NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

DATA ACQUISITION AND PROCESSING REPORT FOR KE012

Site Name:	Kuroshio Extension Observatory (KEO)
Deployment Number:	**KE012**
Year Established:	2004
Nominal Location:	32.3°N 144.6°E
Anchor Position:	32.39°N 144.54°E
Deployment Date:	June 25, 2014
Recovery Date:	September 7, 2015
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: Tropical Storm Fengshen passed KE012 on 9/9/14, causing strong mixing and internal waves. The current meter at 16m slid down the wire, and then failed on 8/9/14. Bad TCP data at 150m were flagged 7/8/14 – recovery.

Table of Contents

List of Tables

List of Figures

Data Acquisition and Processing Report for OCS Mooring KE012

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.

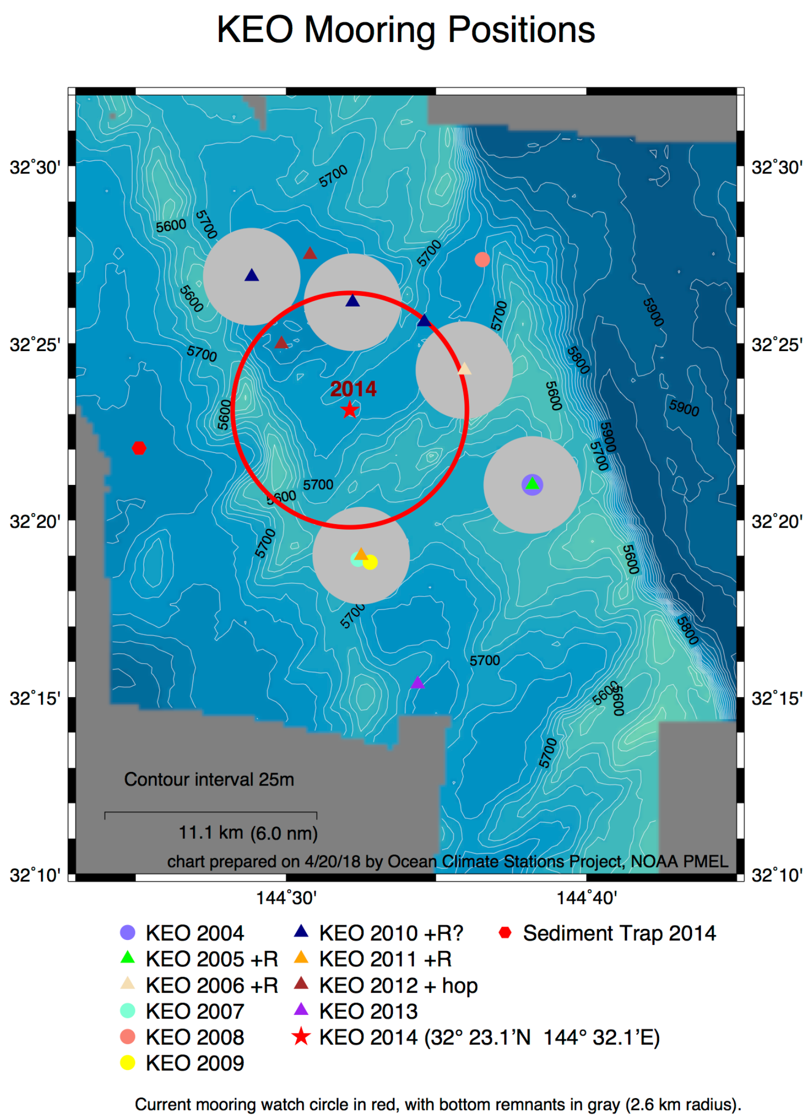

Figure 1: KEO regional map, with the KE012 (red star), and JAMSTEC sediment trap (red hexagon).

KE012 was the 11th deployment at the KEO site (the KE004 name was given to a buoy deployed at the nearby JKEO site, maintained by JAMSTEC). With funding support from NOAA's Climate Observation Division of its Climate Program Office, KE012 was deployed on June 25, 2014 aboard the R/V KAIYO, and recovered on September 7th, 2015 from the M/V BLUEFIN. The captain and crew of both vessels are gratefully acknowledged.

During the fall 2014 typhoon season, the mooring survived tropical storm Fengshen (not to be confused with a typhoon of the same name in 2008), which passed close to KE012 on September 9, 2014. Damage to meteorological sensors occurred and is detailed in Section 2.3.

1.1 Mooring Description

The KE012 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 KE012 mooring, in collaboration with the PMEL Carbon Group. OCS is not responsible for the acquisition or processing of these data. No further discussion of that system is included in this report.

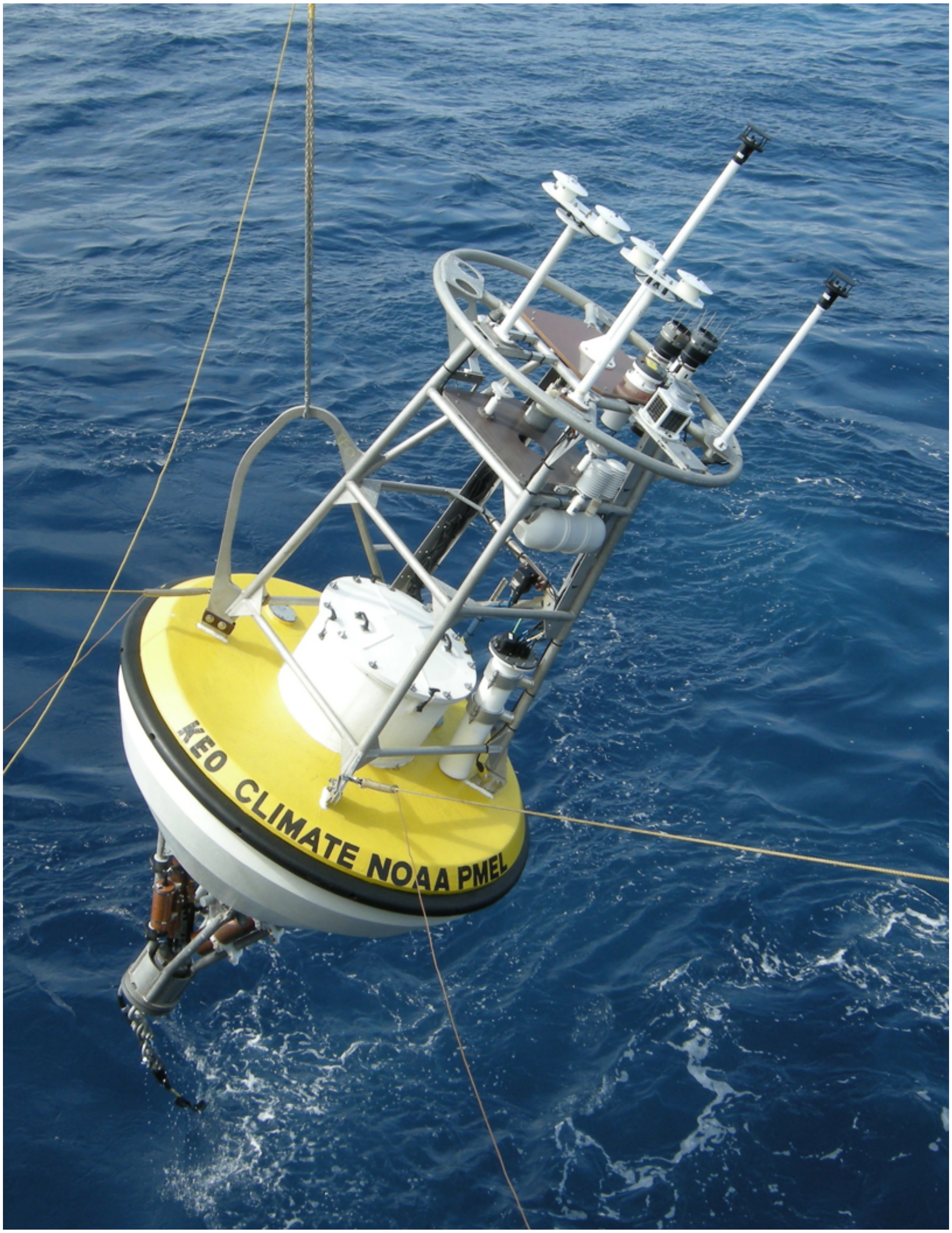

Figure 2: KE012 as deployed.

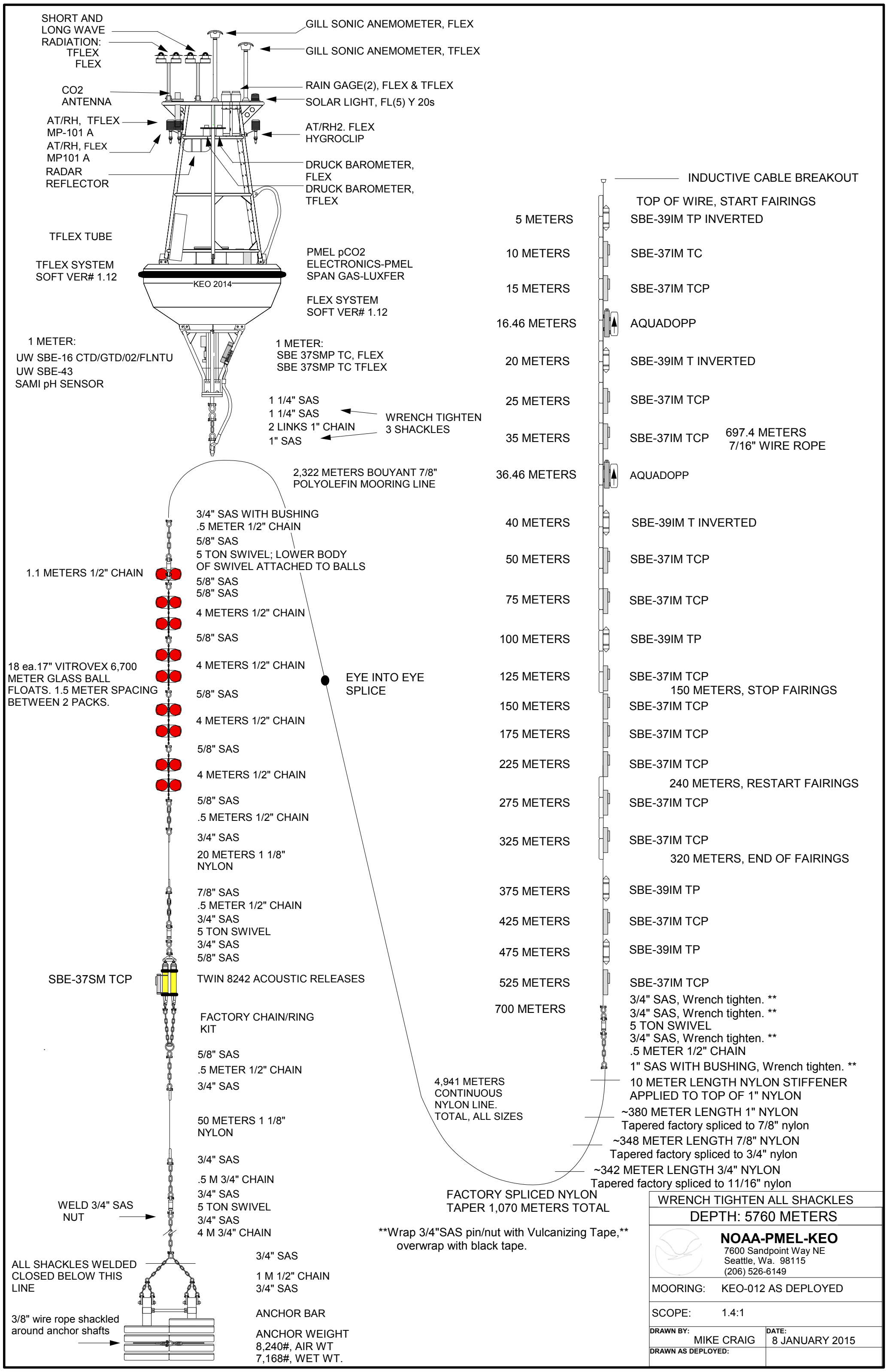

Figure 3: KE012 mooring diagram.

1.2 Instrumentation on KE012

The following instrumentation was deployed on KE012. 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:		**KEO June 2014**	KE-012		
		KE012 32°N, 145°E			
Met Sensors		**Model**	**Serial #**		**Notes**
Height	Acquisition	**Flex**	0008	FP7/8	FW 1.12 140211
2.6m	ATRH	Rotronics MP-101A	51042		
4.2m	Wind	Gill	10510080		
2.4m	BP	Druck	2153676		
3.1m	Rain	RM Young	738-4		
3.6m	SWR	Eppley PSP	35569		
3.6m	LWR	Eppley PIR	37080		
2.6m	ATRH2	Rotronics HygroClip	61222400		
2.5m	BP2	Vaisala WXT520	B2140048		
	Acquisition	**TFLEX**	2002		
2.6m	ATRH	Rotronics MP-101A	133374		
3.8m	Wind	Gill	08170010		
2.4m	BP	Druck	2153585		
3.1m	Rain	RM Young	1682		
3.6m	SWR	Eppley PSP	32281		
3.6m	LWR	Eppley PIR	34945		
CO2	Electronics	PMEL	154		
	Span Gas	Luxfer	JB03209		
Subsurface Instrumentation					
Bridle		**Model**	**Serial #**		**Notes**
1m	SST/C	SBE37SMP - TC	7088		Flex
1m	SST/C	SEB37SMP - TC	11552		TFLEX
1m	pH	Sami	3		CO2, v1.28 software
1m	SST/C	SBE16+V2	6567		CO2
1m	Oxygen	Optode	1724		Attached to CO2 SBE16+
1m	Fluorescence	ECO FLNTUS	1819		Attached to CO2 SBE16+
1m	Gas Tension	GTD	122464		Attached to CO2 SBE16+ (UW)
Depth		**Model**	**Serial #**	**IM ID**	**Notes**
5m	TP	SBE39IM - TP	4358	01	Inverted start 11 June 0000Z
10m	TC	SBE37IM - TC	7793	02	start 16 June 23:59:00 Z
15m	TCP	SBE37IM - TCP	9413	03	V4 - AA batteries
16.46m	ADCP	AquaDopp	5954	04	start 16 June 23:59:00 Z
20m	T	SBE39IM - T	3283	05	Inverted start 11 June 0000Z
25m	TCP	SBE37IM - TCP	7103	06	
35m	TCP	SBE37IM - TCP	7104	07	
36.46m	ADCP	AquaDopp	6808	08	start 16 June 23:59:00 Z
40m	T	SBE39IM - T	3285	09	Inverted start 9 June 0000Z
50m	TCP	SBE37IM - TCP	7105	10	
75m	TCP	SBE37IM - TCP	7106	11	
100m	TP	SBE39IM - TP	4359	12	start 11 June 0000Z
125m	TCP	SBE37IM - TCP	7107	13	
150m	TCP	SBE37IM - TCP	7108	14	
175m	TCP	SBE37IM - TCP	7780	15	
225m	TCP	SBE37IM - TCP	7781	16	
275m	TCP	SBE37IM - TCP	7782	17	
325m	TCP	SBE37IM - TCP	7783	18	
375m	TP	SBE39IM - TP	4360	19	start 11 June 0000Z
425m	TCP	SBE37IM - TCP	7784	20	
475m	TP	SBE39IM - TP	4378	21	start 11 June 0000Z
525m	TCP	SBE37IM - TCP	7091	22	2013 batts (spare 2013)
700m	End of Wire				
Release	TCP	SBE37SM - TCP	11926	-	V4 - AA batteries

Table 1: Instruments deployed on KE012.

