NOTES ON CTD/O_2 DATA ACQUISITION AND PROCESSING USING SEA-BIRD HARDWARE AND SOFTWARE (AS AVAILABLE)

K.E. McTaggart[1], G.C. Johnson[1], M.C. Johnson[2], F.M. Delahoyde[2], and J.H. Swift[2]

[1] NOAA/Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE Bldg. 3, Seattle WA 981115, U.S.A, e-mail: gregory.c.johnson@noaa.gov, kristene.e.mctaggart@noaa.gov.
[2]University of California San Diego, Scripps Institution of Oceanography, 9500 Gilman Dr., MC-0214, La Jolla CA 92093-0214, U.S.A. e-mail: mcjohnson@ucsd.edu, fdelahoyde@ucsd.edu, jswift@ucsd.edu

1. INTRODUCTION

The predecessors of today's CTD (conductivity-temperature-depth) instruments were introduced in the 1940s, with modern accurate instruments developed in the 1970s (Emery and Thomson, 1998). Accuracy standards for these instruments remain at the WOCE targets: 0.002°C (ITS-90) for temperature, 0.002 g kg^{-1} (TEOS-10) for salinity, and 3 dbar for pressure. Here we discuss some aspects of acquisition, processing, and calibration of Sea-Bird Electronics Inc. (hereafter SBE) 9plus CTD data. Oceanic measurement and calibration techniques are subject to improvement. This outline should be viewed only as a supplement to the existing literature, manufacturer documentation, and manufacturer instructions.

2. PRE-CRUISE PREPARATION

Cruises can be stopped by equipment failures, so carrying back-up equipment is very important. Take a sufficient number of 9plus CTDs, sensors (temperature, conductivity, and dissolved oxygen), pumps, and cables to build 2-3 systems, as it is not uncommon to change out underwater components during a cruise. While only one oxygen sensor is usually deployed at a time, consider using duplicate temperature (SBE 3plus) and conductivity (SBE 4C) sensors, as well as a more accurate though slower-response reference thermometer (SBE 35) during bottle-closing stops, to allow sensor inter-comparisons and thus monitor sensor stability during the cruise. Bring sufficient supplies to redo the underwater termination several times during a long cruise. Bring a spare CTD deck unit and spare data acquisition and processing computers.

An accurate means of assessing the distance of the package from the bottom is necessary to attain the recommended GO-SHIP target of sampling to within 10 m of the bottom. The position of the package relative to the bottom can be assessed by using a 12 kHz pinger mounted on the CTD frame with accompanying shipboard transducer and display or an altimeter connected to a voltage channel on the CTD. Consider mounting both a pinger and an altimeter as the transducer display may not always produce a distinct bottom trace and the altimeter may not work well over some bathymetry.

Calibrate SBE 9plus pressure sensors at 1-3 year intervals to ensure accurate pressure data. Calibrate temperature, conductivity and oxygen sensors as close to the start of the cruise as logistically prudent, and have oxygen sensors refurbished as necessary prior to the cruise. Examination of sensor calibration histories and pre-cruise calibrations can aid in the selection of sensors for a cruise.

For instance, temperature sensors with small changes between calibrations and with a general linear trend in calibration history are most desirable.

3. SENSOR LOCATION AND MAINTENANCE

Temperature, conductivity, and oxygen sensors on SBE 9plus CTDs are all plumbed in a ducted system. The manufacturer provides details on recommended ducting configurations. Data quality can be improved by placing the intakes of the sensors in a location on the underwater instrument package chosen to minimize sampling of turbulent shed wakes, especially during the descent, or downcast, of the package. That is to say, the sensor intakes should be in a location where they see clean water below them. In addition, deploying the package in a manner that minimizes the influence of ship roll on the package is also desirable. Actions in this regard might include deploying from amidships rather than from the stern, using a dynamic mechanism to compensate for ship-roll, or even decoupling the package from the ship using a slide-down-the-wire system.

