NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

DATA ACQUISITION AND PROCESSING REPORT FOR KE013

Site Name:	Kuroshio Extension Observatory (KEO)
Deployment Number:	**KE013**
Year Established:	2004
Nominal Location:	32.3°N 144.6°E
Anchor Position:	32.39°N 144.54°E (triangulated)
Deployment Date:	September 7th, 2015
Recovery Date:	August 1st, 2016
Project P.I.:	Dr. Meghan F. Cronin
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Data Processors:	N.D. Anderson
Date of Report:	September 8, 2020
Revision History:	

Special Notes:

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Data Acquisition and Processing Report for OCS Mooring KE013

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.

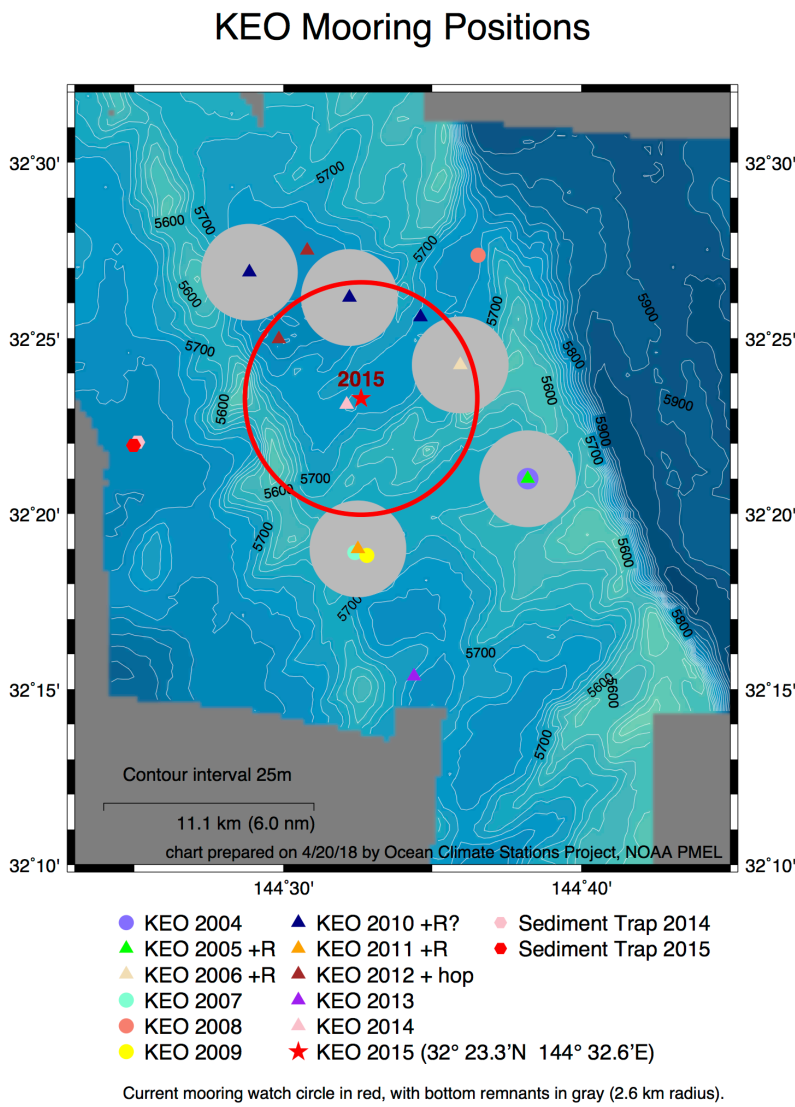

Figure 1: KEO regional map, with the KE013 (red star) and JAMSTEC sediment trap (red hexagon).

KE013 was the 12th 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, KE013 was deployed on September 7, 2015 and recovered on August 1, 2016 by the M/V BLUEFIN. The captain and crew of the BLUEFIN are gratefully acknowledged. Mooring assistance from National Data Buoy Center (NDBC) and JAMSTEC personnel was also greatly appreciated.

1.1 Mooring Description

The KE013 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 KE013 mooring, in collaboration with the PMEL Carbon Group. The SAMI pH instrument would not communicate, except via USB, but was successfully deployed. KE013 also included new instruments from partner organizations. The University of Washington included a Passive Acoustic Listening (PAL) device at 200m, which was lost during the yearlong deployment. No data were recovered. Collaboration with JAMSTEC allowed for the inclusion of two backscatter meters at 33m and 123m. OCS is not responsible for the acquisition or processing of these data. No further discussion of these systems or instruments is included in this report.

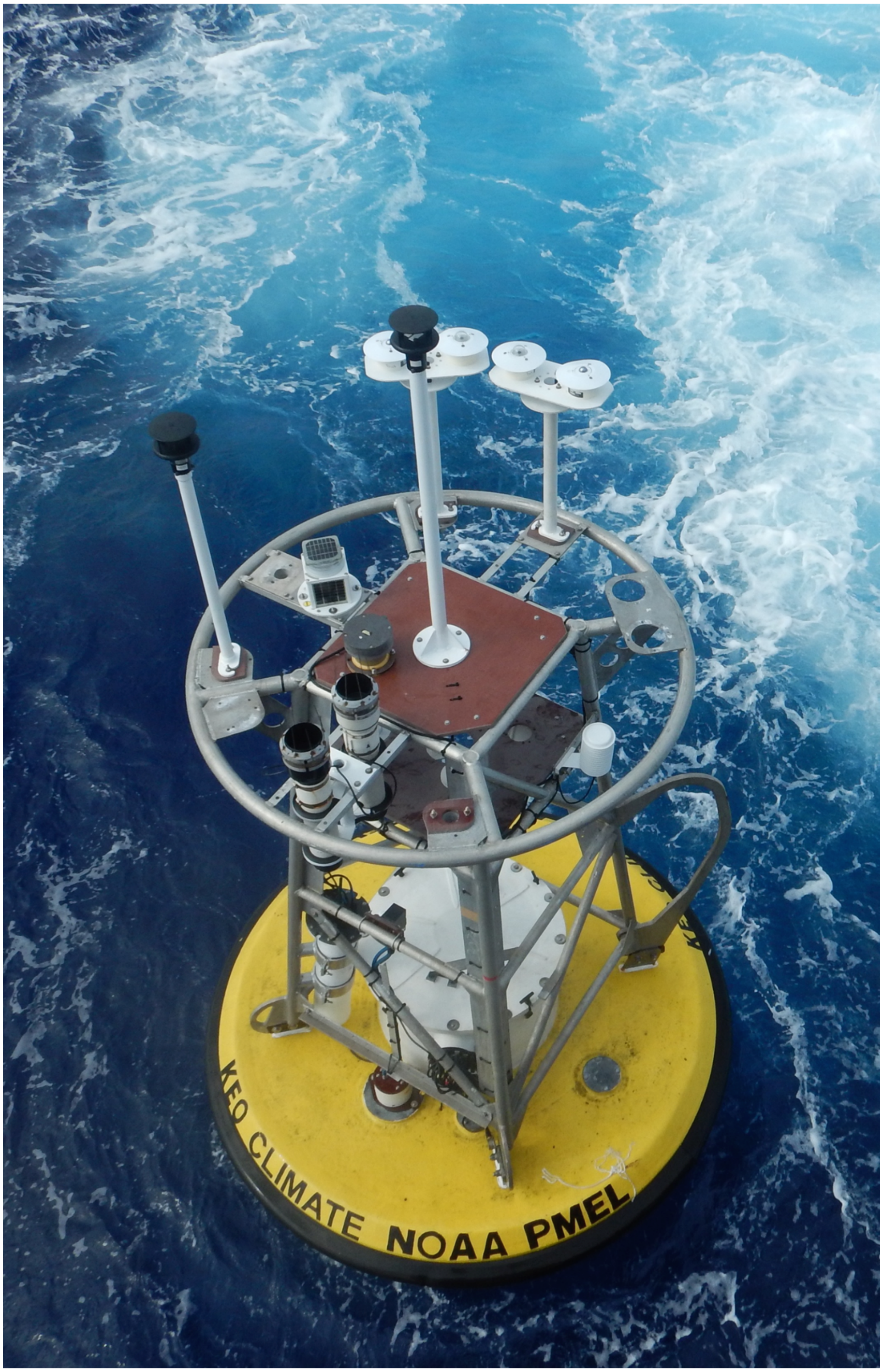

Figure 2: KE013 as deployed.

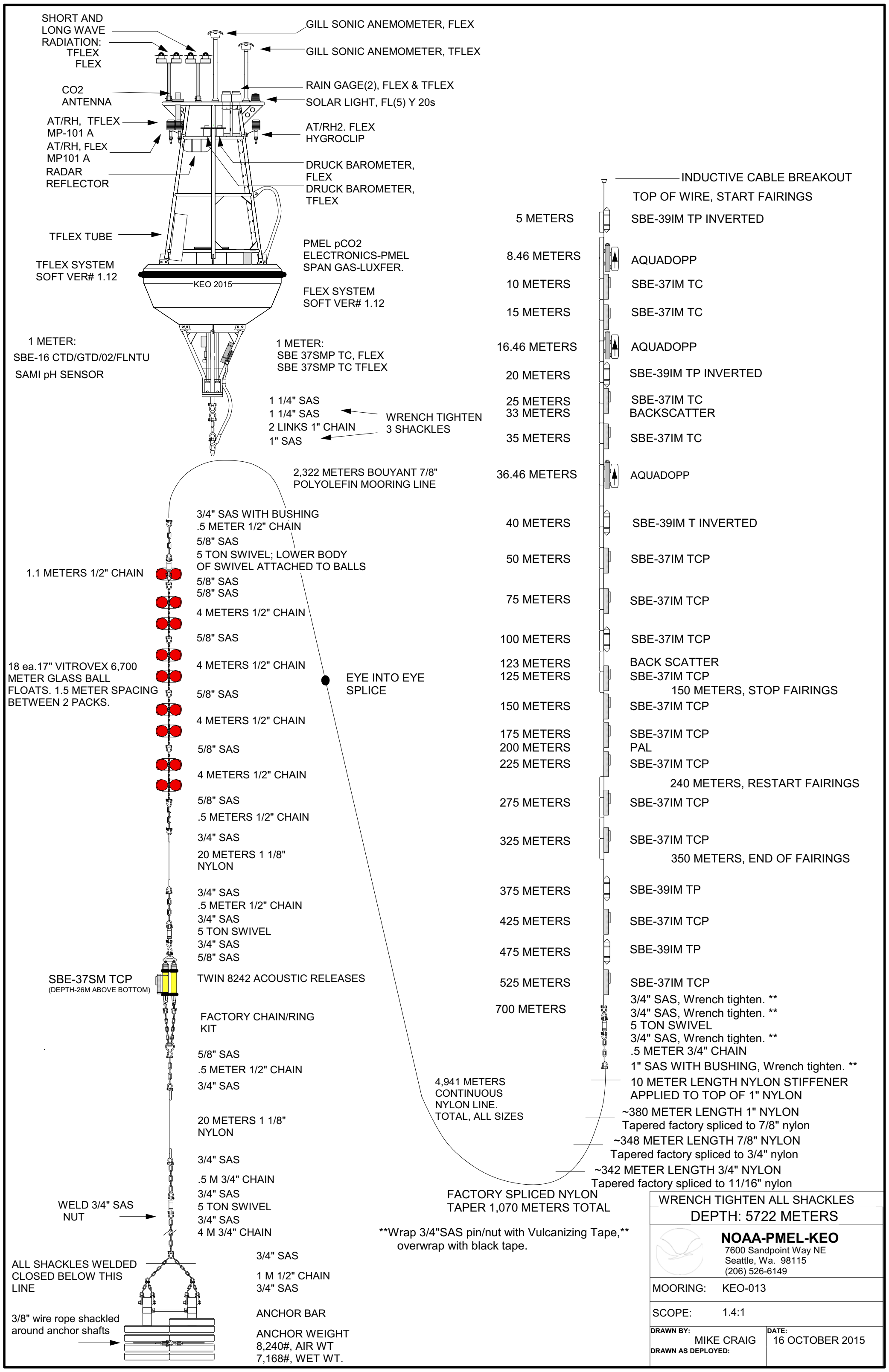

Figure 3: KE013 mooring diagram.