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.

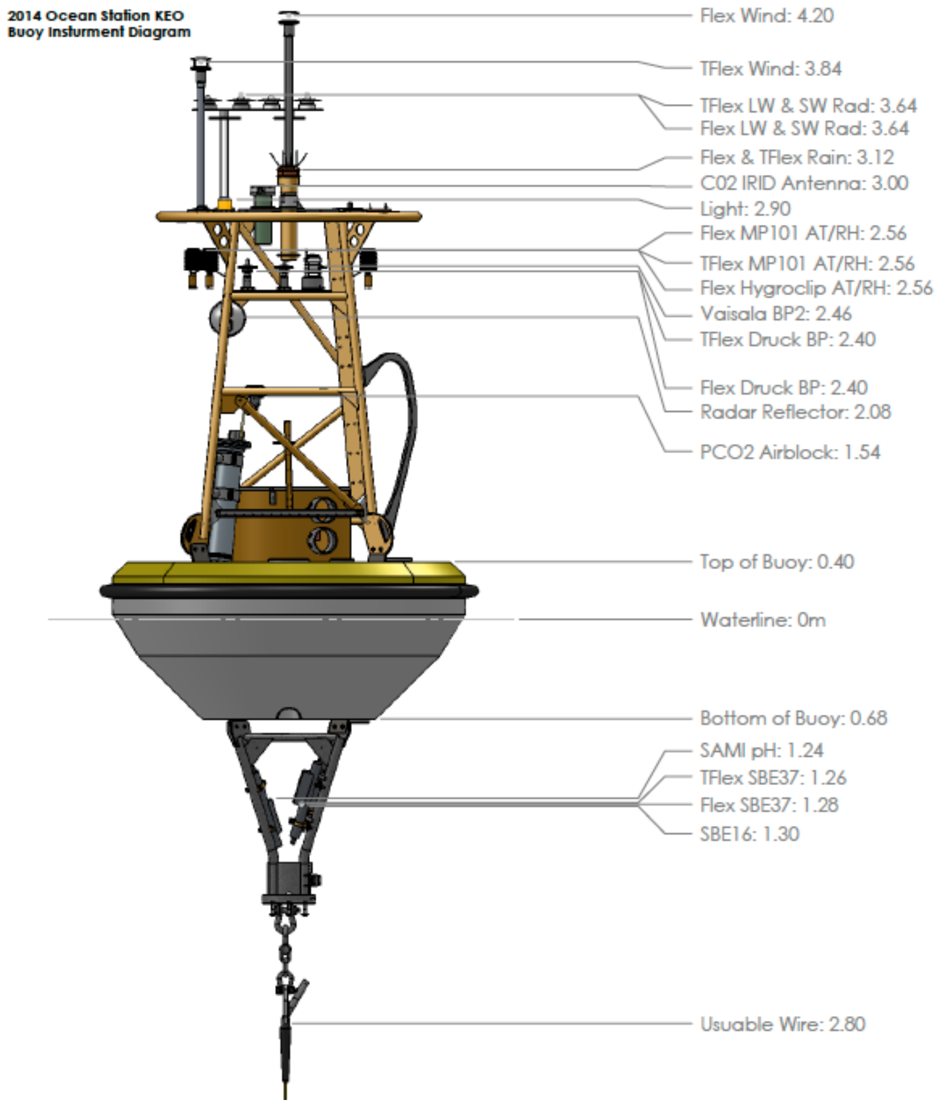

Figure 4: Buoy diagram showing bridle arrangement. The SBE16 package contains a suite of sensors.

2.0 Data Acquisition

Two independent data acquisition systems were deployed on KE012, 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. KE012 was the first 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 KE012 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	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 Positions	1 per hr	Instant.	~0000, 0100…	1 hr	FLEX

Table 2: Sampling parameters of primary sensors on KE012.

SECONDARY SENSORS

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

Table 3: Sampling parameters of secondary sensors on KE012.

2.2 Data Returns

Calculated data returns are displayed on the following pages. TFlex data returns are lower than other deployments due to the TFlex failure on April 17, 2015.

Flex 0008:

Data Return Summary
2014-06-25 05:29:00 to 2015-09-07 06:48:00

Sensor	Deployed	Obs	Return
AT1	63223	63163	99.9%
AT2	63223	10931	17.3%
RH1	63223	63163	99.9%
RH2	63223	10931	17.3%
WIND1	63223	31135	49.2%
BP1	63223	63163	99.9%
BP2	63223	11324	17.9%
RAIN1	632239	597921	94.6%
SWR1	632239	598228	94.6%
LWR1	632239	498450	78.8%

Subsurface Temperature Profile

1m	63223	57942	91.6%
5m	63223	63224	100.0%
10m	63223	63223	100.0%
15m	63223	63224	100.0%
20m	63223	28415	44.9%
25m	63223	23797	37.6%
35m	63223	63224	100.0%
40m	63223	63224	100.0%
50m	63223	63224	100.0%
75m	63223	63224	100.0%
100m	63223	37518	59.3%
125m	63223	63224	100.0%
150m	63223	3010	4.8%
175m	63223	63224	100.0%
225m	63223	63224	100.0%
275m	63223	63224	100.0%
325m	63223	63224	100.0%
375m	63223	39939	63.2%
425m	63223	63224	100.0%
475m	63223	36157	57.2%
525m	63223	63224	100.0%
5669m	63223	63224	100.0%
Total	1390906	1175137	84.5%

Subsurface Pressure Profile

5m	63223	63224	100.0%
15m	63223	40287	63.7%
25m	63223	23797	37.6%
35m	63223	63224	100.0%
50m	63223	63224	100.0%
75m	63223	63224	100.0%
100m	63223	37518	59.3%
125m	63223	63224	100.0%
150m	63223	3010	4.8%
175m	63223	63224	100.0%
225m	63223	63224	100.0%
275m	63223	63224	100.0%
325m	63223	63224	100.0%
375m	63223	39939	63.2%
425m	63223	63224	100.0%
475m	63223	36157	57.2%
525m	63223	63224	100.0%
5669m	63223	63224	100.0%
Total	1138014	939396	82.5%

Subsurface Salinity Profile

1m	63223	57942	91.6%
10m	63223	63223	100.0%
15m	63223	8751	13.8%
25m	63223	23797	37.6%
35m	63223	63224	100.0%
50m	63223	63224	100.0%
75m	63223	63224	100.0%
125m	63223	63224	100.0%
150m	63223	3010	4.8%
175m	63223	63224	100.0%
225m	63223	63224	100.0%
275m	63223	63224	100.0%
325m	63223	63224	100.0%
425m	63223	63224	100.0%
525m	63223	63224	100.0%
5669m	63223	63224	100.0%
Total	1011568	852187	84.2%

AQD Current Velocity

36m	63223	63224	100.0%
Total	63223	63224	100.0%

* Note that the 16m AQD failed (slid + flooded). Realtime data through August 9 are available.

TFlex 2002:

Data Return Summary
2014-06-25 05:29:00 to 2015-09-07 06:48:00

Sensor	Deployed	Obs	Return
AT1	63223	42662	67.5%
RH1	63223	42662	67.5%
WIND1	63223	42662	67.5%
BP1	63223	42662	67.5%
RAIN1	632239	422905	66.9%
SWR1	632239	423371	67.0%
LWR1	632239	401564	63.5%
SST1	63223	63223	100.0%
SSC1	63223	63223	100.0%
SSS1	63223	63223	100.0%

2.3 Known Sensor Issues

The TFlex system stopped real-time communication on April 17, 2015 at 18:00 UTC, with the last delayed-mode data (a radiation measurement) at 23:03 UTC. Upon recovery, water damage was found in the interior circuits, and no TFlex data exists beyond this point. The water intrusion was caused by a defect in the RF antenna's seal to the TFlex faceplate. Analysis at the lab showed corrosion on the circuit boards. An improved seal should prevent this issue in future deployments.

To assess TFlex instrument performance while the system was functional, data returns were recalculated up until the point of failure. High data returns prompted some swaps of primary instruments from Flex to TFlex or splices of Flex data onto TFlex data.

TFlex 2002 (through April 17, 2015):

Data Return Summary
2014-06-25 05:29:00 to 2015-04-17 23:00:00

Sensor	Deployed	Obs	Return
AT1	42729	42661	99.8%
RH1	42729	42661	99.8%
WIND1	42729	42661	99.8%
BP1	42729	42661	99.8%
RAIN1	427291	422902	99.0%
SWR1	427291	423367	99.1%
LWR1	427291	401562	94.0%
SST1	42729	42729	100.0%
SSC1	42729	42729	100.0%
SSS1	42729	42729	100.0%

The 15m instrument showed a gradual positive drift for salinity and conductivity and was flagged Q5 (sensor failed - removed) starting August 25, 2014, after an intensifying density inversion was observed in the data. Pressure was flagged Q5 after April 1, 2015, when data values became noisy and failed to fit into the context of surrounding pressure sensors. Extreme values ranging from -43.5 dbar to 53 dbar appeared, and no confident correction could be applied. The post-recovery calibration provided by the manufacturer stated "calibration after modification," meaning the instrument was modified before being calibrated. The new calibration was not applied, since it did not represent the true (and nonlinear) drift of the instrument as deployed.

Two Nortek Aquadopp instruments were deployed on KE012 at 16m and 36m. The sensor at 16m slid down the line to 19m on July 11, 2014. The instrument lost communication and failed on August 9th, with its final measurement at 13:00 UTC. It briefly came online again on September 28, 2014, but was flagged due to intermittency and clock time errors. Invalid characters and data parsing errors caused PMEL scientists to send a disable command to the 16m Aquadopp. Upon recovery, it was found that the Aquadopp (cracked and waterlogged) and the SBE39IM-T at 20m (shield missing, dead battery January 8, 2015), had further slid down and were resting on the SBE37IM-TCP at 25m. No delayed-mode data could be retrieved from the 16m Aquadopp.

Fishing net, wire, hooks, and other materials were found wrapped around the mooring line to a depth of about 20m. It is unknown if these materials affected instrument operation, but they could have contributed to the subsurface instrument cascade and damage.

Tropical storm Fengshen passed on September 9, 2014, with wind speeds up to 27m/s and gusts to 37m/s reported. Atmospheric pressure dropped to a minimum of 971mb. All primary instruments appeared to survive the storm intact, but RH sensors exhibited more variability after this point. The Rotronic Hygroclip (test sensor) drifted and failed soon after the storm. In November 2015, the Hygroclip air temperature and relative humidity sensor failed the post-recovery calibration, backing the decision to withhold this data. The Flex Vaisala WXT barometer, another tertiary sensor, failed September 27, 2014, but had started drifting away from the primary and secondary sensors coincident with Fengshen's passage. Tertiary sensor data are not distributed.

On January 27, 2015, the Gill WindSonic instrument stopped reporting U, V, gust, and wind speed. This was likely caused by the loss of the sensor's top plate, which was missing upon recovery. Good compass values indicate that the bottom portion of the sensor remained functional.

The Flex LWR sensor stopped reporting July 12, 2015, and erratic values were intermittently returned in August. The glass dome atop the recovered instrument was cracked and pieces were missing. A discussion about switching primary LWR sensors can be found in Section 3.2.7.

In the first weeks of the deployment, the TFlex GPS reported intermittently. The TFlex system was rebooted remotely on July 10, 2014, which corrected the issue. Similar problems occurred in early February 2015, and a reset again fixed the problem.

Throughout January and into February 2015, all real-time subsurface data became intermittent (see Appendix B). The leading hypothesis for these real-time gaps is a poor connection in the inductive loop. Delayed-mode data were recovered successfully, aside from the issues discussed in this section.

Many subsurface instruments had dead batteries upon recovery. The Flex bridle instrument became constant and was flagged on August 1, 2015. Since the bridle instruments log internally, the TFlex SSTC had 100% data return for the entire deployment, even though the TFlex logger failed early. This instrument was considered primary. Battery failure indicated by constant values, truncated values, or missing data were also seen in the 20, 25, 100, 150, 375, and 475m instruments. Data were flagged accordingly, based on the mode and time of failure.

3.0 Data Processing

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

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

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

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

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

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

3.1 Buoy Positions

Since 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, discussed in the current meter section below.

3.2 Meteorological Data

Most primary meteorological sensors on KE012 remained functional at or near 100% throughout the deployment. Flex and TFlex wind data ended early, and air temperature, relative humidity, and radiation data were combined across data acquisition systems in order to produce a more complete, finalized time series.

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 KE012 buoy had secondary air temperature, relative humidity, wind, rain, air pressure, and radiation sensors. Tertiary test sensors included a Rotronic HygroClip measuring air temperature and relative humidity, and a Vaisala WXT520 measuring barometric pressure. These tertiary data from test sensors were not distributed in any format. More information about test sensors can be found in Technical Notes 3 and 5, which can be found here: https://www.pmel.noaa.gov/ocs/technical-notes

3.2.1 Winds

KE012 Gill wind sensor data were manually flagged upon review. The TFlex wind was chosen as the primary, due to damage to the Flex Gill sensor (Figure 5). The last Flex measurement occurred on January 27th, 2015 at 15:50 UTC. Dents and scuffing to the buoy disc and top ring were noted during recovery. Combined with the broken Flex Gill top plate, a boat impact is suspected. The day prior, anomalous low measurements from the subsurface pressure sensors suggest a boat had tied up and tensioned the mooring line. Wind data were unavailable after the TFlex went offline on April 17, 2015.

Figure 5: Damaged KE012 Flex Gill wind sensor (left), and the intact TFlex Gill (right).

