NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

DATA ACQUISITION AND PROCESSING REPORT FOR KE001

Site Name:	Kuroshio Extension Observatory (KEO)
Deployment Number:	**KE001**
Year Established:	2004
Nominal Location:	32.3°N 144.6°E
Anchor Position:	32.35°N 144.64°E
Deployment Date:	June 16, 2004
Recovery Date:	May 28, 2005 (Top 700m)
Project P.I.:	Dr. Meghan F. Cronin
Report Authors:	J.A. Keene, M.F. Cronin, K.B. Ronnholm, H.P. Freitag, N.D. Anderson
Data Processors:	S. Brown, S. Moon, L. Rainville
Date of Report:	July 13, 2016
Revision History:	

Special Notes:
This was the first deployment of the NOAA Ocean Climate Station mooring at the KEO site. It was also the first year of the Kuroshio Extension System Study.

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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. This deployment was part of the first year of the two-year Kuroshio Extension System Study (KESS). KE001 was located next to the Woods Hole Oceanographic Institution (WHOI) KESS-7 subsurface mooring (Figure 1). More information about the K7 mooring can be found in Appendix C.

The KE001 mooring was deployed by the R/V THOMPSON, and its surface buoy and top 700m of wire and instruments were recovered in May 2005 by the R/V REVELLE. After deployment, anchor location was triangulated using a Workboat solution corroborated by WHOI triangulation and redundant Workboat solutions. Both cruises were KESS mooring cruises, with Drs. S. Jayne and N. Hogg (WHOI) as chief scientists. The KEO project office is grateful to Drs. Jayne and Hogg and other KESS PIs for inviting the KEO group to participate on the cruises. The mooring operation assistance from the KESS scientists and technicians, and the captains and crews of the R/V THOMPSON and REVELLE are also gratefully acknowledged. For further information on KESS, see http://uskess.whoi.edu and Donohue et al. (2008).

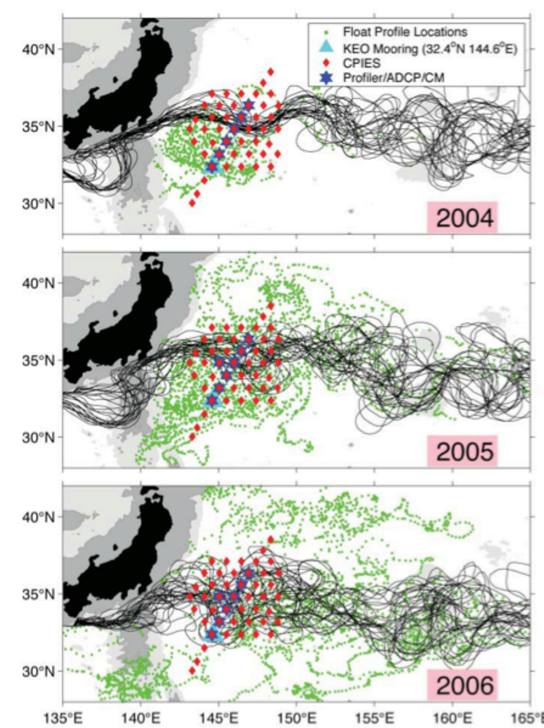

Figure 1: Maps of the KESS array during 2004-2006, from Donohue et al. 2008. Black lines are the biweekly Kuroshio Extension path based on the 170 cm contour of sea surface height.

1.1 Mooring Description

The KE001 mooring was a slack-line mooring, with a nominal scope of 1.4. The scope is defined as the ratio of the mooring length, 7,910m, to the water depth, 5,650m. 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 to a depth of 500m. The remainder of the mooring line consisted of plaited 8-strand nylon line, spliced to buoyant polyolefin, as shown in Figure 3. There were four glass balls in line above the acoustic release. The 6,820lb (3,094kg) 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. Pressure measurements were recorded at three nominal depths of 150 m, 300 m, and 500 m. Time series of pressure at other sensor levels were interpolated from observed values, and both observed and interpolated pressure time series are included with the data.

The surface buoy was a 2.3m fiberglass-over-foam toroid buoy, with extra flotation glassed smooth into the center of the toroid. It had an aluminum tower and a stainless steel bridle.

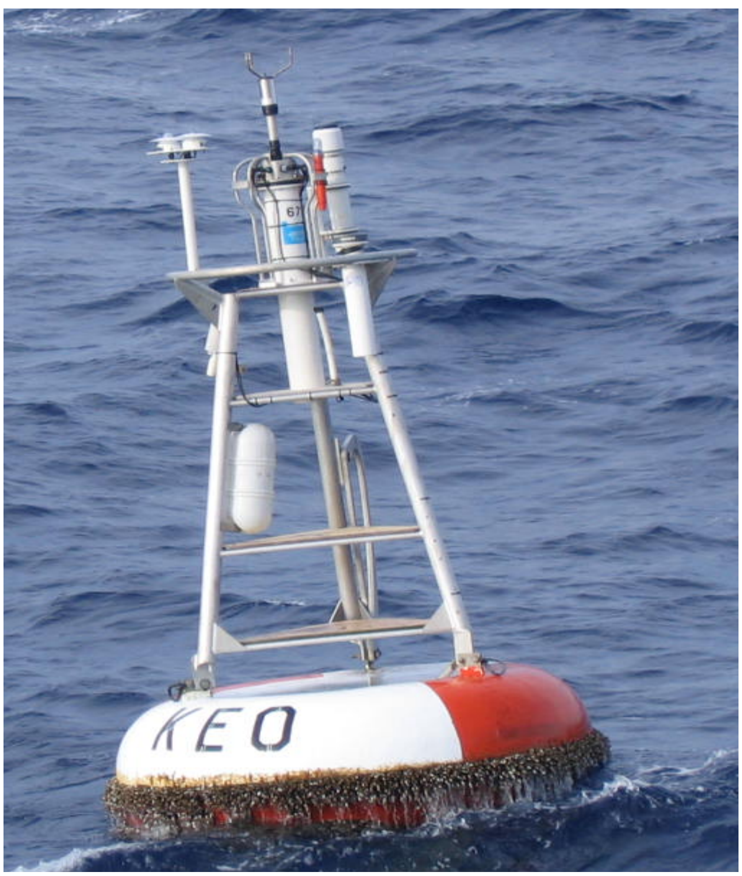

Figure 2: KE001 buoy as deployed.