1.2 Instrumentation on KE013

The following instrumentation was deployed on KE013. 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:		**KE013**			
Met Sensors		**Model**	**Serial #**		**Notes**
Height	Acquisition	**FLEX**	0009	FP8	
2.6m	ATRH	Rotronics MP-101A	118825		
2.6m	ATRH2	Rotronics HygroClip	61334287		
4.2m	Wind	Gill	073805		
2.4m	BP	Druck	2153683		
3.1m	Rain	RM Young	1629		
3.6m	SWR	Eppley PSP	35934		
3.6m	LWR	Eppley PIR	33341		
	Acquisition	**TFLEX**	2004		
2.6m	ATRH	Rotronics MP-101A	133390		
3.8m	Wind	Gill	042213		
2.4m	BP	Druck	4249223		
3.1m	Rain	RM Young	747		
3.6m	SWR	Eppley PSP	32421		
3.6m	LWR	Eppley PIR	35962		
CO2	Electronics	PMEL	0020		
	Span Gas	Luxfer	JB03400		
Subsurface Instrumentation					
Bridle		**Model**	**Serial #**		**Notes**
1m	SST/C	SBE37SMP - TC	3802		Flex
1m	SST/C	SBE37SMP - TC	11554		TFLEX
1m	pH	Sami	P0031/0192		CO2
1m	SST/C	SBE16+V2	7138		CO2
1m	Oxygen	Optode	1569		Attached to CO2 SBE16+
1m	Fluorescence	ECO FLNTUS	1950		Attached to CO2 SBE16+
1m	Gas Tension	GTD	110303		Attached to CO2 SBE16+ (owned by UW)
Depth		**Model**	**Serial #**	**IM ID**	**Notes**
5m	TP	SBE39IM-TP	4361	01	Inverted
8.46m	ADCM	AquaDopp	12026	02	New sensor at this depth
10m	TC	SBE37IM - TC	6076	03	
15m	TC	SBE37IM - TC	6077	04	
16.46m	ADCM	AquaDopp	9980	05	
20m	TP	SBE39IM-TP	4377	06	Inverted
25m	TC	SBE37IM - TC	6078	07	
33m		Backscatter			JAMSTEC
35m	TC	SBE37IM - TC	6079	08	
36.46m	ADCM	AquaDopp	5952	09	
40m	T	SBE39IM-T	3287	10	Inverted
50m	TCP	SBE37IM - TCP	12519	11	Has AA batteries
75m	TCP	SBE37IM - TCP	7093	12	
100m	TCP	SBE37IM - TCP	7094	13	
123m		Backscatter			JAMSTEC
125m	TCP	SBE37IM - TCP	7095	14	
150m	TCP	SBE37IM - TCP	7096	15	
175m	TCP	SBE37IM - TCP	7097	16	
200m		PAL	CURLEW		UW APL
225m	TCP	SBE37IM - TCP	7098	17	
275m	TCP	SBE37IM - TCP	7099	18	
325m	TCP	SBE37IM - TCP	7100	19	
375m	TP	SBE39IM-TP	4379	20	
425m	TCP	SBE37IM - TCP	7101	21	
475m	TP	SBE39IM-TP	4859	22	
525m	TCP	SBE37IM - TCP	7785	23	
700m	End of Wire				
Release	TCP	SBE37SM - TCP	10504	-	Has AA batteries

Table 1: Instruments deployed on KE013.

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.

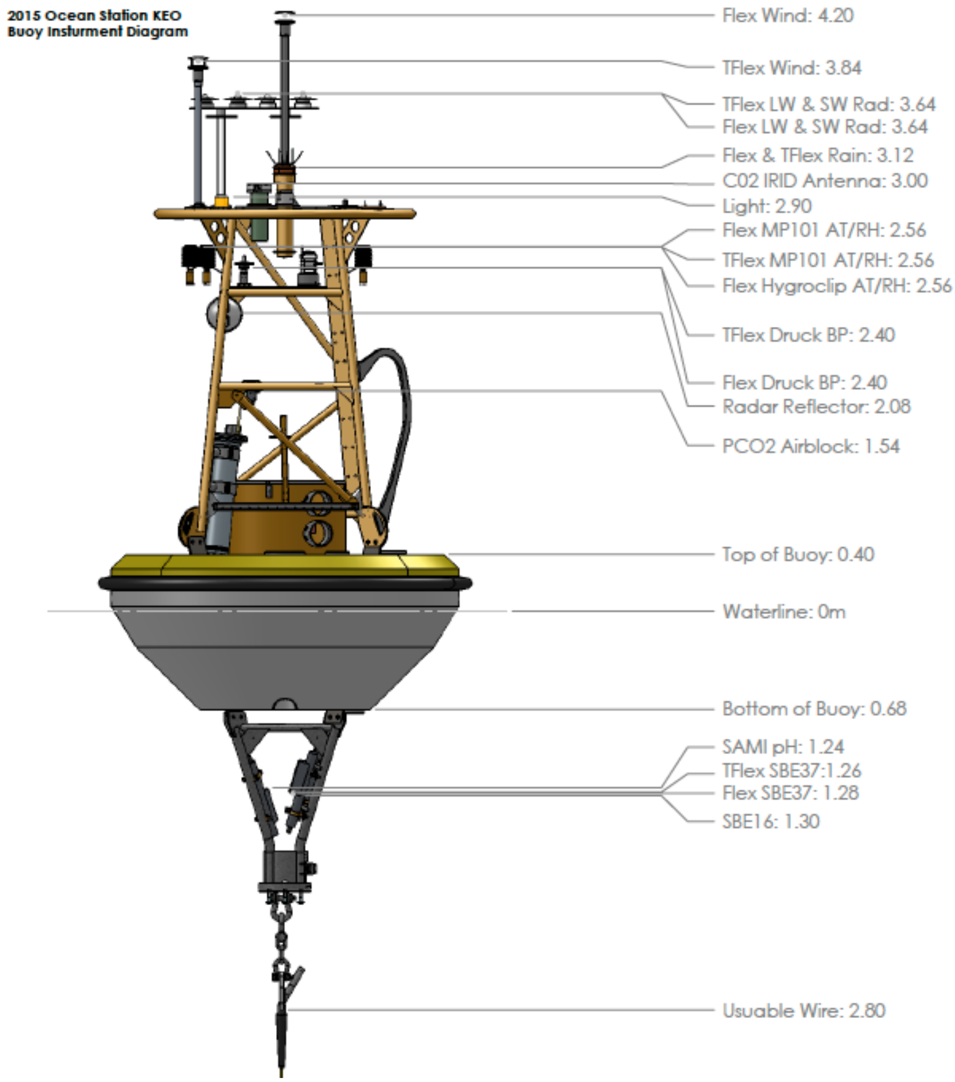

Figure 4: Buoy diagram showing bridle arrangement. The SBE16 package contains a suite of sensors.

2.0 Data Acquisition

Two independent data acquisition systems were deployed on KE013, 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. KE013 was the second 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 6 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.

The TFlex GPS was not responsive during this deployment, and no fixes were obtained by this system throughout the deployment.

2.1 Sampling Specifications

The following tables describe the high-resolution sampling schemes for the KE013 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	TFLEX
Air Temperature + Relative Humidity	1 Hz	2 min	2359-0001, 0009-0011…	10 min	TFLEX
Barometric Pressure	1 Hz	2 min	2359-0001, 0009-0011…	10 min	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
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 KE013.

SECONDARY SENSORS

Measurement	Sample Rate	Sample Period	Sample Times	Recorded Resolution	Acquisition System
Wind Speed/Direction	2 Hz	2 min	2359-0001, 0009-0011…	10 min	FLEX
Air Temperature + Relative Humidity	1 Hz	2 min	2359-0001, 0009-0011…	10 min	FLEX
Barometric Pressure	1 Hz	2 min	2359-0001, 0009-0011…	10 min	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
SSTC	1 per 10 min	Instant.	0000, 0010,…	10 min	Internal
GPS Position					None (Failed)

Table 3: Sampling parameters for the secondary sensors on KE013.

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. Tables 4 and 5 show the data returns from the surface measurements on KE013.

Sensor	S/N	Obs	Deployed	Return	Instrument Type
AT	118825	47125	47363	99.5%	MP101
AT 2	61334287	47125	47363	99.5%	HygroClip
RH	118825	37813	47363	79.8%	MP101
RH 2	61334287	47125	47363	99.5%	HygroClip
WIND	073805	47080	47363	99.4%	GILL
RAIN	1629	126721	473632	26.8%	RMYCRG
BP	2153683	47125	47363	99.5%	RPT350
SWR	35934	446968	473632	94.4%	PICSWR
LWR	33341	446843	473632	94.3%	PICLWR

Table 4: Flex data returns (%) from surface measurements on KE013.

Sensor	S/N	Obs	Deployed	Return	Instrument Type
AT	133390	47363	47363	100.0%	MP101
RH	133390	47363	47363	100.0%	MP101
WIND	042213	47363	47363	100.0%	GILL
RAIN	747	469686	473632	99.2%	RMYCRG
BP	4249223	47363	47363	100.0%	RPT350
SWR	32421	470295	473632	99.3%	PICSWR
LWR	35962	470814	473632	99.4%	PICLWR

Table 5: TFlex data returns (%) from surface measurements on KE013.

* Full record available at 40m, but see Section 3.3.1 for details on noise/flagging.

Sensor Depth	S/N	Deployed	Obs	Data Returns		
				T	C	P
1m (Flex)	3802	47363	47363	100.0%	100.0%	N/A
1m (TFlex)	11554	47363	47363	100.0%	100.0%	N/A
5m	4361	47363	37804	79.8%	N/A	79.8%
10m	6076	47363	47363	100.0%	100.0%	N/A
15m	6077	47363	47363	100.0%	100.0%	N/A
20m	4377	47363	41954	88.6%	N/A	88.6%
25m	6078	47363	47363	100.0%	100.0%	N/A
35m	6079	47363	47363	100.0%	100.0%	N/A
40m	3287	47363	47363	100.0%*	N/A	N/A
50m	12519	47363	47363 P = 28891	100.0%	100.0%	61.0%
75m	7093	47363	47363	100.0%	100.0%	100.0%
100m	7094	47363	47363	100.0%	100.0%	100.0%
125m	7095	47363	47363	100.0%	100.0%	100.0%
150m	7096	47363	47363	100.0%	100.0%	100.0%
175m	7097	47363	47363	100.0%	100.0%	100.0%
225m	7098	47363	47363	100.0%	100.0%	100.0%
275m	7099	47363	47363	100.0%	100.0%	100.0%
325m	7100	47363	47363	100.0%	100.0%	100.0%
375m	4379	47363	45484	96.0%	N/A	96.0%
425m	7101	47363	47363	100.0%	100.0%	100.0%
475m	4859	47363	42575	89.9%	N/A	89.9%
525m	7785	47363	47363	100.0%	100.0%	100.0%
				Aquadopp Returns		
8m	12026	47363	33233	70.2%		
16m	9980	47363	47363	100.0%		
36m	5952	47363	47363	100.0%		

Table 6: Data returns (%) from subsurface measurements on KE013.

2.3 Known Sensor Issues

Daily shortwave radiation had a percent difference of 3.3%, with the TFlex measuring higher values during a majority of the deployment. Using criteria developed at PMEL, the TFlex was chosen as the primary for SWR and LWR. Some high spikes and regions where LWR sensors differed by more than 20 W/m^2 required flagging.

The TFlex ATRH sensor (S/N 133390) was made primary after reviewing the data. The choice was confirmed when the Flex sensor (S/N 118825) relative humidity data diverged from neighboring sensors on May 20, 2016, and failed its post-recovery calibration.

The Flex rain gauge (S/N 1629) was intermittent starting December 10, 2015, and failed by mid-January. The TFlex rain gauge (S/N 747) was designated the primary instrument.

Several subsurface instruments were erratic or failed during the deployment. A summary is provided here, with additional text descriptions below.

Instrument	Time of Incident or Failure	Comment
1m SST/C (Flex)	October 20, 2015	>50% real-time data missing 100% delayed-mode data recovered, designated primary
5m TP	October 5, 2015 May 26, 2016	Instrument likely pulled up by fishing gear (Pressure <3db). Data assigned standard quality. Sensors remained functional, and can deviate from nominal depths at KEO. Data Flatlined
8m Aquadopp	April 25, 2016	Battery died
20m TP	June 24, 2016	Battery died
40m Temperature	April 14, 2016	Noisy, high readings
50m Pressure	March 25, 2016 February 8, 2017	Jumps between 573dbar and -595dbar. Salinity returns after March 25 were possible w/ pressure interpolation from other depths. Post-calibration pressure indicated “calibration after modifications”
375m TP	July 18, 2016	Battery died
475m TP	June 28, 2016	Battery died

In November 2015, inductive data dropouts from the subsurface instruments began occurring about 10% of the time. The frequency of the dropouts increased to 20-40% in December, and 50-80% in January 2016. The data required hourly manual review to correct erroneous strings from an Aquadopp, which appeared to be impacting the other data records. On January 21, a command was sent to the buoy to shut down the real-time Aquadopp transmissions, which restored good communications from all other subsurface instruments. On February 25, 2016, another command was sent to reactivate the Aquadopp transmissions, which resumed without impacting other transmissions.

The 8m Aquadopp (S/N 12026) failed due to a depleted battery on April 25, 2016, and a command to turn off real-time communications to it was sent the following day. When recovered, the instrument would not communicate with the manufacturer's software, even with external power applied. The battery compartment was opened and the desiccant pack was found to have burst. Data download was successful after cleaning the internal compartment. Having removed the battery pack, no post-deployment compass check was possible. A contributing factor to the Aquadopp failure could have been the 10m instrument, which was found forced up against the Aquadopp at 8m while remaining clamped to the line securely enough to hold its new position.

SBE39 S/N 3287 at 40m had a dead battery at recovery. When new batteries were installed, the status showed the sample number was 0, indicating there were no data in memory. It is likely that the sample pointer had reset when the batteries were removed. The instrument was delivered to Seabird and the data in memory were recovered. The delayed-mode data were noisy (jumping to >40°C), mirroring the real-time data, starting in mid-April. The data were flagged Q5 after this point, as the temperatures no longer fit into context with the surrounding sensors. Other SBE39 instruments also had dead batteries, but data were retrievable using fresh batteries. Unfortunately, this meant that clock errors could not be checked on any of the SBE39s.

The pressure sensor on SBE37 S/N 12519 reported values outside of realistic bounds, between -595dbar and 573dbar, starting March 25, 2016. Salinity calculations could proceed because pressures were interpolated after the failure.