Zonal (U) and meridional (V) velocities were examined, and the redundant sensors often provided overlapping data. Periods of significant wind variability resulted in the largest discrepancies between the two Gill sensors. Flagging was performed based on context within each time series and consistency between the primary and secondary instrument. In general, if the instruments differed, individual data points were flagged as Q5 unless there was reason to side with one measurement (e.g. low variability/smooth time series when the other exhibited high variability). Unrealistic data were flagged in rare cases where the wind speed exceeded the gust speed.

3.2.2 Air Temperature

The air temperature sensors on KE012 varied in terms of longevity and measurement accuracy. The Flex system lasted the full deployment, whereas the TFlex cut out on April 17, 2015. However, the TFlex relative humidity sensor passed its post calibration while the Flex RH did not. The instrument on the TFlex system was made the primary ATRH until it failed. The Flex data were then spliced to the TFlex data after April 17, 2015 at 23:10Z, and the spliced data constitute the full primary record.

Since both air temperature instruments passed their post calibrations (only the Flex RH failed), the spliced temperature data are still assigned a standard quality of Q2. All ATRH instruments were bent inward upon recovery (Figure 6).

Figure 6: KE012 AT/RH sensors upon recovery.

3.2.3 Relative Humidity

The primary RH data is a spliced data set of TFlex and Flex data. In general, the Flex RH reported a wider range of values than the TFlex sensor, and drifted upward over time, reaching maximum values near 104% toward the end of the deployment. The Flex RH drift began after tropical storm Fengshen passed on September 9, 2014. By April 2015, the difference was enough to warrant Q4 flags. Confirming the drift, the Flex RH failed its post calibration. As the only sensor to have survived to the end of the deployment, the Flex RH Q4 data was spliced onto the TFlex data after the TFlex failed.

3.2.4 Barometric Pressure

Atmospheric pressure was measured using a Druck RPT350 sensor on both Flex and TFlex, complemented by a tertiary Vaisala WXT520 test sensor (not distributed) on the Flex system, which failed early in the deployment (Figure 7). Measurements from the primary and secondary sensors tracked until the TFlex failure. As the lone functional barometric pressure sensor, the Flex instrument was considered primary.

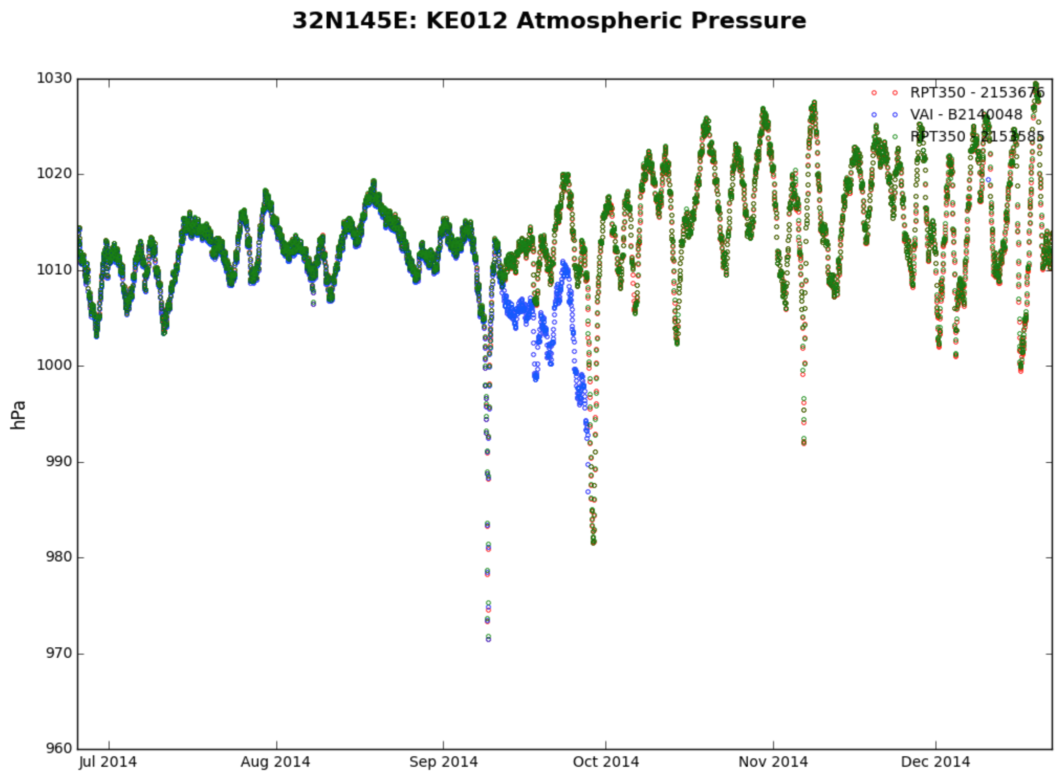

Figure 7: Barometric pressure intercomparison, showing agreement between primary and secondary sensors. The tertiary Vaisala instrument drifted and failed, due to storms Fengshen and Kammuri.

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.

The Flex rain gauge was considered primary, as the catchment funnel on the TFlex rain gauge was completely missing at recovery (Figure 8, left). The failure was evident when comparing accumulations, and the time of failure was estimated as 23:40 UTC on December 16, 2014, during a period of active rainfall according to the Flex sensor. The rain gauges quickly diverged as the TFlex gauge became erratic and failed to report positive accumulations. Flags of Q5 were applied to the remainder of the TFlex dataset.

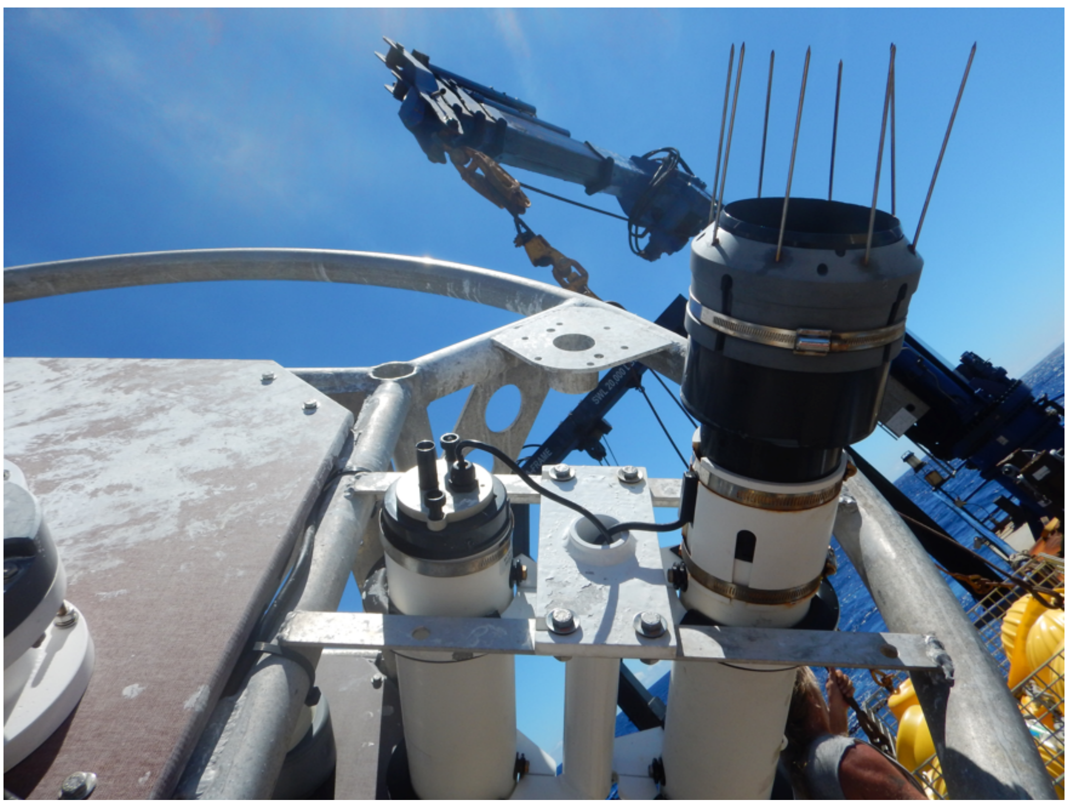

Figure 8: Redundant rain gauges upon recovery (TFlex left, Flex right).

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

KE012 was a special case where the TFlex reported higher values, but the Flex maximized the time period of data. The decision to prioritize criteria from top to bottom was made on March 14, 2016. Thus, the TFlex SWR is considered primary, and the Flex SWR is secondary until the TFlex system failed. Data distributed on the OCS webpage are a mix of Flex data spliced onto the end of TFlex data. On OceanSITES, primary and secondary data are distributed by instrument.

An unusual spike to ~1400W/m^2 was observed in the shortwave data during this deployment (Figure 9). Since both sensors were in agreement, standard data quality was assigned. Considering the solar constant at the top of the atmosphere is around 1367W/m^2, the higher measurements could be due to reflection or refraction.

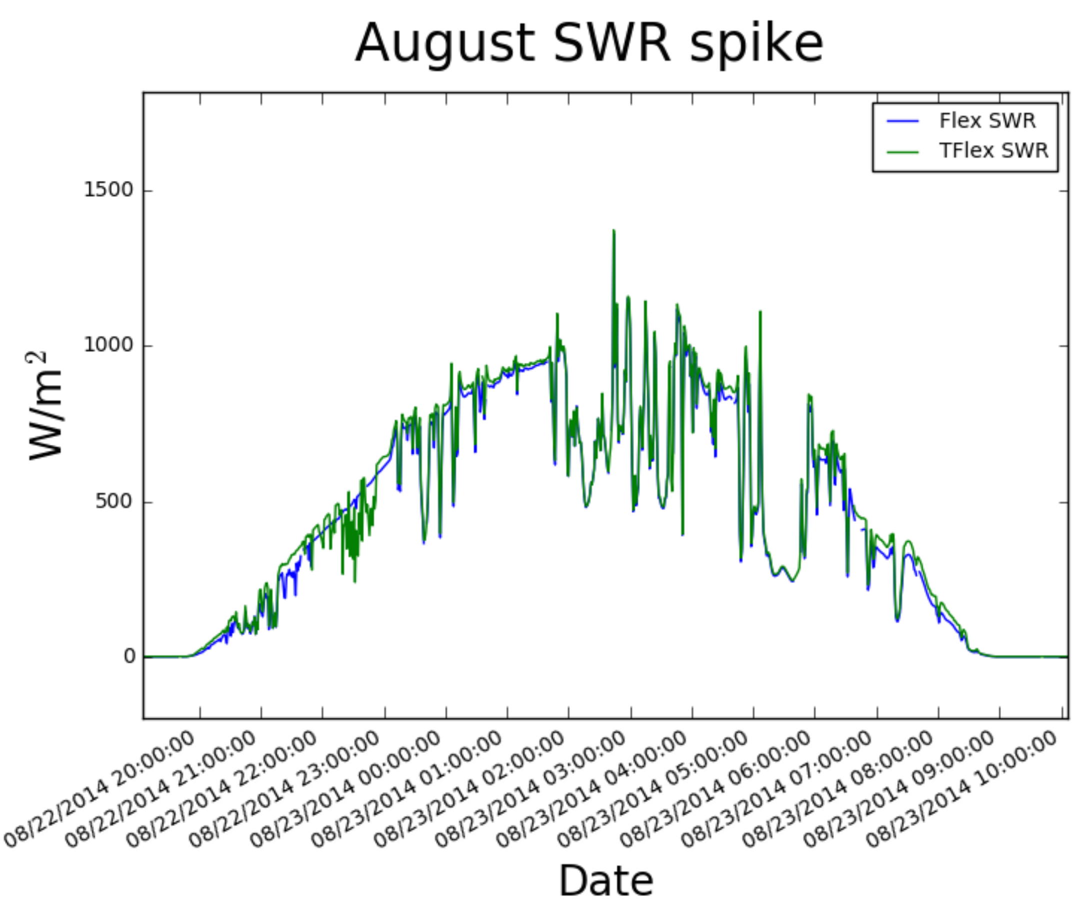

Figure 9: Example of a data spike confirmed by two SWR instruments.

Shortwave radiation is processed into hourly and daily average 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.

During recovery, the TFlex radiation mast was found lying on its side and dangling by its cords, while the Flex radiation mast was nearly vertical (Figure 10). Since the TFlex SWR and LWR reported similar values through April 17th, 2015, it was determined that the mast tipped after this date.

Since the TFlex stopped reporting on April 17th, 2015, primary LWR values were also spliced together, starting with TFlex and ending with Flex data for the OCS website. Close examination of the Flex LWR sensor revealed cracks and a few missing pieces of glass (Figure 10, inset). Damage is suspected to have occurred on July 12th, when the Flex instrument stopped reporting data. The instrument began reporting intermittent values again on August 13, 2015 (1:52 UTC), which remained intermittent until complete failure on August 27, 2015.

Data from this intermittent period were examined closely and flagged as lower quality (Q4), as the glass damage had likely occurred prior to August. The entire data set was reviewed, and data outside of typical seasonal ranges were flagged Q5. Frequent spikes of unrealistic and unseasonal values were more prevalent during August's intermittent data returns.

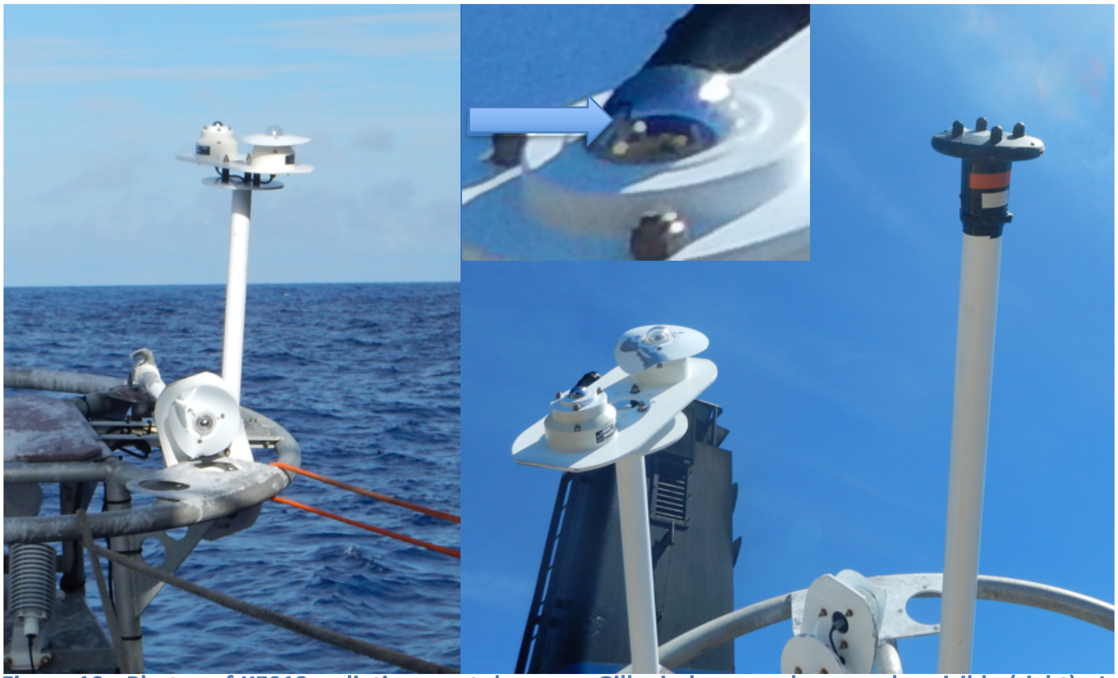

Figure 10: Photos of KE012 radiation mast damage. Gill wind sensor damage also visible (right). Inset shows zoom on broken glass.