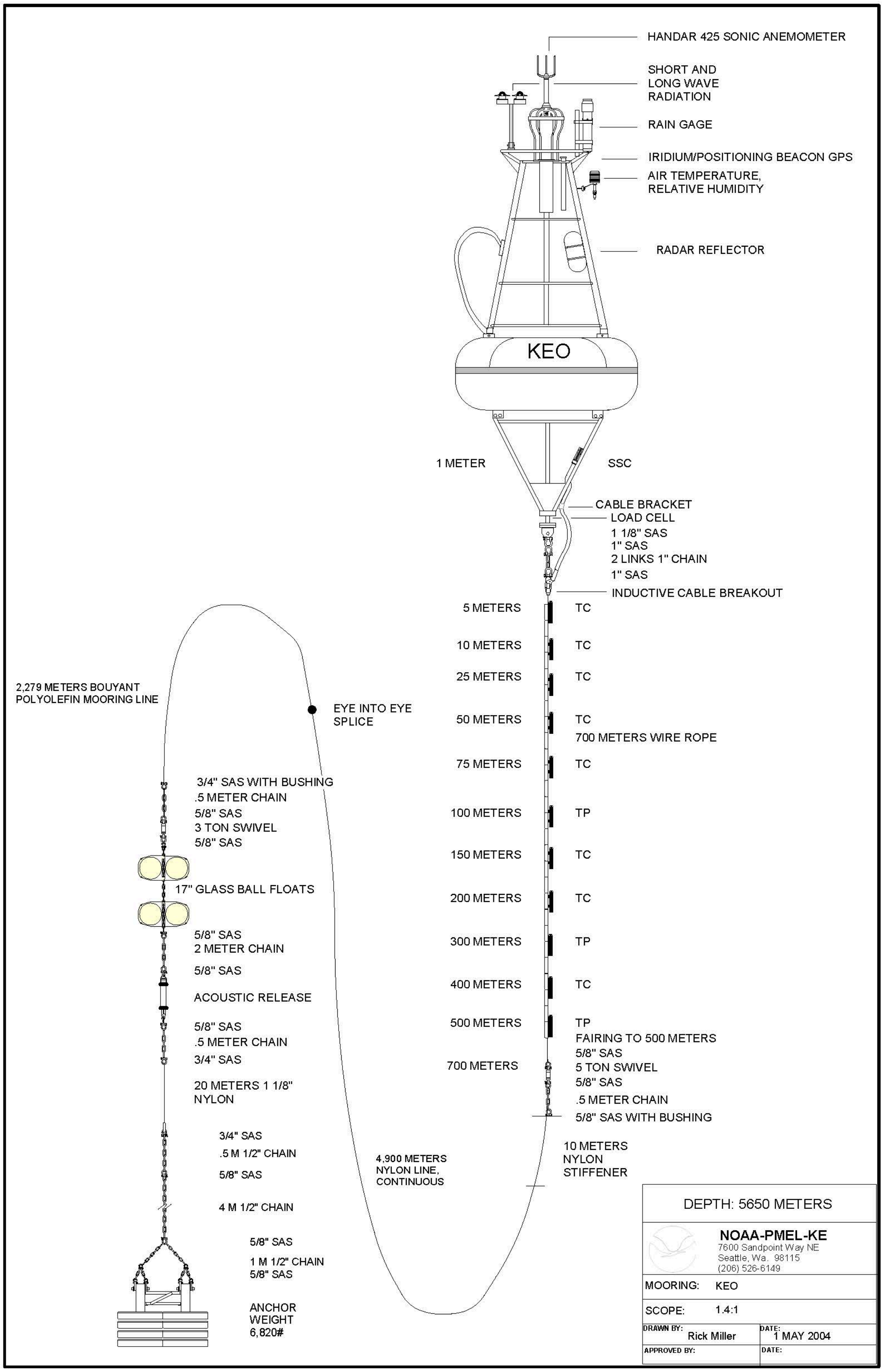

Figure 3: KE001 mooring diagram.

1.2 Instrumentation on KE001

The following instrumentation was deployed on KE001. The ATLAS data acquisition system was used, and there was no CO_2 system on the first deployment.

Deployment:		**KE001**			
Met Sensors		**Model**	**Serial #**		**Notes**
Height	Acquisition	ATLAS	671		
3m	ATRH	Rotronics MP-101A	59305		
3.5m	Rain	RM Young	1175-4		
3.5m	SWR	Eppley PSP	32419		
3.5m	LWR	Eppley PIR	32219		
4m	Wind	Vaisala (Handar)	Y2210002		
Subsurface Instrumentation					
Bridle		**Model**	**Serial #**		**Notes**
1m	SSC	ATLAS Module	11580		White
2m	Load Cell		V910		
Depth on Line		**Model**	**Serial #**		**Notes**
5m	TC	ATLAS Module	13135		White
10m	TC	ATLAS Module	13136		Inverted, White
25m	TC	ATLAS Module	13137		Inverted, White
50m	TC	ATLAS Module	13138		Inverted, White
75m	TC	ATLAS Module	13346		Inverted, White
100m	TP	ATLAS Module	13180		Inverted, White
150m	TC	ATLAS Module	13348		White
200m	TC	ATLAS Module	13351		Tube config 'T', White
300m	TP	ATLAS Module	12983		Tube config 'T', Black
400m	TC	ATLAS Module	13349		White
500m	TP	ATLAS Module	13299		White

Table 1: Instruments deployed on KE001.

2.0 Data Acquisition

The ATLAS data acquisition system transmits daily average and intermittent spot meteorological measurements to shore through Service Argos satellites. High-resolution data are logged internally, and downloaded upon recovery of the mooring. Subsurface instruments log internally throughout the deployment.

The ATLAS system does not acquire or store position information, but buoy positions are provided by the Service Argos satellites. When four or more satellites are in the buoy's field of view during data transmissions, the satellites assess the Doppler shift of the known transmission frequency to generate estimates of latitude and longitude. These opportunistic position estimates are then appended to the data transmissions.

More accurate Global Positioning System (GPS) data were also acquired and telemetered to shore, via an Iridium Positioning beacon System (IPS) on the buoy. GPS/IPS positions were acquired at irregular time intervals, ranging from six hours to three days between fixes.

2.1 Sampling Specifications

Table 2 describes the high-resolution sampling scheme for the KE001 mooring. Observation times in data files are assigned to the center of the averaging interval.

