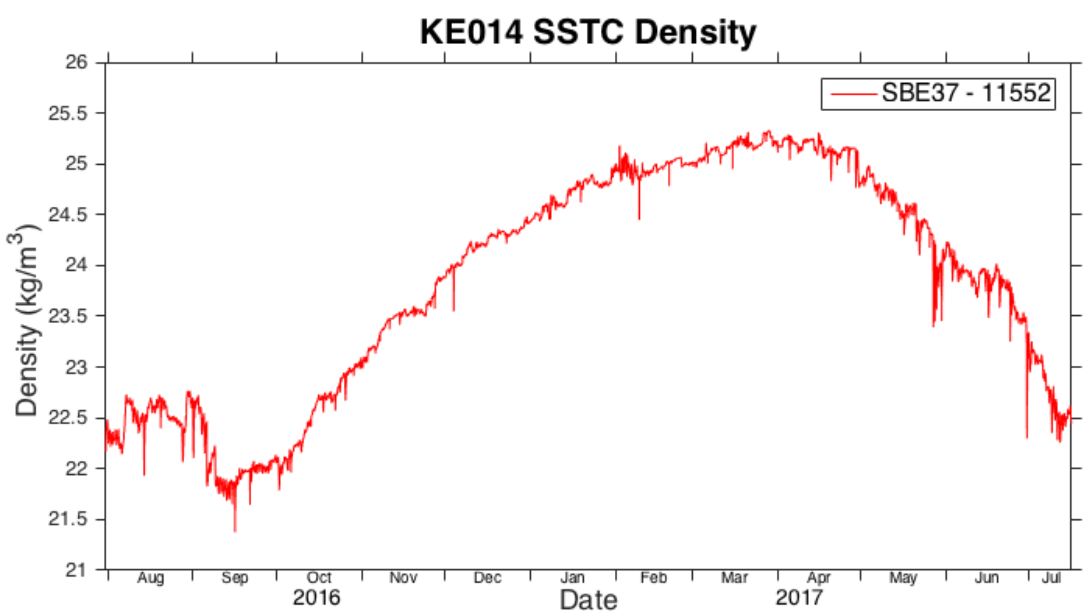

Figure C 10: Secondary (TFlex) SSTC Density.