During the KE013 recovery, physical damage was noted on the instruments below 400m. The 425m instrument had a bent guard, while the guards were missing on the 475m and 525m instruments. Secured to the instruments with four screws, the titanium guards usually protect the conductivity cell and thermistor, which was bent on the 525m sensor. Long-line fishing gear is suspected of applying the extreme force required to fold the titanium housing.

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.

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, 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 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.

As described in Section 2.0, GPS units on the Flex and CO_2 systems acquired position data for KE013. The TFlex did not return regular positions.

3.2 Meteorological Data

All primary meteorological sensors on KE013 remained functional at or near 100% throughout the deployment. Many TFlex instruments were considered primary in this deployment due to higher data returns or failed Flex instrument post-recovery 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 KE013 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

A majority of wind speed and direction data were assigned the standard quality flag of Q2. A few measurements where the wind speed exceeded the wind gust values were flagged Q5, and were usually found near data gaps.

The TFlex Gill snapped off during recovery, as shown in Figure 5. The ability to obtain post-recovery calibration coefficients from the Flex sensor was weighed against the modestly higher data returns from the TFlex instrument. Ultimately, the TFlex sensor was considered primary, since no drift was apparent between the wind sensors, and the Flex Gill passed its post-recovery calibration. The largest wind differences were due to data spikes that occurred in the Flex Gill time-series, which were removed.

Figure 5: Image of the missing TFlex Gill wind sensor.

3.2.2 Air Temperature

Both air temperature sensors performed well. The TFlex MP101 was made primary due to the failure of the Flex MP101 relative humidity sensor. Limited Q4 flags were assigned to the secondary (Flex) air temperature measurements where there were differences with the primary instrument, which remained at standard quality.

3.2.3 Relative Humidity

The relative humidity sensor in the Flex MP101 began steadily drifting upward from the beginning of the deployment. By May 2016, the TFlex – Flex difference averaged around 2% (Figure 6), and the variability in the differences had increased (Figure 7). Considering the smooth but consistent departure from the other two time-series, the Flex RH time-series was flagged Q4 throughout, with Q5 flags applied when it jumped to ~105% on May 20, 2016, shortly before failure. The Flex RH sensor also failed its post-recovery calibration, suggesting that it produced lower quality data.

Due to the observed issues with the Flex MP101, the TFlex relative humidity sensor was made the primary measurement for KE013.

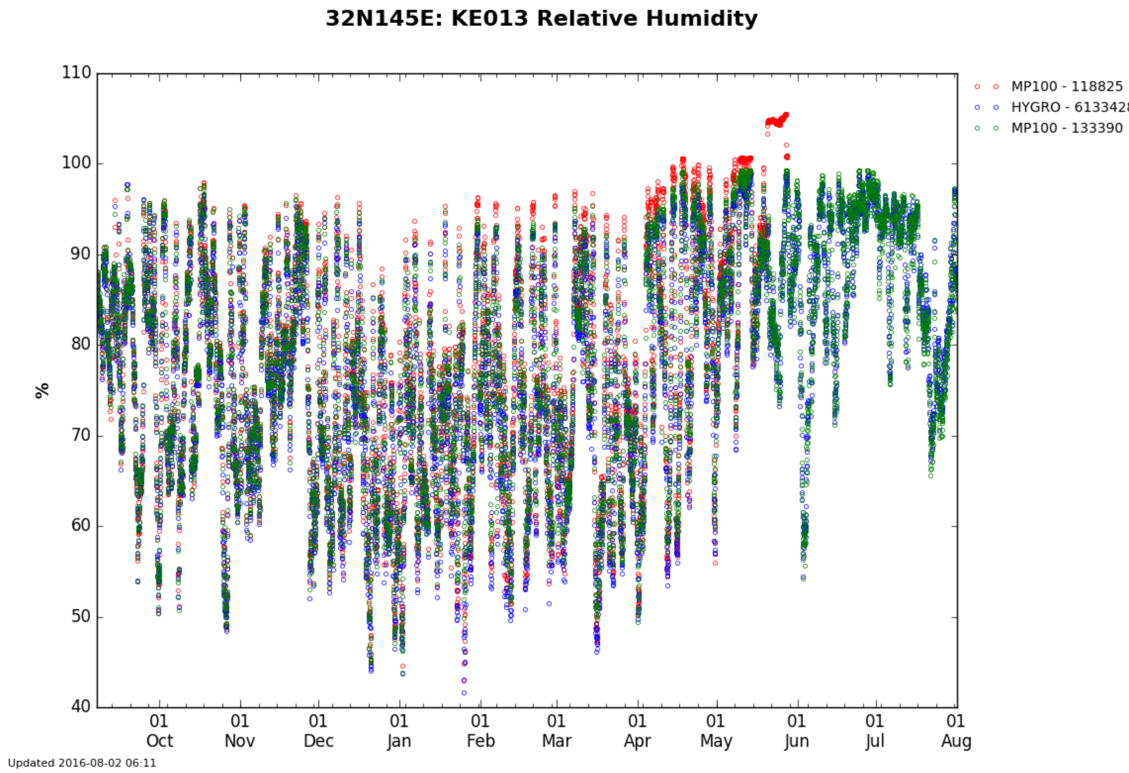

Figure 6: Relative humidity time-series comparison.

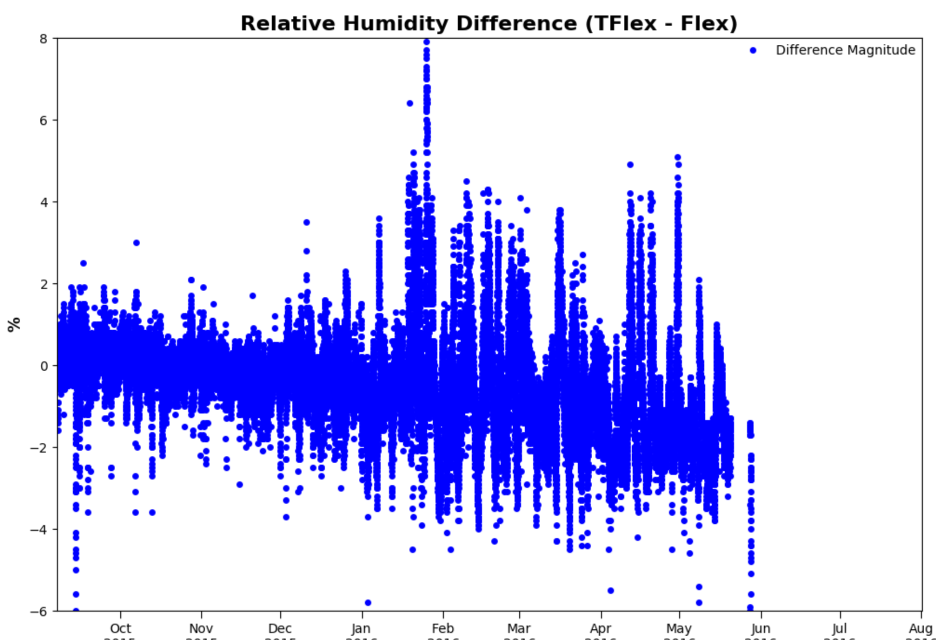

Figure 7: Relative humidity (TFlex – Flex) difference plot.

3.2.4 Barometric Pressure

Atmospheric pressure was measured using a Druck RPT350 sensor on both Flex and TFlex. Measurements from the calibrated sensors tracked closely throughout the deployment, with a mean difference of 0.1mb, never differing by more than 0.8mb. The TFlex had slightly higher data returns, and was chosen as primary.

Tropical storm Etau was southwest of KEO during deployment, followed closely by typhoon Kilo on September 10. Typhoon Krovanh's closest passage was on September 20, 2015. Typhoon Choi-Wan passed nearby on October 7, 2015 with a minimum pressure of 993.5 mb. The lowest observed pressures of 990.3 mb and 991.4 mb were from unnamed low-pressure systems on January 18, 2016 and March 14, 2016.

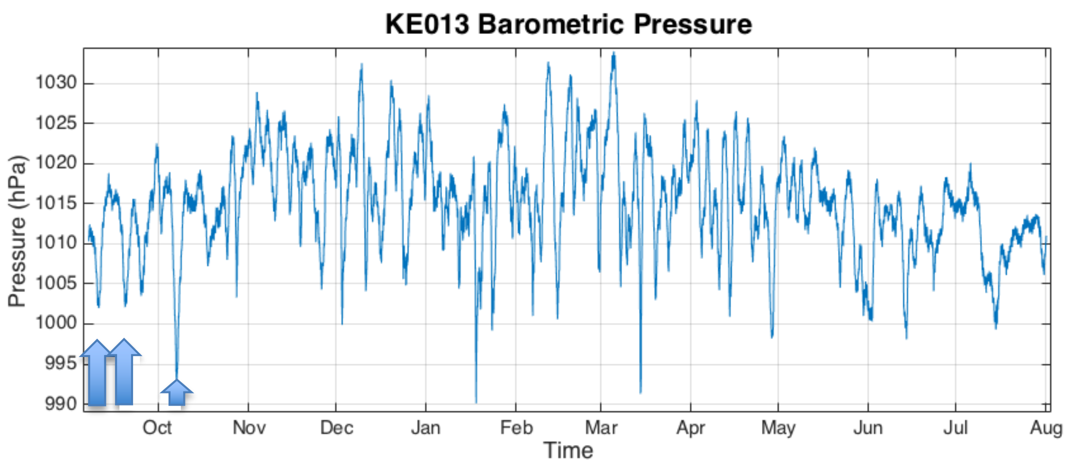

Figure 8: KE013 Barometric Pressure. Several storms passed KE013, and can be seen in the BP record. Arrows point to the combined effects of typhoons Kilo, Krovanh, and Choi-Wan.

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. 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.

KE013 Flex rain (S/N 1629) data became erratic December 10, 2015, and appeared to fail on January 12, 2016. The remainder of the deployment was flagged Q4, since intermittent data occurred weeks later. Automated scripts detected instances of accumulation noise and anomalous accumulation events. Standard processing routines resulted in 3,645 Q5 flag entries (single points or continuous segments of flagging) to remove noise in the accumulations. The TFlex rain gauge (S/N 747) had only 41 Q5 flag entries, lasted throughout the deployment, and was designated primary.

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 KE013 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 3.32%. Clouded glass on the Flex radiometer could explain the difference, and provides additional reason to classify the TFlex radiometer as the primary sensor.

Figure 9: TFlex (left) and Flex (right) 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 will bias the data. The average will be biased high when nighttime (0) values are missing, and low if daytime values are not present. In keeping with GTMBA processing methods for SWR, 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 to generate hourly and daily averages.

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 KE013 TFlex LWR, which also had the higher data return, was designated primary. A few spikes were noticed while plotting data, and were flagged Q5 (removed). Small spikes, such as the ones on July 6, 2016, are left at standard quality, since it is unclear which sensor matches reality, and the magnitude of the noise is within seasonal bounds.

Two periods of data in early July were assigned Q4, when the sensors diverged (see Figures 10 and 11). The underlying cause remains unknown, but the anomaly appears in the raw data download. The lower quality flags were additionally justified because Flex and TFlex values exceeded both seasonal bounds and the Stefan-Boltzmann law (σT^4), when air or sea surface temperatures were used for T.

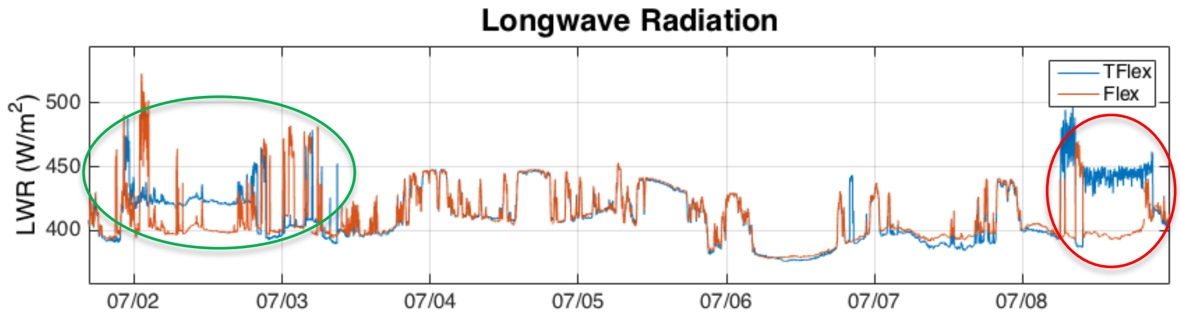

Figure 10: Downwelling LWR time-series showing two regions of lower quality data. The data circled in green have a visible offset, while the data in red (zoomed in the next figure) have an offset and a brief data swap anomaly.