Measurement	Sample Rate	Sample Period	Sample Times	Recorded Resolution	Acquisition System
Wind Speed/Direction	2 Hz	2 min	2359-0001, 0009-0011…	10 min	ATLAS
Air Temperature	2 Hz	2 min	2359-0001, 0009-0011…	10 min	ATLAS
Relative Humidity	2 Hz	2 min	2359-0001, 0009-0011…	10 min	ATLAS
Rain Rate	1 Hz	1 min	0000-0001, 0001-0002…	1 min	ATLAS
Shortwave Radiation	1 Hz	2 min	2359-0001, 0001-0003…	2 min	ATLAS
Longwave Radiation (Thermopile, Case & Dome Temperatures)	1 Hz	2 min	2359-0001, 0001-0003…	2 min	ATLAS
Seawater Temperature, Pressure & Conductivity	1 per 10 min	Instant.	0000, 0010,…	10 min	Internal

Table 2: Sampling parameters of primary sensors on KE001.

2.2 Data Return

ATLAS Tube 671, software version 4.09:

Wind	Y2210002	100%
AirT	59305	100%
RH	59305	100%
Rad(SWR)	32419	100%
LWR	32219	100%
Rain	1175	100%

Modules:

1m	SSC	11580	100.0%	t&c
5m	TC	13135	100.0%	t&c
10m	TC	13136	100.0%	t&c
25m	TC	13137	100.0%	t&c
50m	TC	13138	100.0%	t&c
75m	TC	13346	3.2%	t&c
100m	TP	13180	100.0%	t&p
150m	TC	13348	100.0%	t&c
200m	TC	13351	100.0%	t&c
300m	TP	12983	100.0%	t&p
400m	TC	13349	100.0%	t&c
500m	TP	13299	100.0%	t&p

2.3 Known Sensor Issues

The ATLAS TC module at 75m contained very little data, even though the battery voltage appeared normal after recovery. All other data were recovered at 100%.

3.0 Data Processing

Processing of data from OCS moorings is contracted to the PMEL Tropical Atmosphere Ocean (TAO) project group. Data processing follows the methods described below. The process includes assignment of quality flags for each observation, which are described in Appendix A. Any issues or deviations from standard methods are noted in processing logs, and in this report.

Raw data recovered from the internal memory of the data acquisition system are first processed using computer programs. Pre-deployment calibrations are applied to raw ATLAS data (recorded as sensor counts), to generate a data time series in engineering units. 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 temperature and 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.

Individual time series and statistical summaries are examined by trained analysts. 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 position of the buoy rather than its nominal position.

As described in Section 2.0, position data for KE001 were acquired by two methods; Service Argos location estimates, and the more accurate GPS fixes. The Service Argos and GPS position data were combined and distributed at their native resolution, which ranged from six hours to three days between position fixes. The native GPS data were also converted into 10-minute, hourly, and daily values to match the resolutions of other measurements from the mooring. The 10-minute and hourly resolutions were calculated through linear interpolation of the native GPS data. Daily GPS positions were the median value of the interpolated 10-minute data for each day.

3.2 Meteorological Data

All primary meteorological sensors on KE001 remained fully functional throughout the deployment.

3.2.1 Winds

All of the wind direction data were assigned a quality flag of Q4 (lower quality), due to a post deployment compass calibration showing errors of 6 – 13 degrees.

3.2.2 Air Temperature

There are no special processing notes for air temperature at KE001. Refer to section 3.0 for general remarks.

3.2.3 Relative Humidity

There are no special processing notes for relative humidity at KE001. Refer to section 3.0 for general remarks.

3.2.4 Rain

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

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

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

3.2.5 Shortwave Radiation

There are no special processing notes for shortwave radiation at KE001. Refer to section 3.0 for general remarks.

3.2.6 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).

3.3 Subsurface Data

3.3.1 Temperature

The temperature drifts for the ATLAS modules are calculated as an average over all temperature set points from the pre-deployment and post-recovery calibrations.

ATLAS Module Temperature Drifts in °C (post - pre):

Depth:	**Drift:**
1m	-0.0073
5m	-0.0417
10m	-0.0187
25m	-0.0150
50m	-0.0222
75m	-0.0049
100m	-0.0370
150m	-0.0201
200m	-0.0196
300m	-0.0115
400m	-0.0075
500m	-0.0112

Drift corrections are applied to the data as a linear function over time. The pre-deployment calibration coefficients are given a weight of one at the beginning of the deployment, and zero at the end, while the post-recovery calibration coefficients are weighted zero at the start of deployment, and one at the end.

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 calculated pressures contained in the data file.

Pressure measurements were recorded at three depths: 150 m, 300 m, and 500 m. Time series of pressure at other sensor levels were interpolated from observed values, and both observed and interpolated pressure time series are included with the data.

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.

ATLAS Module Salinity Drifts in PSU (post - pre):

Depth:	Drift:
1m	0.0072
5m	0.0373
10m	1.2640
25m	-0.0062
50m	0.0841
75m	-0.0090
150m	-0.0047
200m	-0.0227
400m	-0.0148

The values above indicate the change in calculated salinity data values when post-recovery calibrations are applied to the conductivity measurement, 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's effective cross-sectional area. This expansion is possibly due to scouring of the cell wall by abrasive material in the sea water. Positive values indicate decrease in the cell's effective cross-sectional area, presumably due to fouling, and secondarily due to fouling or loss of material on the cell electrodes.

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

Manual Salinity Adjustments

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

Based on manual review of the data, the ATLAS modules at 5m and 25m performed well, with no corrections needed in the data. Since the 25m data had a slight downward trend, the 5m data were used as the reference for adjustments to the data from 1m, 10m, 50m, and 200m. It was noted that the temperature drift of -0.0417°C of the 5m module also introduced a salinity drift at that depth.

For KE001, there was no previous mooring with which to compare the data, and no CTD cast was performed at the site to allow additional data comparisons.

Start and end points of the adjustment segments shown below are in the format of Year, Year day, Hour, Minute, Second (YYYYDDDHHMMSS). The adjustment amounts listed were applied linearly to the measured values over that time period, as shown in Figures 4 – 7. After all adjustments were applied, salinity data were sub-sampled to hourly intervals.

