


Module 7

Getting the Highest Accuracy Data: Profiling Applications

Overview



Getting the Highest Accuracy Data: Profiling Applications

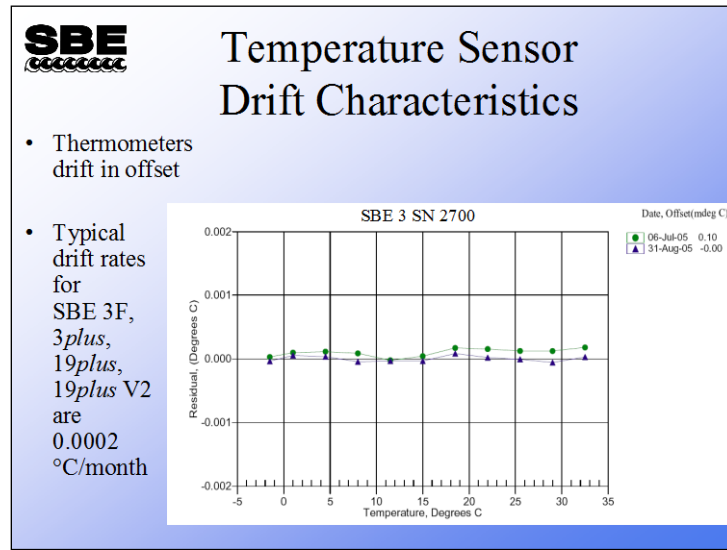
- Care of sensors in field
- Calibrations in general
- Sensor drift characteristics
- Pre- and post-deployment calibrations

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.

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:

$$\text{Residual} = \text{instrument output} - \text{true value}$$

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 Thermometers in the Field




Care of Thermometers in the Field

- Thermistor-based thermometers are very resistant to mechanical shock
- To avoid drift caused by exposure to heat, keep them below 60 °C
- Keep inlet to TC duct free of debris

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

Care of Conductivity Sensors in the Field

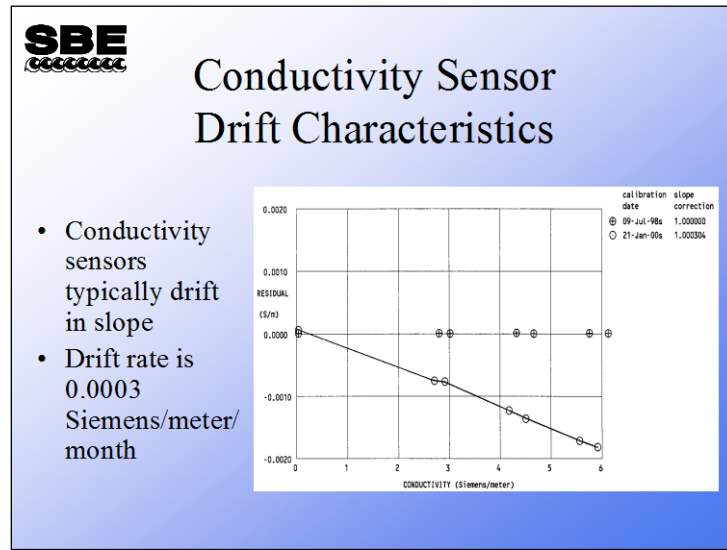


Care of Conductivity Sensors
in the Field

- Primary cause of cell coatings is oil on water surface
- Rinse with a non-ionic detergent such as Triton-X to remove existing coatings
- Rinse with Triton-X before a cast to keep oil from being deposited as cell goes through sea surface

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.

Care of Conductivity Sensors in the Field



Routine Cleaning of Conductivity Sensors

- Agitate a warm 50:1 chlorine bleach solution through the cell
- Follow with a warm 1% - 2% Triton X solution
- In rare instances, coatings may be inorganic in nature
 - These may be removed with a 10% HCl solution
- Never run a brush through a cell to clean it
 - Each platinum foil electrode has a coating of platinum black and is very delicate


The cleaning with dilute bleach and Triton-X may be repeated several times for badly fouled sensors.

Sea lore has it that in some environments CaCO_3 or other inorganic coatings may accrete on the inside of the cell. This is more likely in a moored instrument. An HCl solution will dissolve these. Rather than doing this aggressive cleaning yourself, Sea-Bird recommends that the sensor be returned to the factory for cleaning and inspection.

- For the SBE 37-IMP, 37-IMP-IDO, 37-SMP, 37-SMP-IDO, 37-SIP, and 37-SIP-IDO MicroCAT; SBE 49 FastCAT; and any other instruments with an integral internal pump: **Do not perform acid cleaning**; it must be performed at the factory to avoid damage to the pump.

See **Application Note 2D** on our website for complete details on cleaning conductivity cells.

