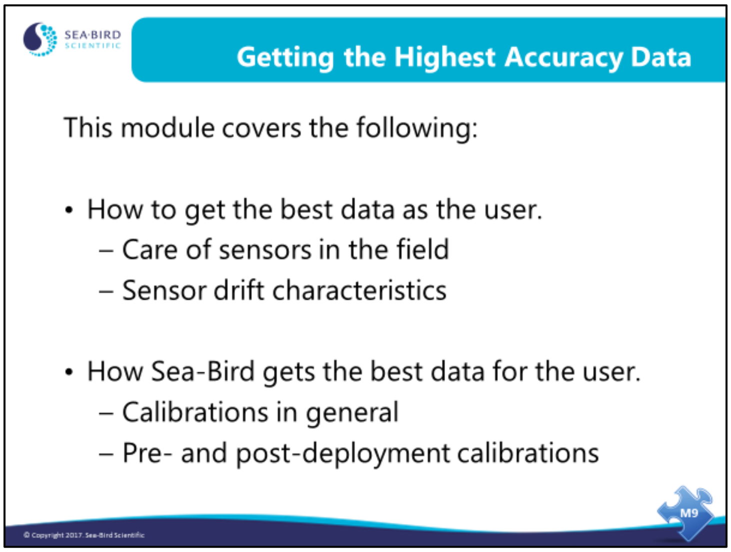
Getting the Highest Accuracy Data: CTD Care and Calibrations

Sea-Bird Scientific University Module 9

M9

Overview

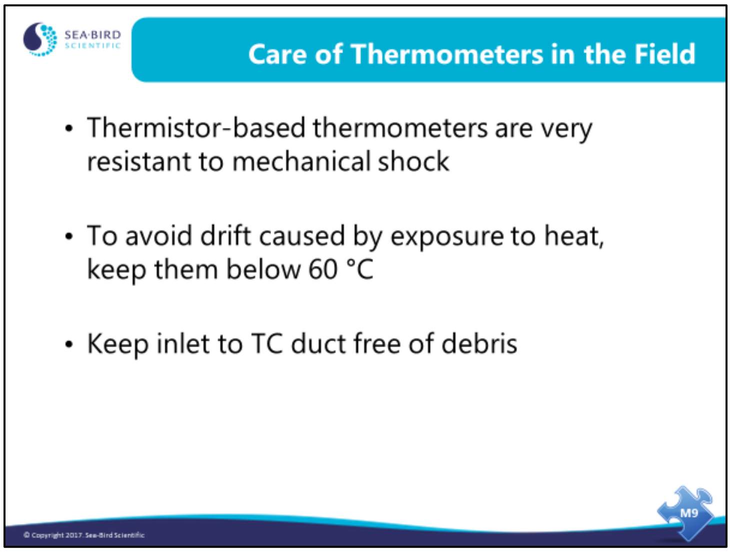


This module covers activities that will improve your data accuracy. Receiving the highest accuracy data from your instrument requires careful handling and attention to calibration. While thermometers are very robust and low maintenance, they still require regular calibration to make sure they are on their historical drift trajectory. A sensor that has a surface that interacts with the seawater, such as conductivity or dissolved oxygen, is another matter. These require careful handling, attention to calibration, and field calibration to assure the highest quality data.

When we finish this module you should be able to:

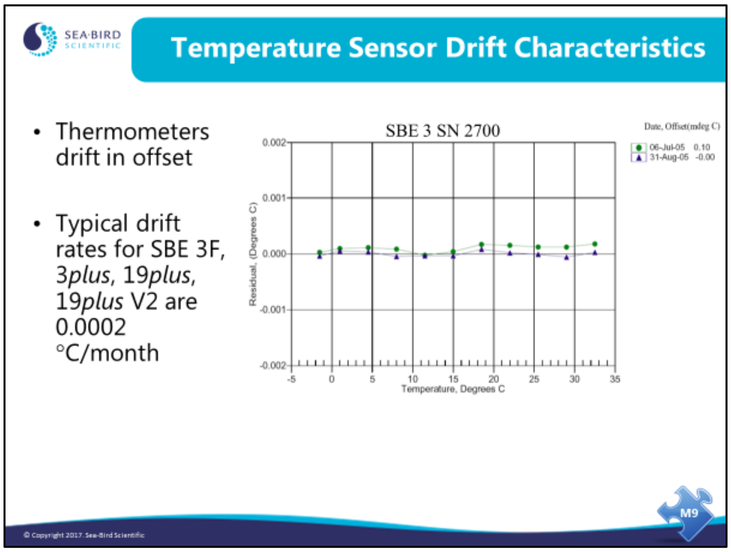
- Minimize handling-induced problems with your sensors.
- Correct your data for calibration drift.

Care of Thermometers in the Field



SBE 3 thermometers are essentially trouble-free. They are mechanically robust and are unaffected by extremes in temperature up to 60 degrees C.

Temperature Sensor Drift Characteristics



Temperature sensors tend to drift in offset – that is, the measurements drift in a uniform way over the entire range of measurement. For temperature sensors, the drift direction is dependent on the instrument electronics, and is unique to each temperature sensor. This drift typically continues in the same direction for the entire life of the instrument.

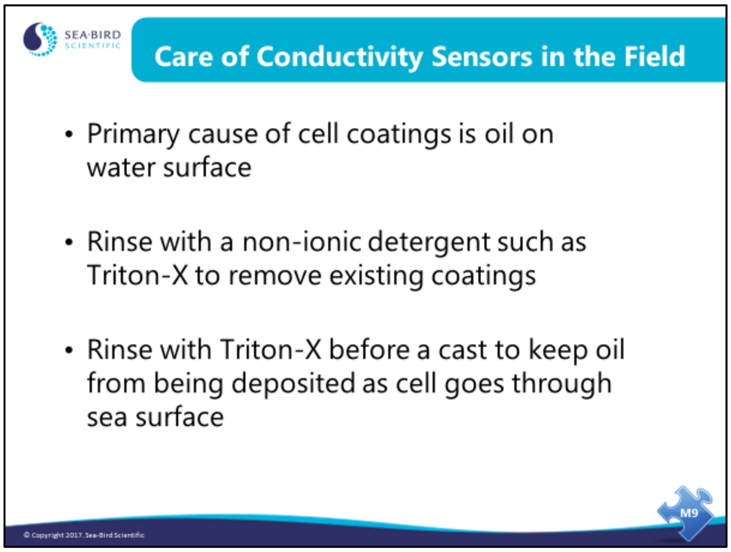
Sea-Bird calculates residual as:

Residual = instrument output – true value

Our calibration certificates always plot the residual on the y axis.

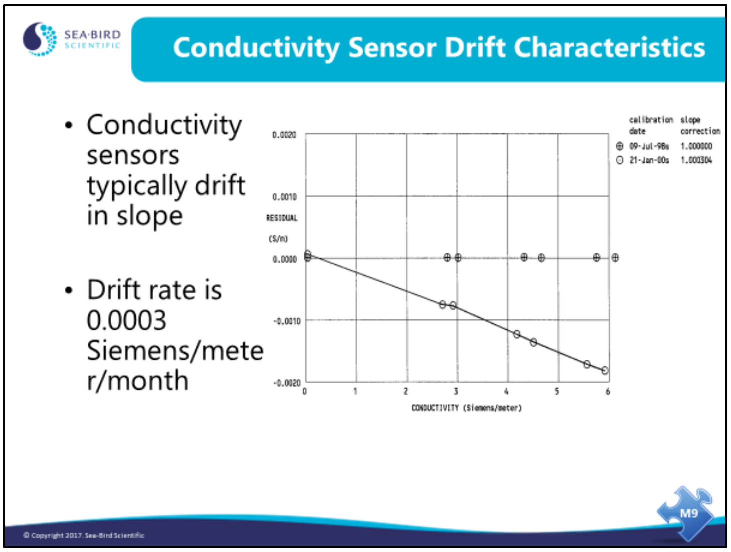
For the plot above, a new calibration on August 31 shows a residual of 0 millidegrees. A check of the same sensor using the new calibration with the old bath data from July 6 shows a residual of 0.10 millidegrees. As you can see, the residual is fairly constant across the entire range of the temperature calibration.