1m Salinity Adjustments

2004168113000(0.0238) - 2004323123000 (0.0238)
2004323124000(0.0074) - 2004327044000 (0.0556)
2004327045000(0.0238) - 2005099113000 (0.0074)
2005099114000(0.0556) - 2005133222000 (0.0148)
2005133223000(0.0148) - end (0)

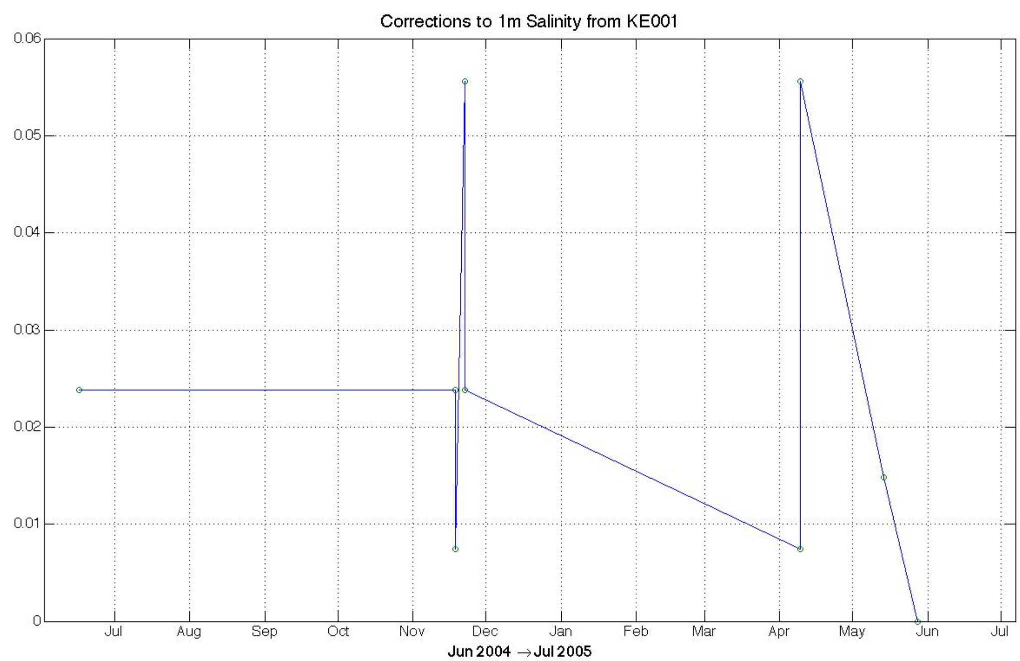

Figure 4: Linear corrections applied to 1m salinity data.

10m Salinity Adjustment 1

start (0) - end (-1.2)   large drift for the whole period.

(NOTE: This large drift correction essentially backed out most of the correction previously applied based on the post-recovery calibration, indicating that the calibration did not accurately reflect the sensor condition when recovered.)

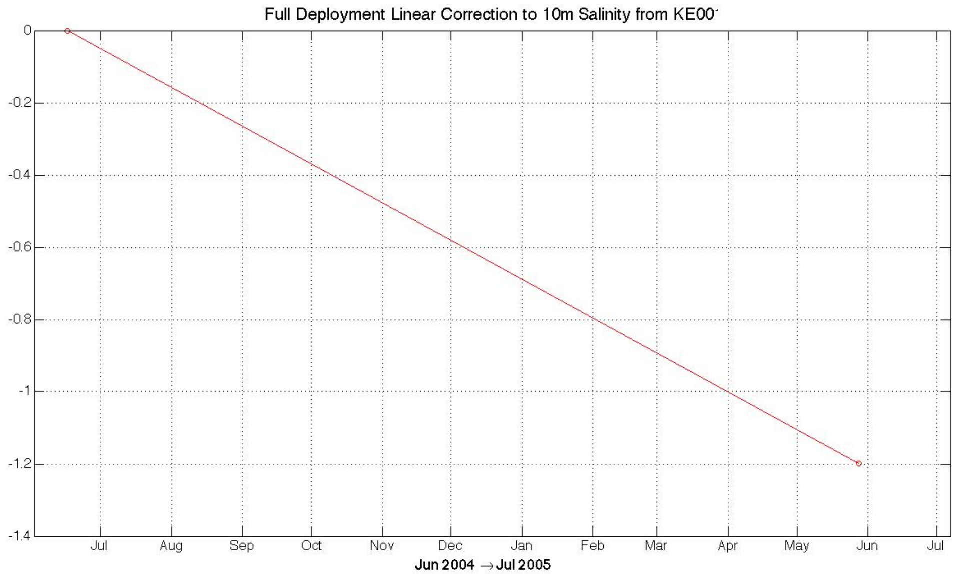

Figure 5: Correction of linear drift over entire deployment applied to 10m salinity data.

10m Salinity Adjustments 2

2004291064000 (0) - 2004309140000 (-0.009)
2004309141000 (-0.009) - 2004340192000 (-0.017)
2004340193000 (-0.017) - 2004363100000 (0)
2005009191000 (0)- 2005121055000 (-0.049)
2005121060000 (-0.049) - end(0)

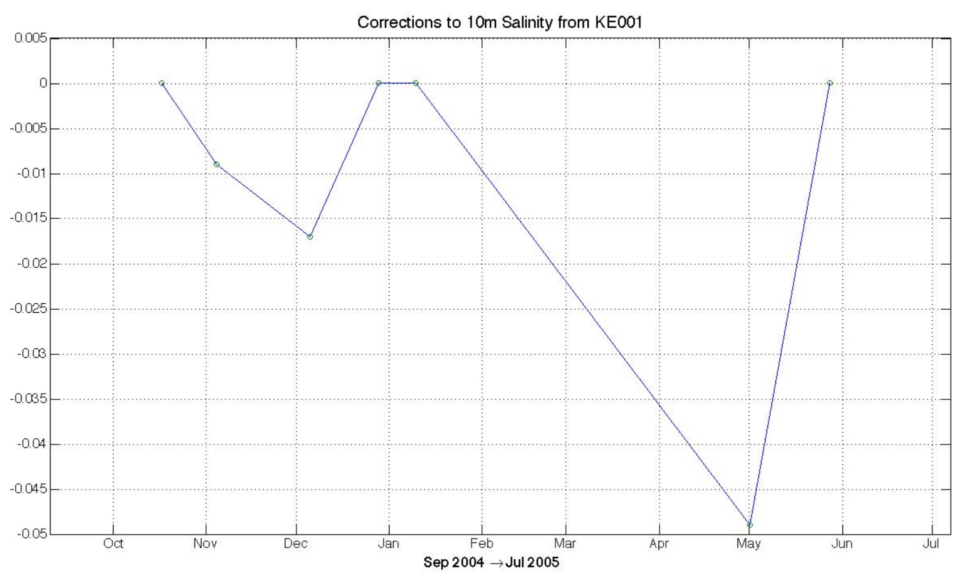

Figure 6: Additional linear correction segments applied to 10m salinity data.