Care of Conductivity Sensors in the Field (*continued*)

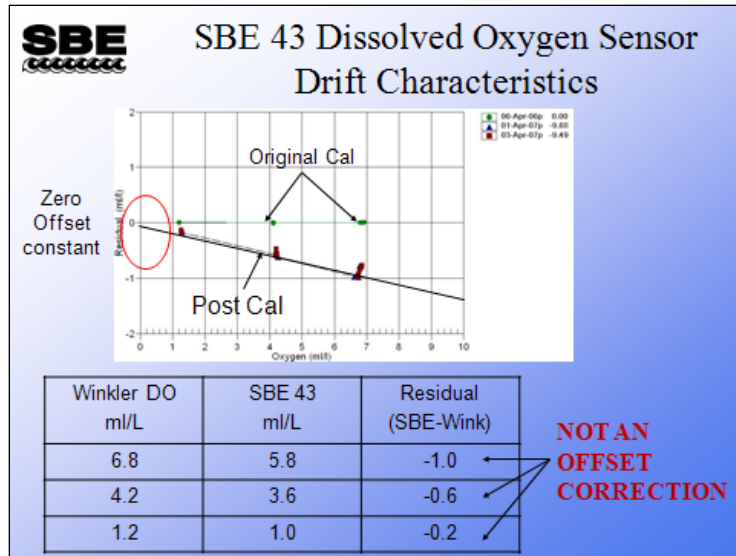


Care of Conductivity Sensors
in the Field

- How to tell when cell has sustained physical damage or is dirty
 - Rinse cell thoroughly with distilled or de-ionized water
 - Check sensor frequency (*zero frequency*) against calibration certificate
 - Numbers should agree to within a few tenths of a Hz
 - Noisy readings indicate a dirty cell

Every conductivity calibration certificate has a frequency output for zero conductivity. This is obtained from a cell thoroughly rinsed in distilled or de-ionized water, with all the water shaken out. This means there are no electrical paths within the cell. A zero frequency that has changed by more than a few tenths of a Hertz may indicate a cell that is damaged or considerably out of calibration. Noisy readings (\pm a few tenths of a Hertz) indicate a dirty cell; we suggest a good rinse with dilute bleach and Triton-X.

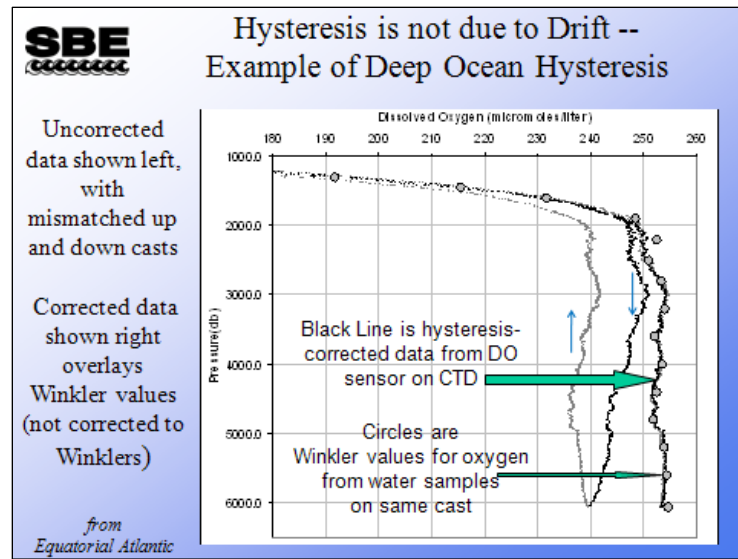
Dissolved Oxygen Sensor Drift Characteristics



Dissolved oxygen sensor drift, like conductivity sensor drift, can be episodic in nature. It also has similar causes. The sensor depends on the diffusion of oxygen through a Teflon membrane. Any surface coating that slows the diffusion will affect the sensor sensitivity and its time response.


The oxygen sensor drifts in slope. The equation that converts sensor output to dissolved oxygen has a slope term, S_{oc} , which gets larger as the sensitivity of the sensor decreases. Because the electrode is always polarized, the sensor drifts on the shelf.

Dissolved Oxygen Sensor Drift Characteristics (continued)



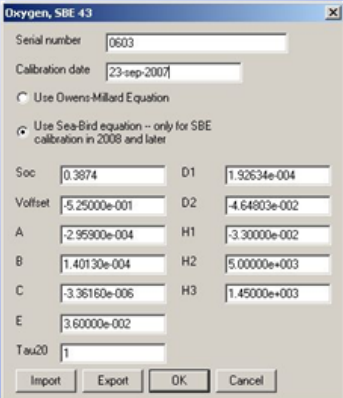
- Under high pressure, physical changes occur in gas permeable Teflon membranes that affect the permeability characteristics. The high-pressure, time-dependent effects have long time constants which *predictably* reduce the sensor's output.
- The deep-ocean hysteresis effect is viewed as a mismatch between CTD-DO data and bottle data and a mismatch between up and down cast DO data traces at depths below 1000 dbar.
- The effect causes sensors to read low of correct at depths 1000 dbar and greater.
- Time at depth will very slowly add to this offset, which is why the down cast oxygen values will typically be higher than the upcast oxygen trace.
 - Both the up and down cast traces can be low of the bottle data collected at corresponding depths when deep ocean hysteresis is occurring.
- The effect is modeled by a simple exponential function, so the temporal and pressure dependencies are i) predictable, and ii) correctable, and iii) require a continuous time series.
- **NOTE:** Deep-ocean hysteresis is separate from sensor-alignment-caused hysteresis observed throughout the water column (a mismatch due to position of sensor on the sample package).