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 11). Positive clock errors were most common, meaning the instrument drifted ahead of the actual time. 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-TC	7088	4:24:24	4:24:35	0:00:11	KEO12a-	6.38 /		59833
1	SBE37-TC	11552	4:15:15	4:15:02	-0:00:13	KEO12a-	13.59/3.21		65529
2	SAMI pH	P03							
3	SBE 16v2	6567							
4	O2	1724							
5	ECO	1819							
6	GTD	RD13							
7	SBE39-TP	4358	4:05:55	4:07:24	0:01:29	KEO12a-	n/a		65689
8	SBE37-TC	7793	00:28:45	00:29:20	0:00:35	KEO12a-		missing an anti-foul. Not	65373
9	SBE37-	9413	00:46:40	00:46:59	0:00:19	KEO12a-	13.45/3.20		65525
10	AquaDopp	5954						Cracked/flooded	
11	SBE39-T	3283						Not responding prints "$"	65976
12	SBE37-	7103						not responding	
13	SBE37-	7104	00:08:30	00:09:00	0:00:30	KEO12a-	6.41/3.19		65521
14	AquaDopp	6808	3:53:08	3:53:26	0:00:18				
15	SBE39-T	3285	3:58:25	3:59:53	0:01:28	KEO12a-	n/a		65976
16	SBE37-	7105	01:14:18	01:14:38	0:00:20	KEO12a-	5.97/3.19		65528
17	SBE37-	7106	3:44:50	3:45:29	0:00:39	KEO12a-	6.04/3.22		65543
18	SBE39-TP	4359	4:52:50	4:54:32	0:01:42	KEO12a-	n/a		39568
19	SBE37-	7107	3:59:20	3:59:43	0:00:23	KEO12a-	6.25/3.19		65400
20	SBE37-	7108						not responding	
21	SBE37-	7780	2:42:45	2:43:25	0:00:40	KEO12a-	6.27/3.19		65393
22	SBE37-	7781	2:27:55	2:28:33	0:00:38	KEO12a-	6.38.3.20		65391
23	SBE37-	7782	2:01:30	2:02:13	0:00:43	KEO12a-	6.57/3.22		65388
24	SBE37-	7783	3:08:00	3:08:35	0:00:35	KEO12a-	6.40/3.19		65395
25	SBE39-TP	4360	4:44:20	4:45:39	0:01:19	KEO12a-			41989
26	SBE37-	7784	3:20:20	3:20:44	0:00:24	KEO12a-	6.39/3.22	Missing conductivity	65397
27	SBE39-TP	4378	4:30:05	4:31:34	0:01:29	KEO12a-	n/a		38045
28	SBE37-	7091	3:34:40	3:35:09	0:00:29	KEO12a-	6.25/3.21		65388
29	SBE37-	11926	5:44:05	5:44:09	0:00:04	KEO12a-	6.96/3.27		64115
30									
31									
32									
33									
34									
35									

Figure 11: Recovery log displaying instrument clock errors, when 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.

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.
Figure 12 shows the effects of (in order) a strong branch of the Kuroshio current, followed by storms Fengshen and Kammuri, which appear in the data as short-lived spikes.

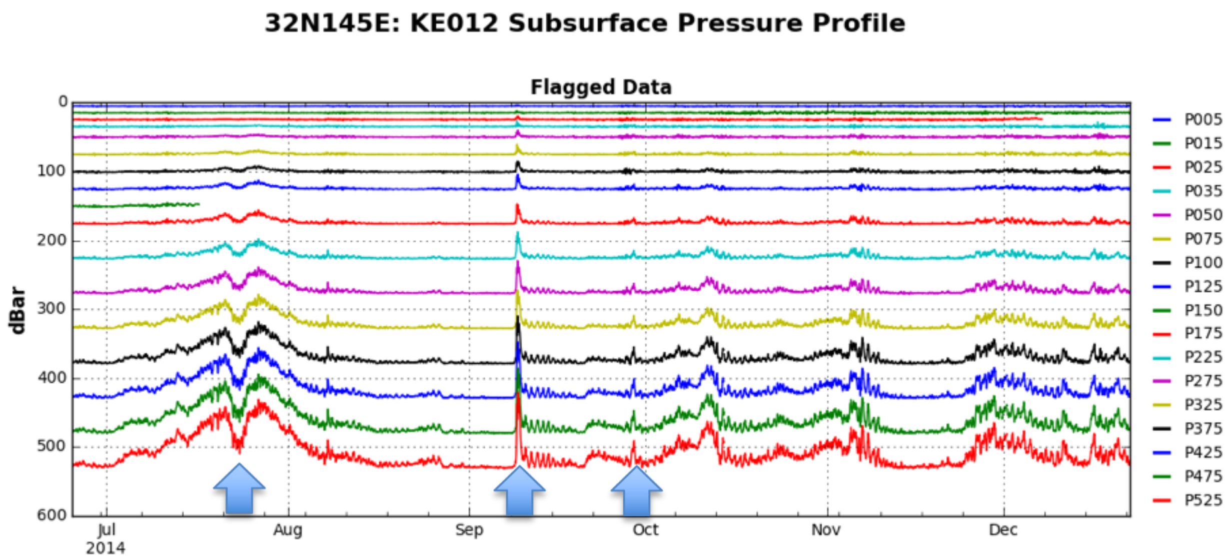

Figure 12: Pressure data, showing a branch of the Kuroshio, followed by storms Fengshen and Kammuri (arrows). Image was captured halfway through the deployment.

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-recovery calibration coefficients. Salinities were calculated from both the pre and post conductivity values, to determine the drift in the salinity measurement.

During salinity processing, automated scripts detected out-of-range pre-to-post calibration salinity drift in the instruments at 1m (Flex, SN 7088) and 10m (SN 7793). Calibration files revealed that the 1m sensor had been modified (likely with a new conductivity cell) and recalibrated by Seabird. While not detected by automated scripts due to a small resultant drift, the 15m calibration file also showed sensor modification and recalibration. Since the 1m and 15m post-recovery calibrations were not valid for the instruments as deployed on KE012, they were discarded. The 10m sensor had a valid post-calibration, and matched surrounding instruments, indicating the large instrument drift was correctly quantified.

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

Depth:	**Drift:**
1m (TFlex)	-0.0609
1m (Flex)	-0.5409 *
10m	-0.1002 **
15m	0.0010 *
25m	-0.0265
35m	-0.0480
50m	-0.0626
75m	-0.0394
125m	-0.0338
150m	-0.0014
175m	-0.0295
225m	-0.0479
275m	-0.0331
325m	-0.0297
425m	-0.0203
525m	-0.0069

* Post-cal was discarded. Instrument was modified before post-cals were returned. At 15m, QC procedures truncated 15m data where substantial drift occurred.

** Calibration drift was large, but the pre-post interpolation matched surrounding depths.

The values above indicate the change in calculated salinity data values when post-recovery calibrations were applied to the conductivity measurements, versus when pre-deployment calibrations were applied. Negative differences suggest that the instrument drifted towards higher values while deployed, and indicate expansion of the conductivity cell effective cross-sectional area. This expansion is possibly due to scouring of the cell wall by abrasive material in the seawater. Positive values indicate 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. Since KEO deployments are miles apart, and spatial differences can exceed instrument specifications (e.g. temperature accuracy is ±0.002°C–0.003°C, depending on instrument), the instrument specifications were not used for quality control in this comparison.

Additional linear corrections were 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 at nighttime). These *in situ* calibration procedures are described by Freitag et al. (1999).

Redundant SBE37 instruments were deployed on the bridle, which required the most adjustment. The TFlex bridle instrument was designated as primary due to 100% data return and a post-calibration record from Seabird that reflected the instrument as recovered (the Flex instrument was modified prior to post-recovery calibration).

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

Primary (TFlex)
2014-06-24 12:20:58 to 2014-12-31 07:41:21 at 1 m adjusted 0.0028 to 0.0040
2014-12-31 07:41:21 to 2015-03-07 19:48:20 at 1 m adjusted 0.0040 to 0.0131
2015-03-07 19:48:20 to 2015-04-17 02:47:46 at 1 m adjusted 0.0131 to 0.0222
2015-04-17 02:47:46 to 2015-05-13 07:55:20 at 1 m adjusted 0.0222 to 0.0176
2015-05-13 07:55:20 to 2015-05-27 09:47:11 at 1 m adjusted 0.0176 to 0.0210
2015-05-27 09:47:11 to 2015-06-21 03:57:40 at 1 m adjusted 0.0210 to -0.0040
2015-06-21 03:57:40 to 2015-07-13 11:53:00 at 1 m adjusted -0.0040 to -0.0074
2015-07-13 11:53:00 to 2015-07-31 09:00:34 at 1 m adjusted -0.0074 to -0.0006
2015-07-31 09:00:34 to 2015-08-27 21:12:13 at 1 m adjusted -0.0006 to -0.0108
2015-08-27 21:12:13 to 2015-09-09 06:56:18 at 1 m adjusted -0.0108 to -0.0085
2014-06-24 10:20:58 to 2015-04-25 16:55:35 at 1 m adjusted -0.0022 to 0.0056*
2015-04-25 16:55:35 to 2015-06-02 09:34:48 at 1 m adjusted 0.0056 to 0.0034*
2015-06-02 09:34:48 to 2015-06-12 04:07:11 at 1 m adjusted 0.0034 to -0.0011*
2015-06-12 04:07:11 to 2015-08-04 05:20:09 at 1 m adjusted -0.0011 to 0.0011*

Secondary (Flex)
2014-06-24 22:07:50 to 2014-07-21 23:29:52 at 1 m adjusted 0.0007 to -0.0038
2014-07-21 23:29:52 to 2014-07-25 07:14:40 at 1 m adjusted -0.0038 to -0.0015
2014-07-25 07:14:40 to 2014-08-01 21:31:23 at 1 m adjusted -0.0015 to -0.0038
2014-08-01 21:31:23 to 2014-08-08 01:37:27 at 1 m adjusted -0.0038 to -0.0015
2014-08-08 01:37:27 to 2015-04-06 04:57:58 at 1 m adjusted -0.0015 to -0.0333
2015-04-06 04:57:58 to 2015-05-04 05:07:04 at 1 m adjusted -0.0333 to -0.0493
2015-05-04 05:07:04 to 2015-06-03 14:13:55 at 1 m adjusted -0.0493 to -0.0413
2015-06-03 14:13:55 to 2015-07-04 22:07:50 at 1 m adjusted -0.0413 to -0.0515
2015-07-04 22:07:50 to 2015-07-31 23:29:52 at 1 m adjusted -0.0515 to -0.0481
2014-06-25 01:14:55 to 2015-08-02 16:39:27 at 1 m adjusted 0.0000 to -0.0110 *

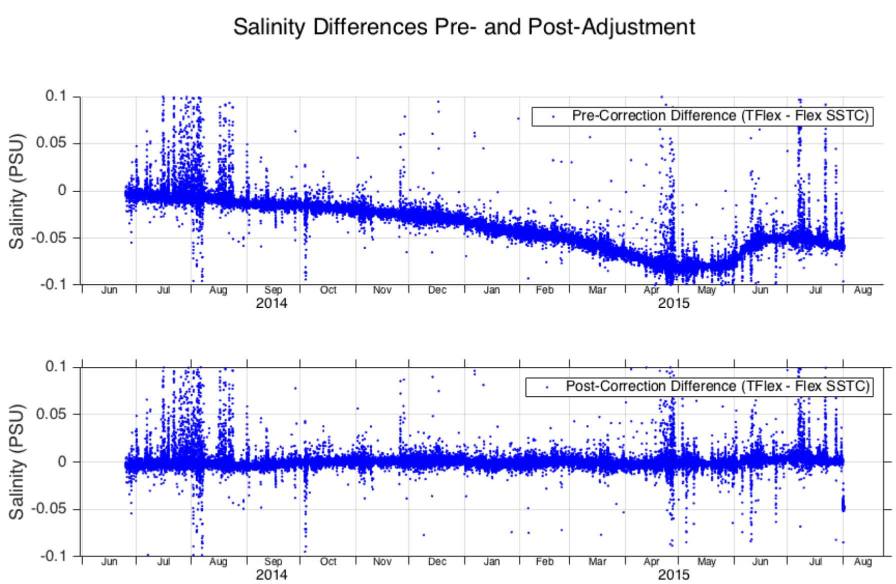

Figure 13: SSTC salinity differences before (top) and after (bottom) corrections. Both instruments required adjustments based on density comparisons with neighboring instruments.

Corrections are pulled from density difference plots, but applied to salinity. As salinity and density vary together, but not perfectly 1-1, a less aggressive second iteration is often required, and is indicated by "*" in the list on page 25.

Two CTD casts were performed aboard the KAIYO on June 27, 2014, to 2000m and 300m respectively. No recovery cast was available. Since all moored instruments in the mixed layer effectively overlapped at the start of the deployment, no changes were made to the data based on the CTD casts.

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.

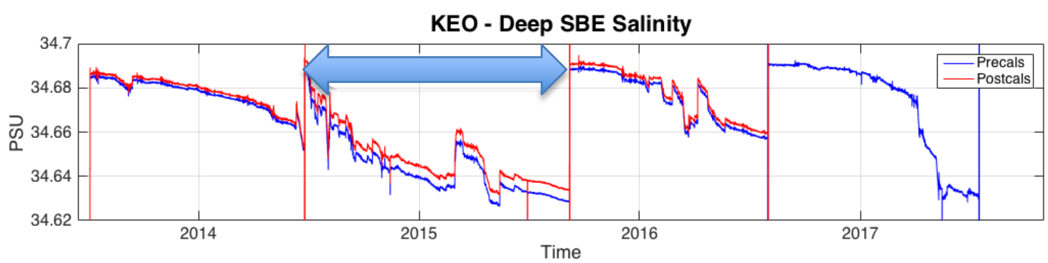

Figure 14: KEO deep ocean measurement, showing annual salinity drift. The arrow highlights KE012.