50m Salinity Adjustments

2004291150000 (-0.012) - 2005049044000 (-0.059)
2005049045000 (-0.059) - 2005078113000 (-0.0215)
2005078114000 (-0.0215) - end (-0.0215)
2005112000000 - end flagged out of range

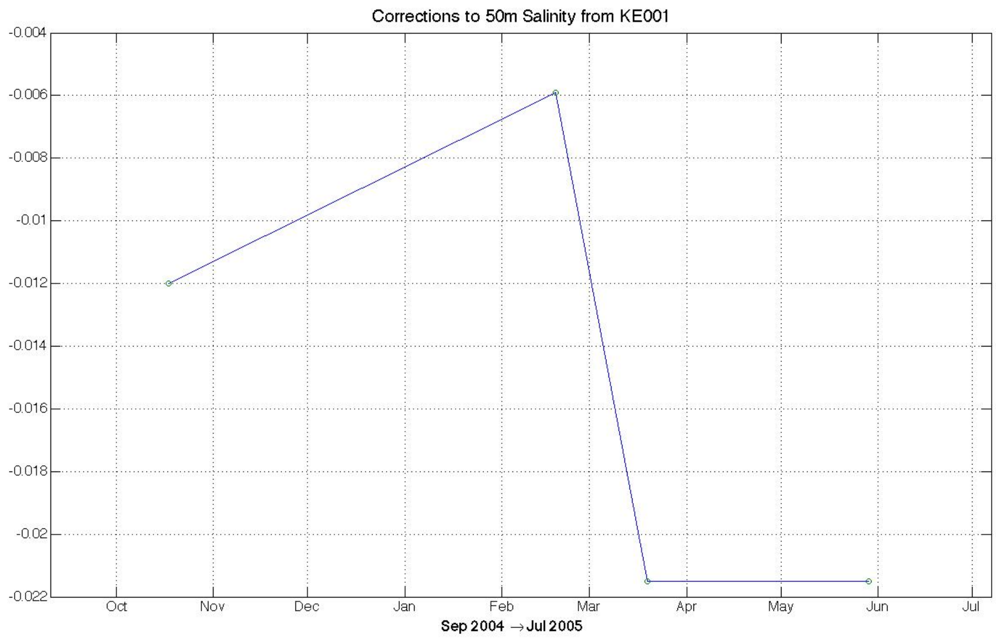

Figure 7: Linear corrections applied to 50m salinity data.

200m Salinity Adjustments

2004362224000 (0.027) - 2005127151000 (0.027)

3.3.4 Load Cell

A load cell on the bridle provided tension readings from the mooring until it failed in December 2004. These measurements were intended only for internal engineering diagnostics, and were not made publicly available.

4.0 References

Donohue, K.A., et al., 2008: Program Studies the Kuroshio Extension, Eos Trans. AGU, 89(17), 161–162.

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.

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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.

Rainville, L., S. Jayne, N. Hogg, and S. Waterman, 2009: KESS Data Report – WHOI subsurface moorings. 15 pp.

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5.0 Acknowledgements

S. Brown and S. Moon (both of UW JISAO) processed the ATLAS meteorological, subsurface temperature, pressure and conductivity/salinity data. Dr. L. Rainville (formerly of WHOI, now at UW APL) processed the ADCP data from the instrument loaned by Dr. P. Stabeno (NOAA PMEL).

The OCS project office is grateful to Drs. Jayne and Hogg and other KESS PIs for inviting the KEO group to participate on the cruises. S. Kunze (NOAA PMEL) participated in the deployment cruise; M. Cronin, M. Strick (both of NOAA PMEL), and S. Moon (UW JISAO) participated in the recovery cruise. Mooring operation assistance from the KESS scientists and technicians, and the captains and crews of the R/V THOMPSON and REVELLE are also gratefully acknowledged.

6.0 Contact Information

For more information about this mooring and data set, please contact:

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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 v1.2 format, the standard TAO quality flags described above are mapped to the different OceanSITES quality flags shown below:

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

APPENDIX B: High Resolution Data Plots

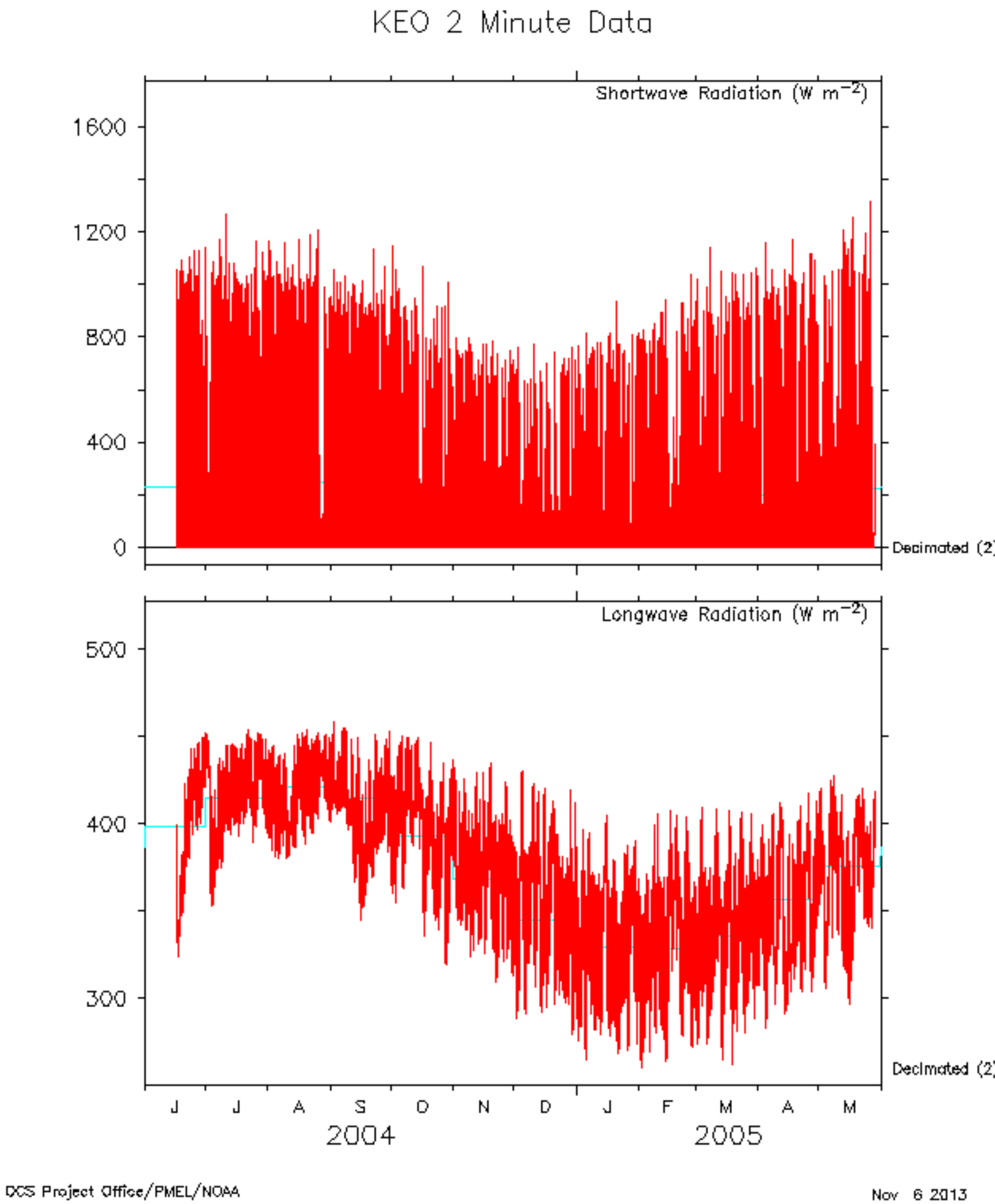

Figure B 1: KE001 shortwave and longwave radiation data in 2-min resolution (decimated).

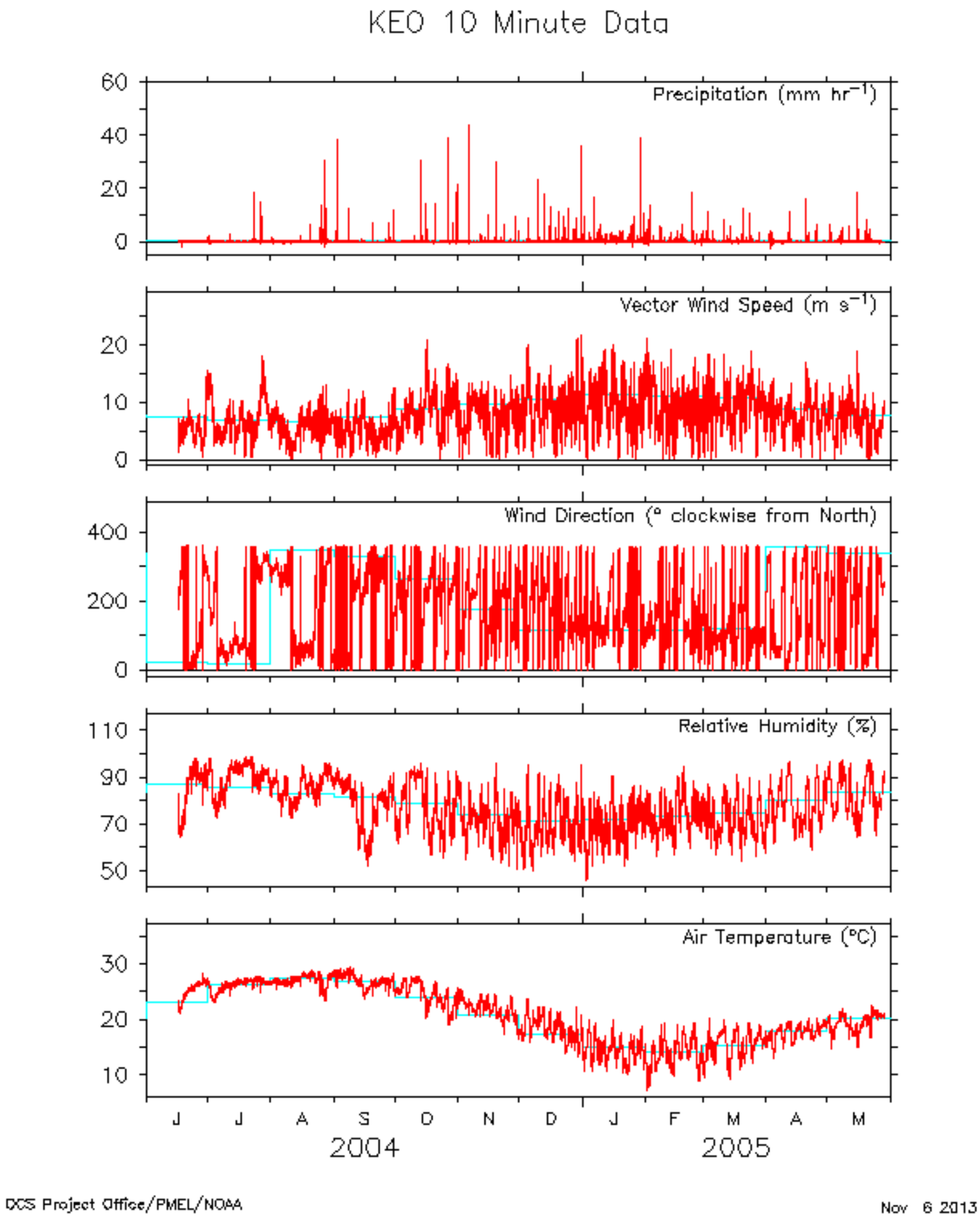

Figure B 2: KE001 meteorological data in 10-min resolution.