Field Calibrations: Dissolved Oxygen Pressure Effects



Dissolved O₂ Deep-Ocean Hysteresis

- H1, H2, and H3 coefficients correct for deep-ocean hysteresis (> 1000 m depth)
- Consistent between sensors
 - Coefficients generally do not differ or change with time
- Deep-ocean hysteresis correction is enabled/disabled on Miscellaneous tab in Data Conversion (SBE Data Processing) and/or Miscellaneous tab in Configure Inputs (Seasave)



Parameter	Value	Parameter	Value
Soc	0.3874	D1	1.92634e-004
Voffset	-5.25000e-001	D2	-4.64803e-002
A	-2.95900e-004	H1	-3.30000e-002
B	1.40130e-004	H2	5.00000e+003
C	-3.36160e-006	H3	1.45000e+003
E	3.60000e-002		
Tau20	1		

To perform deep-water hysteresis corrections on your SBE 43 oxygen data, select *Apply hysteresis correction to SBE 43 when Sea-Bird equation selected in .con or .xmlcon file* on the Miscellaneous tab in the Data Conversion dialog box. Ranges and default values for the hysteresis correction are:

- H1 - amplitude, range -0.03 to -0.05, **default = -0.033**.
- H2 - non-linear component, does not require tuning between sensors, **default = 5000**.
- H3 - time constant, range 1200 to 2000 sec, **default = 1450 sec**.

These parameters can be adjusted if needed for high accuracy applications, but default values typically produce excellent results.

Hysteresis responses of membranes on individual SBE 43 sensors are very similar; in most cases the default parameters provide the accuracy specification of within 2% of true value. For users requiring higher accuracy ($\pm 1 \mu\text{mol/kg}$), the parameters can be fine-tuned if a complete profile (descent and ascent) made preferably to > 3000 meters is available. Hysteresis can be eliminated by alternately adjusting H1 and H3 in the .con or .xmlcon file during comparison of the complete profile with corresponding Winkler water sample values. Once established, these parameters should be stable, and can be used without adjustment on other casts collected using the same SBE 43.

Be sure to perform hysteresis corrections to deep profile data being used to modify the Soc term.

Care of Oxygen Sensors in the Field



Care of Oxygen Sensors in the Field

- Oxygen sensors measure flux of oxygen across a Teflon membrane
- The measurement is sensitive to membrane permeability
- The membrane permeability is decreased by oil or bacterial coating
- SBE 43 does not have a field replaceable membrane
 - Cleaning of sensor used to restore performance

Care of Oxygen Sensors in the Field (*continued*)



Care of SBE 43 Oxygen Sensors in the Field

- Oxygen sensitivity may be maintained by briefly rinsing the sensor with 0.1% Triton X, and then rinsing thoroughly with distilled water
- Oxygen sensitivity may be restored by:
 1. Briefly (1 minute) rinsing with 0.1% Triton X,
 2. Rinsing thoroughly (5 minutes) with distilled water,
 3. Soaking (1 minute) in dilute chlorine bleach,
 4. Rinsing thoroughly (5 minutes) in distilled water.

In the past, we recommended using Triton X-100 for the combined purpose of degreasing and discouraging biological growth. We recently discovered that prolonged exposure of Triton X-100 to the sensor membrane is harmful and causes the sensor's calibration to drift. Our present recommendation is to continue to use Triton X-100 for degreasing (with a short wash), and to use a short wash with a dilute chlorine bleach solution to reduce biological growth.

- Avoid fouling the membrane with oil or grease as this directly affects (reduces) sensor output.
- **Preventive Field Maintenance between Profiles:** After each cast, flush with a 0.1% solution of Triton X-100, using a 60 cc syringe, then rinse thoroughly with fresh water. Between casts, ensure that the membrane remains shaded from direct sunlight and stays cool and humidified.
- **Routine (post-cruise) Cleaning (no visible deposits or marine growths on sensor):**
 1. Soak the sensor for 1 minute in a 50:1 solution of bleach (50 parts de-ionized water to 1 part chlorine bleach). After the soak, drain and flush with warm (not hot) fresh water for 5 minutes.
 2. Soak the sensor for 1 minute in a 1% solution of Triton X-100 warmed to 30 °C. After the soak, drain and flush with warm (not hot) fresh water for 5 minutes.
- **Cleaning severely fouled sensors (visible deposits or marine growths on sensor):** Repeat the *Routine Cleaning* procedure up to 5 times.
- **Long-Term Storage (after field use): Do not fill the tubing with water, Triton solution, or Bleach solution.**
 - If there is no danger of freezing, loop tubing from inlet to outlet. Place a small piece of clean sponge, *slightly dampened* with fresh, clean water, in the center of the tubing (not near the membrane).
 - **If there is danger of freezing, shake all excess water out of the plenum and loop tubing from inlet to outlet, leaving the sensor membrane dry.**
 - To minimize drift during storage, connect 1 end of the tubing loop to the plenum, displace the air in the plenum and tubing with Nitrogen gas, and connect the other end of the tubing to the plenum.