Data quality can also be impacted by electronics noise induced by seawater leaks in underwater connections and even cable failures. Careful mating of underwater cables to connectors that are well cleaned and lightly greased with an electrical insulating compound will help to minimize leaks. Tidy, well-secured cables that avoid sharp bends will help to minimize cable fatigue from flow-induced vibration.

Data quality can be improved by proper care of the sensors between casts. Use 60-ml syringes fitted with Tygon tubing and filled with fresh, very dilute detergent (Triton-x) solution in deionized water to rinse all of the sensors after each cast. Leave the syringes attached to the sensor intakes between casts, with the solution bathing the temperature and conductivity sensors (but not the oxygen sensor) to help keep the conductivity sensor clean. Also, rinsing the bottle-release mechanism (pylon or carousel) with warm freshwater after each cast can help to prevent salt accumulation and thus bottle misfires.

4. RECORD KEEPING

Complete record keeping at sea is very important. A complete log from system assembly and testing, through every cast, must be kept, detailing the system configuration and related parameters. Every untoward event and change, indexed by date, time, station/cast and any other relevant information, should also be logged. System set-up records should include every device attached to the instrument package, and when they were used, as in the example (Table 1).

5. DATA ACQUISITION

The deck unit should be powered up with the CTD on deck for at least ten minutes prior to the deployment of the instrument package to allow the electronics time to equilibrate. The data should be acquired at the full 24-Hz resolution; *Seasave V7* is the SBE-supplied software for this purpose (*Seasave* or *SBE Data Processing* features will be referred to in *italics* hereafter where pertinent). While the CTD is on deck it is useful to capture a data record using *Mark Scan* prior to each cast for pressure sensor evaluation purposes. Lowering the package to a depth of 10-m and holding it there until the pump has been running for at least one minute clears air from the plumbing. The package can then be brought up to just below the surface, and again *Mark Scan* can be used to indicate the top of the cast just prior to starting the downcast.

Maintaining relatively slow descent speeds (ca. 0.5 m s^{-1}) through the surface mixed layer and thermocline during the downcast allows better resolution, less chance of slack-loading in large swell, and reduced sensor response errors. When the package is below the surface layer and still clear of the bottom, descent speeds can approach 1 m s^{-1} as equipment and conditions allow. Bottom approaches should be done cautiously (slowing to 0.5 m s^{-1} several tens of meters above the bottom depending on conditions) with the target of sampling to within 10 m above the bottom. This 10-m goal can be relaxed slightly under adverse conditions (in high seas, strong currents, or bathymetry where the distance of the package from the bottom is uncertain).

Water samples are collected on the upcast, with the first sample usually collected at the deepest level. The CTD console operator should hold the CTD stopped for 30 seconds before tripping a bottle to allow the package wake to dissipate, the bottles to flush, and the surrounding water to settle to equilibrium. The CTD should be held stopped for another 10-15 seconds after the trip is confirmed to allow time for bottle closure and to collect CTD data appropriate for comparison to the water sample data (Uchida et al. 2007). A roughly 8-second average (about the period of sea swell) centered around the bottle trip of CTD values should be recorded at each bottle trip (along with SBE-35 data if that sensor is used). Between bottles ascent speed can approach 1 m s^{-1}, again as equipment and conditions allow, but keeping peak cable tensions at safe levels. Caution and slower speeds are again warranted when approaching the surface. At the conclusion of the cast, use *Mark Scan* to indicate an on-deck data record for pressure sensor evaluation purposes.

6. DATA QUALITY CONTROL

After each cast the differences of the primary and secondary temperature and conductivity sensors should be examined over the most nearly homogenous part of the water column (usually the deeper portion of the cast). Compare the SBE-35 temperature data, if available, with the CTD temperatures at bottle stops. Both pre-cast and post-cast on-deck pressure sensor histories over the cruise should be examined. All data from the most recent cast, including CTD oxygen sensor data, should be compared to previous casts. CTD conductivity and oxygen data should also be compared to water sample data throughout the cruise as they become available. If sensor drift appears to exceed 0.002 ºC in temperature, 0.005 mS cm^{-1} in conductivity, 15 μmol kg^{-1} in oxygen, or 2 dbar in pressure (based on pre-cast and post-cast on-deck pressure values), consider replacing the suspect sensor. A pressure sensor drift would usually require the CTD to be replaced.