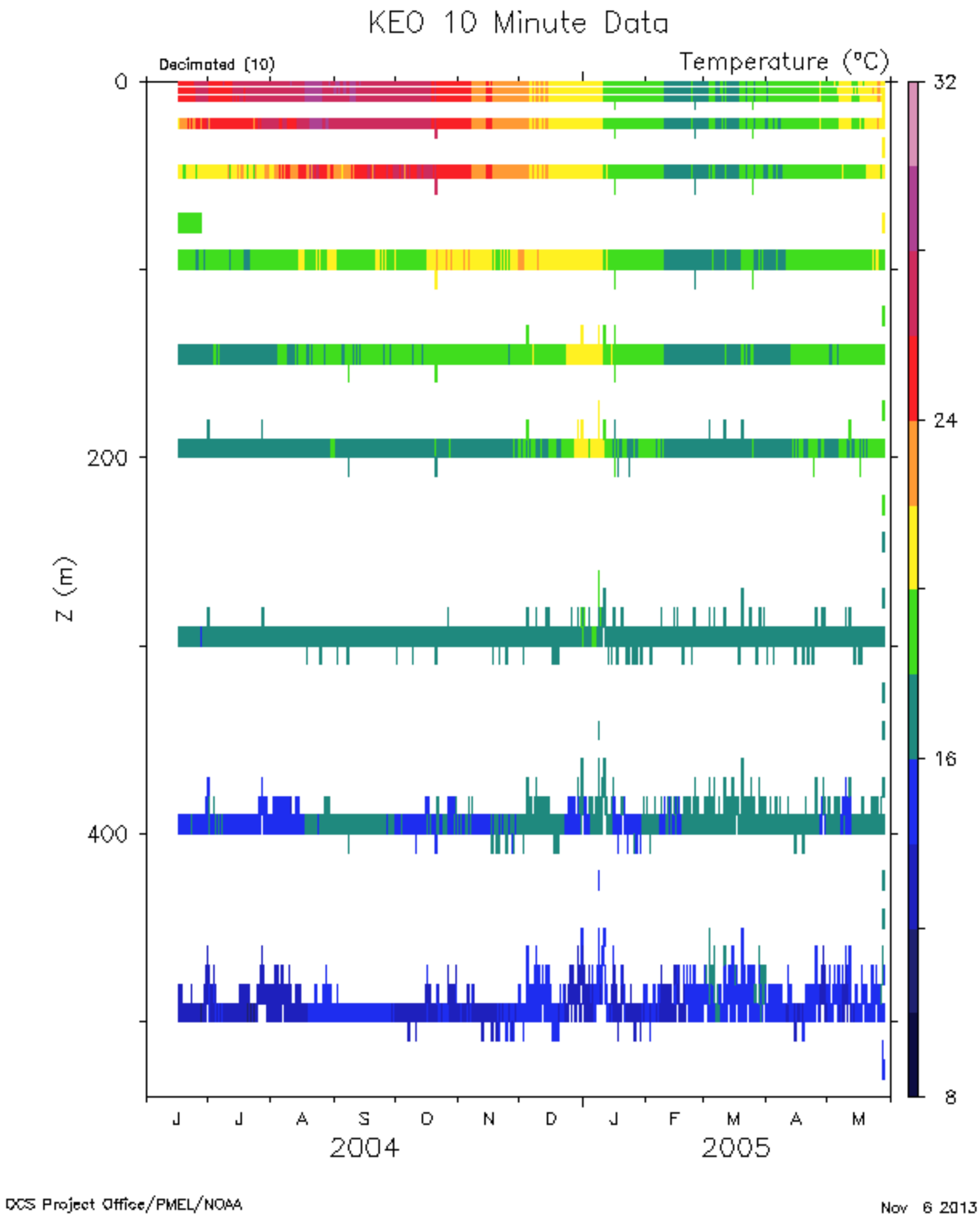

Figure B 3: KE001 subsurface temperature profile in 10-min resolution (decimated).

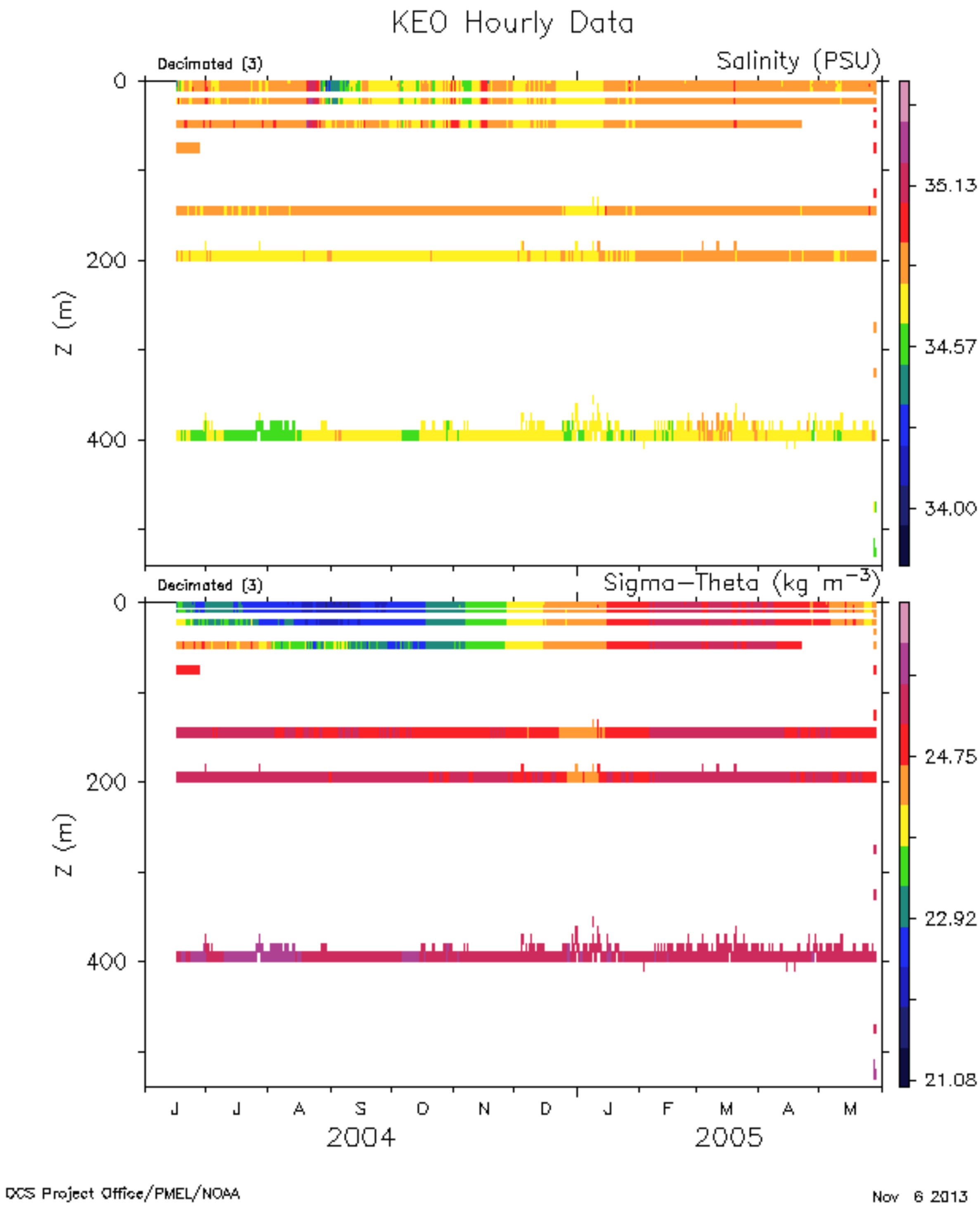

Figure B 4: KE001 subsurface salinity and density profiles in hourly resolution (decimated).

APPENDIX C: KESS-7 Subsurface Mooring

Mooring Description

As part of the Woods Hole Oceanographic Institution's (WHOI's) Kuroshio Extension System Study (KESS), an array of moorings were deployed in the Kuroshio Extension region (Section 1.0). The KESS-7 (K7) subsurface ADCP mooring was deployed near the OCS KEO buoy, at nominal location 32.4°N 144.6°E. The K7 mooring held an upward-looking, narrow-band Acoustic Doppler Current Profiler (ADCP, S/N 461) borrowed from the NOAA/PMEL/FOCI group. A mooring diagram is shown in Figure C1.