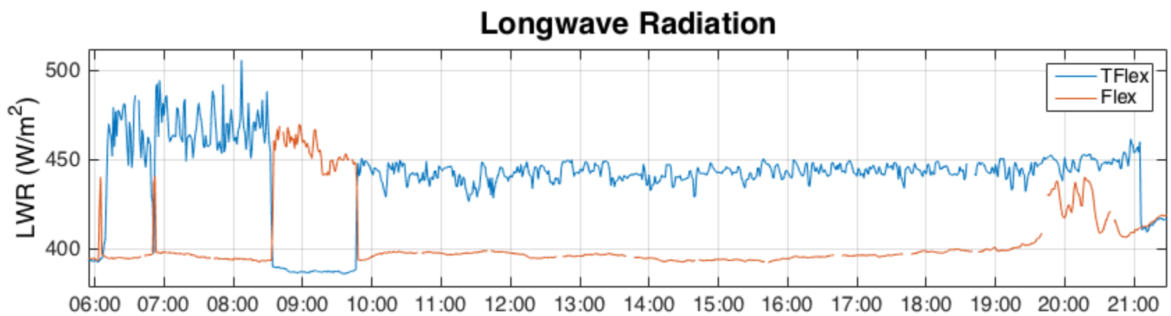

Figure 11: Zoomed region (7/8/2016) of lower quality LWR data, where the time-series diverge, then appear to swap for a 1 hour duration. Note that the recurring missing values are due to realtime transmission interference.

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 on the mooring wire 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 12). No clock errors exceeded half the sampling interval, so measurements were mapped to the nearest 10-minute time increment.

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-	3802	00:24:50	00:25:04	0:00:14		6.02/3.21		
1	SBE37-	11554	00:34:15	00:34:01	-0:00:14		13.58/3.24		
2	SAMI pH	P0031							
3	SBE16+	7138							
4	O2	1569							
5	ECO	1950							
6	GTD	Unknown							
7	SBE39-	4361						*SBE39s downloaded	
8	Aquadopp	12026						AQD DL failed w/ ext.	
9	SBE37-	6076	08:17:35	08:17:29	-0:00:06		6.77/3.18		
10	SBE37-	6077	07:59:40	07:59:37	-0:00:03		6.78/3.25		
11	Aquadopp	9980	11:16:40	11:17:13	0:00:33			Old AQD install=no batts	
12	SBE39-	4377						*	
13	Backscatt	891						JAMSTEC	
14	SBE37-	6078	09:08:05	09:07:56	-0:00:09		6.71/3.20		
15	SBE37-	6079	10:12:45	10:12:45	0:00:00		6.63/3.21		
16	Aquadopp	5952	11:29:15	11:29:31	0:00:16			Old AQD install=no batts	
17	SBE39-T-	3287						*	
18	SBE37-	12519	10:43:35	10:43:16	-0:00:19		13.89/3.25		
19	SBE37-	7093	08:08:40	08:08:49	0:00:09		6.99/3.22		
20	SBE37-	7094	10:02:25	10:02:42	0:00:17		6.51/3.26		
21	Backscatt	905						JAMSTEC	
22	SBE37-	7095	09:24:50	09:24:54	0:00:04		6.55/3.18		
23	SBE37-	7096	08:28:05	08:28:12	0:00:07		6.66/3.20		
24	SBE37-	7097	09:52:50	09:52:54	0:00:04		6.49/3.16		
25	PAL	CURLEW						PARTNER INST	
26	SBE37-	7098	09:44:05	09:43:53	-0:00:12		6.94/3.31		
27	SBE37-	7099	09:34:45	09:34:40	-0:00:05		6.60/3.16		
28	SBE37-	7100	09:15:30	09:15:40	0:00:10		6.61/3.20		
29	SBE39-	4379						*	
30	SBE37-	7101	07:48:10	07:48:26	0:00:16		6.70/3.21		
31	SBE39-	4859						*	
32	SBE37-	7785	07:26:35	07:26:39	0:00:04		6.71/3.22		
33	SBE37-	10504	00:05:40	00:05:24	-0:00:16		6.96/3.22		
34	*NOTE:								
35									

Figure 12: Filemaker log displaying all instrument clock errors. Note at bottom reads "SBE39 batteries died; no instrument times available."

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. There was no evidence of drift in the temperature measurements based on post-calibrations, so no corrections were applied. Several instruments stopped logging early, due to low batteries.

The temperature sensor at 40m became highly variable in the last third of the deployment. Data were flagged Q5 from 2016-04-14 14:20 UTC to the end of the deployment.

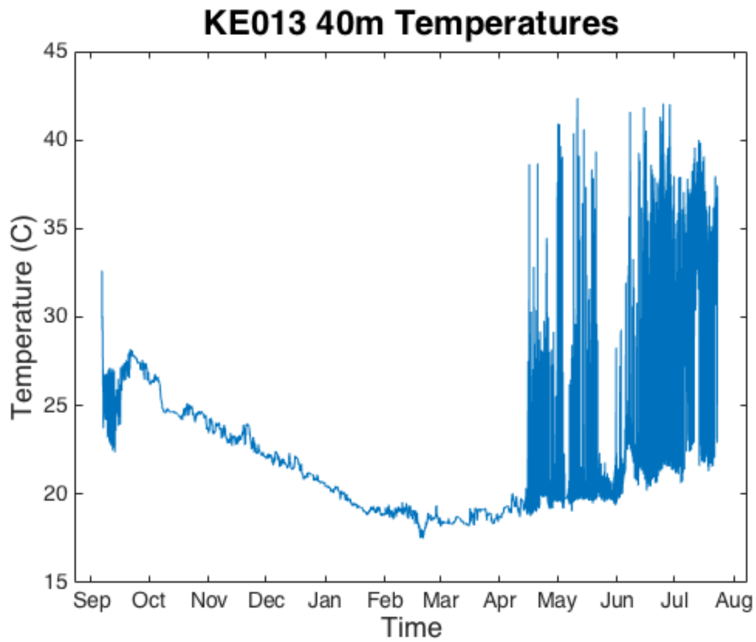

Figure 13: KE013 raw 40m temperatures showing unrealistic temperatures starting mid-April.

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 50m instrument failed differently than previous pressure sensor failures. After March 25, 2016, interpolated pressures were used in place of the noisy data returned by the instrument.

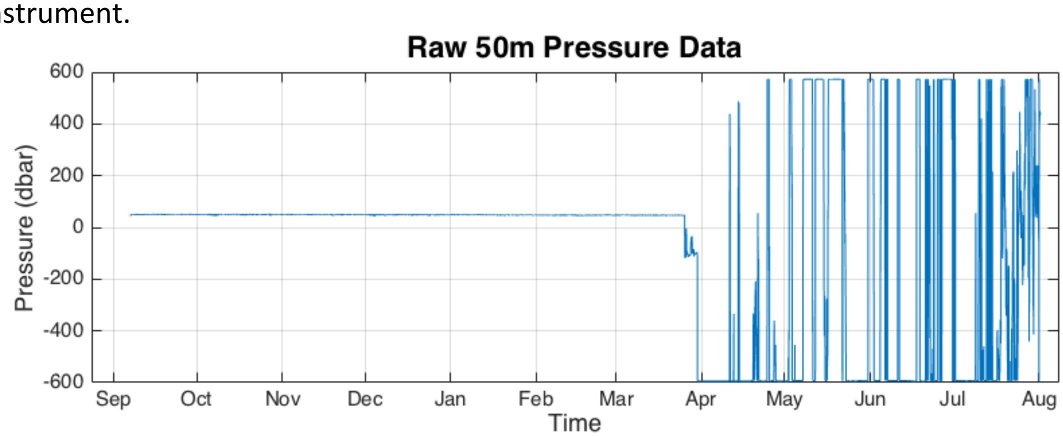

Figure 14: Failure of the 50m pressure sensor.

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)	-0.0302
1m (Flex)	-0.0565
10m	-0.0609
15m	-0.0284
25m	-0.0192
35m	-0.0281
50m	-0.0180
75m	-0.0536
100m	-0.0291
125m	-0.0193
150m	-0.0166
175m	-0.0308
225m	-0.0176
275m	-0.0250
325m	-0.0168
425m	-0.0139
525m	-0.0164

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 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 seawater. Positive values indicate a decrease in the cell's 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.

Manual Salinity Adjustments

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

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 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, the following adjustments were made:

Primary 1m SSTC (Flex)
2015-09-06 02:27:41 to 2016-01-23 17:50:46 adjusted 0.0000 to -0.0047
2016-01-23 17:50:46 to 2016-04-23 04:55:23 adjusted -0.0047 to 0.0024
2016-04-23 04:55:23 to 2016-05-13 03:02:45 adjusted 0.0024 to 0.0165
2016-05-13 03:02:45 to 2016-06-04 16:42:15 adjusted 0.0165 to 0.0071

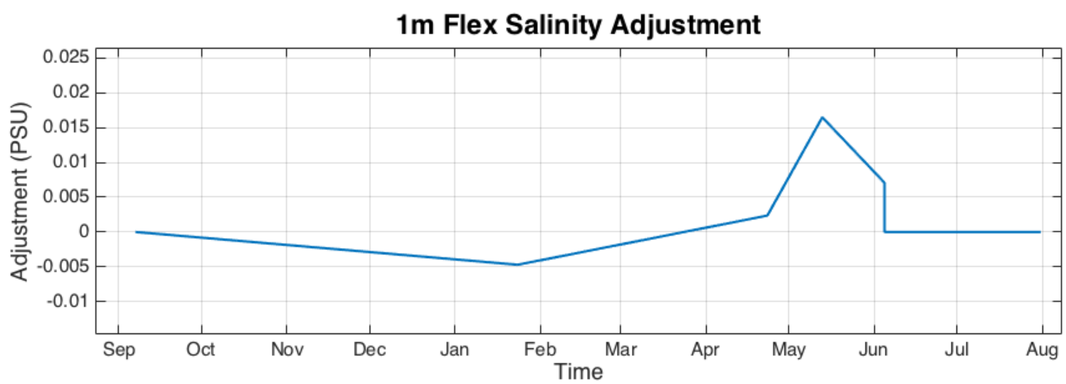

Figure 15: Flex SSTC Salinity Adjustments on KE013.

Secondary 1m SSTC (TFlex)
2015-09-06 22:48:47 to 2015-10-05 04:54:58 adjusted 0.0142 to 0.0017
2015-10-05 04:54:58 to 2015-10-08 17:40:44 adjusted 0.0017 to 0.0074
2015-10-08 17:40:44 to 2016-04-06 05:03:41 adjusted 0.0074 to -0.0187
2016-04-06 05:03:41 to 2016-04-28 19:32:38 adjusted -0.0187 to -0.0142
2016-04-28 19:32:38 to 2016-05-16 19:50:04 adjusted -0.0142 to -0.0074
2016-05-16 19:50:04 to 2016-06-05 22:58:58 adjusted -0.0074 to -0.0131
2016-06-05 22:58:58 to 2016-08-01 19:39:53 adjusted -0.0131 to -0.0344

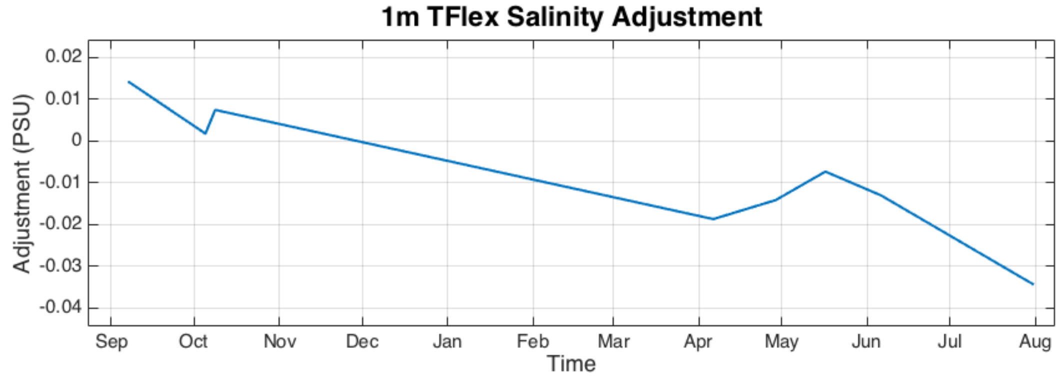

Figure 16: TFlex SSTC Salinity Adjustments on KE013.

10m

2015-09-06 06:42:39 to 2015-12-29 03:46:01 adjusted 0.0000 to -0.0052
2015-12-29 03:46:01 to 2016-05-13 22:55:38 adjusted -0.0052 to 0.0180
2016-05-13 22:55:38 to 2016-06-01 20:58:52 adjusted 0.0180 to 0.0000

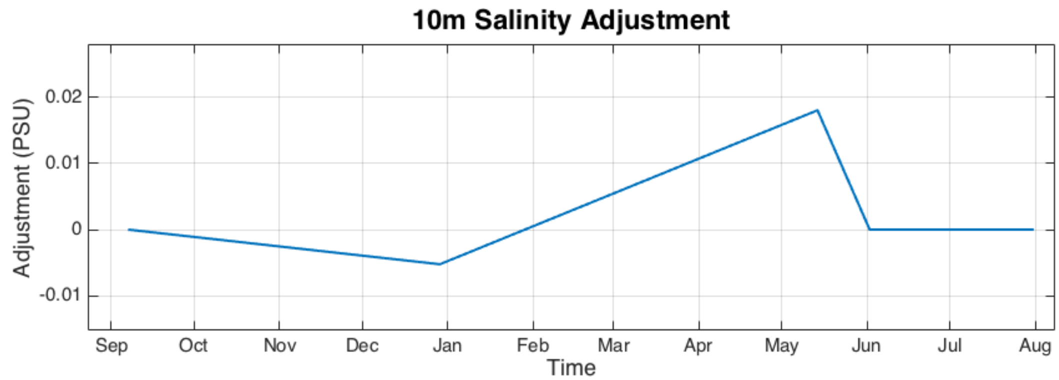

Figure 17: 10m Salinity Adjustments on KE013.