7. DATA PROCESSING

CTDO data are acquired at 24 Hz, full resolution. The reduction of Sea-Bird CTDO data begins with a standard suite of processing modules using the latest version of Sea-Bird processing software in the following order: *Data Conversion*, *Align CTD*, *Bottle Summary*, *Wild Edit*, *Filter*, *Cell Thermal Mass*, *Loop Edit*, *Derive*, *Bin Average*, and *Translate*.

Data Conversion converts raw data in hex format to engineering units. Both down and up casts are processed for scan number, elapsed time (s), pressure (dbar), primary t0 (°C), secondary t1 (°C), primary c0 (mS cm^{-1}), secondary c1 (mS cm^{-1}), and oxygen voltage. Optical sensor data can also be converted and carried through the processing stream, usually as voltages. The output files are in binary format for more efficient handling. The surface CTD soaking time can be removed in *Data Conversion* using the appropriate *Mark Scan* value as the number of scans to skip over. Oxygen sensor hysteresis and time lag corrections can also be applied in *Data Conversion*. However, applying the latter using nominal laboratory coefficients is not necessarily recommended (see the oxygen sensor calibration chapter).

For every plumbed configuration of temperature, conductivity (and oxygen) sensors on the underwater package, an alignment in time relative to pressure should be applied to conductivity to minimize salinity spiking in high gradient regions of the water column (e.g. Gregg and Hess, 1985). It is not necessary to align temperature, as it is the first sensor to see a parcel of water. Neither is it necessary to align oxygen, because an oxygen sensor lag is determined and applied later in the calibration process (again, see the oxygen sensor calibration chapter). Aligning conductivity assures that derived parameters such as salinity and density are estimated using measurements from the same parcel of water. Primary conductivity is automatically advanced in a V1 deck unit by the nominal value of 0.073 seconds. Secondary conductivity is also automatically advanced in a V2 deck unit by the same amount. *Align CTD* can be used to advance the secondary conductivity by this amount if using a V1 deck unit.

It is good practice to check the salinity traces for spiking in high-gradient regions of the water column and make slight adjustments to the alignment times using *Align CTD* for each temperature-conductivity sensor pair as warranted. It may be possible to greatly reduce most of the salinity spikes by making small adjustments to the conductivity advance time. Small changes to the nominal advance time, once determined, should hold until some physical change is made to the plumbed configuration of the CTD sensors. If slight adjustments of the alignment time do not remediate salinity spikes, or large deviations from the nominal values are required, there could be a pump or cabling problem.

Bottle Summary can be used to average upcast data over an 8-second interval ($\pm$4 seconds of the confirm bit in the data stream) and derive primary and secondary salinity, potential temperature, potential density anomaly, and dissolved oxygen concentration (μmol kg^{-1}). These values can be used to make corrections to the CTD temperature sensors relative to a SBE-35 reference thermometer. They can also be used along with bottle salinity sample data to calibrate the conductivity sensors, and with oxygen titration data and downcast profile data to calibrate the oxygen sensors (again, see the CTD oxygen calibration chapter).

Wild Edit can be used to remove extreme outliers by making two passes through the data in 100-scan bins. The first pass flags points within each bin that are greater than 2 standard deviations from the mean. The second pass estimates a new mean and standard deviation with these flagged points excluded and removes points greater than 20 new standard deviations from the new mean.

Filter can be used to smooth some of the digitization noise in pressure by applying a low pass filter to pressure with a recommended time constant of 0.15 seconds. In order to produce a zero phase (no time shift) record, the filter is first run forward through the file and then run backwards through the file.