See **Application Note 64** on our website for complete details on cleaning and maintenance.

Care of pH Sensors in the Field

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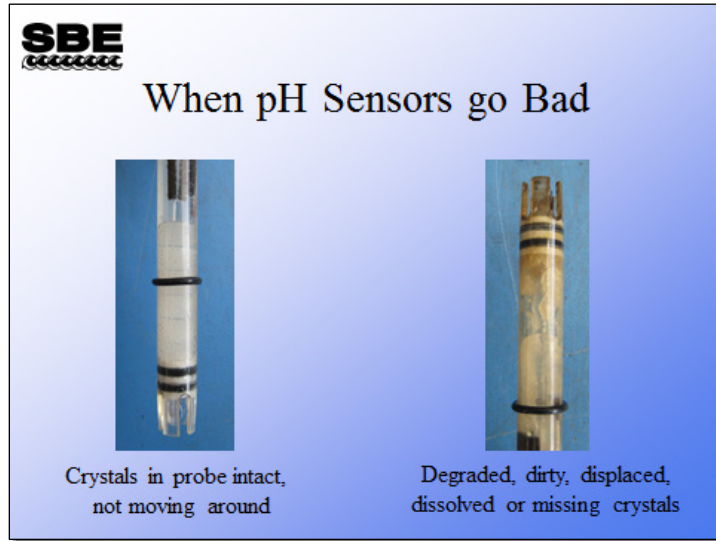
Care of pH Sensors in the Field

- pH sensors should always be stored in a buffer solution saturated with potassium chloride (KCl)
- The sensor will be damaged if it is allowed to dry out




The pH electrode is porous and will dry out if left open to the air. It is always a good practice to keep it in clean, pH 4 buffer solution that has been saturated with potassium chloride (KCl). The electrolyte inside the pH sensor is saturated KCl.

Care of pH Sensors in the Field (*continued*)



Pressure Sensor Drift Characteristics



Pressure Sensor Drift Characteristics

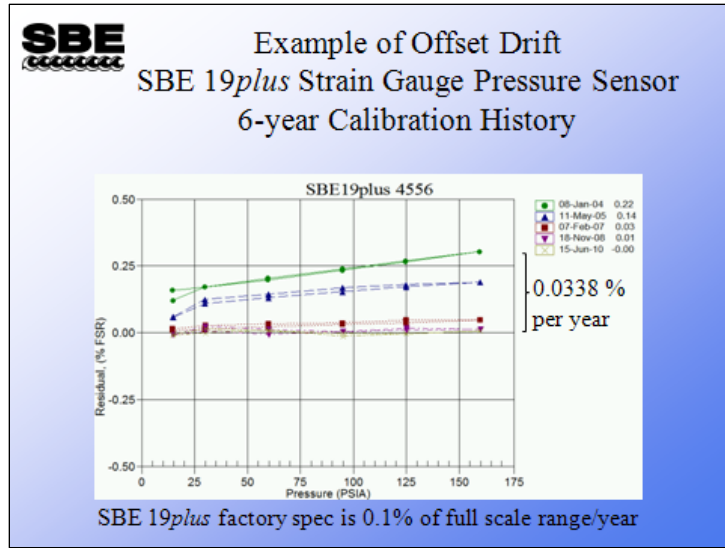
- Pressure sensors tend to drift in offset
- Typical drift rates are 0.018% - 0.05% of full scale / year
- This is easily observed on deck before a cast
- Occasionally, pressure sensors will exhibit hysteresis (different deck reading at start of cast than end of cast)

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

SBE *ocean* **Converting Sensor Output to MKS, CGS, or *Other* Units**

- Sensor converts physical property of the environment to an electrical signal
 - SBE 3 converts temperature to an AC signal; frequency of this signal varies with temperature
 - SBE 4 and SBE conductivity cells also are frequency sensors
- Sensor output can be frequency or voltage
- Sensor output is converted to MKS via polynomial
 - For example, a conductivity sensor has frequency output f :
 - $C = (g + hf^2 + if^3 + jf^4) / (10 (1 + \delta t + \epsilon p))$
 - Coefficients (g, h, i, j) are obtained by calibration
 - δ and ϵ are nominal values, characteristics of glass

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:

$$T [^{\circ}\text{C}] = [1 / (g + h \ln(f_0/f) + i \ln^2(f_0/f) + j \ln^3(f_0/f))] - 273.15$$

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

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

Converting to Scientific Units: Calibration



How Do We Calibrate?