Care of Conductivity Sensors in the Field



Sea-Bird supplies a small amount of Triton-X non-ionic detergent for cleaning conductivity cells. This will remove any oily coating, and an application before deployment will keep films from being deposited as the cell goes through the sea surface. Triton-X is a surfactant. A pre-deployment coating has the added advantage of wetting the electrodes, giving their surface a higher affinity to water.

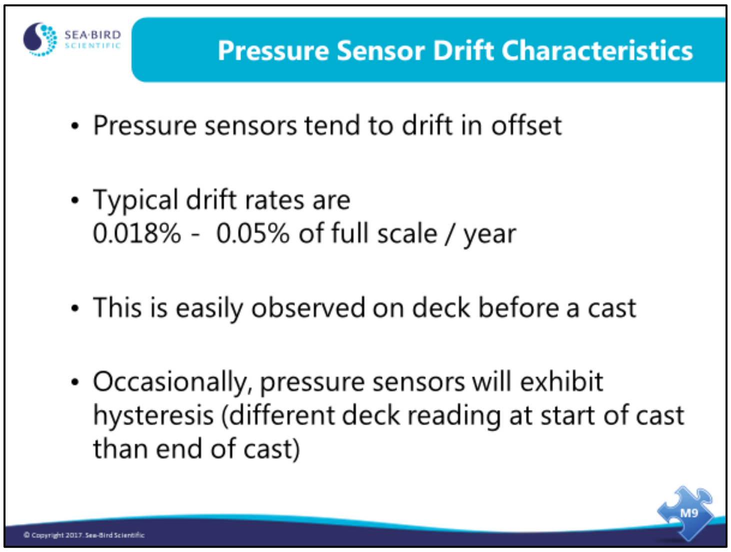
Conductivity Sensor Drift Characteristics



Conductivity sensors usually lose sensitivity as they drift. The drift takes the form of a slope. This is because the conductivity measured by the cell depends on the cell dimensions, which typically change due to fouling.

Note that conductivity cell drift is often episodic rather than linear. This is because fouling events often cause the most significant drift. Perhaps the sensor passes through an oil film when it enters the water, or sits on deck in a warm place full of seawater, growing bacteria on the cell surface.

Pressure Sensor Drift Characteristics

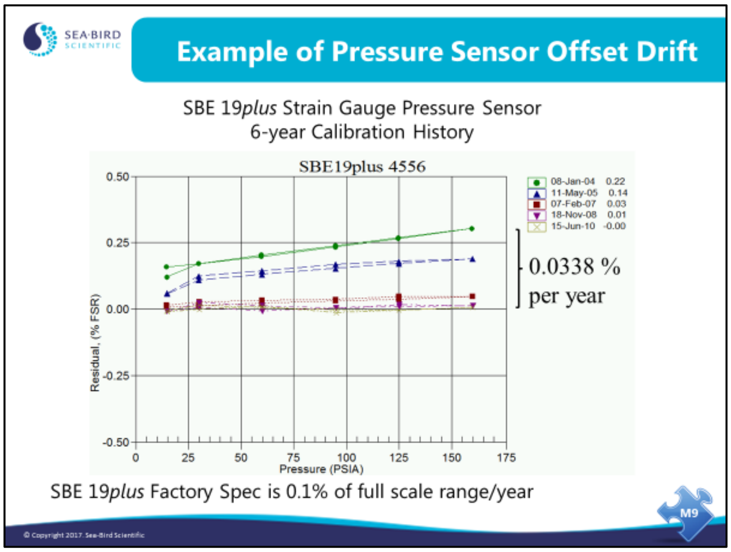


Pressure sensors are usually trouble-free. Drifts are generally in offset. The drift may be read on deck and entered into the coefficient dialog box to make the correction.

When calculating the offset correction:

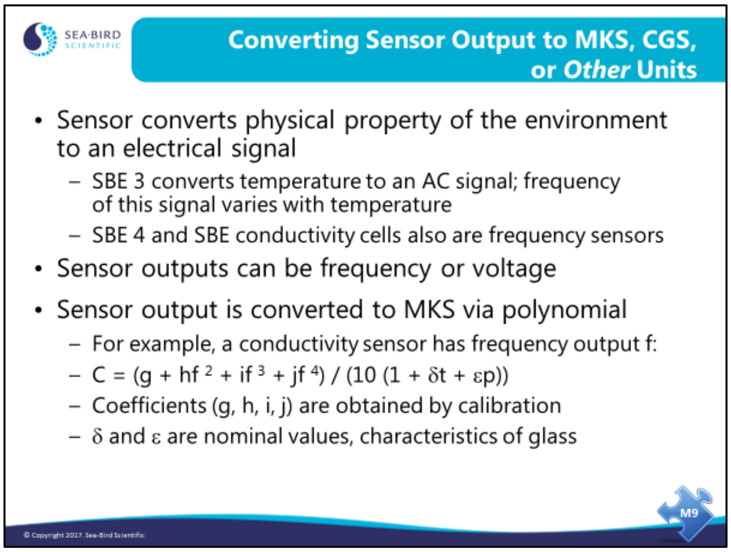
1. Place the instrument in the orientation it will have when deployed.
2. Allow the instrument to equilibrate (with power on) in a reasonably constant temperature environment for at least 5 hours before starting.

Pressure Sensor Drift Characteristics (*continued*)



Here is a plot showing the drift of a strain gauge pressure sensor over a 6-year period. This sensor meets its drift specification of 0.1% of Full Scale per year.

Converting Sensor Output to Scientific Units



As we have discussed, a sensor has an active element that interacts with the environment, and a conditioning circuit that converts the reaction into a signal that is measurable with normal techniques (e.g., Analog/Digital conversion or counting of a frequency). Having acquired a digital representation of temperature or conductivity, we need to convert this into units useful to scientists and engineers.

The simplest sensor might have a linear response to the environmental parameter of interest. For example, a transmissometer has a simple relationship between voltage output and percent transmittance of the water within its path:

$$\%T = (\text{slope} * \text{voltage output}) + \text{offset}$$

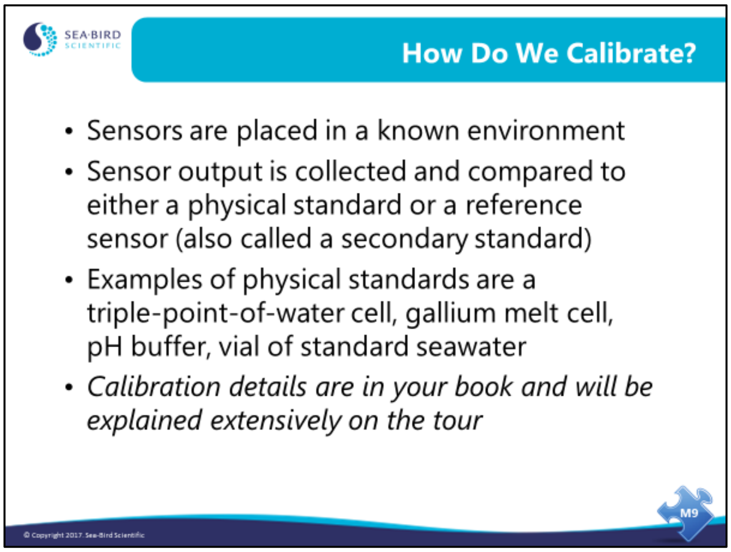
Unfortunately, the output of most sensors in response to environmental parameters is a complex polynomial, often parametric in nature. Consider the equation for conversion from SBE 3 output frequency to temperature. The response is a polynomial because the thermistor responds to changes in temperature in a non-linear fashion:

$$T\ [°C] = [1 / (g + h\,ln(fo/f) + i\,ln^2(fo/f) + j\,ln^3(fo/f))] - 273.15$$

The conductivity sensor's response is a polynomial and parametric, because the sensor has secondary response to temperature and pressure:

$$C = (g + hf^2 + if^3 + jf^4) / (10\,(1 + \delta t + \varepsilon p))$$

Converting to Scientific Units: Calibration

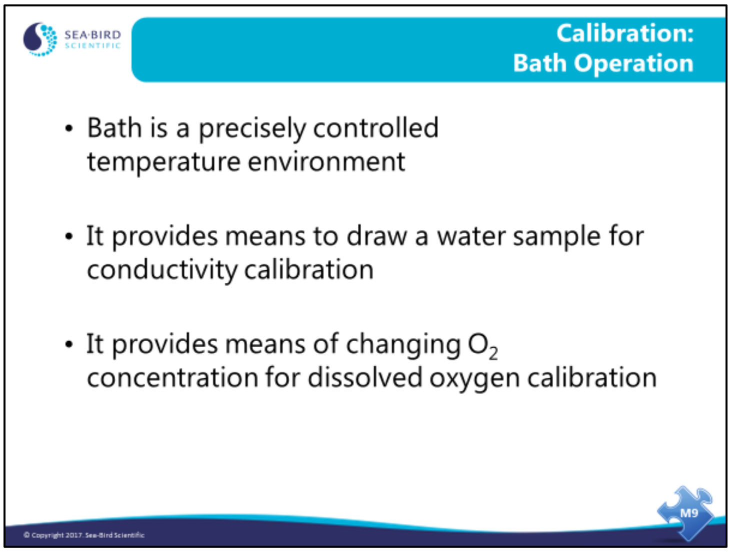


To calibrate a sensor, it is placed in a precisely controlled environment. The output of the sensor is collected at the same time as the environment is measured with a reference sensor. The reference sensor is carefully calibrated and has a well-known history. To gain the careful calibration and history, the reference is calibrated against physical standards such as the triple point of water and the melting point of gallium, or an agreed-upon standard such as IAPSO standard seawater.

Converting to Scientific Units: Calibration (*continued*)

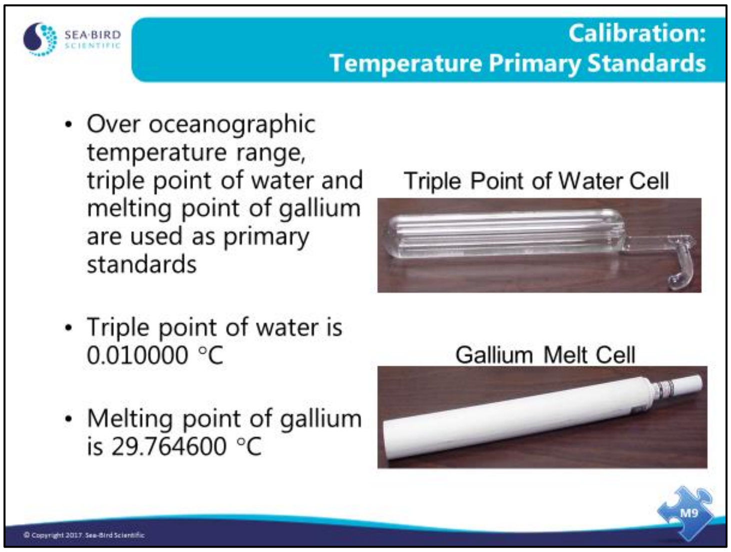
This bath design is common to all of Sea-Bird’s calibration activities. The baths are highly insulated and well stirred, and they typically hold temperature to better than 0.0005 °C.

Converting to Scientific Units: Calibration (*continued*)



Baths of this design have been adapted for calibration of all of Sea-Bird's products. The basis is precisely controlled temperature and the ability to draw a water sample for salinity determination. The means to change partial pressures of Oxygen for SBE 43 calibration has been added.

Converting to Scientific Units: Calibration (*continued*)



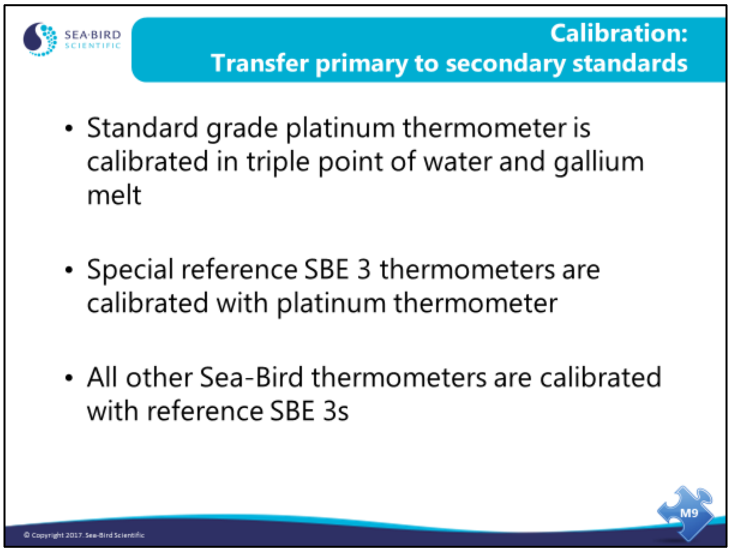
For calibration, one runs into the problem of knowing exactly what the temperature of a particular object is. If we only had thermometers to rely on, how do you know which one is right? Instead, we use physical standards. The Celsius temperature scale decrees that water freezes at 0 °C and boils at 100 °C; however, the freezing and boiling points are subject to uncertainties such as atmospheric pressure. So, instead of the freezing and boiling points, we use two other points:

- The triple point - the temperature at which water exists as a liquid, a vapor, and a solid. The triple point of water is measured in a specially constructed cell that contains no air, only H_20, and occurs at 0.010000 °C. Because of a pressure effect, the temperature at the depth where we actually take the measurement is 0.00997 °C
- The melting point of extremely pure gallium, 29.764600 °C. Because of a pressure effect, the temperature at the depth where we actually take the measurement is 29.76458 °C. This pins down the other end of the oceanographic scale.

We calibrate platinum reference thermometers at these points and then calibrate reference SBE 3 sensors with the platinum thermometers. This allows us to trace the temperature measurement used to calibrate all other thermometers back to the physical standards.