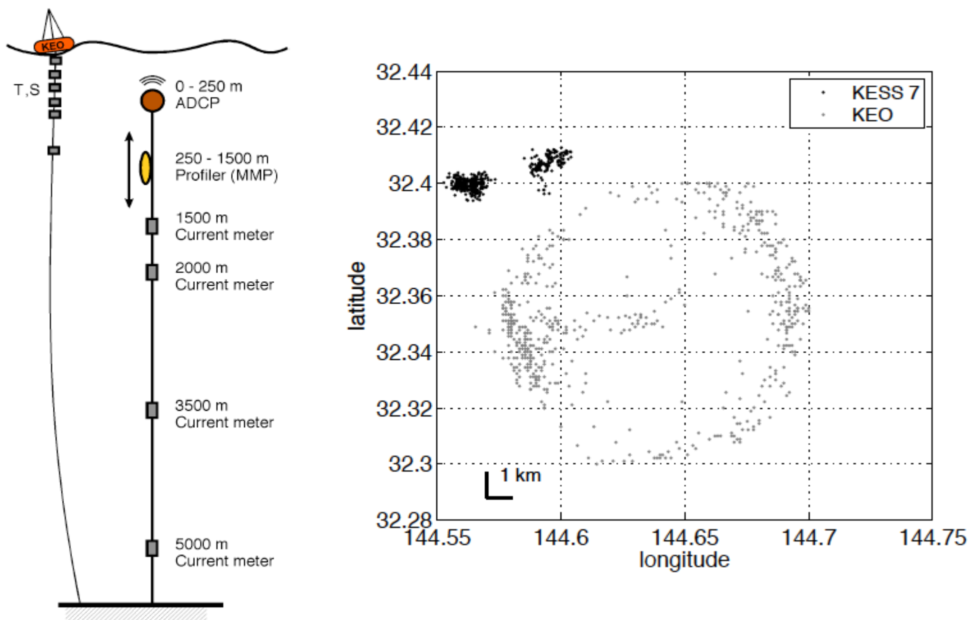

Figure C 1: KESS K7 mooring schematic (left), and position relative to the KEO mooring (right). From Rainville et al. 2009.

Data Processing

The K7 ADCP data were initially processed at WHOI. Data were shifted onto a surface-relative depth grid, with 10m bins from the surface to the instantaneous head depth. Deviations from the ADCP's nominal 250m head depth due to mooring motions were accounted for in this processing (Rainville et al. 2009).

Additional processing was done at PMEL to remove side-lobe contamination near the surface. The following equation, provided by the instrument manufacturer, was used to calculate the depths to which side-lobe contamination from the surface occurs:

$$C = R(1-\cos(\theta))$$

R is the depth of the transducer head, θ is the beam angle from vertical (30°), and C is the contamination depth. Any bins shallower than the contamination depth were removed from the final file.

Data Plots

The processed ADCP data from the first K7 deployment are plotted in Figure C2. Processing information and data plots from the second KESS deployment are included in the OCS KE002 data report.

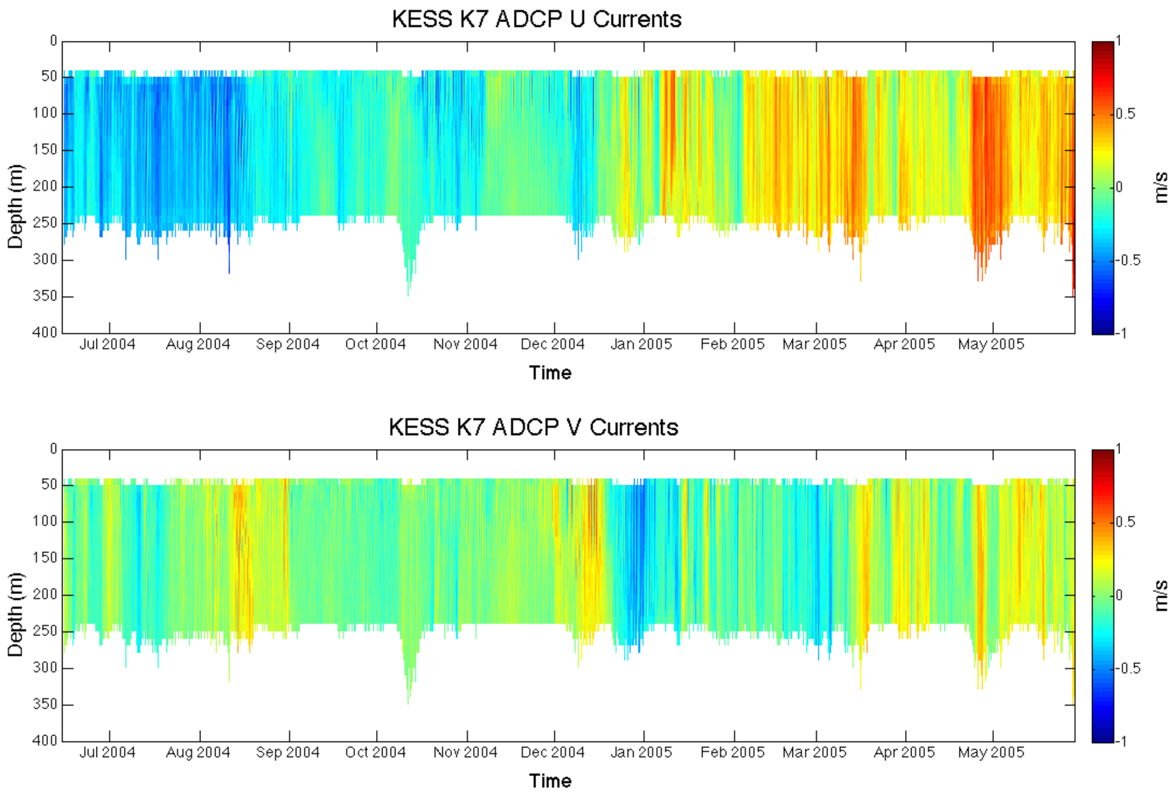

Figure C 2: ADCP U (top) and V (bottom) velocity data from the KESS K7 subsurface mooring.

KESS Resources

Additional data from the KESS project, along with more information, is available through the project website:
http://uskess.whoi.edu

The KESS Data Report can be found here:
http://uskess.whoi.edu/data/KESS Data Report – WHOI subsurface moorings.pdf