- Sensors are placed in a known environment
- Sensor output is collected and compared to either a physical standard or a reference sensor (also called a secondary standard)
- Examples of physical standards are a triple-point-of-water cell, gallium melt cell, pH buffer, vial of standard seawater
- *Calibration details are in your book and will be explained extensively on the tour*

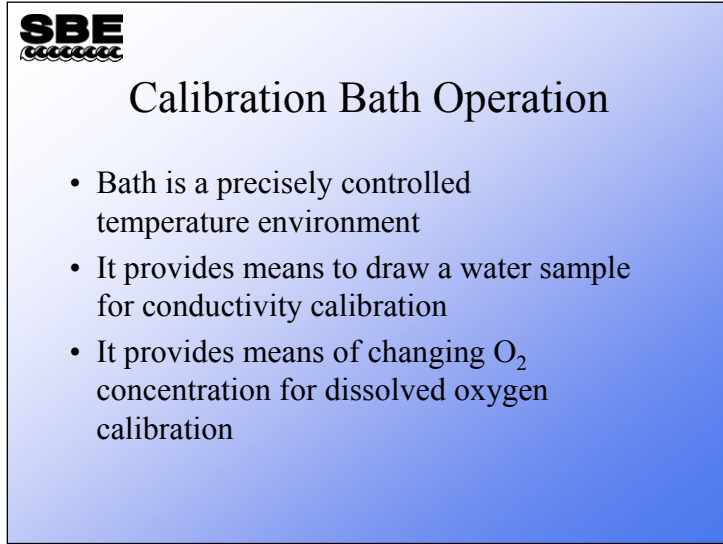
To calibrate a sensor, it is placed in a precisely controlled environment. The output of the sensor is collected at the same time as the environment is measured with a reference sensor. The reference sensor is carefully calibrated and has a well-known history. To gain the careful calibration and history, 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*)

A blue gradient rectangular box containing the SBE logo and text. The logo is in the top left corner. The title 'Calibration Bath Operation' is centered. Below the title is a bulleted list of three points.

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Calibration Bath Operation

- Bath is a precisely controlled temperature environment
- It provides means to draw a water sample for conductivity calibration
- It provides means of changing O₂ concentration for dissolved oxygen calibration

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*)

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Temperature Primary Standards

- Over oceanographic temperature range, triple point of water and melting point of gallium are used as primary standards
- Triple point of water is 0.010000 °C
- Melting point of gallium is 29.764600 °C

Triple Point of Water Cell



Gallium Melt Cell




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 H₂O, 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*)




Transfer Standards

- Standard grade platinum thermometer is calibrated in triple point of water and gallium melt
- Special reference SBE 3 thermometers are calibrated with platinum thermometer
- All other Sea-Bird thermometers are calibrated with reference SBE 3s

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*)



Conductivity Primary Standard

- Standard seawater: North Atlantic water filtered and adjusted to be 35.000 psu
- Used as primary standard for seawater conductivity measurements worldwide


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*)

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Pressure Standards


- Digi quartz pressure sensor serves as secondary standard for all instruments



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

For instruments (SBE *9plus*, *26plus*, *53*, etc.) that have a Digi quartz pressure sensor, a true calibration of the sensor is performed by the pressure sensor manufacturer. The quality of the Digi quartz 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 Digi quartz 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 Digi quartz pressure sensor as a secondary standard.

Converting to Scientific Units: Calibration (*continued*)



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Dissolved O₂ and pH Standards

- Winkler titrations for Dissolved Oxygen
- Standard buffer solutions for pH

Dissolved oxygen sensors are calibrated in a bath that is plumbed with oxygen and nitrogen inputs. As gas concentrations are varied during calibration, Winkler samples are collected. These are titrated for dissolved oxygen concentration during the time of the calibration.

pH sensors are calibrated with commercially available buffer solutions.

Converting to Scientific Units: Calibration (*continued*)



Calibration Certificates

- Calibration Coefficients are arrived at by mathematically fitting calibration data to an equation
- Certificates list coefficients and equation to convert sensor output to MKS units
- A plot and table of residuals are included as an indication of goodness-of-fit