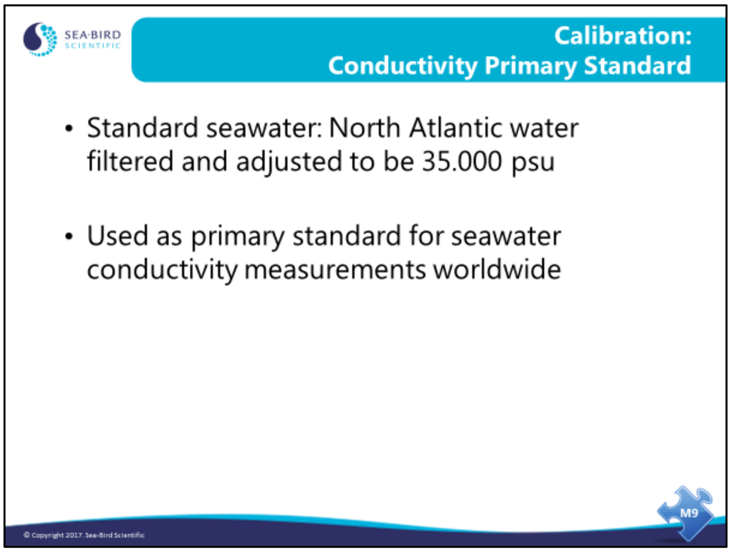
Fixed point cells are called this because when they are in the proper condition their temperature is fixed by the physics of the materials they are constructed of to be a single temperature. The triple point cells are maintained in a water bath very near their natural temperature. This allows them to last a long time. The gallium cells are melted slowly in an oven; the temperature where the gallium changes phase from solid to liquid is used as the calibration temperature.

Converting to Scientific Units: Calibration (*continued*)



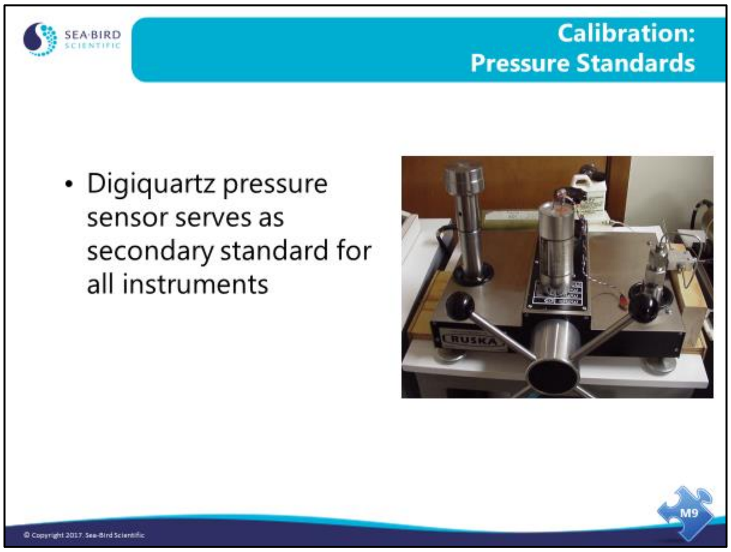
As was previously mentioned, a platinum thermometer is calibrated in the fixed point cells and then used to calibrate the SBE 3 reference thermometers. The platinum thermometer is susceptible to calibration shift due to impact or vibration; because of this it is impractical to use it in routine calibration. The SBE 3s are much more robust. By careful selection of the SBE 3 and the accumulation of a drift history, very accurate calibrations can be accomplished.

Converting to Scientific Units: Calibration (*continued*)



Unlike temperature, a primary standard for the conductivity of seawater is more difficult to come by. In recognition of this, IAPSO commissions the Ocean Scientific International Corporation to provide *standard seawater*. Ocean Scientific sends small ships out into the North Atlantic with large tanks to collect seawater. The seawater is filtered and adjusted in salinity to be 35.000. It is then sealed in vials or bottles and shipped to laboratories worldwide to be used in standardizing laboratory salinometers. Because everyone uses the same water to standardize their salinometers, we are all synchronized with Ocean Scientific. The standard seawater service has been going on for decades under the auspices of various committees of scientists. It was first produced by a laboratory in Copenhagen and was initially dubbed *Copenhagen water*.

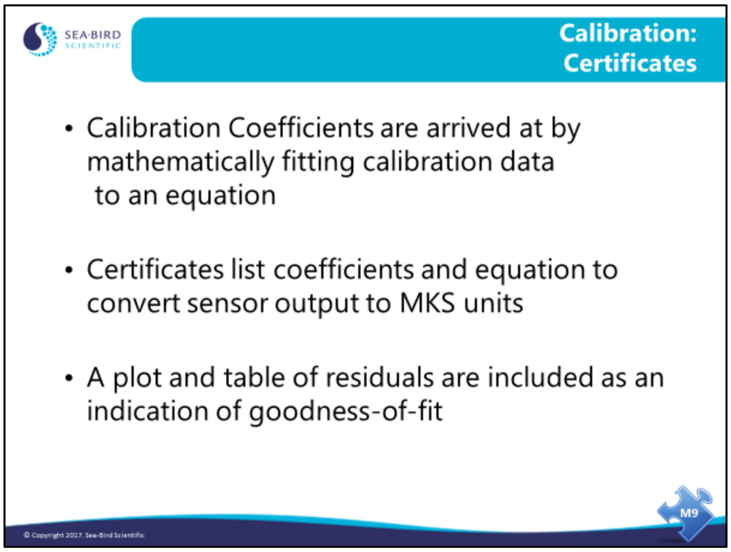
Converting to Scientific Units: Calibration (*continued*)



For instruments that have a strain gauge pressure sensor (Druck, Paine, Ametek, etc.), a complete pressure calibration is performed at Sea-Bird, using our Digiquartz pressure sensor as a secondary standard.

For instruments (SBE 9*plus*, 26*plus*, 53, etc.) that have a Digiquartz pressure sensor, a true calibration of the sensor is performed by the pressure sensor manufacturer. The quality of the Digiquartz is such that an adequate calibration requires a local gravity survey and dead weight tester parts that are certified by the National Institute of Standards and Technology. These requirements, plus the stability of the Digiquartz sensor, make the maintenance of this capability not cost effective for Sea-Bird. However, we do perform a slope and offset check of the pressure sensor in these instruments, using our Digiquartz pressure sensor as a secondary standard.

Converting to Scientific Units: Calibration (*continued*)

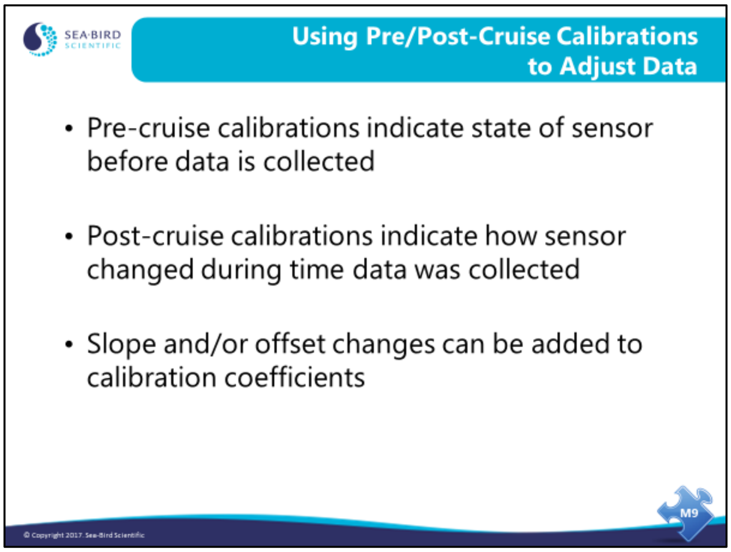


The calibration certificate is a listing of all the information required to convert sensor output to scientific units. There is also a table of calibration data and a plot of residuals that indicates a goodness-of-fit. Residuals are expressed as the difference between the instrument parameter and the bath parameter (the *true* value):