15m

2015-09-05 17:22:26 to 2016-05-25 07:35:12 adjusted 0.0000 to 0.0092
2016-05-25 07:35:12 to 2016-06-06 20:32:07 adjusted 0.0092 to 0.0000

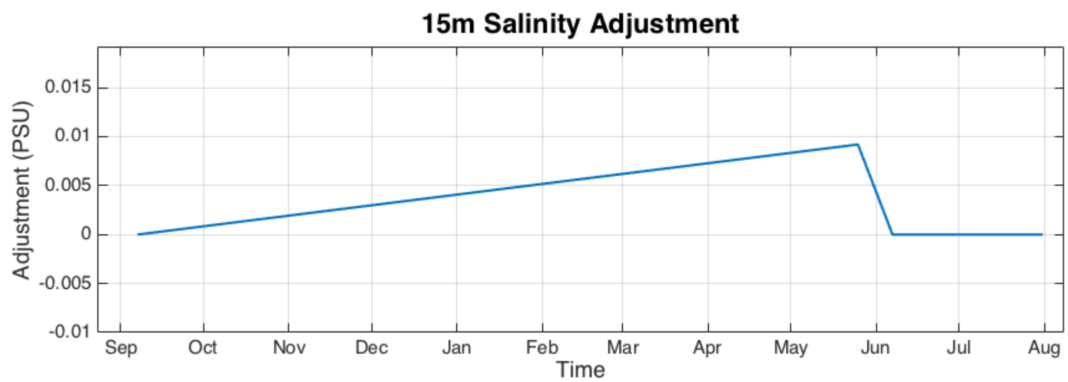

Figure 18: 15m Salinity Adjustments on KE013.

50m

2015-09-01 09:29:33 to 2016-03-26 05:14:42 adjusted 0.0028 to 0.0051

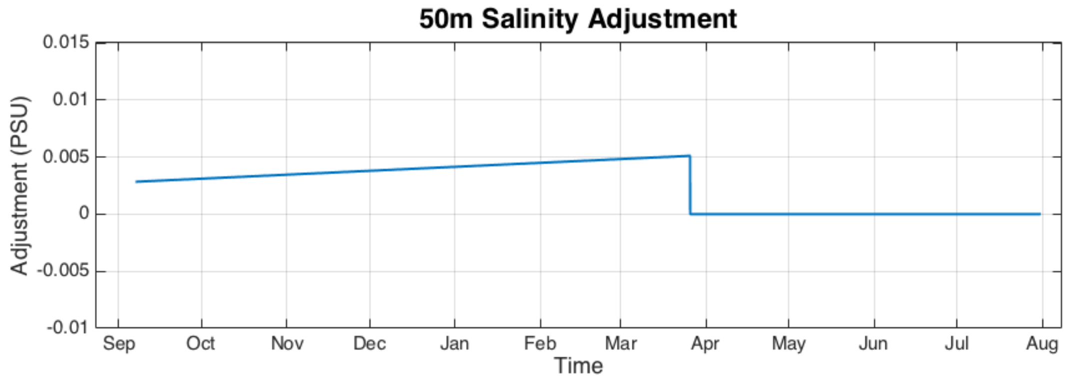

Figure 19: 50m Salinity Adjustments on KE013.

Note that all but one adjustment is below the instrument accuracy of 0.02 PSU. The instruments performed well during this deployment, and the adjustments made based on neighboring instruments were small.

Two CTD comparisons were available for KE013. A mid-deployment cast to 2000m was performed by Xiaopei Lin on a cruise to recover and deploy the M1/M2 moorings. The cast location was 32.1772°N 144.4947°E, while the KEO buoy was around 32.3881°N 144.5435°E. It was decided that the minor differences observed could be due to distance, and no corrections were made based on this cast.

The second cast was a designated KEO pre-recovery cast. By matching CTD pressures with pressures from the instruments on the mooring line, equivalent depths could be compared. Near-surface differences were attributed to the CTD equilibrating, when initially immersed. Below that, sensors on the line compared favorably, with mean absolute CTD density differences of just 0.0195 kg/m^3 below 40m.

The second CTD also descended at a rate of ~1m/s, passing through gradients in the water. A temperature gradient of ~2°C was observed between 25 - 35m, and the CTD appeared to have retained heat, as the 35m cast temperature was biased high on the downcast and the 25m cast temperature was biased low on the upcast. Data processors conferred and no changes were made to the mooring data based on this CTD.

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 (2018).

A known issue at KEO is deep salinity drift (freshening) of 0.03 – 0.06 PSU per year. The cause is not definitive, and information will be updated in OCS Technical Note 9 as it becomes available. An update log on the OCS data delivery page will be maintained to note any changes made to the data, as drift hypotheses are eliminated or confirmed.

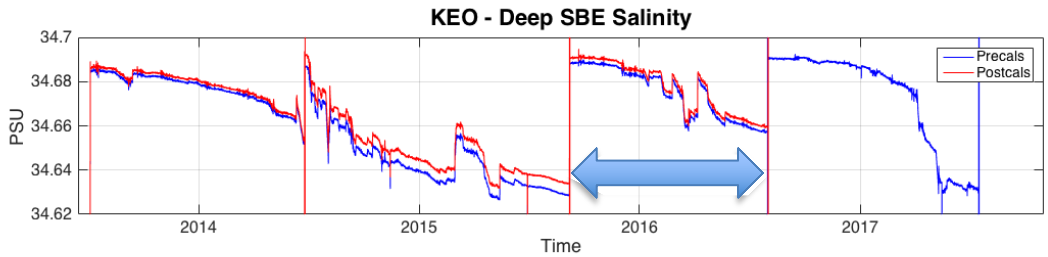

Figure 20: KEO deep ocean measurement, showing annual salinity drift. The arrow highlights KE013.

As of April 2018, no confident correction could be made to the deep SBE data. Data are distributed with pre-calibration coefficients applied (see Figure 20). 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 KE013 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 KE013 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 delayed-mode data. A thirteen-point Hanning filter is applied to 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 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 21.

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.

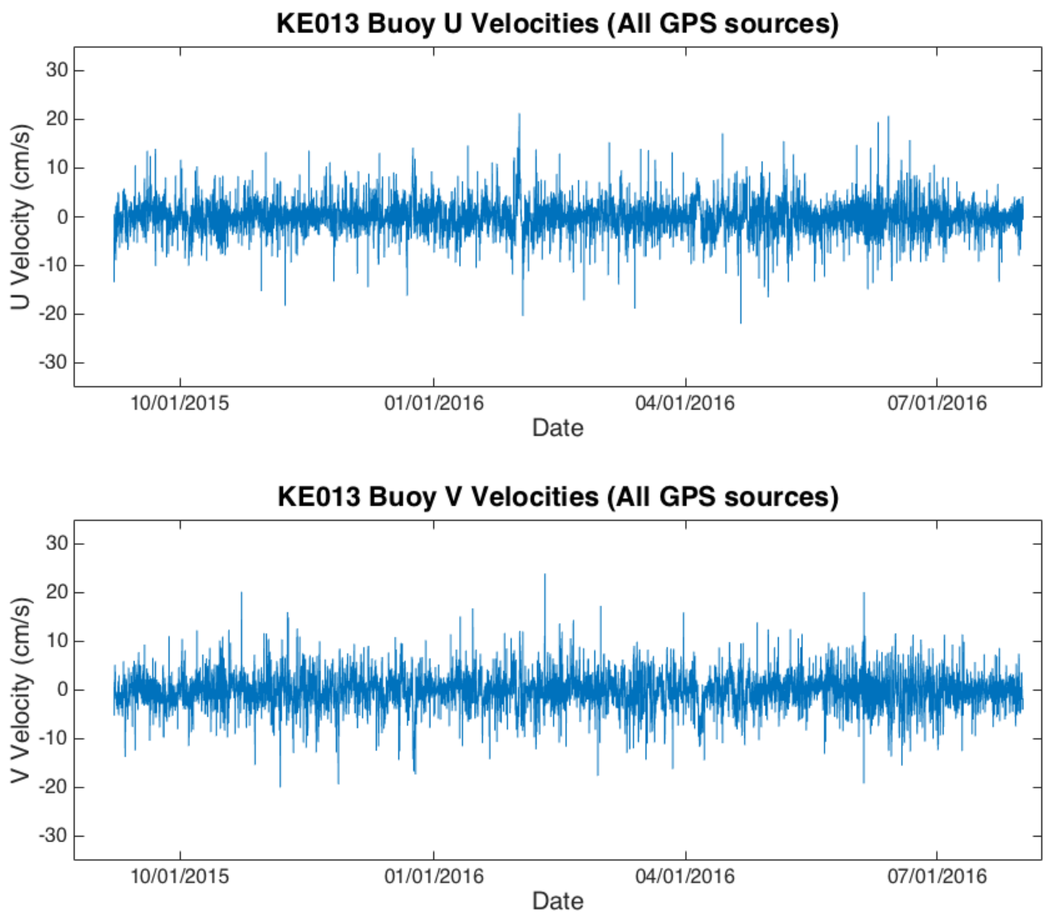

Figure 21: KE013 buoy velocities used to correct currents.

The Aquadopp at 8m lost realtime communications on April 24, 2016, due to a low battery (8.0 V). The delayed-mode record also terminated at this time.

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

N. Anderson (UW JISAO) processed the Flex/TFlex data, with initial assistance from C. Fey (UW JISAO) in developing scripts to handle the Flex/TFlex data. D. Dougherty (UW JISAO) is recognized for designing and generating the initial python files from which processing begins, and for the quality control of 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 both the deployment and recovery cruises. Dr. Makio Honda and Akira Watanabe (JAMSTEC), as well as Will Thomson and Lee Tretbar (NDBC) are acknowledged for their assistance in deployment, suggestions, and general work ethic while underway. Will's macro made easy work of the IMM subsurface sensor programming, which calls and initializes each instrument. Mariela White (UW) participated in the recovery cruise, and greatly assisted with sampling and operations.

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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

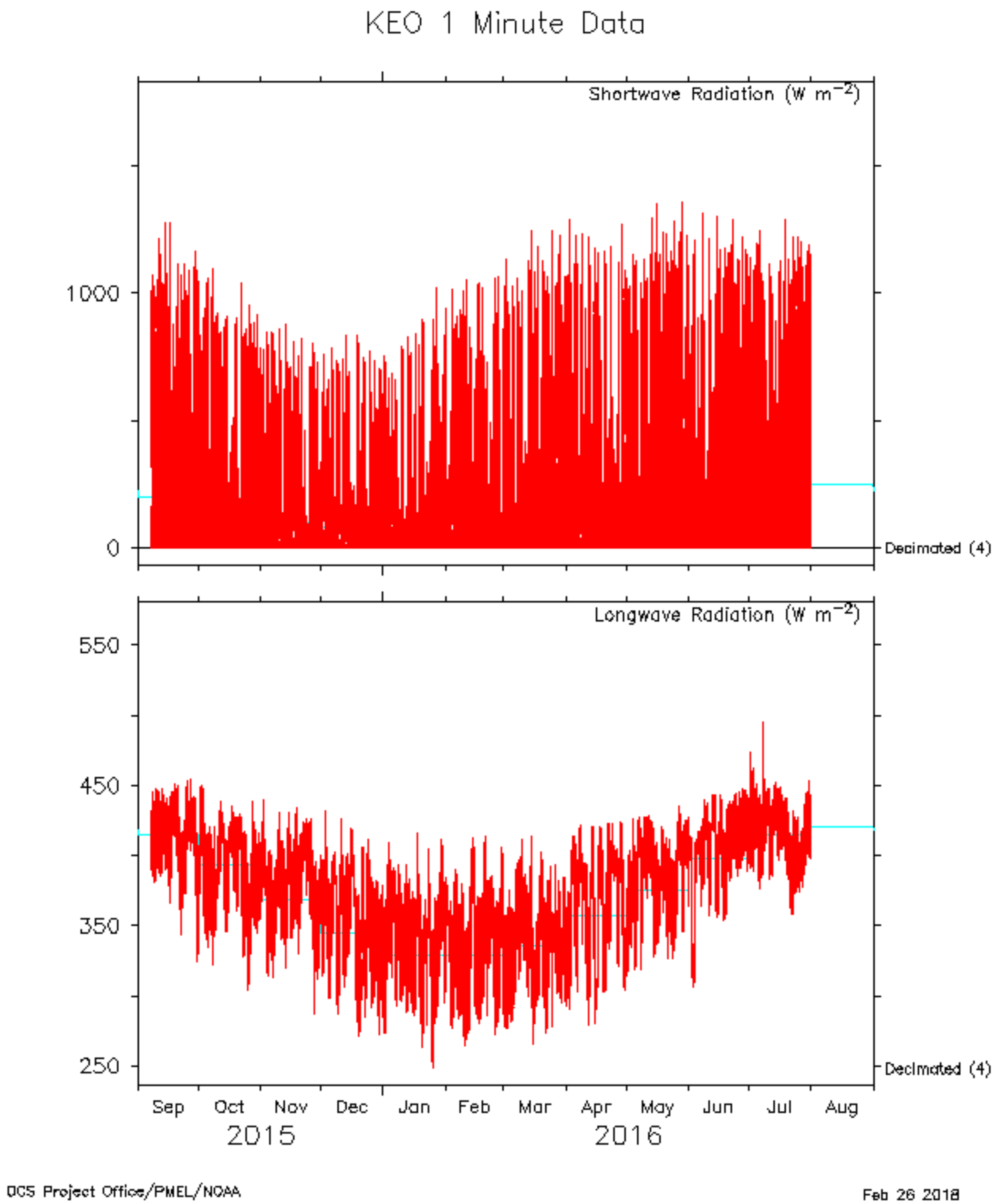

Figure B 1: KE013 primary shortwave and longwave radiation data at 1-min resolution (TFlex).