As of April 2018, no confident correction could be made to the deep SBE data. Data are distributed with pre-deployment calibration coefficients applied. 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 two depths on the KE012 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 16.46m and 36.46m measured velocities at 16m and 36m, respectively. Both current meters deployed on KE012 were Nortek Aquadopps.

Upon recovery, the 16.5m Aquadopp was found to have slid down the wire, cracked, and flooded. No delayed-mode data were retrieved, and real-time data were only available up until the instrument stopped transmitting on August 9, 2014. These data are corrected for magnetic declination, but realtime data are not corrected for buoy motion.

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 15. The brief velocity spikes were likely real, often corresponding to tropical storms or typhoons. Spikes could also be due to strong currents, as water speeds exceeding 150cm/s were observed during KE012. Theoretically, spikes can result when two GPS positions with a small spatial error are sampled within seconds of each other. This type of error is rare, given that aggregated data are rounded to the minute, and the GPS accuracy is 10m.

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.

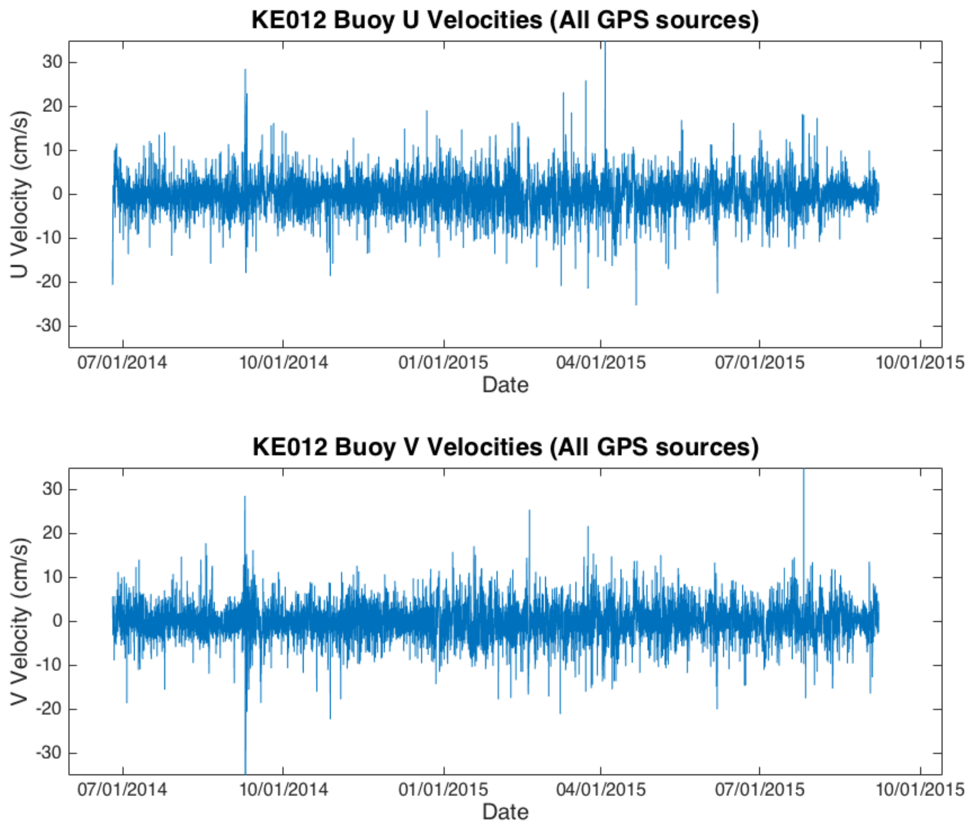

Figure 15: KE012 buoy velocities used to correct currents.

4.0 References

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5.0 Acknowledgements

C. Fey and N. Anderson (both of UW JISAO) processed the Flex/TFlex data, and developed scripts to handle the new case of deployments without ATLAS systems. 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. S. Brown (UW JISAO) was consulted in the development of new salinity processing scripts.

The OCS project office is grateful to the captains and crews of the R/V KAIYO and M/V BLUEFIN, who made the deployment and recovery operations possible. K. Ronnholm and D. Zimmerman (both of UW JISAO) participated in the deployment cruise; N. Anderson, D. Rivera, and P. Berk (all UW JISAO) participated in the recovery cruise. Dr. Makio Honda and Akira Watanabe (JAMSTEC), as well as Will Thomson and Lee Tretbar (NDBC) are acknowledged for their help on the recovery mission.

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6.0 Contact Information

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7600 Sand Point Way NE
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

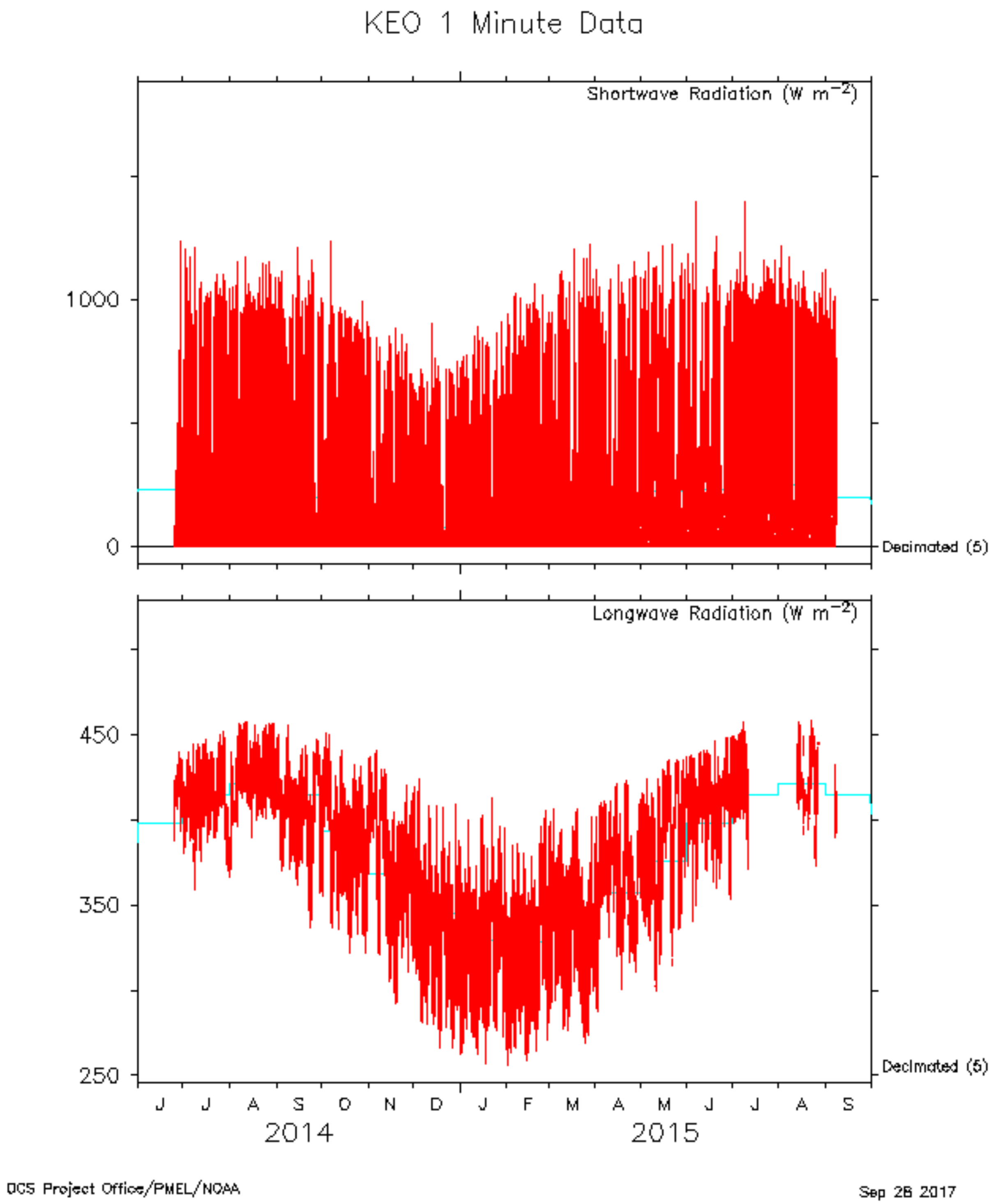

Figure B 1: KE012 primary shortwave and longwave radiation data at 1-min resolution (mixed TFlex/Flex). The TFlex radiation mast was horizontal on recovery, but the damage occurred after April when the TFlex failed.

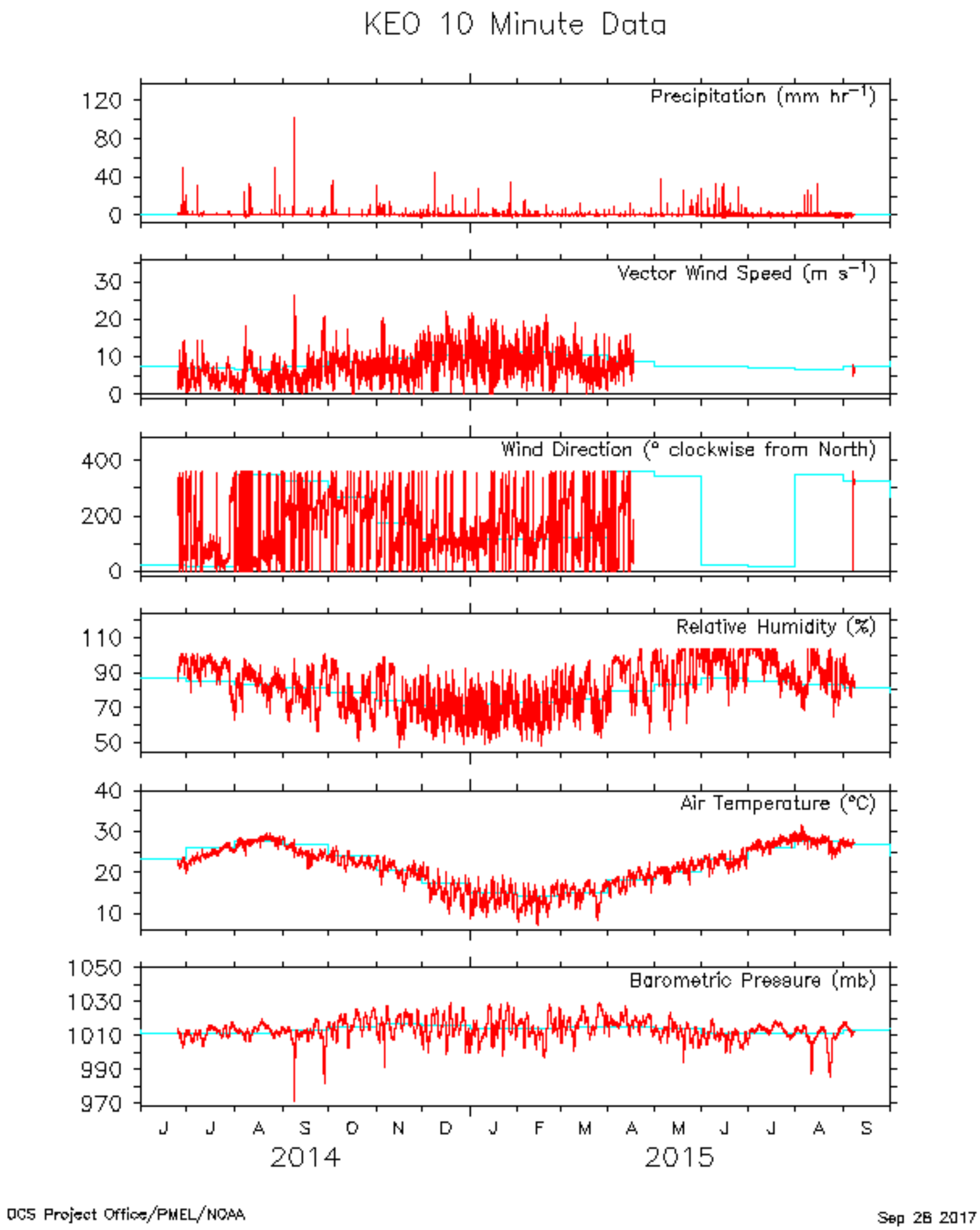

Figure B 2: KE012 meteorological data at 10-min resolution. ATRH is spliced TFlex/Flex data, and winds are TFlex data, which failed April 17, 2014. The Flex Gill had failed previously, so no additional data are available.

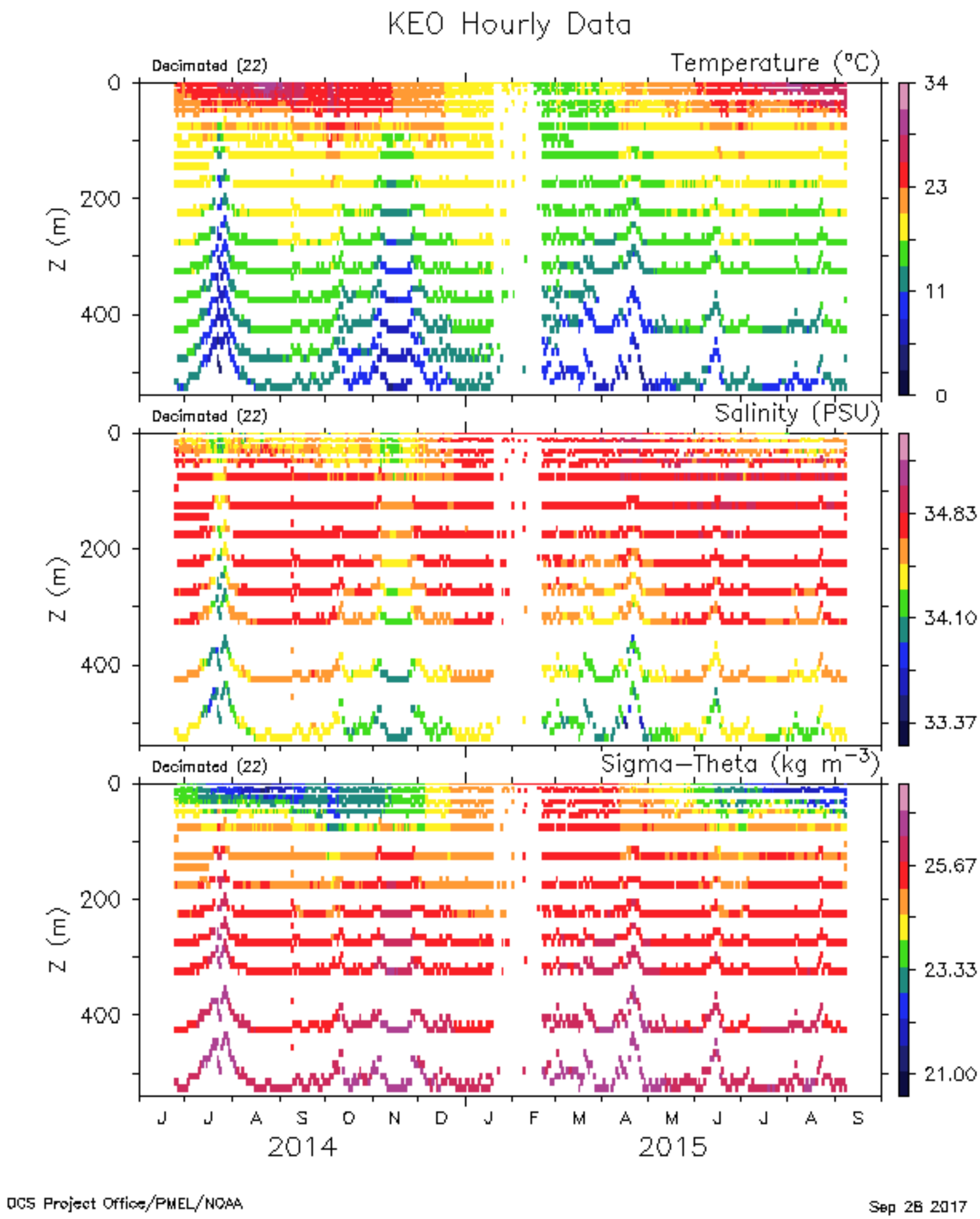

Figure B 3: KE012 *realtime* subsurface temperature, salinity, and density at hourly resolution (decimated). Vertical streaks show the inductive dropouts in early 2015.