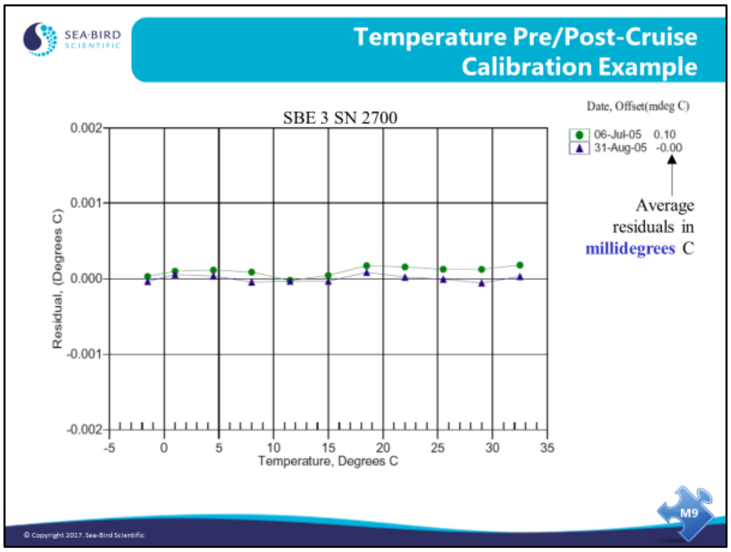
residual = instrument – bath

If the residual is positive, the sensor is reading high of reality; if negative, the sensor is reading low.

Using Calibrations to Improve your Data



Temperature: Using Calibrations to Improve your Data

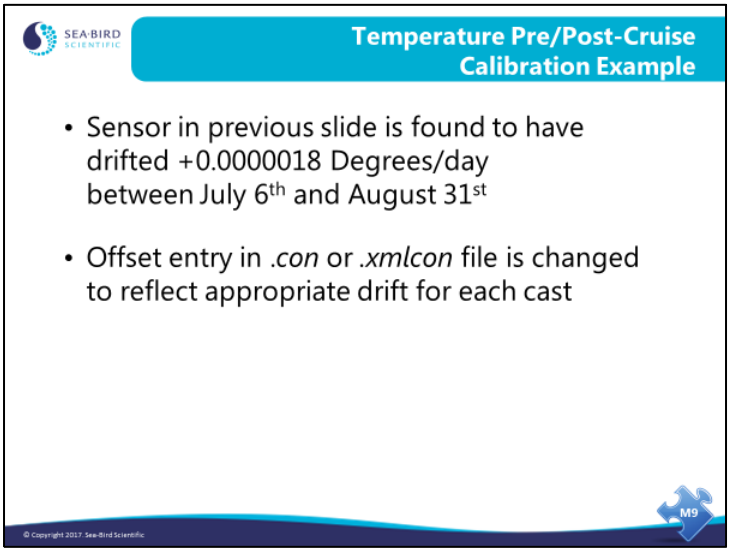


The average residuals (residual = instrument temperature – true temperature) are shown to the right of the plot.

This plot is an example of the calibration sheet plot sent to the customer when a temperature sensor is recalibrated by Sea-Bird. New (*post-cruise*) calibration coefficients are calculated, and two lines are plotted:

- Residuals are calculated using bath data (bath temperatures and temperature sensor frequencies) from the *post-cruise* calibration (31-Aug-05) and the new (*post-cruise*) calibration coefficients. The average residual should be approximately 0, indicating that the new calibration coefficients provide a good fit for the data across the entire calibration range.
- Residuals are also calculated using data (bath temperatures and temperature sensor frequencies) from the *pre-cruise* calibration (06-Jul-05) with the new (*post-cruise*) calibration coefficients. The average residual is the calibration drift between the two calibration dates.

Temperature: Using Calibrations to Improve your Data (*continued*)

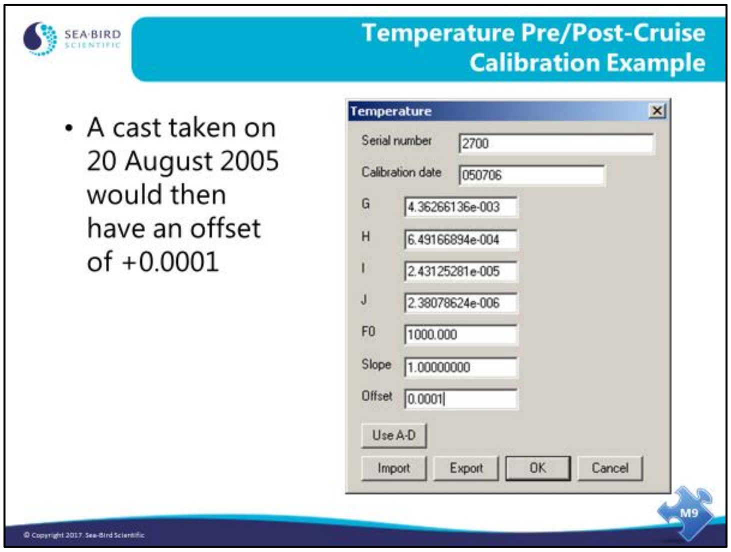


The SBE 3 in the previous slide drifted +0.0001 degrees over 56 days, this is +0.0000018 degrees per day.

Application Note 31 has a detailed discussion of correcting thermometers with pre-cruise and post-cruise calibrations. Briefly:

1. Calibration coefficients are calculated with the post-cruise calibration.
2. Using the post-cruise calibration coefficients and the pre-cruise calibration data (bath temperatures and sensor frequencies), a mean residual over the calibration range is calculated (residual = instrument temperature - bath temperature).
3. The mean residual is divided by the number of days since the pre-cruise calibration. This number is the offset per day.
4. The offset per day is multiplied by the number of days between the pre-cruise calibration and the day the data was collected to get the offset that should be entered into the configuration file, while using the *pre-cruise* G, H, I, J calibration coefficients.

Temperature: Using Calibrations to Improve your Data (*continued*)



As we noted in the previous slide, the SBE 3 drifted +0.0001 degrees over 56 days, this is +0.0000018 degrees per day. The first day of the cruise is August 20th. Therefore, the offset will be +0.000081 (0.0000018 degrees/day x 45 days since the calibration) and will increase +0.0000018 every day of the cruise. In the slide above we have rounded the offset to +0.0001.

Activity: Correct T via Pre / Post-Cruise Calibrations

Pressure db	CTD Temperature (ITS-90)	CTD Conductivity	Uncorrected CTD Salinity	Corrected CTD Temp (ITS-90)	Corrected CTD Cond	Corrected CTD Salinity	Water Bottle Salinity	Corrected CTD Salinity- Water Bottle Salinity
4.9	24.0798	5.236377	35.1885				35.2055	
519	6.6922	3.439905	34.0769				34.0848	
850.6	4.4142	3.276592	34.3667				34.3738	
1000.8	4.003	3.254754	34.4616				34.472	
1202.3	3.5221	3.224822	34.5083				34.5148	
1401	3.039	3.193778	34.5452				34.5503	
1599.6	2.6724	3.171902	34.5692				34.5769	
1800.5	2.3456	3.153669	34.5947				34.601	
1999.1	2.1309	3.1445	34.6131				34.6194	
2200.8	1.9531	3.138118	34.6259				34.6351	
2400.2	1.7884	3.132729	34.6392				34.6463	
2601.2	1.6718	3.131169	34.6486				34.6562	
2798.9	1.5911	3.132338	34.6563				34.6645	
3000	1.5372	3.135717	34.6623					
3200.1	1.4927	3.1397	34.6674				34.676	
3399.7	1.4739	3.145626	34.6708				34.6789	
3600.3	1.4587	3.151747	34.6737				34.6829	
3800.4	1.4465	3.157985	34.6763				34.6846	
4001.5	1.4537	3.165678	34.6772				34.6853	
4201.2	1.4608	3.173241	34.6785				34.689	
4401.9	1.4766	3.181421	34.6790				34.6871	
4500.7	1.4868	3.185577	34.6788				34.6883	
4600.8	1.4969	3.189761	34.6789				34.6883	
4809.4	1.5119	3.19792	34.6795				34.6884	