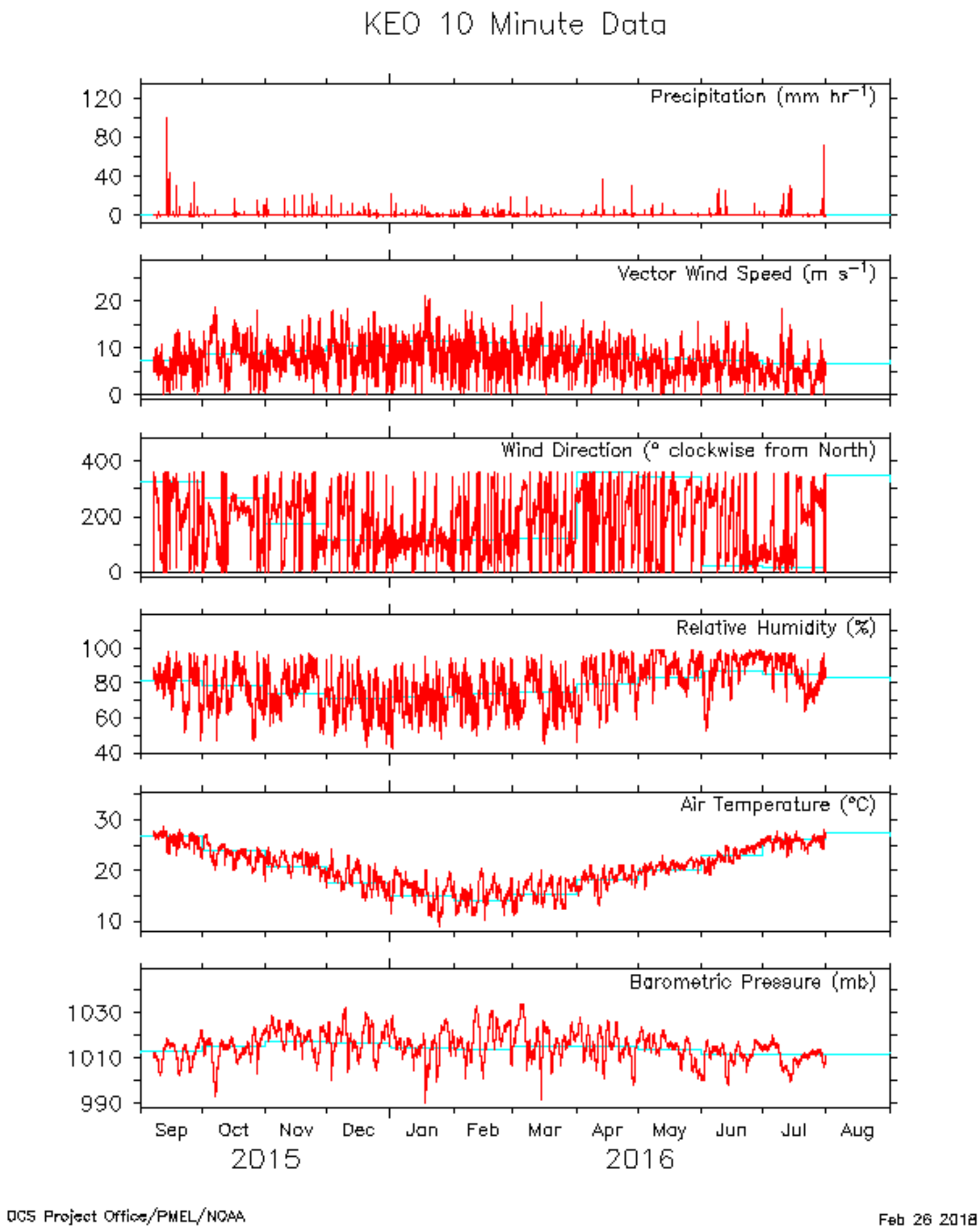

Figure B 2: KE013 primary meteorological data at 10-min resolution. All data are from TFlex, which outperformed the Flex sensors.

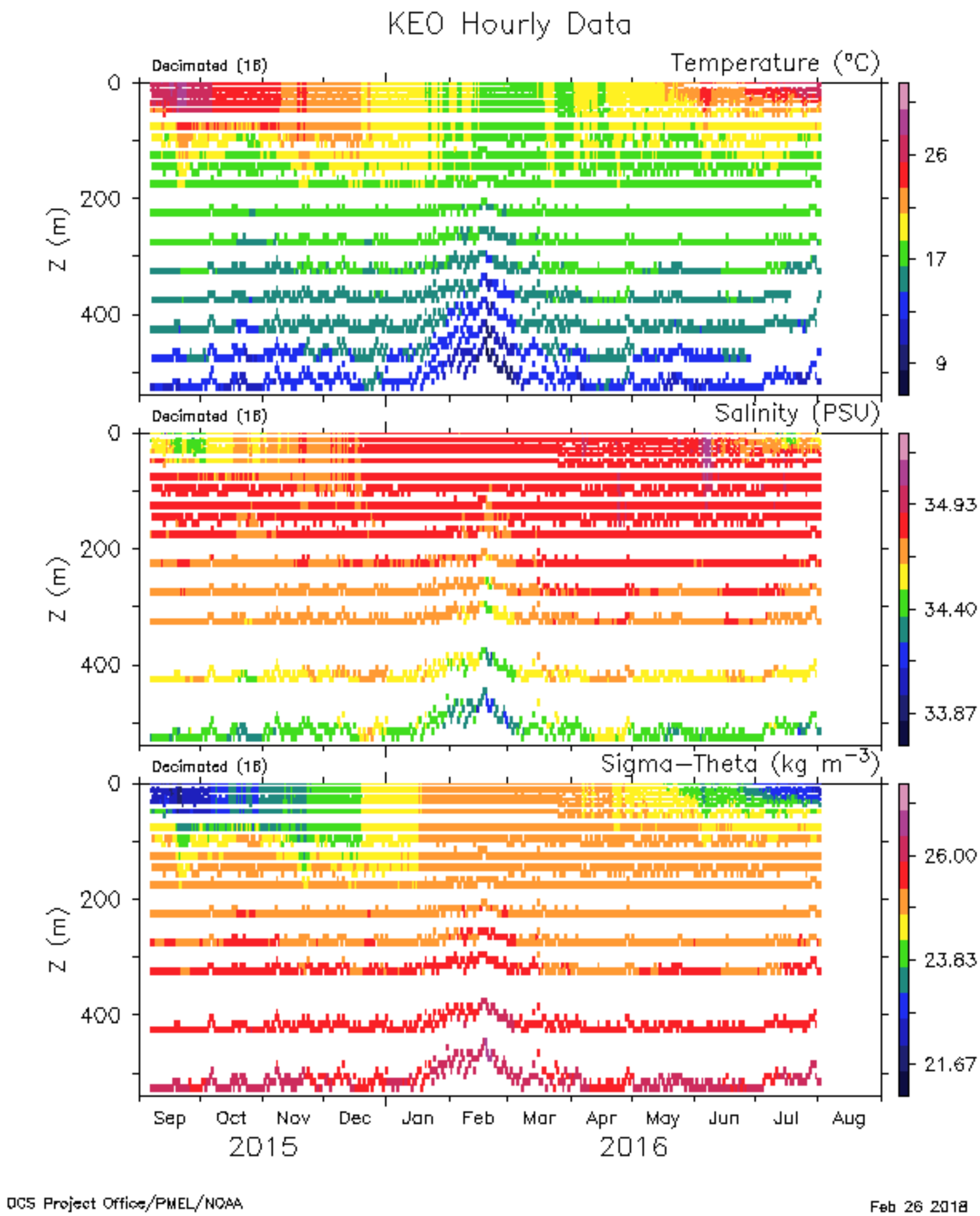

Figure B 3: KE013 subsurface temperature, salinity, and density at hourly resolution (decimated).

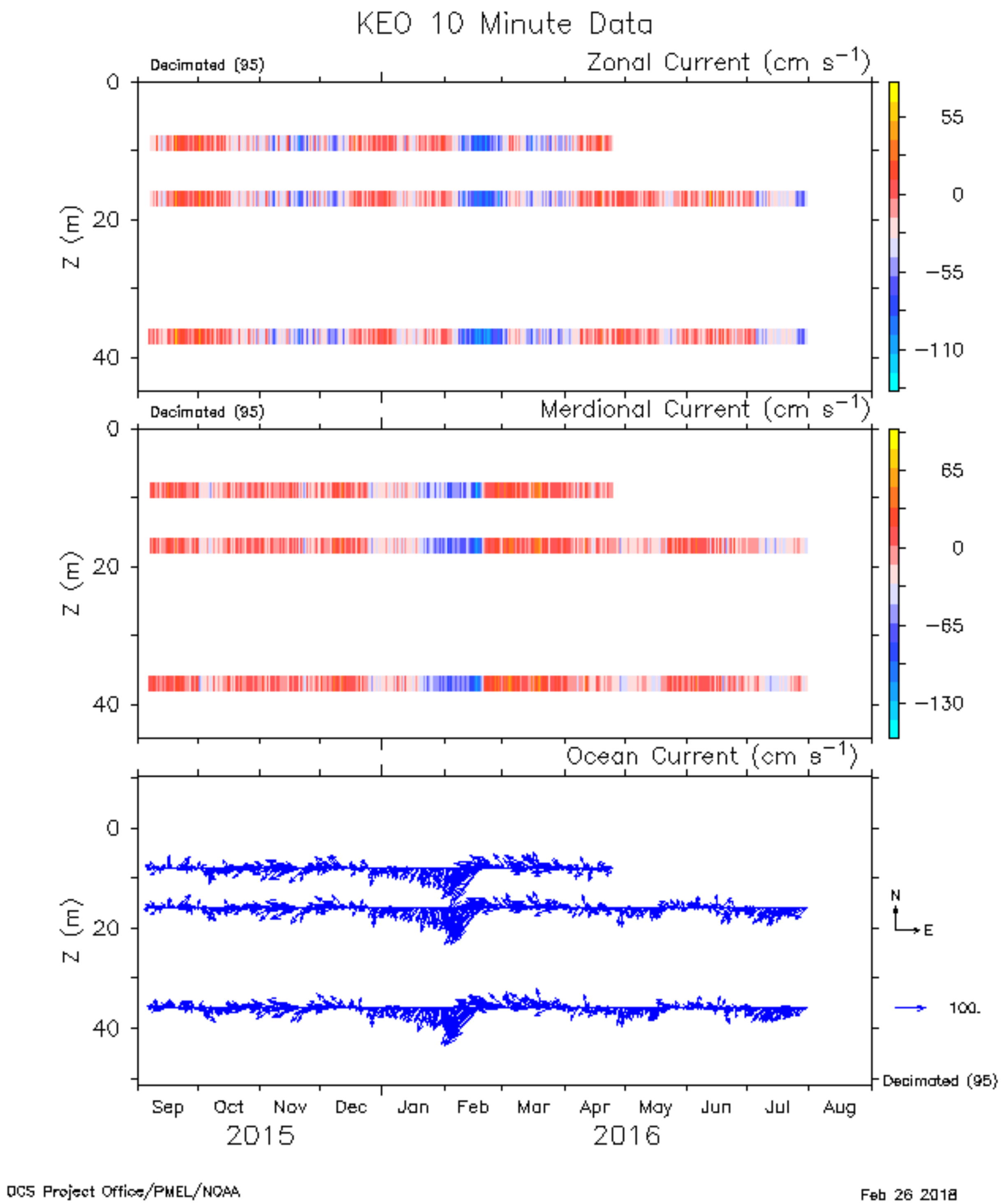

Figure B 4: Zonal and meridional current meter data (decimated) from KE013. The 8m AQD failed in April, when its battery voltage dropped below 8V. Realtime and delayed-mode data were equally affected.