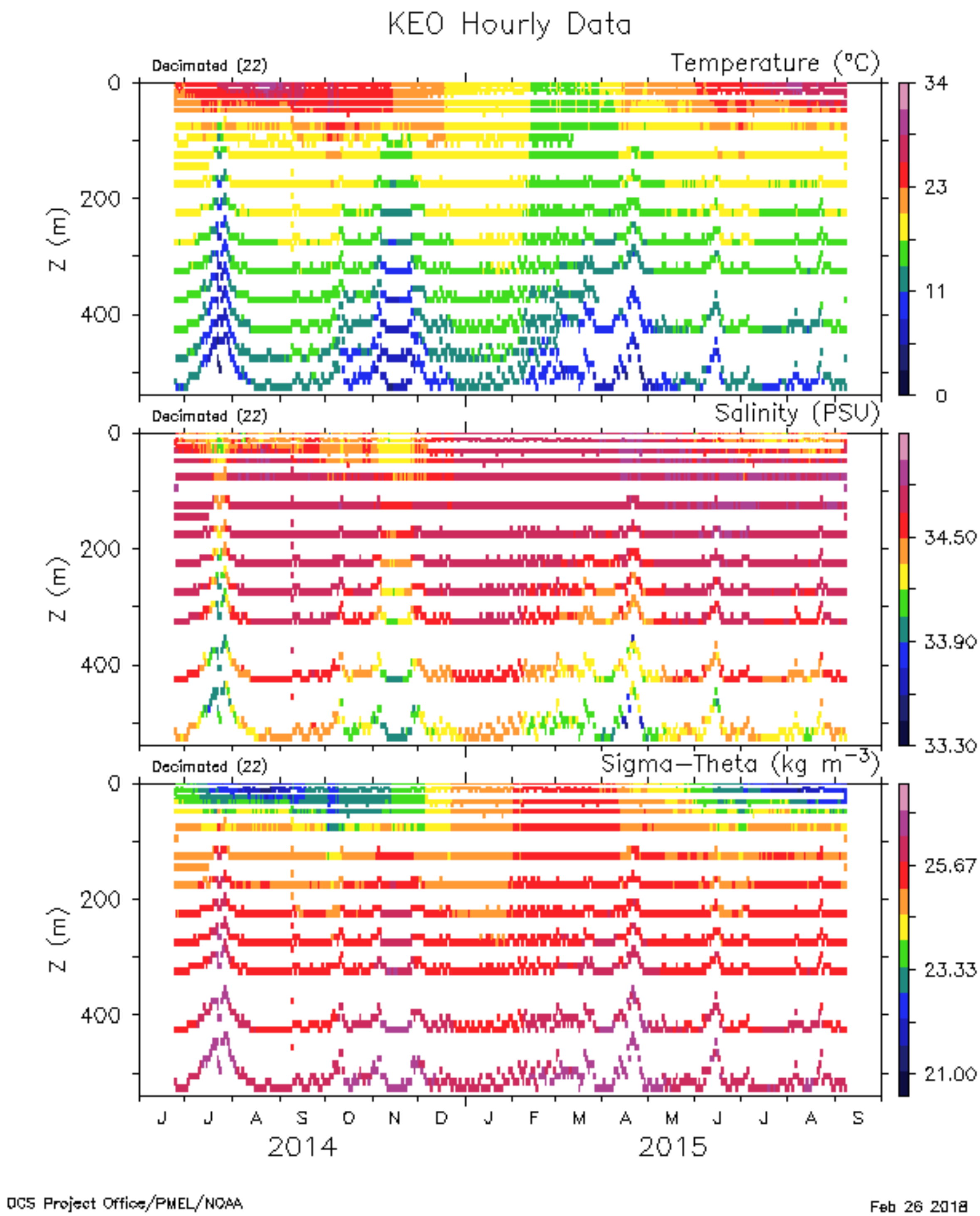

Figure B 4: KE012 *delayed-mode* subsurface temperature, salinity, and density at hourly resolution (decimated).

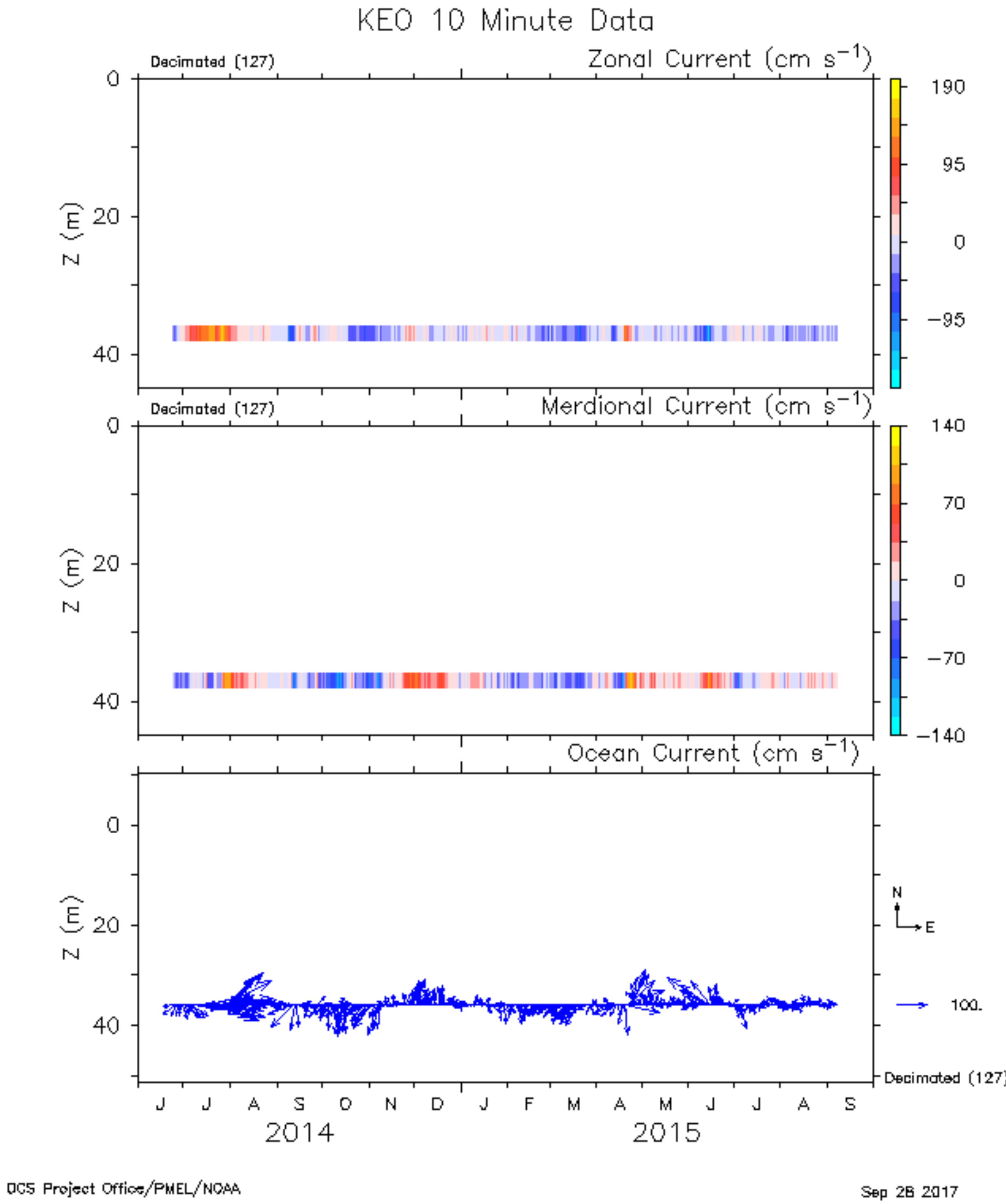

Figure B 5: Zonal and meridional current meter data (decimated) from KE012. The 16.46m Aquadopp slid down the line and flooded early in the deployment (realtime data at hourly and daily resolutions are available).

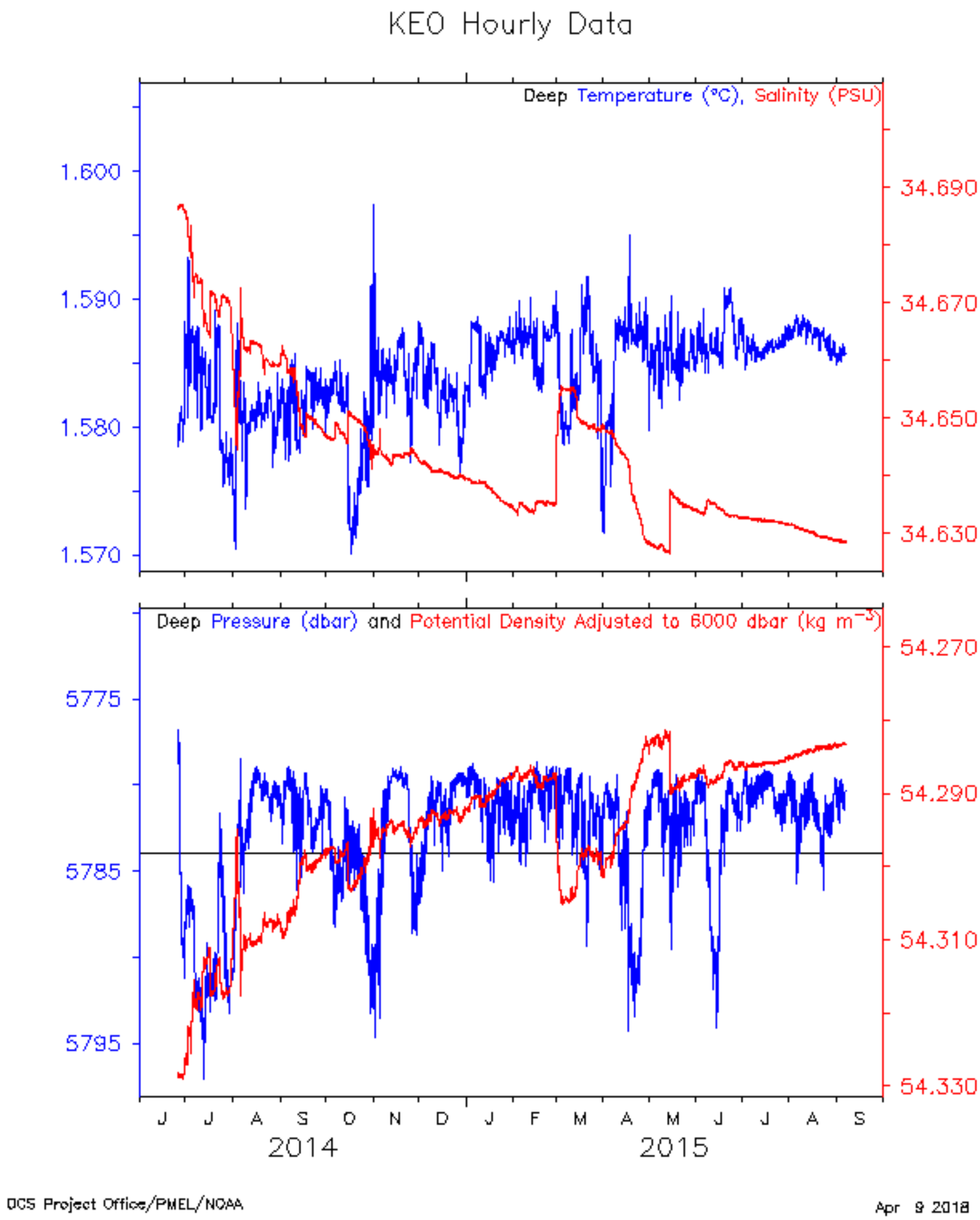

Figure B 6: Deep Seabird instrument temperature, pressure, salinity, and potential density. Pre-deployment calibration coefficients were applied.

APPENDIX C: Secondary Instrument High Resolution Data Plots

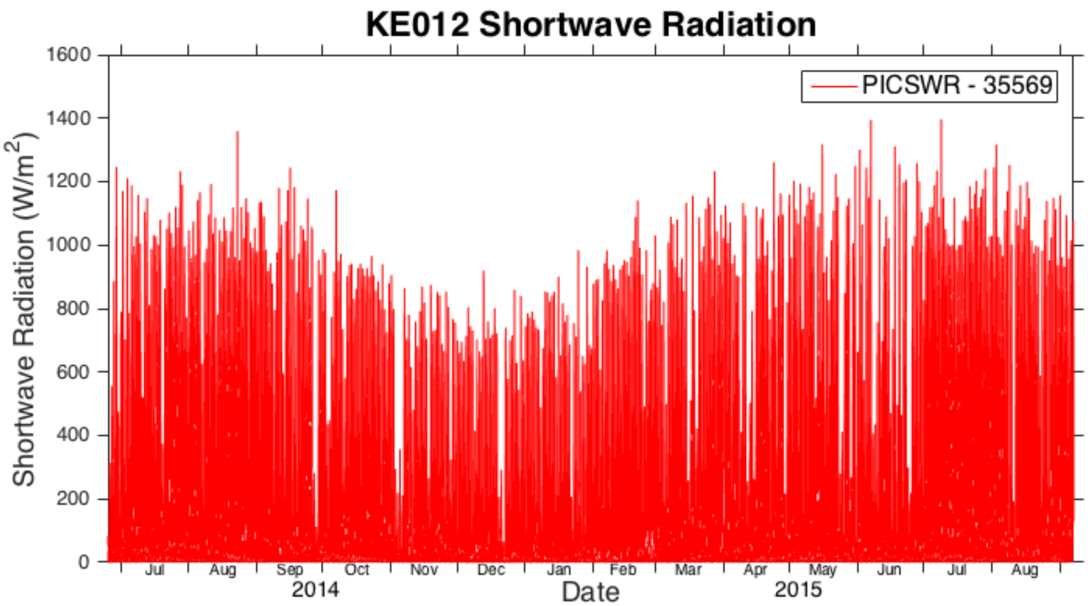

Figure C 1: Secondary (Flex Eppley PSP) shortwave radiation sensor. This sensor became primary after the TFlex failure.