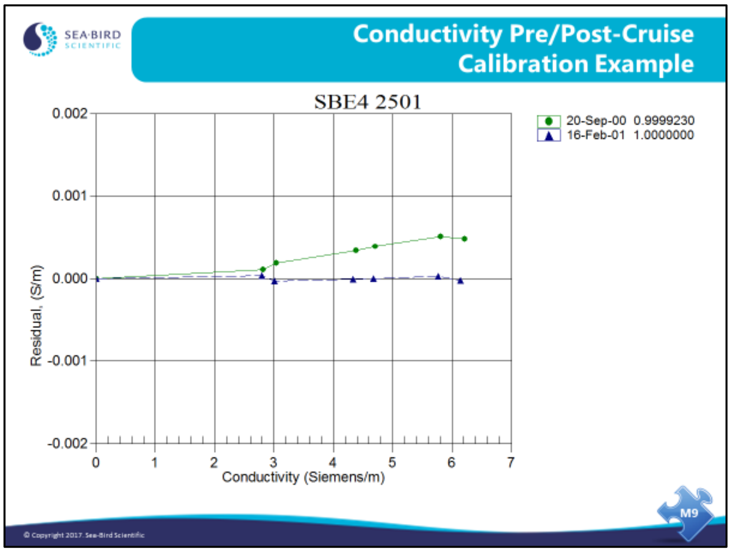
Note: Cruise date is 15 December 1999, Julian day 348.

(dates from calibration sheets)	**Temperature**
Pre-cruise calibration	23 November 1999, Julian day 326
Post-cruise calibration	28 December 1999, Julian day 361

Use the calibration data from the T calibration sheets on the following pages to answer the following question and **fill in the top three rows of the table**:

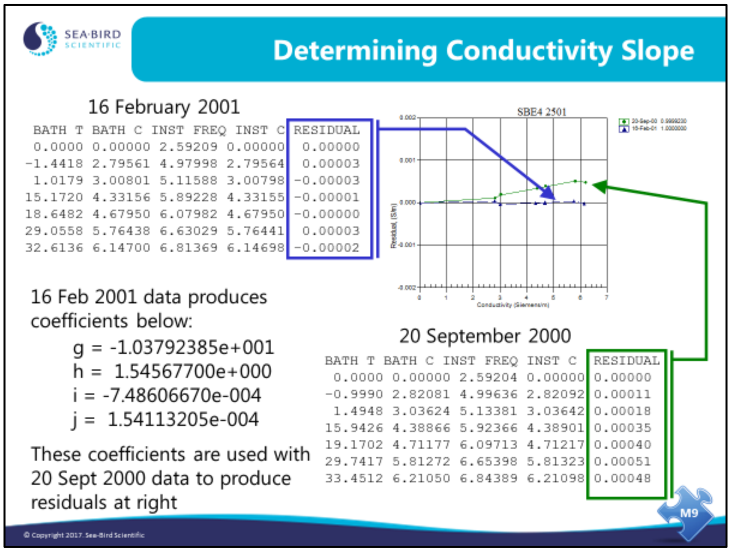
1. Calculate a temperature offset for the cruise; apply the offset to the temperature data.

Conductivity: Using Calibrations to Improve your Data



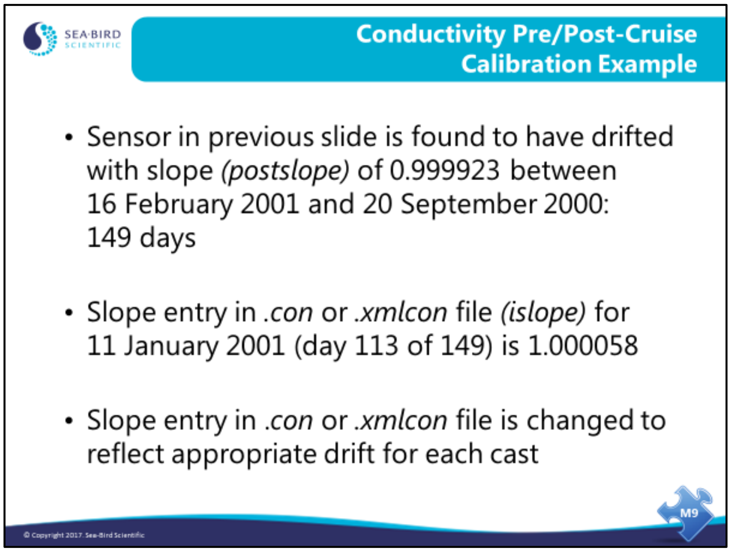
Conductivity sensors usually lose sensitivity as they drift. The drift takes the form of a slope. This is because the conductivity measured by the cell depends on the cell dimensions, which typically change due to fouling.

Conductivity: Using Calibrations to Improve your Data (*continued*)



Conductivity slope is determined by calculating calibration coefficients using data from one calibration date and applying the coefficients to data from another calibration date. Note that the residuals (instrument conductivity – true conductivity) are very small for the 16 February 2001 data. Using the calibrations coefficients calculated from the 16 February 2001 calibration data to calculate instrument conductivities results in the larger residuals seen in the 20 September 2000 data. The results of this show the error that would be incurred from calibration drift.

Conductivity: Using Calibrations to Improve your Data (*continued*)



See Application Note 31 for a detailed discussion of how to apply pre- / post-cruise calibrations to SBE 4 conductivity sensors. Briefly, a calibration is done before and after the cruise. Let alpha be the conductivity that the instrument measured in the pre-cruise calibration, calculated using post-cruise coefficients. Let beta be the true conductivity of the pre-cruise calibrations. Then:

$$postslope = \frac{\sum_{i=1}^{n} \alpha_i \beta_i}{\sum_{i=1}^{n} \alpha_i \alpha_i}$$

Where: i = 1..n calibration points

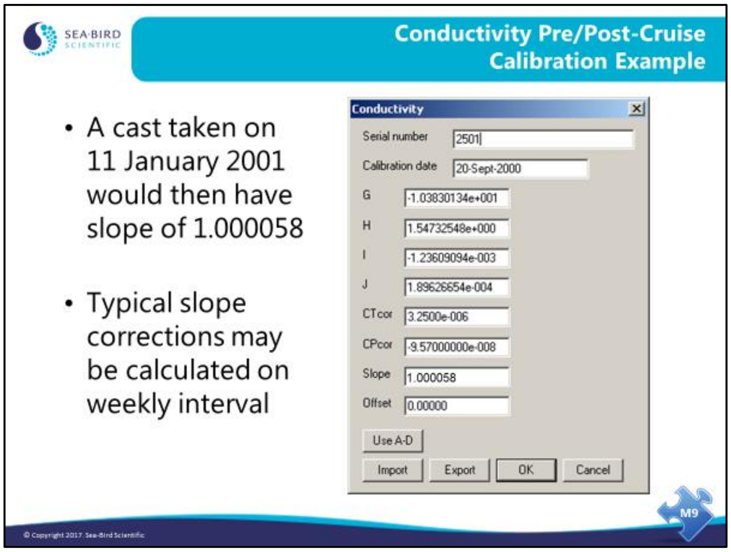
The interpolated slope, which is entered in the coefficient dialog box, is:

$$islope = 1 + \left(\frac{b}{n}\right)\left(\frac{1}{postslope} - 1\right)$$

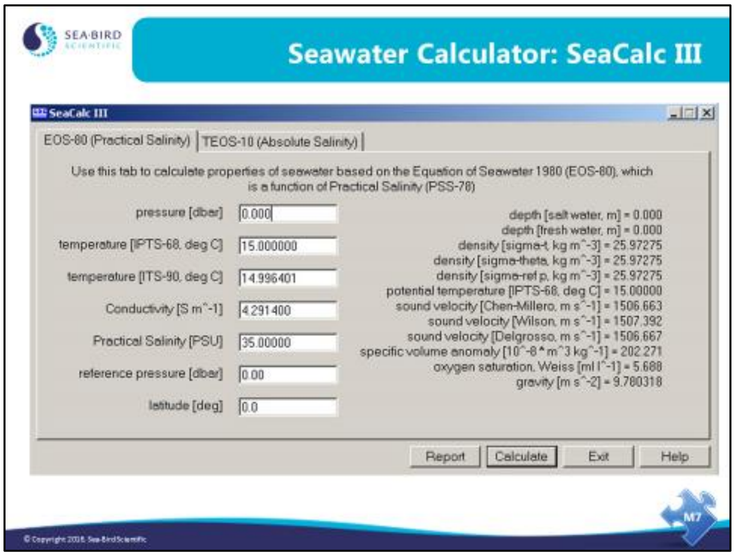
Where:
n = number of days between pre- and post-cruise calibrations
b = number of days between pre-cruise calibration and the cast to be corrected
islope = interpolated slope, which is entered as the slope in the coefficient dialog box
postslope is calculated above

> Example: Calculate *islope* for day 113 (11 January 2001) using calibration data from previous slide -
> *postslope* = 0.999923 (at top right of calibration sheet in previous slide)
> *islope* = 1 + (113 / 149) [(1 / 0.999923) – 1] = 1.000058

Conductivity: Using Calibrations to Improve your Data (*continued*)



Calculating Parameters with SeaCalc III



SeaCalc is a seawater calculator in SBE Data Processing that computes a number of derived variables from one user-input scan of pressure, temperature, and either conductivity or salinity. On the ***Practical Salinity (EOS-80)*** **tab**:

- Enter temperature in ITS-68 or ITS-90; SeaCalc automatically computes the other value.
- SeaCalc *remembers* whether you last changed conductivity or salinity, and calculates other parameters based on this. For example, if you change conductivity, salinity is recalculated; if you then change temperature, salinity is recalculated again (based on input conductivity and temperature). Conversely, if you change salinity, conductivity is recalculated; if you then change temperature, conductivity is recalculated again (based on input salinity and temperature).
- Reference pressure is used only to compute Sigma-ref.
- Latitude is used only to compute gravity and salt water depth.

There is also an ***Absolute Salinity (TEOS-10)*** **tab** in SeaCalc. SeaCalc automatically populates this tab with the Practical Salinity, Temperature, Pressure, Reference Pressure, and Latitude values from the Practical Salinity tab, and requires a Longitude entry to calculate Absolute Salinity as well as a number of other parameters derived from Absolute Salinity. Application Note 90 on our website provides a discussion of Absolute Salinity (www.seabird.com/document/an90-absolute-salinity-and-teos-10-sea-birds-implementation).

Activity: Correct C via Pre / Post-Cruise Calibrations

Pressure db	CTD Temperature (ITS-90)	CTD Conductivity	Uncorrected CTD Salinity	Corrected CTD Temp (ITS-90)	Corrected CTD Cond	Corrected CTD Salinity	Water Bottle Salinity	Corrected CTD Salinity- Water Bottle Salinity
4.9	24.0798	5.236377	35.1885				35.2055	
519	6.6922	3.439905	34.0769				34.0848	
850.6	4.4142	3.276592	34.3667				34.3738	
1000.8	4.003	3.254754	34.4616				34.472	
1202.3	3.5221	3.224822	34.5083				34.5148	
1401	3.039	3.193778	34.5452				34.5503	
1599.6	2.6724	3.171902	34.5692				34.5769	
1800.5	2.3456	3.153669	34.5947				34.601	
1999.1	2.1309	3.1445	34.6131				34.6194	
2200.8	1.9531	3.138118	34.6259				34.6351	
2400.2	1.7884	3.132729	34.6392				34.6463	
2601.2	1.6718	3.131169	34.6486				34.6562	
2798.9	1.5911	3.132338	34.6563				34.6645	
3000	1.5372	3.135717	34.6623					
3200.1	1.4927	3.1397	34.6674				34.676	
3399.7	1.4739	3.145626	34.6708				34.6789	
3600.3	1.4587	3.151747	34.6737				34.6829	
3800.4	1.4465	3.157985	34.6763				34.6846	
4001.5	1.4537	3.165678	34.6772				34.6853	
4201.2	1.4608	3.173241	34.6785				34.689	
4401.9	1.4766	3.181421	34.6790				34.6871	
4500.7	1.4868	3.185577	34.6788				34.6883	
4600.8	1.4969	3.189761	34.6789				34.6883	
4809.4	1.5119	3.19792	34.6795				34.6884	

Note: Cruise date is 15 December 1999, Julian day 348.

(dates from calibration sheets)	**Temperature**	**Conductivity**
Pre-cruise calibration	23 November 1999, Julian day 326	17 June 1999, Julian day 167
Post-cruise calibration	28 December 1999, Julian day 361	30 December 1999, Julian day 363

Use the calibration data from the C and T calibration sheets on the following pages to answer these questions and **fill in the top three rows of the table**:

1. Calculate a temperature offset for the cruise; apply the offset to the temperature data.
2. Calculate a conductivity slope for the cruise; apply the slope to the conductivity data.
3. Calculate corrected CTD salinity with SeaCalc III. Compare the corrected CTD salinity to the salinity measured from the water bottle samples.