The conductivity cell is located downstream of the thermistor in a SBE 9plus CTD. Because the conductivity cell exchanges heat with water passing through it, the temperature of a parcel of water is not necessarily the same in the conductivity cell as it was in the thermistor. This effect causes a conductivity cell thermal mass error in computed salinities if not corrected (Lueck, 1990). *Cell Thermal Mass* uses a recursive filter to alleviate cell thermal mass effects from measured conductivity. The nominal values used for the thermal anomaly amplitude and time constant are 0.03 and 7.0 s, respectively. The cell thermal mass error correction is initially on the order of 0.2 g kg^{-1} for every 1.0 °C s^{-1} of temperature gradient seen by the CTD. The correction is negligible in many areas of the ocean at profiling speeds of 1.0 m s^{-1} because the temperature gradients experienced by the CTD are small.

It is good practice to check the up versus down potential temperature–salinity (θ–S) curves in strong gradient regions or to examine θ and S structure in thermohaline staircases when they are present to assess the conductivity cell thermal mass error (Lueck and Picklo, 1990). Divergence in the up versus down θ–S curves (especially if the up and down portions of the cast are close in time and distance) can mean that adjustments need to be made to the nominal cell thermal mass error coefficients until the curves match (Morrison et al., 1994). This method usually only determines the product of these two coefficients, because closing the θ–S curves gives only one degree of freedom. Thermohaline staircases provide a better means of estimating the cell thermal mass error coefficients for a given sensor, adjusting both coefficients until salinity is as uniform as temperature within the risers of each staircase. However, the combination of a large underwater package and ship roll can complicate either of these methods for adjusting cell thermal mass error coefficients. The underwater package has a wake and carries water with it, shedding the wake as the package accelerates and decelerates with ship roll. This wake, carried water, and shed water all perturb both θ–S curves and thermohaline staircase measurements.

As just noted, package slowdowns and reversals owing to ship roll can move mixed water in tow ahead of the CTD sensors and create artificial density inversions and other artifacts. *Loop Edit* can be used to remove scans associated with pressure slowdowns and reversals. The Pacific Marine Environmental Laboratory (PMEL) CTD group uses *Loop Edit* such that if the CTD descent velocity is less than 0.25 m s^{-1} or the pressure is not greater than the previous maximum scan, the scan is omitted.

Derive uses the bin-averaged pressure, temperature, and conductivity to compute primary and secondary salinity, as well as any other desired parameters such as dissolved oxygen.

Bin Average averages the sensor-response corrected 24-Hz data into 1- or 2-dbar bins. Each bin is centered on an integer pressure value, e.g. the 1-dbar bin averages scans where pressure is between 0.5 dbar and 1.5 dbar. There is no surface bin. The number of points averaged in each bin is included in the data file.

Translate converts the binary data file to ASCII format.

Some additional clean-up or flagging of data may be necessary after the SBE modules have been run. For instance, in addition to *Loop Edit*, PMEL uses their own code to look for inversions in the processed, binned repeat hydrography cruise CTD data. They compute the centered square of the buoyancy frequency, N^2, for each bin and linearly interpolate temperature, conductivity, and oxygen voltage over those records where $N^2 \leq -1 \times 10^{-5}\ s^{-2}$, where there appear to be density inversions. While these could be actual inversions in the CTD records, it is much more likely that shed wakes cause these anomalies. Records that fail the density inversion criteria in the top 20 meters are retained, but flagged as questionable. The codes also manually remove spikes or glitches from profiles as necessary, and linearly interpolate over them.

8. CORRECTION SOFTWARE

We are not aware of Sea-Bird code for adjusting CTD data beyond using laboratory calibration values. Users must generate or otherwise procure their own code for applying further correction adjustments to CTD pressure, temperature, salinity, or oxygen values.

9. PRESSURE SENSOR DATA CORRECTIONS

As mentioned above, it is good practice to monitor on-deck pressure values at the beginning and end of every cast, and from cast to cast. Usually no additional adjustment is necessary, and on-deck pressure stays within 1 dbar of pre-cruise calibrations. Some groups adjust pressure values using the deviation of the equilibrated surface pressure reading (10 minutes after the unit is powered on) from atmospheric pressure. If a drift of 2 dbar in pressure (based on pre-cast and post-cast) on-deck pressure values is observed, consider replacing the suspect sensor, which usually requires the CTD to be replaced. For most cruises the pre-cruise pressure calibration can be used for the final calibration, unless on-deck pressure readings or post-cruise calibration of the pressure sensor suggests a significant (> 2 dbar) drift has occurred. It can also be useful to track residual pressure offsets (the difference between the pre- and post-cast on deck pressures) as an additional monitor of pressure sensor performance and drift.