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):

$$\text{residual} = \text{instrument} - \text{bath}$$

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

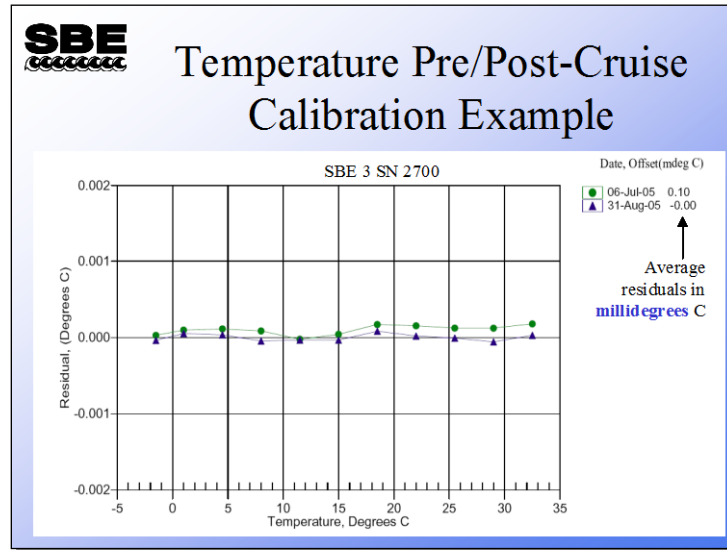
Using Calibrations to Improve your Data



Using Pre/Post-Cruise Calibrations to Adjust Data

- Pre-cruise calibrations indicate state of sensor before data is collected
- Post-cruise calibrations indicate how sensor changed during time data was collected
- Slope and/or offset changes can be added to calibration coefficients

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)



Temperature Pre/Post-Cruise Calibration Example

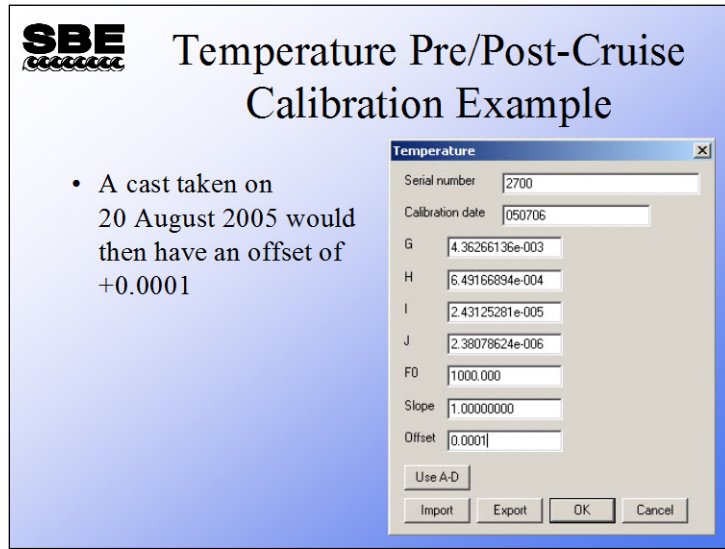
- Sensor in previous slide is found to have drifted +0.0000018 Degrees/day between July 6th and August 31st
- Offset entry in *.con* or *.xmlcon* file is changed to reflect appropriate drift for each cast

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.

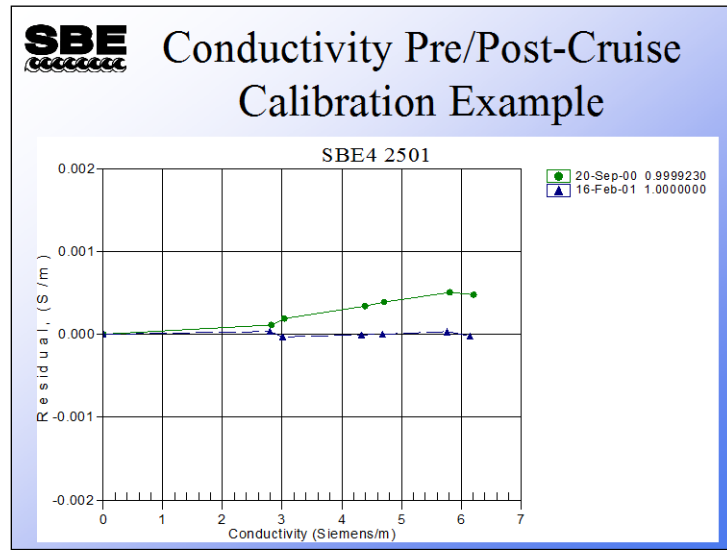
Temperature: Using Calibrations to Improve your Data (continued)



The slide features the SBE logo in the top left corner. The main title is "Temperature Pre/Post-Cruise Calibration Example". To the left of a screenshot is a bullet point: "A cast taken on 20 August 2005 would then have an offset of +0.0001". The screenshot shows a "Temperature" dialog box with the following fields: Serial number (2700), Calibration date (050706), G (4.36265136e-003), H (6.49166894e-004), I (2.43125281e-005), J (2.38078624e-006), F0 (1000.000), Slope (1.00000000), and Offset (0.0001). At the bottom of the dialog are buttons for "Use A-D", "Import", "Export", "OK", and "Cancel".