Corrected T and C using Pre- / Post-Cruise Calibrations

Pressure db	CTD Temperature (ITS-90)	CTD Conductivity	Uncorrected CTD Salinity	Corrected CTD Temp (ITS-90)	Corrected CTD Cond	Corrected CTD Salinity	Water Bottle Salinity	Corrected CTD Salinity- Water Bottle Salinity
4.9	24.0798	5.236377	35.1885	24.0798	5.237190	35.1947	35.2055	-0.0108
519	6.6922	3.439905	34.0769	6.6922	3.440439	34.0828	34.0848	-0.0020
850.6	4.4142	3.276592	34.3667	4.4142	3.277101	34.3726	34.3738	-0.0012
1000.8	4.003	3.254754	34.4616	4.003	3.255259	34.4676	34.472	-0.0044
1202.3	3.5221	3.224822	34.5083	3.5221	3.225323	34.5143	34.5148	-0.0005
1401	3.039	3.193778	34.5452	3.039	3.194274	34.5511	34.5503	0.0008
1599.6	2.6724	3.171902	34.5692	2.6724	3.172395	34.5753	34.5769	-0.0016
1800.5	2.3456	3.153669	34.5947	2.3456	3.154159	34.6006	34.601	-0.0004
1999.1	2.1309	3.1445	34.6131	2.1309	3.144988	34.6191	34.6194	-0.0003
2200.8	1.9531	3.138118	34.6259	1.9531	3.138605	34.6319	34.6351	-0.0032
2400.2	1.7884	3.132729	34.6392	1.7884	3.133216	34.6452	34.6463	-0.0011
2601.2	1.6718	3.131169	34.6486	1.6718	3.131655	34.6547	34.6562	-0.0015
2798.9	1.5911	3.132338	34.6563	1.5911	3.132824	34.6623	34.6645	-0.0022
3000	1.5372	3.135717	34.6623	1.5372	3.136204	34.6682		
3200.1	1.4927	3.1397	34.6674	1.4927	3.140188	34.6735	34.676	-0.0025
3399.7	1.4739	3.145626	34.6708	1.4739	3.146115	34.6768	34.6789	-0.0021
3600.3	1.4587	3.151747	34.6737	1.4587	3.152236	34.6796	34.6829	-0.0033
3800.4	1.4465	3.157985	34.6763	1.4465	3.158475	34.6823	34.6846	-0.0023
4001.5	1.4537	3.165678	34.6772	1.4537	3.166170	34.6832	34.6853	-0.0021
4201.2	1.4608	3.173241	34.6785	1.4608	3.173734	34.6845	34.689	-0.0045
4401.9	1.4766	3.181421	34.6790	1.4766	3.181915	34.6851	34.6871	-0.0020
4500.7	1.4868	3.185577	34.6788	1.4868	3.186072	34.6849	34.6883	-0.0034
4600.8	1.4969	3.189761	34.6789	1.4969	3.190256	34.6849	34.6883	-0.0034
4809.4	1.5119	3.19792	34.6795	1.5119	3.198417	34.6856	34.6884	-0.0028

Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 2700
CALIBRATION DATE: 28-Dec-99

SBE 3 TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

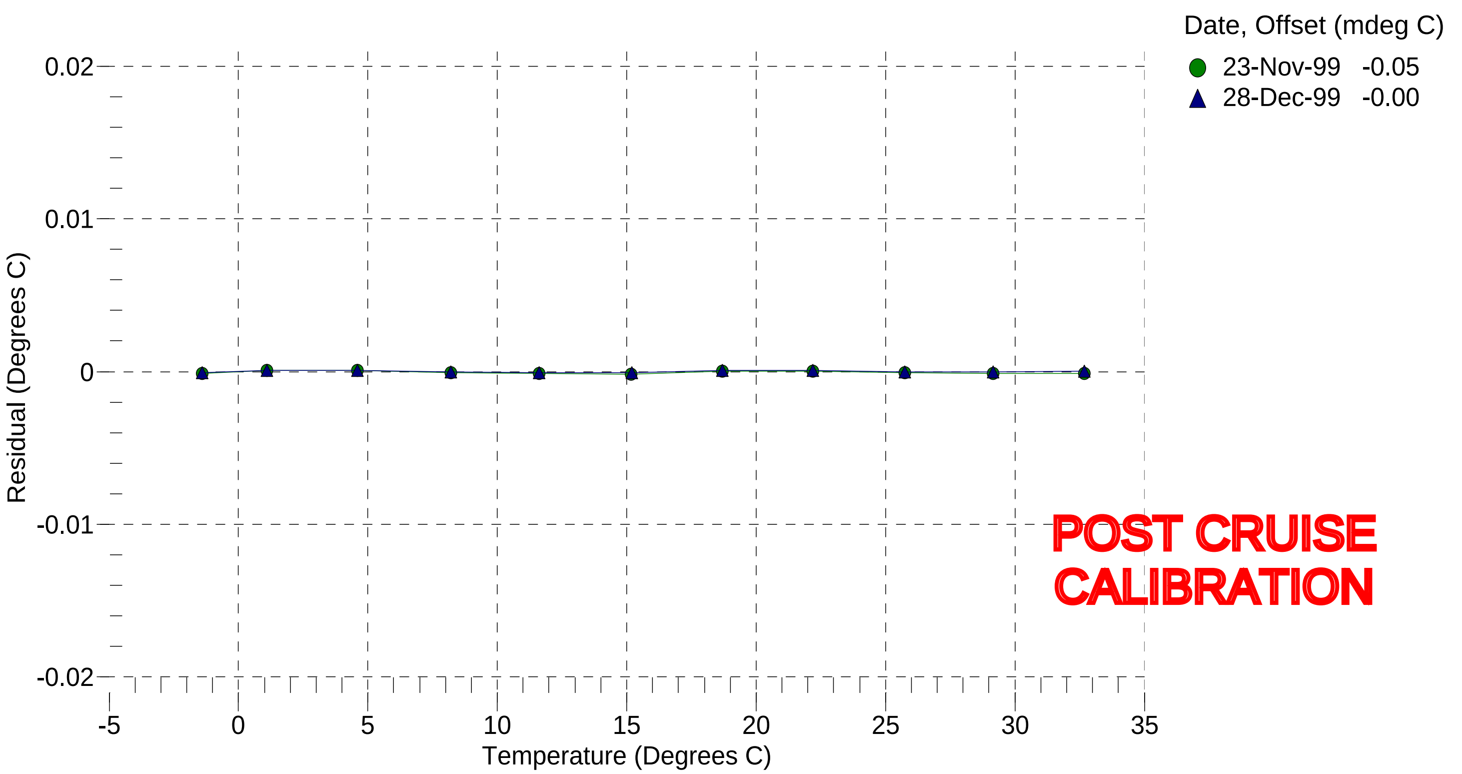
COEFFICIENTS:
g = 4.36260004e-003
h = 6.49083037e-004
i = 2.42497805e-005
j = 2.36365545e-006
f0 = 1000.0

BATH TEMP (° C)	INSTRUMENT OUTPUT (Hz)	INST TEMP (° C)	RESIDUAL (° C)
-1.4039	2978.914	-1.4040	-0.00008
1.1062	3149.847	1.1063	0.00009
4.5979	3399.248	4.5980	0.00007
8.1955	3670.718	8.1954	-0.00004
11.6295	3943.970	11.6295	-0.00007
15.1862	4241.874	15.1861	-0.00009
18.6903	4550.560	18.6904	0.00008
22.1892	4874.139	22.1893	0.00007
25.7491	5219.423	25.7491	-0.00000
29.1638	5566.173	29.1637	-0.00005
32.6970	5941.274	32.6970	0.00001

f = Instrument Output (Hz)

Temperature ITS-90 (°C) = $1/\{g + h[ln(f0 / f)] + i[ln^2(f0 / f)] + j[ln^3(f0 / f)]\} - 273.15$

Residual (°C) = instrument temperature - bath temperature



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USA

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seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 2218
CALIBRATION DATE: 30-Dec-99

SBE 4 CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:
g = -1.02414422e+001
h = 1.49331006e+000
i = -1.50844862e-003
j = 1.99364517e-004

CPcor = -9.5700e-008 (nominal)
CTcor = 3.2500e-006 (nominal)

BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.62109	0.00000	0.00000
-1.3895	35.1839	2.79817	5.06354	2.79815	-0.00002
1.1492	35.1843	3.01746	5.20666	3.01747	0.00001
15.2688	35.1829	4.33837	5.99642	4.33839	0.00002
18.7065	35.1798	4.68224	6.18534	4.68224	-0.00001
29.2500	35.1699	5.78041	6.75306	5.78038	-0.00003
32.6897	35.1622	6.15002	6.93359	6.15004	0.00002

f = Instrument Output (kHz)

t = temperature (°C); p = pressure (decibars); δ = CTcor; ε = CPcor;

Conductivity (S/m) = $(g + h * f^2 + i * f^3 + j * f^4) /10 (1 + \delta * t + \varepsilon * p)$

Residual (Siemens/meter) = instrument conductivity - bath conductivity