10. TEMPERATURE AND CONDUCTIVITY SENSOR DATA CORRECTIONS

SBE temperature and conductivity sensors can exhibit calibration shifts over time scales on the order of weeks. They are also sensitive to mechanical shock that can induce rapid calibration changes. These sensors can have a secondary response to pressure that may not have been measured during the laboratory calibration. It is therefore good practice to make systematic comparisons between sensor data and an independent measure of the primary sensor response as calibration checks. Corrections to the calibration can then be derived and applied to the sensor data. Each cast can potentially have a different set of corrections, although a very few different sets of corrections during a cruise is more typical for properly maintained SBE 3plus sensors, and calibrations for properly maintained SBE 4C sensors may evolve slowly during a cruise, with shifts only owing to physical trauma or fouling events.

When routinely derived, sensor data corrections can also be used as a diagnostic tool to predict sensor failures and help ensure that a failing sensor is promptly replaced.

11. TEMPERATURE SENSOR DATA CORRECTION

Temperature sensors should be laboratory calibrated as close in time to the start and the end of the cruise as possible. The pre-cruise calibrations can be used at sea, applying a viscous heating correction of -0.0006 °C to all temperatures (Larson and Pederson, 1996; Uchida et al., 2007). Most SBE 3plus temperature sensors will exhibit a slow linear drift in their calibration history over time, with any discontinuities in the history usually related to physical trauma or repairs to the sensor. PMEL generally applies a linear fit to the sensor calibration history (including the post-cruise calibration) and uses the fit evaluated at the mid-point of the cruise to adjust the temperatures to their final values. However, the fit must be a good one, with RMS residuals < 0.001 °C, to be used in this fashion.

As noted above, comparison of primary and secondary SBE 3plus temperatures on each cast is important. In addition, the Oceanographic Data Facility (ODF), Scripps Institution of Oceanography, also routinely uses a single SBE 35 as a tertiary temperature check. The SBE 35 is an internally recording temperature sensor that operates independently of the CTD. The SBE 35 is usually located equidistant between the primary and secondary SBE 3plus sensors with all three sensing elements in a horizontal plane. The SBE 35 is triggered by the SBE 32 carousel in response to each bottle closure. According to the manufacturer's specifications, the typical SBE 35 temperature stability is 0.001°C/year. The unit is set to internally average over 8 seconds.

When an SBE 35 is used, pressure dependence (linear or quadratic) of the SBE 3plus sensors relative to the SBE 35 data collected at bottle closures may be removed from the SBE 3plus sensors using an equation of the form: $T_{cor} = T + tp2 \cdot P^2 + tp1 \cdot P + t0$ where T_{cor} is the corrected temperature, T is measured temperature, P is pressure, and $t0$, $tp1$, and $tp2$ are regression coefficients (e.g. Table 2). Over the past few years, ODF SBE 3plus sensors have typically required 0 to 0.002°C correction at deep pressures (ca. 5000 dbar) vs. surface pressures (where the sensors are calibrated in the laboratory) when compared to SBE 35 data (see also Budeas and Scheider, 1998; Uchida et al., 2007). Data from multiple casts using the same sensors are examined together for changes in slopes and offsets, and adjustments can be made as required. Residual temperature differences after correction for pressure dependence are carefully examined in a variety of ways to determine any other dependencies or drifts. Again, an additional benefit of using the SBE 35 is that with three sensors it becomes easier to identify and correct calibration shifts during the cruise. Calibration shifts usually occur because of some physical trauma to the instrument (such as the package hitting the ocean floor or the ship).