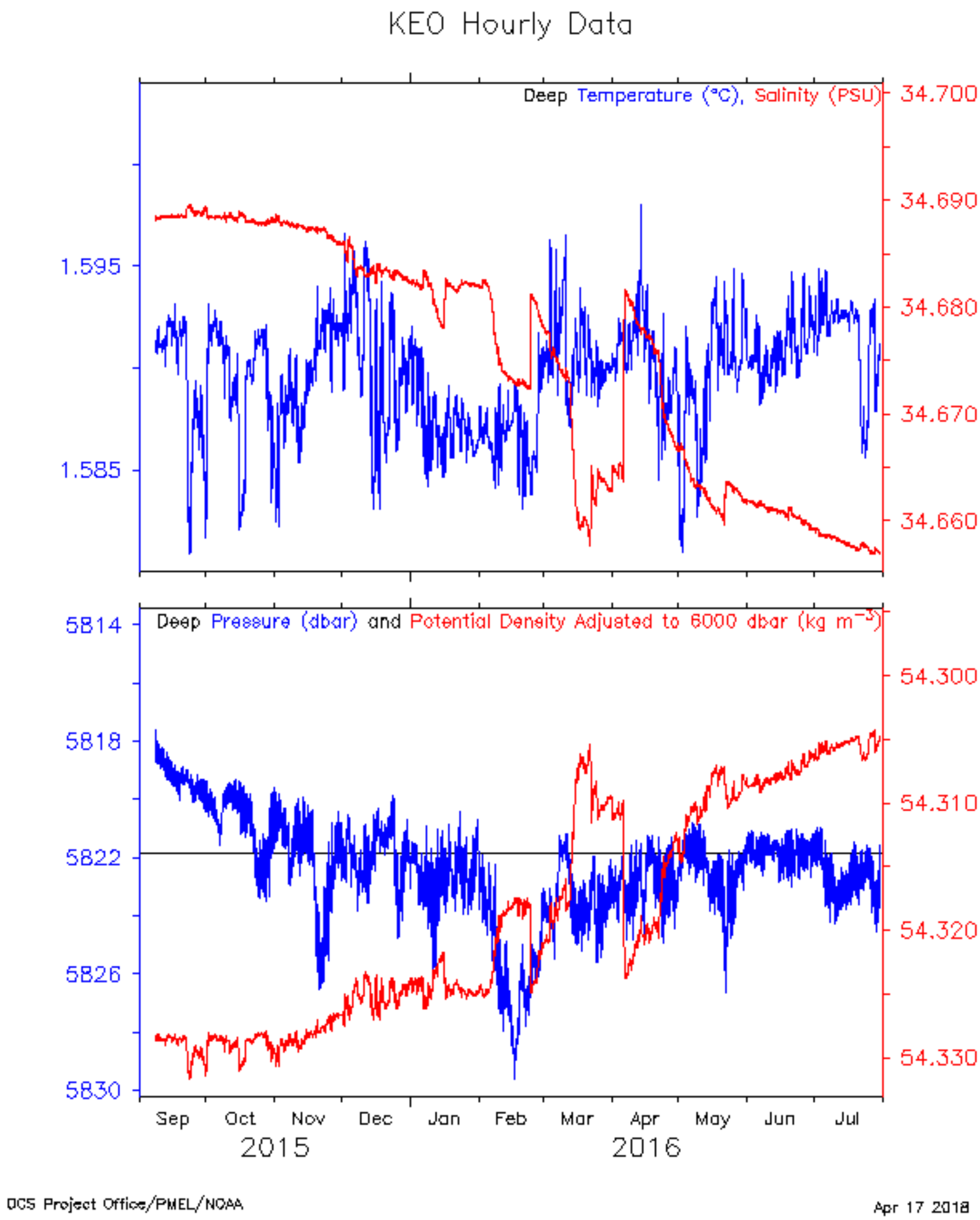

FIgure B 5: Deep Seabird instrument temperature, pressure, salinity, and potential density. Pre-deployment calibration coefficients were applied.

APPENDIX C: Secondary Instrument High Resolution Data Plots

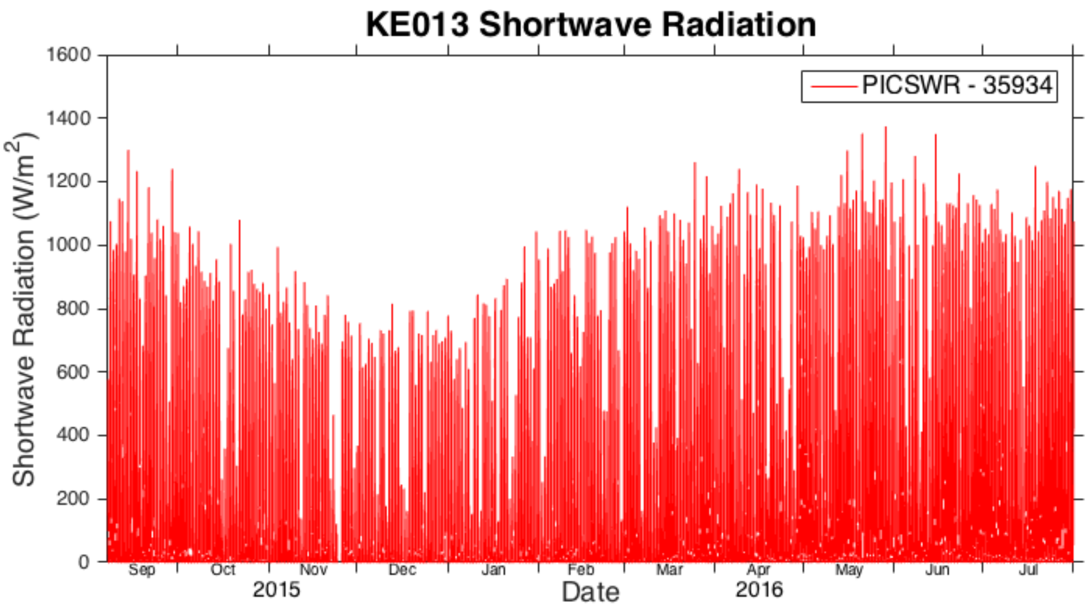

Figure C 1: Secondary (Flex Eppley PSP) shortwave radiation sensor.

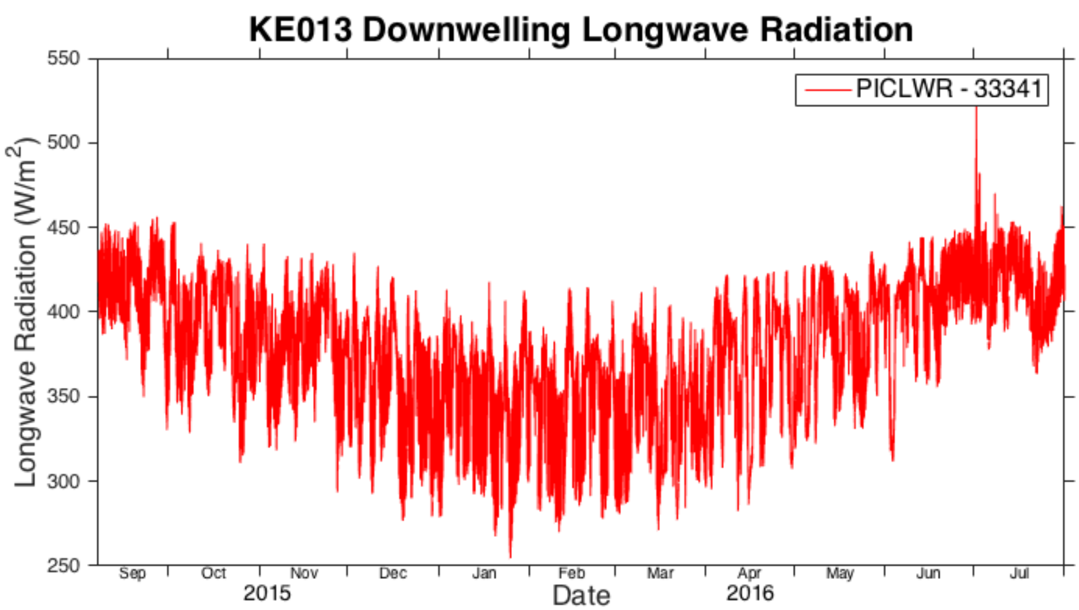

Figure C 2: Secondary (Flex Eppley PIR) longwave radiation sensor.

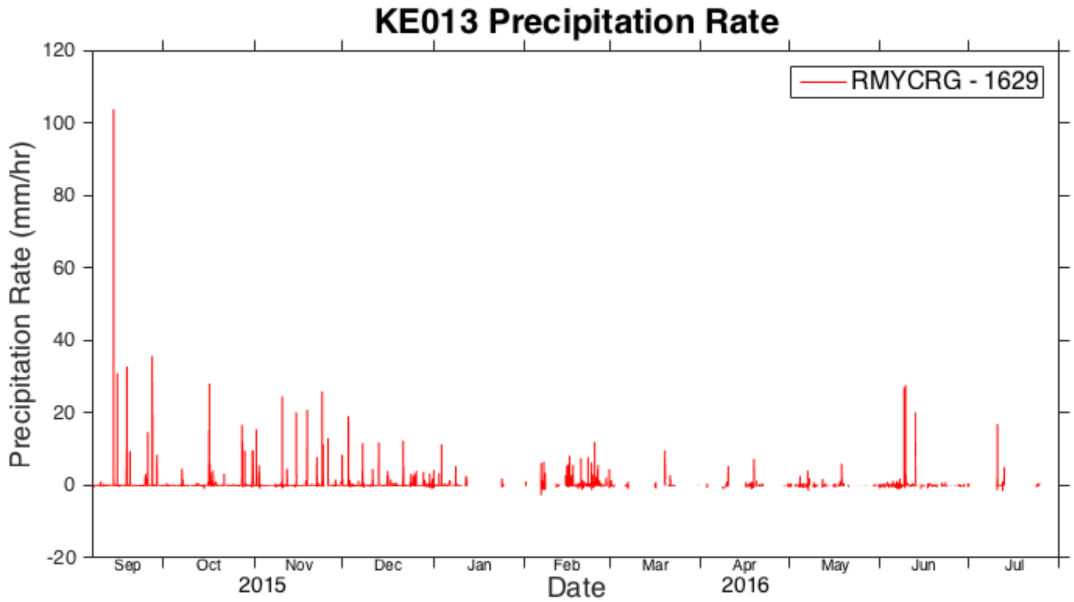

Figure C 3: Secondary (Flex RM Young) rain sensor. Data after January 12, 2016, flagged Q4 (low quality), are visibly noisier. Heavy Q5 (hard) flagging in the accumulation data was required to get reasonable rain rates. Gaps resulted where no reasonable rain rates could be obtained. The source of the noise is unknown.

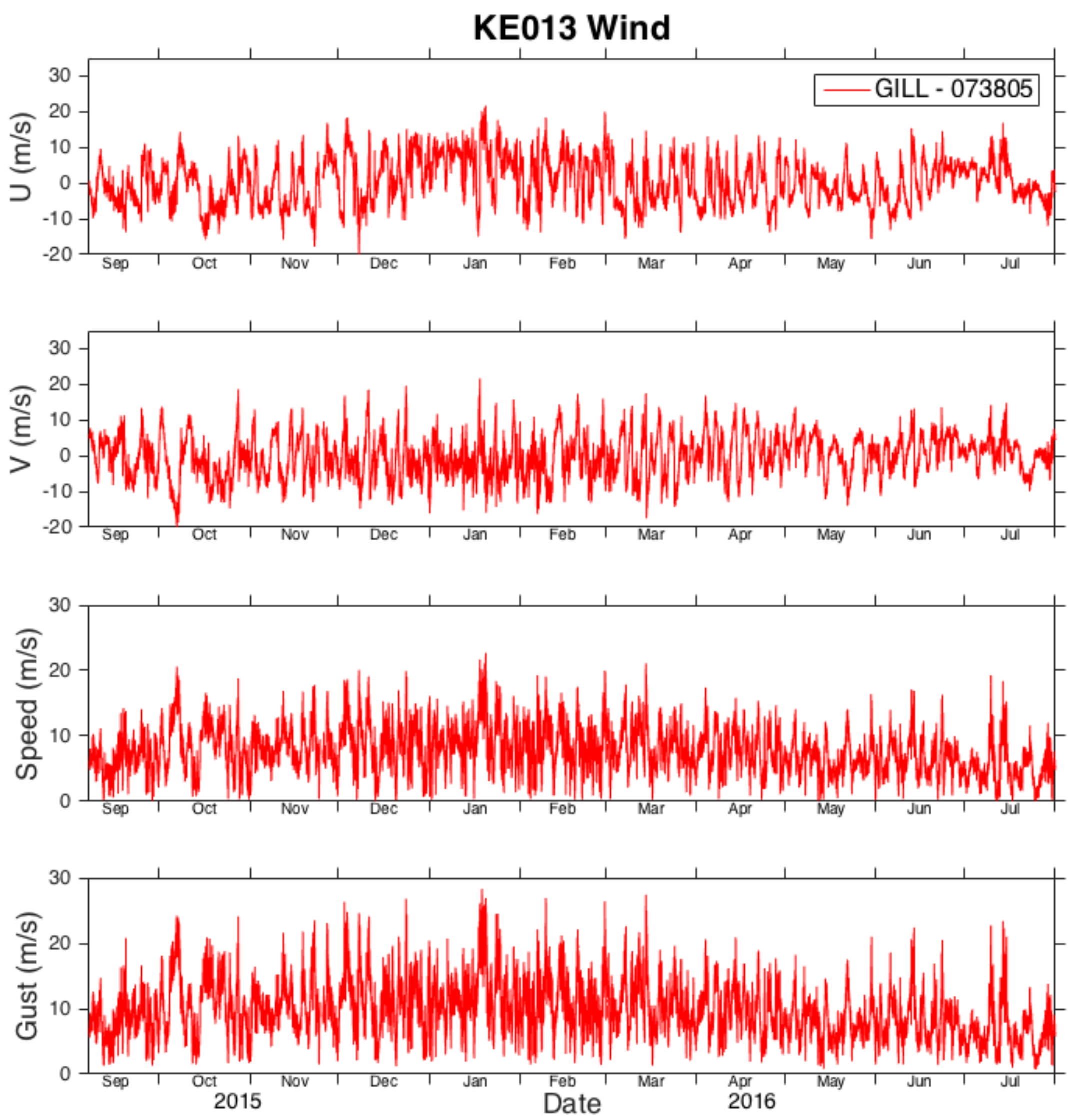

Figure C 4: Secondary (Flex Gill) wind sensor.