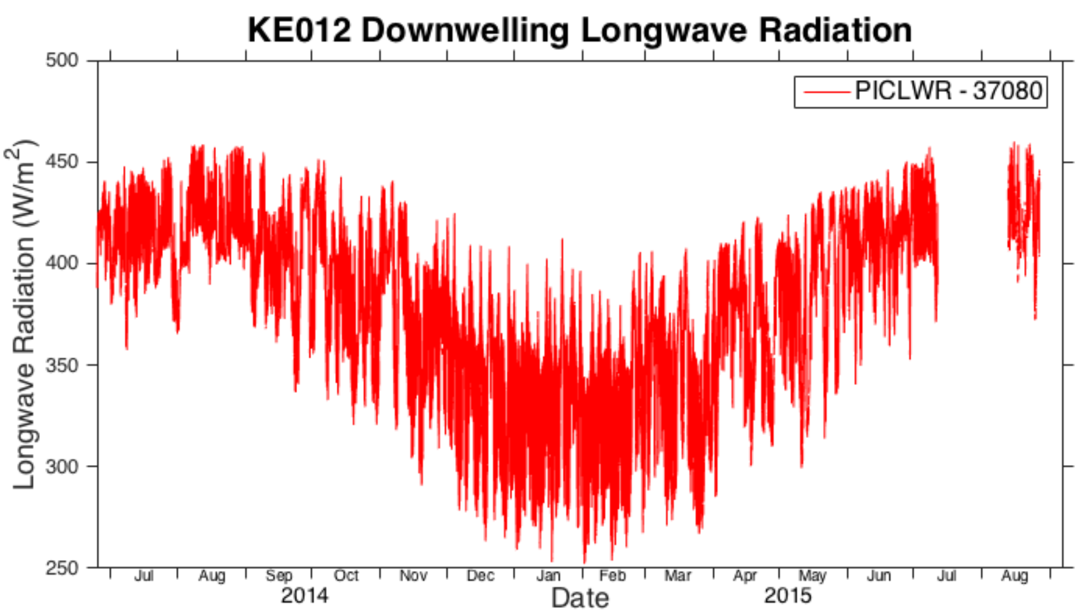

Figure C 2: Secondary (Flex Eppley PIR) longwave radiation sensor. This sensor became primary after the TFlex failure.

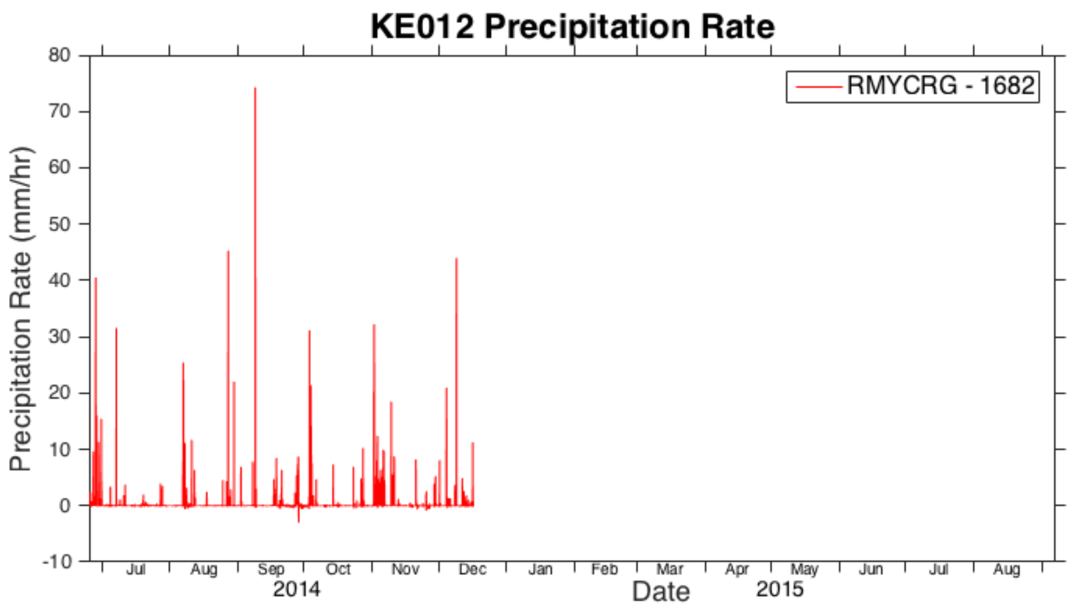

Figure C 3: Secondary (TFlex RM Young) rain sensor. The rain collection funnel was likely damaged by human activity in mid-December.

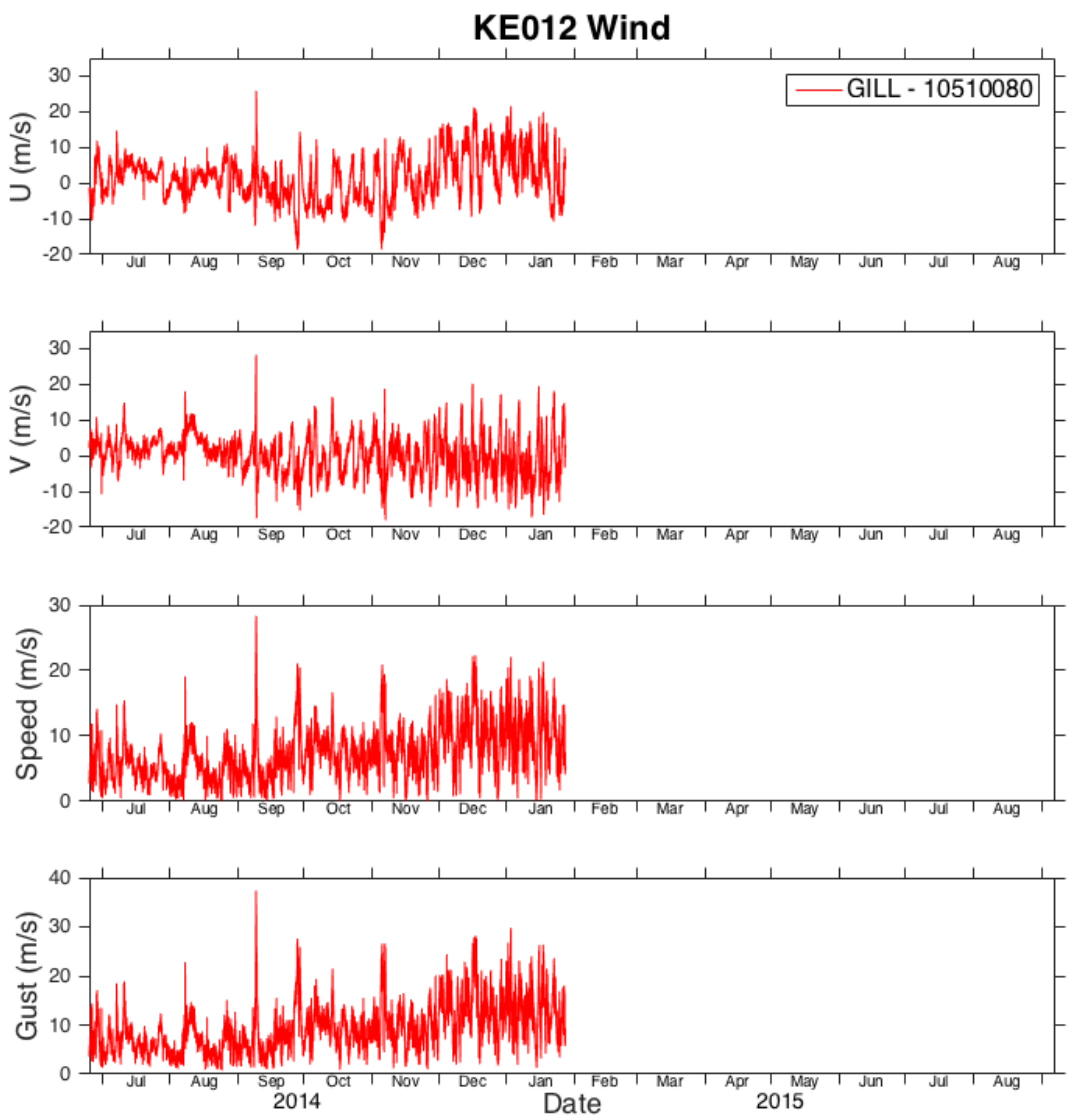

Figure C 4: Secondary (Flex Gill) wind sensor. The top plate was missing upon recovery, explaining the early time-series termination.

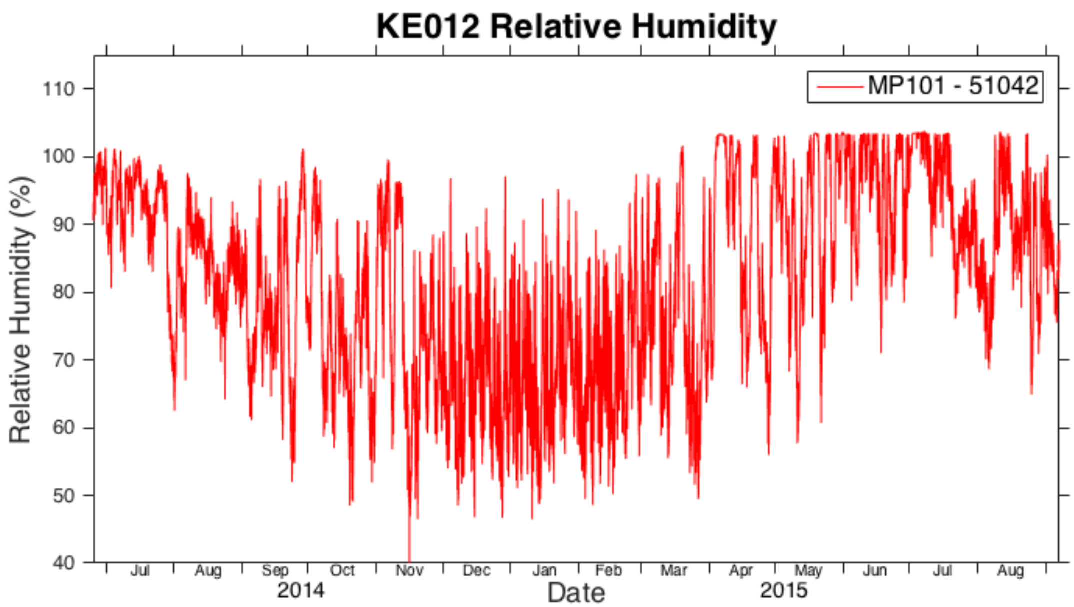

Figure C 5: Secondary (Flex MP101) relative humidity sensor. Since the TFlex failed in April, Flex data are considered primary thereafter, though the latter portion occasionally exceeds 100% and is flagged Q4.

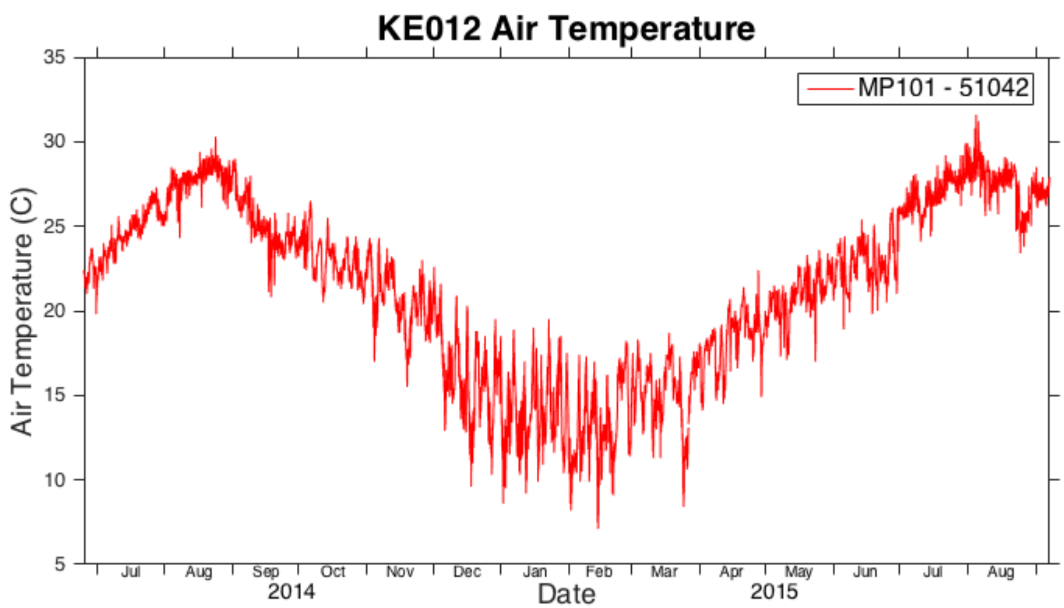

Figure C 6: Secondary (Flex MP101) air temperature sensor.