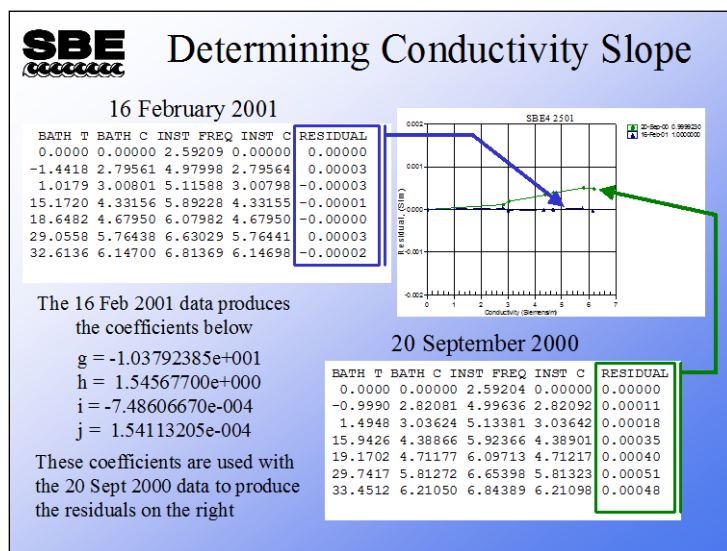
As we noted in the previous slide, the SBE 3 drifted +0.0001 degrees over 56 days, this is +0.0000018 degrees per day. The first day of the cruise is August 20th. Therefore, the offset will be +0.000081 (0.0000018 degrees/day x 45 days since the calibration) and will increase +0.0000018 every day of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

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)



Conductivity Pre/Post-Cruise Calibration Example

- Sensor in previous slide is found to have drifted with slope (*postslope*) of 0.999923 between 16 February 2001 and 20 September 2000: 149 days
- Slope entry in *.con* or *.xmlcon* file (*islope*) for 11 January 2001 (day 113 of 149) is 1.000058
- Slope entry in *.con* or *.xmlcon* file is changed to reflect appropriate drift for each cast

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 -

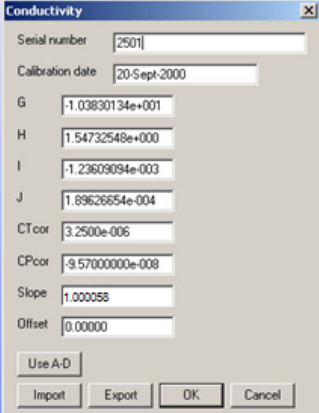
postslope = 0.999923 (at top right of calibration sheet in previous slide)

islope = 1 + (113 / 149) [(1 / 0.999923) - 1] = 1.000058

Conductivity: Using Calibrations to Improve your Data (continued)

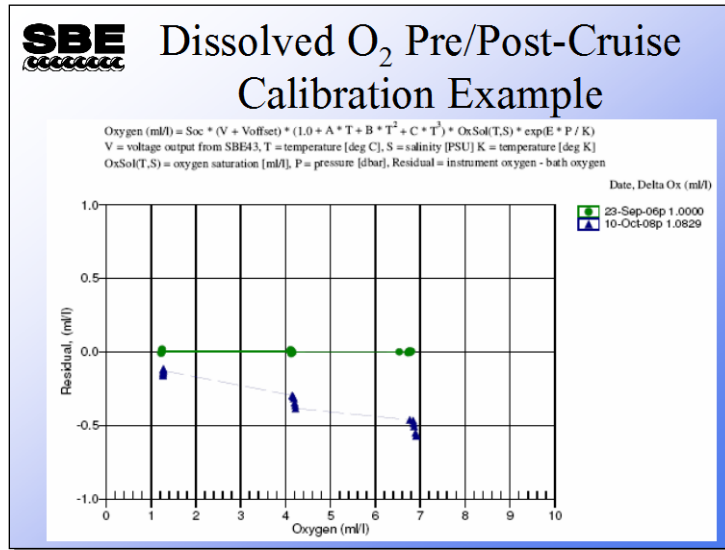
SBE Conductivity Pre/Post-Cruise Calibration Example

- A cast taken on 11 January 2001 would then have slope of 1.000058
- Typical slope corrections may be calculated on weekly interval



Parameter	Value
Serial number	2501
Calibration date	20-Sept-2000
G	-1.03830134e+001
H	1.54732548e+000
I	-1.23609094e-003
J	1.89626654e-004
CTcor	3.2500e-006
CPcor	-9.57000000e-008
Slope	1.000058
Offset	0.00000

Oxygen: Using Calibrations to Improve your Data



Dissolved oxygen sensors are expected to drift in a similar manner to conductivity. For fouling and to a lesser degree chemical reasons, they lose sensitivity over time. The equation for calculating oxygen concentration from sensor output has a slope term, *Soc*, and an offset term, *Voffset*. It is expected that *Soc* will slowly increase with time, indicating a decrease in sensitivity. *Voffset* remains stable, though may vary slightly between calibrations due to fitting all coefficients to cal bath data.