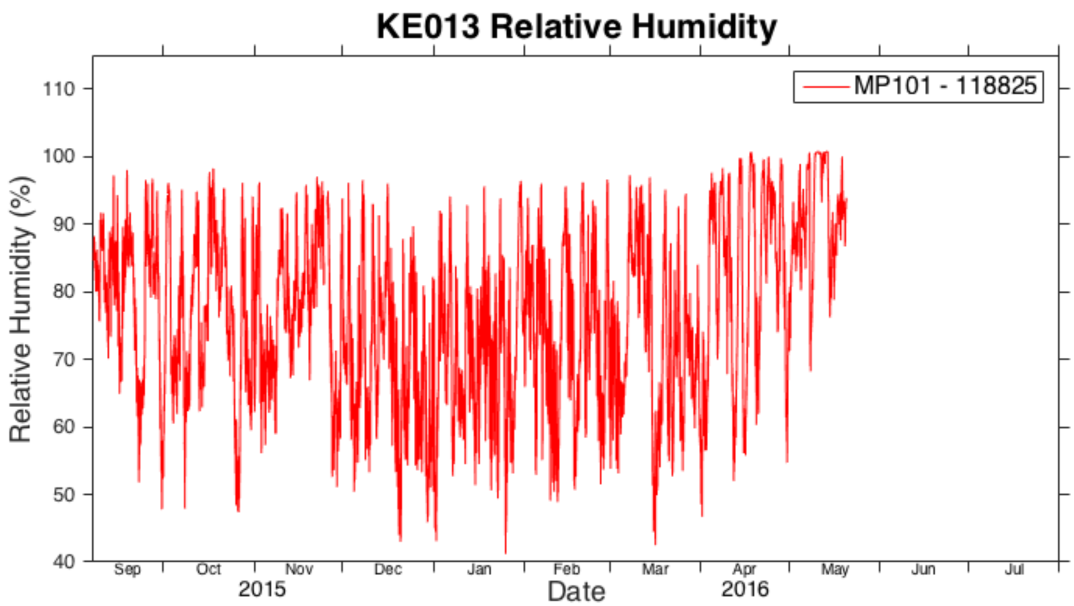

Figure C 5: Secondary (Flex MP101) relative humidity sensor. Time-series ended early after a jump to ~105% (removed here with Q5 flags after May 20, 2016). The instrument failed its post-recovery calibration.

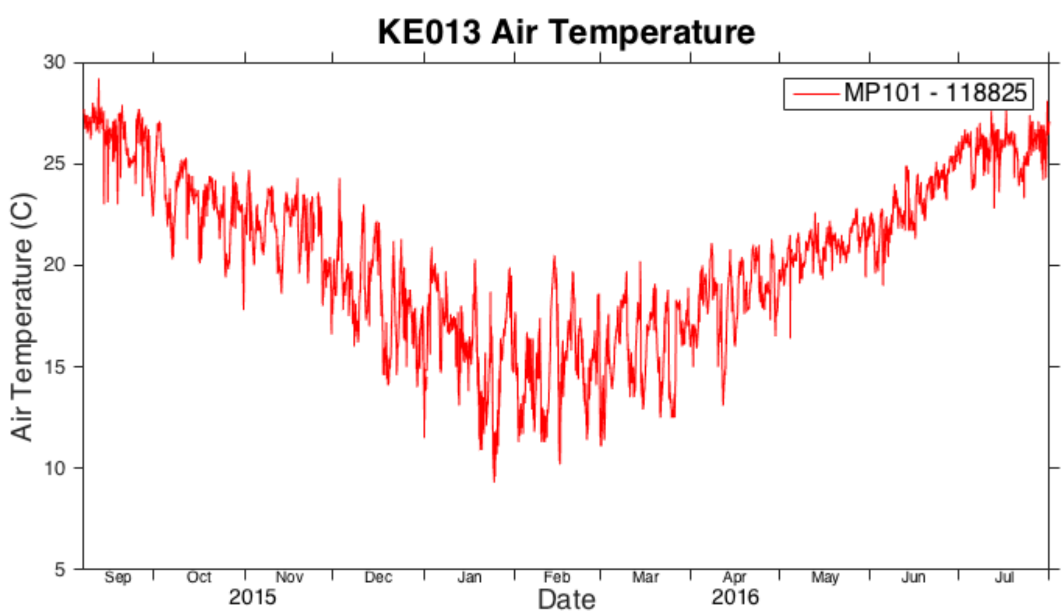

Figure C 6: Secondary (Flex MP101) air temperature sensor.

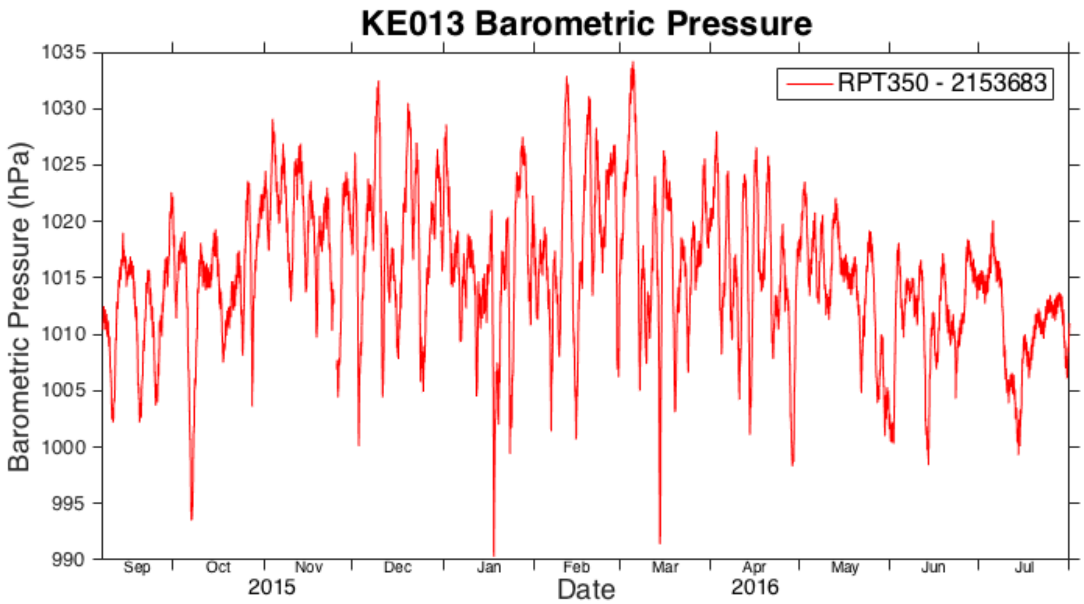

Figure C 7: Secondary (Flex Druck) barometric pressure sensor.

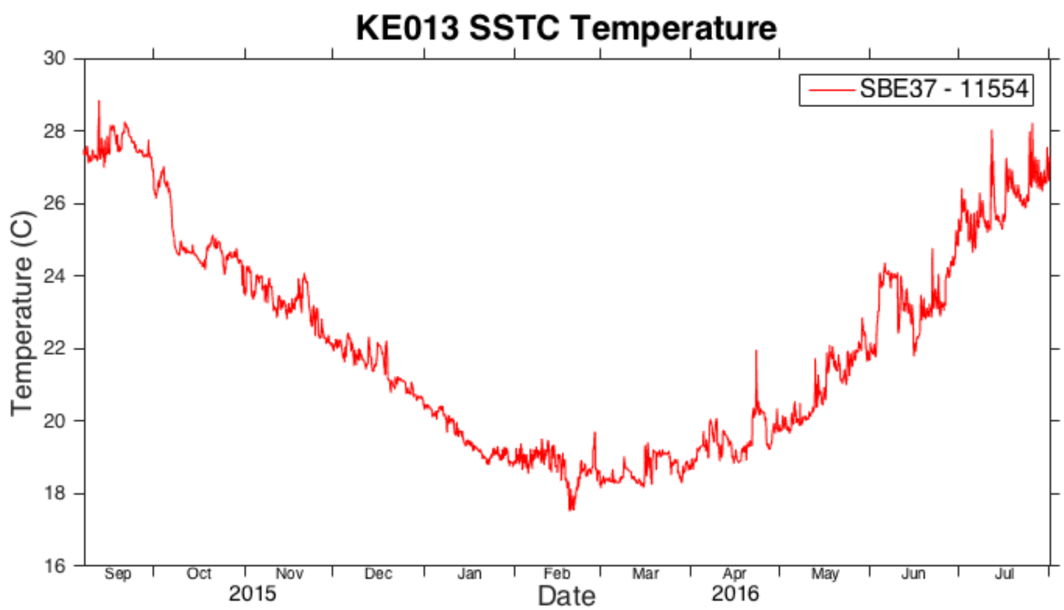

Figure C 8: Secondary (TFlex) SSTC Temperature.

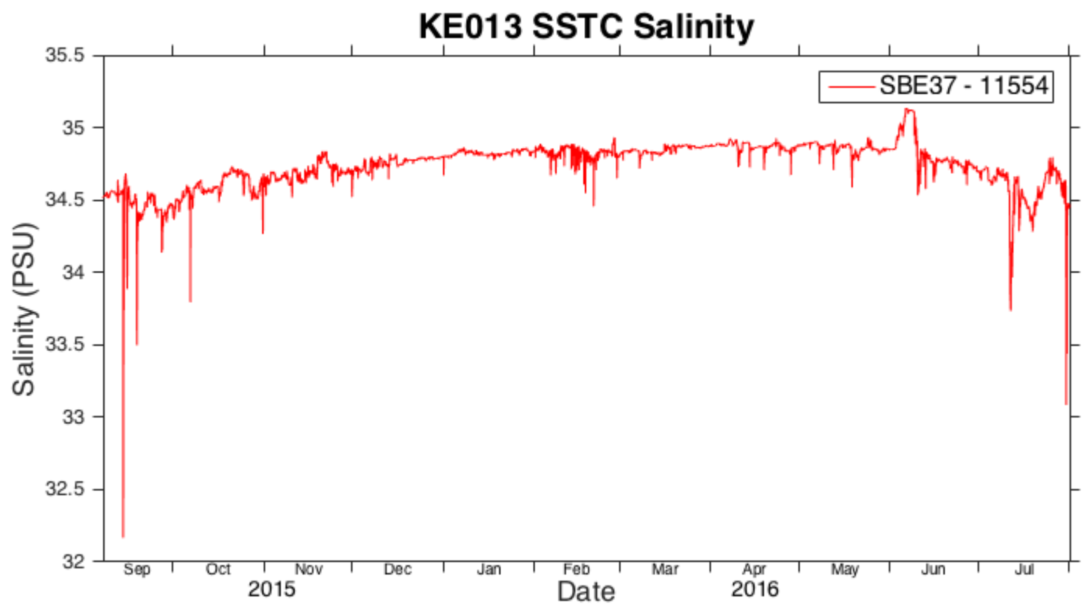

Figure C 9: Secondary (TFlex) SSTC Salinity.

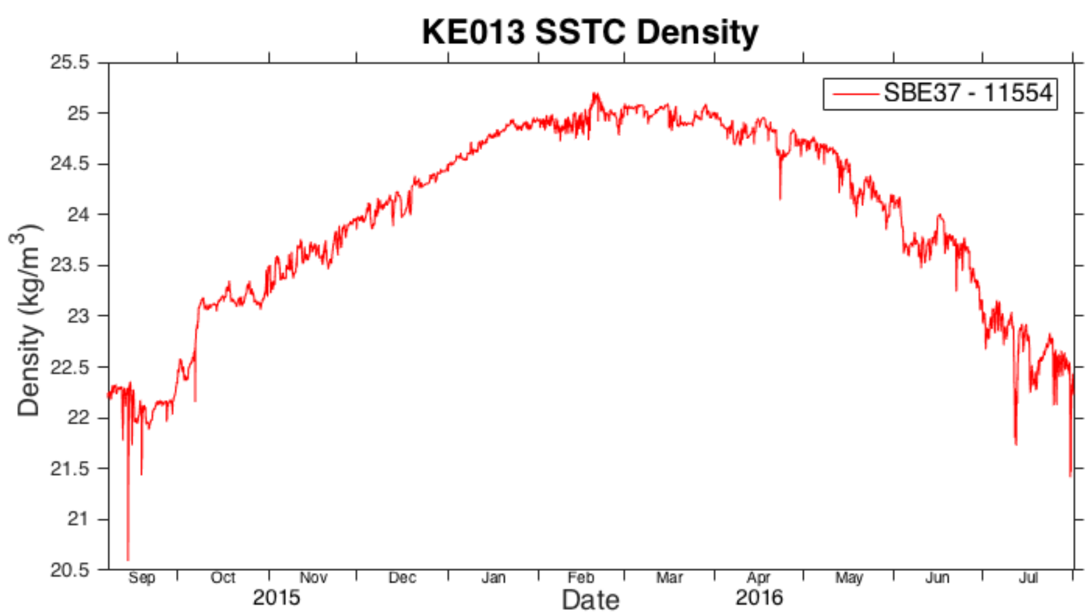

Figure C 10: Secondary (TFlex) SSTC Density.