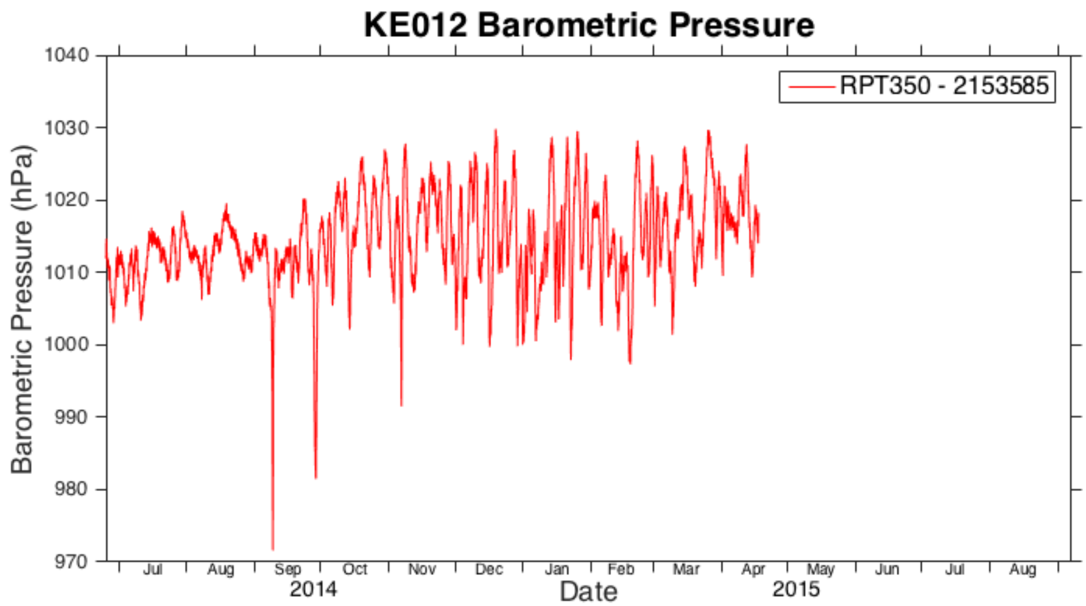

Figure C 7: Secondary (TFlex Druck) barometric pressure sensor. Time-series ends with the TFlex failure.

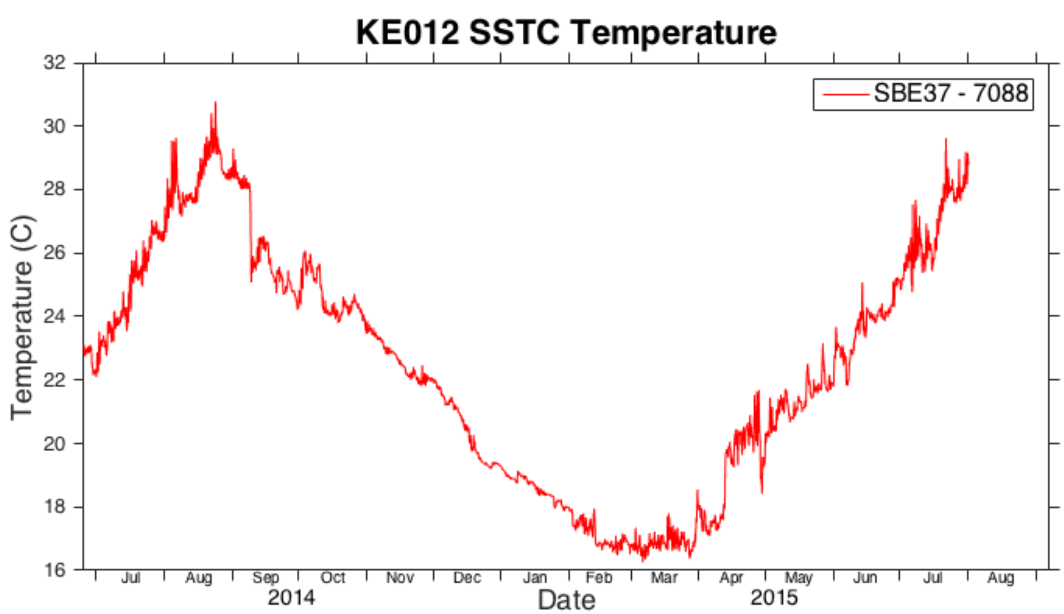

Figure C 8: Secondary (Flex) SSTC Temperature.

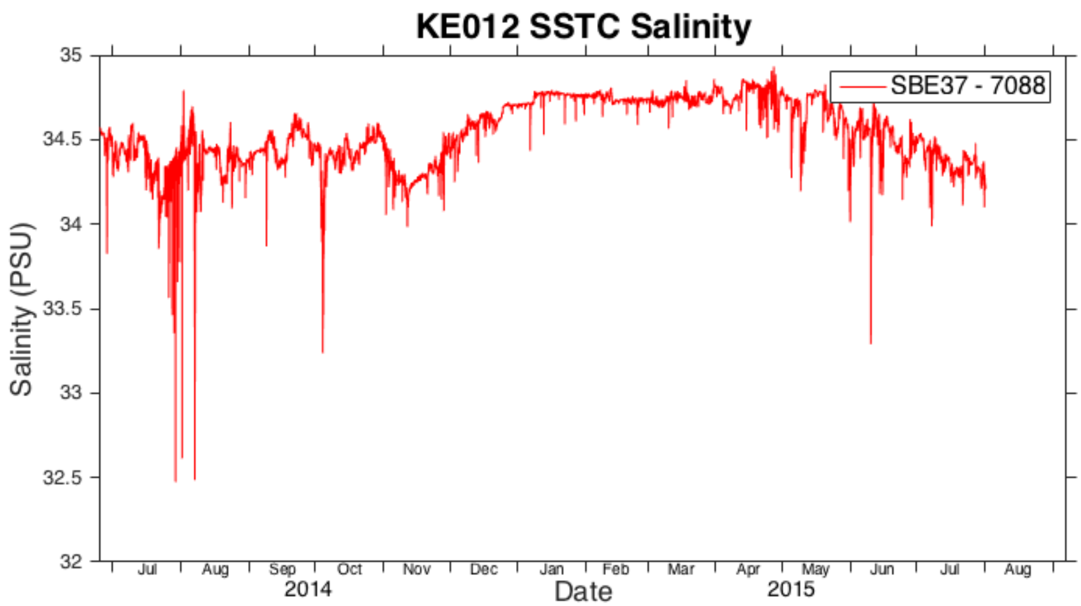

Figure C 9: Secondary (Flex) SSTC Salinity. Low spikes in salinity are allowed to an extent, to account for fresh lenses produced by rain or advection from nearby storms.

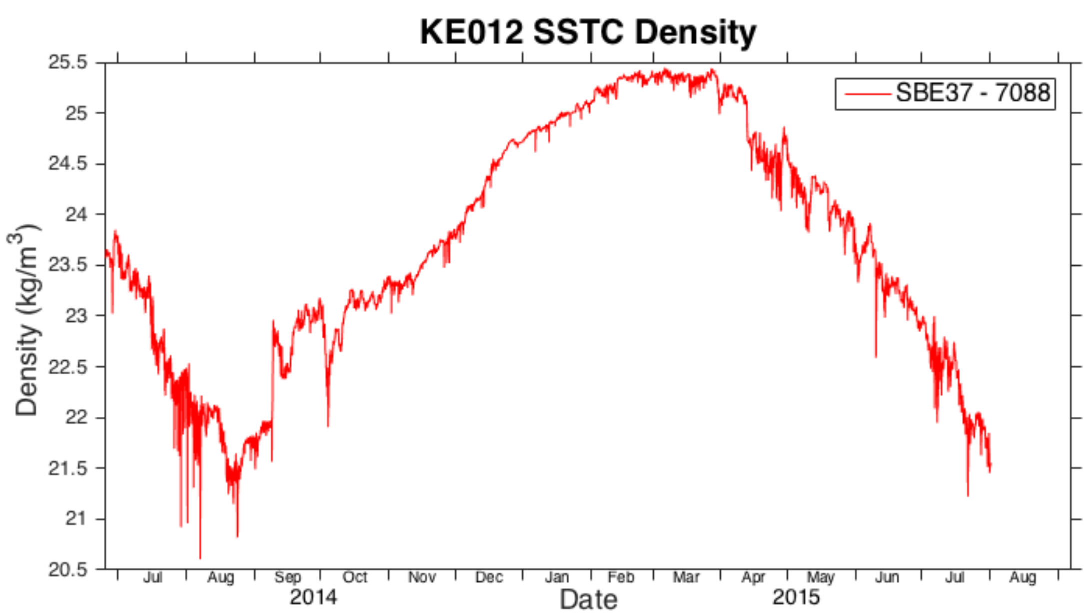

Figure C 10: Secondary (Flex) SSTC Density.

APPENDIX D: Severe Tropical Storm Fengshen

Of the multiple large storms that passed the KE012 mooring, tropical storm Fengshen had the largest effect. While remaining just below typhoon status, the storm was near its maximum strength when it passed. Other storms such as tropical storm Kammuri, typhoon Nuri, and typhoon Atsani were detected in time-series of barometric pressure, water temperature, or winds, but were either weaker or did not approach as directly as Fengshen. Highlights of Fengshen data are presented below.

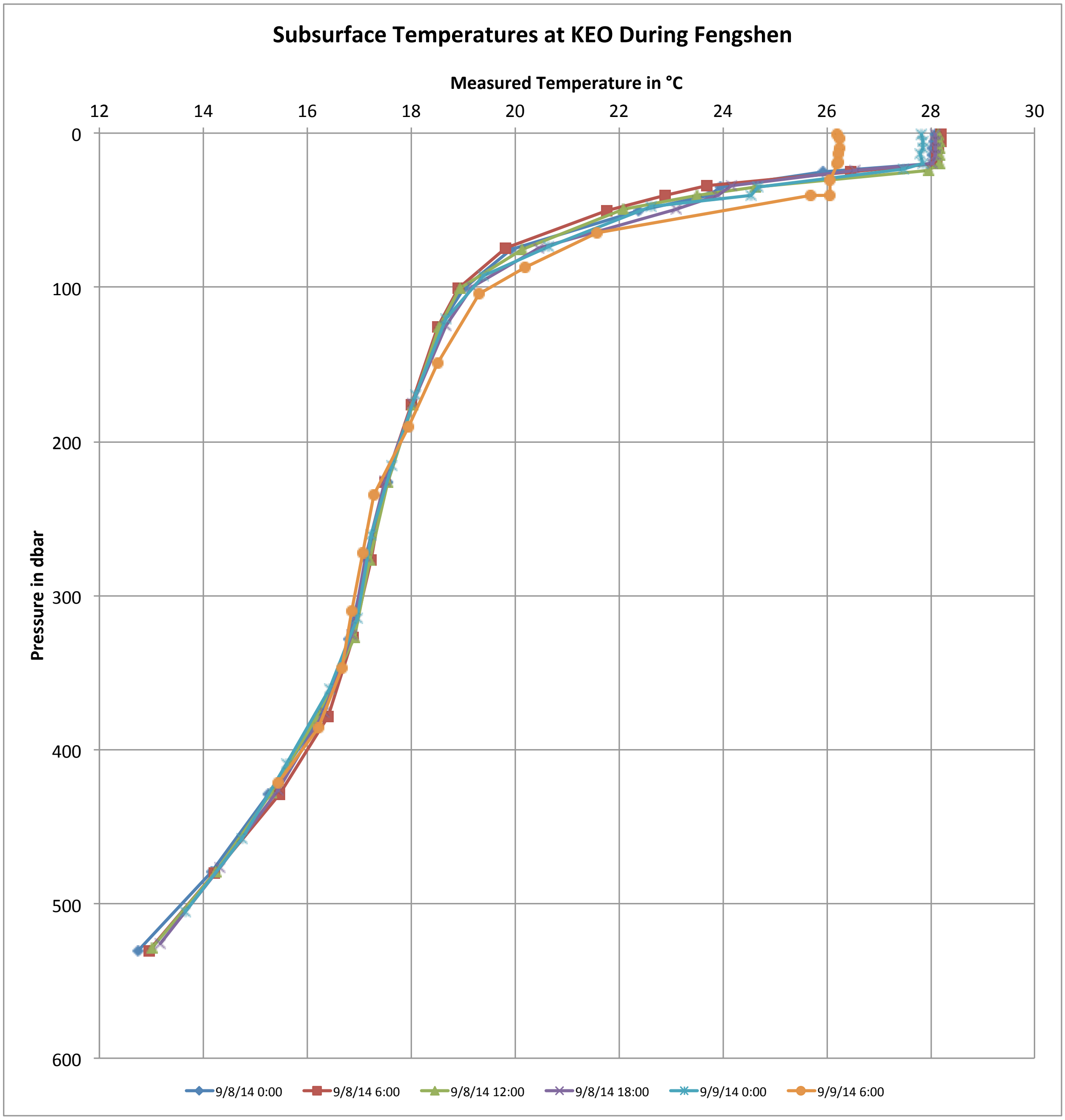

Figure D 1: Subsurface temperature data showing surface cooling and mixing during Fengshen.

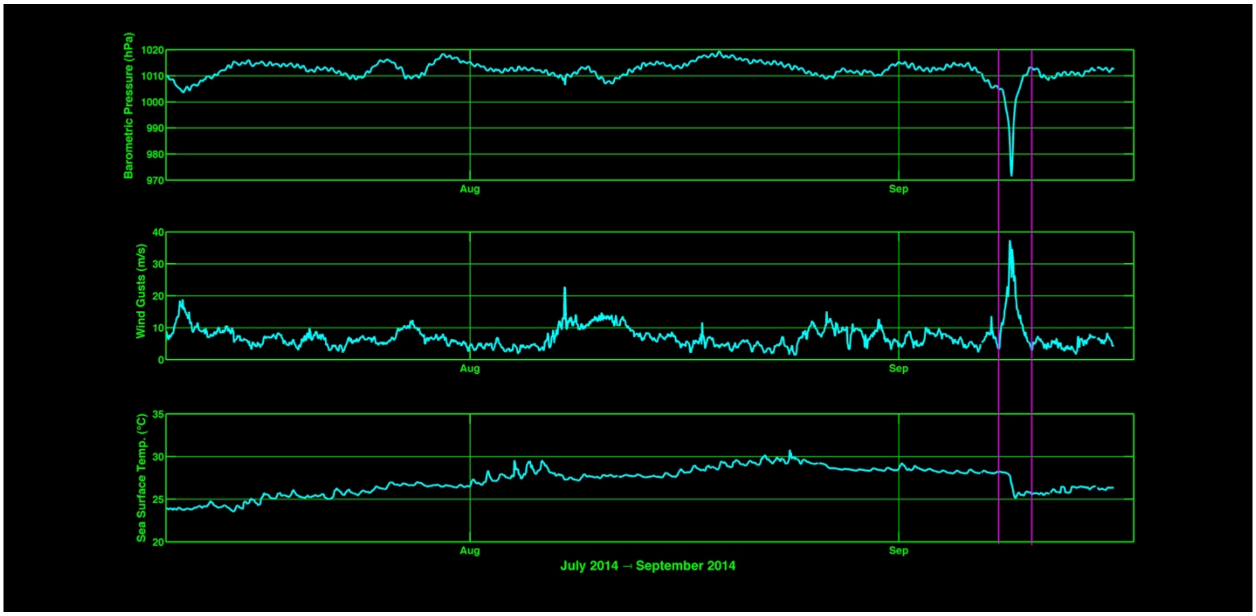

Figure D 2: Barometric pressure, wind gusts, and SST associated with tropical storm Fengshen.

Figure D 3: Satellite image of tropical storm Fengshen.