Oxygen: Using Calibrations to Improve your Data (continued)




Dissolved O₂ Pre/Post-Cruise Calibration Example

- Sensor in previous slide is found to have a beginning *Soc* of 0.3728 and an ending *Soc* of 0.4029
- Length of time between calibrations is 747 days; *Soc* will change 0.00004/day
- *Soc* entry in *.con* or *.xmlcon* file is changed to reflect appropriate drift for each day; the need for accuracy determines the frequency of *Soc* update

The factory oxygen sensor calibration sheet provides the value for *Soc* (that portion of the calibration sheet is not shown in the previous slide).

Note that this strategy of drift correction assumes a uniform, linear change over the time between calibrations. A sensor that is handled carefully and cleaned periodically will exhibit this behavior. However, episodic fouling of the membrane by either oils or bacteria can result in a drift more exponential in nature.

Oxygen: Using Calibrations to Improve your Data (continued)



Dissolved O₂ Pre/Post-Cruise Calibration Example

- A cast taken 23 Sep 2006 has an *Soc* of 0.3728 (factory calibration, shown on calibration sheet)
- A cast taken 23 Sep 2007 has an *Soc* of $0.3728 + (365 * 0.00004) = 0.3874$
- See notes for a discussion of *Tau20*

Oxygen, SBE 43

Serial number: 0603
 Calibration date: 23-sep-2007

Use Owens-Millard Equation
 Use Sea-Bird equation -- only for SBE calibration in 2008 and later

Soc: 0.3874	D1: 1.92634e-004
Voffset: -5.25000e-001	D2: -4.64803e-002
A: -2.95900e-004	H1: -3.30000e-002
B: 1.40130e-004	H2: 5.00000e+003
C: -3.36160e-006	H3: 1.45000e+003
E: 3.60000e-002	
Tau20: 1	

A word about Tau: Tau, a term in the Sea-Bird equation, relates the change in oxygen sensor voltage to dissolved oxygen concentration.

Sea-Bird equation:

$$\text{Oxygen (ml/l)} = \left\{ \text{Soc} * \left(V + \text{Voffset} + \text{tau}(T, P) * \frac{\partial V}{\partial t} \right) \right\} * \text{Oxsol}(T, S) \\ * \left(1.0 + A * T + B * T^2 + C * T^3 \right) * e^{\left(\frac{E * P}{K} \right)}$$

The parts of this equation pertinent to this discussion are:

$\text{tau}(T, P)$ = the term we are discussing = $\text{tau20} * \exp(D1 * P + D2 * [T - 20])$

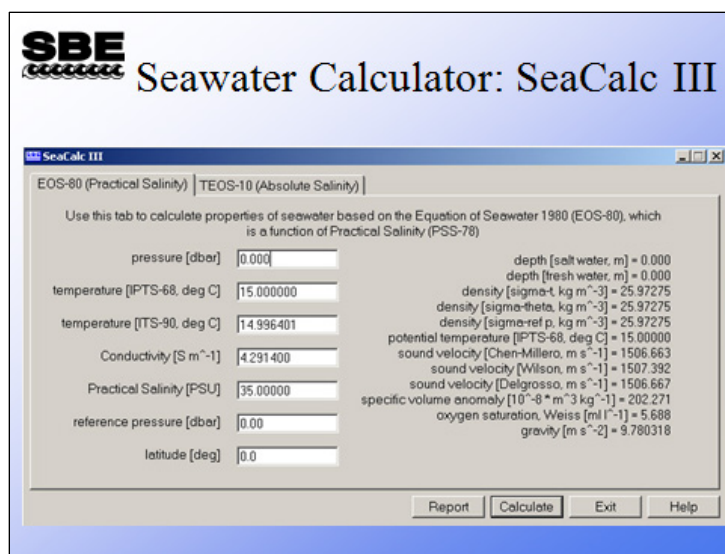
tau20 = sensor time constant $\text{tau}(T, P)$ at 20 °C, 1 atmosphere, 0 PSU;
 slope term in calculation of $\text{tau}(T, P)$

$\delta V / \delta t$ = the change in voltage with time

Thus, $\text{tau}(T, P)$ sharpens the response by adding a term dependent on the change of voltage with time. While this may be helpful in regions of large oxygen gradients, it also amplifies residual noise in the signal (especially in deep water). In some situations, the negative consequence overshadows the gains in signal responsiveness. If you feel that your sensor could benefit from sharpening, feel free to experiment with tau20 .

- To remove the derivative term totally, disable *Apply Tau correction* on the Miscellaneous tab in SBE Data Processing's Data Conversion or Derive module (and on the Miscellaneous tab in Seasave's Configure Inputs); this deletes the term $[\text{tau}(T, P) * \delta V / \delta t]$ from the equation.

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 (http://www.seabird.com/application_notes/AN90.htm).

Activity: Correct T & 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