12. CONDUCTIVITY SENSOR DATA CORRECTION

Adjustments are applied to conductivity, not salinity, since the former is the measured variable both for the CTD and the bottle salinities (bottle salinity determination is discussed in another manual chapter). Corrections for pressure and both CTD temperature sensors are finalized before analyzing conductivity differences. Two independent metrics of conductivity correction accuracy are examined: (1) At each bottle closure, the primary and secondary conductivity are compared with each other. (2) Each sensor is also compared to conductivity calculated from check sample salinities using CTD pressure and temperature. The differences between primary and secondary temperature sensors can be used as filtering criteria to reduce the contamination of conductivity comparisons by package wake.

Physical considerations suggest that a simple station-dependent multiplicative scaling factor to account for changes in cell geometry (biofouling) would be indicated. However, usually a linear, and sometimes even a quadratic fit to conductivity is indicated by bottle residuals. Often residuals also require a linear pressure term or even a quadratic term to remove structure. The corrections for conductivity sensors generally have the form: $C_{cor} = C + cp2 \cdot P^2 + cp1 \cdot P + c2 \cdot C^2 + c1 \cdot C + c0$, where C_{cor} is the corrected conductivity, C is measured conductivity, P is pressure, and $c0$, $c1$, $c2$, $cp1$, and $cp2$ are regression coefficients that should be reported for each station (e.g. Table 2). All PMEL fits are made iteratively, removing outliers greater than 2.8 standard deviations until no more outliers remain.

First attempt to fit all CTD conductivity data for stations that use the same sensor to bottle conductivities as one group using single set of calibration coefficients. Examine the bottle-CTD conductivity residuals plotted versus station number (or time), pressure, and conductivity. Evaluate residuals plotted versus pressure to determine if linear and quadratic pressure correction terms are warranted. Similarly, examine residuals versus conductivity to assess whether or not a quadratic conductivity term should be included in the fit. Look for sudden station-dependent shifts that will require more than one calibration grouping. Note that the rate of change of sensor calibrations may increase, slow, or shift (for example after a day-long break in station work), making it optimal to determine drifts using slightly different methods for different station groups. Deep θ–S overlays of multiple casts, comparing salinities from both pairs of CTD sensors and bottle data on an expanded scale, can often be used to determine if an observed shift between bottle and CTD data is a bottle salinity problem or a CTD salinity issue. CTD conductivity sensors are typically calibrated in station groups by sensor, although a sensor fouling event or failure will usually require corrections of individual stations.

PMEL tends to use conductivity calibration models with a conductivity offset, a linear conductivity term, and a linear pressure term, and allows that linear conductivity term to vary slowly (as a low-order polynomial function of station number) with time. ODF often uses 2nd order pressure and conductivity terms in their calibration models, allowing the conductivity offset term to vary from station-to-station. In any event, the final residual calibrated CTD – bottle conductivity values should be devoid of obvious patterns - within expected data quality specifications - when examined versus station number, pressure, and conductivity.

Post-cruise conductivity sensor laboratory calibrations can serve to check the general health of the conductivity sensors, but are not generally used in the cruise conductivity calibrations when bottle data are available.

13. OXYGEN SENSOR CALIBRATION

Oxygen sensor calibration is described in another manual chapter.

14. REFERENCES

Budeus, G., and W. Schneider, 1998: In-situ temperature calibration: A remark on instruments and methods. *International WOCE Newsletter*, **30**, WOCE International Project Office, Southampton, United Kingdom, 16–18.

Emery, W. J., and R. E. Thomson, 1998, *Data Analysis Methods in Physical Oceanography*, Elsevier Science Inc, New York, pp. 634.
Gregg, M. C., and W. C. Hess. 1985: Dynamic response calibration of Sea-Bird temperature and conductivity probes. *J. Atmos. Oceanic Technol.*, **2**, 304-313.
Larson, N., and A. M. Pedersen, 1996: *Temperature measurements in flowing water: Viscous heating of sensor tips*. Proc. of the First IGHEM Meeting, Montreal, QC, Canada, International Group for Hydraulic Efficiency Measurement. [Available online at http://www.seabird.com/technical_references/viscous.htm.]
Lueck, R. G. 1990: Thermal inertia of conductivity cells: Theory. *J. Atmos. Oceanic Technol.*, **7**, 741-755.
Lueck, R. G., and J. L. Picklo. 1990: Thermal inertia of conductivity cells: Observations with a Sea-Bird Cell. *J. Atmos. Oceanic Technol.*, **7**, 756-768.
Morison, J., R. Anderson, N. Larson, E. D'Asaro, and T. Boyd. 1994: The correction for thermal-lag effects in Sea-Bird CTD data. *J. Atmos. Oceanic Technol.*, **11**, 1151-1164.
Uchida, H., K. Ohyama, S. Ozawa, and M. Fukasawa, 2007: In situ calibration of the SeaBird 9plus CTD thermometer. *J. Atmos. Oceanic Technol.*, **24**, 1961–1967.

15. ACKNOWLEDGEMENTS

Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of any sponsoring or involved agencies. The mention of commercial products or services herein does not constitute endorsement.

Instrument/Sensor	Mfr./Model	Serial Number	A/D Channel	Stations Used
Carousel Water Sampler	Sea-Bird SBE32 (36-Pl.)	3213290-0113	n/a	1-127
CTD	Sea-Bird SBE9*plus*	796	n/a	1-127
Pressure	Paroscientific Digiquartz	98627	n/a	1-127
Primary Temperature (T1)	Sea-Bird SBE3*plus*	03P-4907	n/a	1-127
Primary Conductivity (C1a)	Sea-Bird SBE4C	04-3369	n/a	1-102
Primary Conductivity (C1b)	Sea-Bird SBE4C	04-3430	n/a	103-127
Dissolved Oxygen	Sea-Bird SBE43	43-1508	Aux4/V6	1-127
Primary Pump	Sea-Bird SBE5T	05-4160	n/a	1-127
Secondary Temperature (T2)	Sea-Bird SBE3*plus*	03P-5046	n/a	1-127
Secondary Conductivity (C2)	Sea-Bird SBE4C	04-3578	n/a	1-127
Secondary Pump	Sea-Bird SBE5T	05-5124	n/a	1-127
Transmissometer	WETLabs C-STAR	CST-1115DR	Aux2/V2	1-67,73-127
Transmissometer	WETLabs C-STAR	CST-327DR	Aux1/V1	68-72
Fluorometer	WETLabs CDOM	FLCDRTD-428	Aux1/V0	1-127
Altimeter	Simrad 807	9711091	Aux3/V4	1-127
Reference Temperature	Sea-Bird SBE35	35-0035	n/a	1-127
LADCP	RDI WHM300-I-UG50	13330	n/a	1-127
Deck Unit (in lab)	Sea-Bird SBE11	11P31807-0654	n/a	1-127

Table 1. Example of system set-up record excerpted from a recent U.S. repeat hydrography cruise report.

	ITS-90 Temperature Coefficients			Conductivity Coefficients				
Sta/	$corT = tp2*corP^2 + tp1*corP + t0$			$corC = cp2*corP^2 + cp1*corP + c2*C^2 + c1*C + c0$				
Cast	tp2	tp1	t0	cp2	cp1	c2	c1	c0
001/01	2.7410e-11	-2.4157e-07	0.000098	1.85415e-10	-1.31127e-06	-5.44871e-06	4.30902e-04	-0.006322
002/01	2.7410e-11	-2.4157e-07	0.000098	1.85415e-10	-1.31127e-06	-5.44871e-06	4.30902e-04	-0.006310
003/05	2.7410e-11	-2.4157e-07	0.000098	1.85415e-10	-1.31127e-06	-5.44871e-06	4.30902e-04	-0.006239
003/06	2.7410e-11	-2.4157e-07	0.000098	1.85415e-10	-1.31127e-06	-5.44871e-06	4.30902e-04	-0.006212
004/01	2.7410e-11	-2.4157e-07	0.000098	1.85415e-10	-1.31127e-06	-5.44871e-06	4.30902e-04	-0.006192

Table 2. Example temperature and conductivity calibration coefficients excerpted from a recent US repeat hydrography cruise report.