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**APPLICATION NOTE NO. 31**

**June 2006**

**Computing Temperature and Conductivity *Slope* and *Offset* Correction Coefficients from Laboratory Calibrations and Salinity Bottle Samples**

**Conductivity Sensors**

The conductivity sensor *slope* and *offset* entries in the configuration (.con) file in SEASOFT permit the user to make corrections for sensor drift between calibrations. The correction formula is:

$$\text{(corrected conductivity)} = \text{slope} * \text{(computed conductivity)} + \text{offset}$$

where :

$$\text{slope} = \text{(true conductivity span)} / \text{(instrument reading conductivity span)}$$

$$\text{offset} = \text{(true conductivity - instrument reading conductivity)} * \text{slope} \quad \text{measured at } 0 \text{ S/m}$$

For newly calibrated sensors, use slope = 1.0, offset = 0.0.

Sea-Bird conductivity sensors usually drift by changing span (the slope of the calibration curve), and changes are typically toward lower conductivity readings with time. Any offset error in conductivity (error at 0 S/m) is usually due to electronics drift, typically less than ±0.0001 S/m per year. Offsets greater than ±0.0002 S/m per year are symptomatic of sensor malfunction. **Therefore, Sea-Bird recommends that conductivity drift corrections be made by assuming no offset error, unless there is strong evidence to the contrary or a special need.**

*Example*

true conductivity = 3.5 S/m  
 instrument reading conductivity = 3.49965 S/m  
 slope = 3.5 / 3.49965 = 1.000100

**Correcting for Conductivity Drift Based on Pre- and Post-Cruise Laboratory Calibrations**

Suppose a conductivity sensor is calibrated (pre-cruise), then immediately used at sea, and then returned for post-cruise calibration. The pre- and post-cruise calibration data can be used to generate a slope correction for data obtained between the pre- and post-cruise calibrations.

If  $\alpha$  is the conductivity computed from the **pre-cruise bath data** (temperature and frequency) using **post-cruise calibration coefficients** and  $\beta$  is the true conductivity in the **pre-cruise bath**, then:

$$\text{postslope} = \frac{\sum_{i=1}^n (\alpha_i)(\beta_i)}{\sum_{i=1}^n (\alpha_i)(\alpha_i)} \quad \text{(postslope is typically } < 1.0)$$

Sea-Bird calculates and prints the value for postslope on the conductivity calibration sheet (all calibrations since February 1995).

**To correct conductivity data taken between pre- and post-cruise calibrations:**

$$\text{islope} = 1.0 + (b / n) [(1 / \text{postslope}) - 1.0]$$

where

islope = interpolated slope; this is the value to enter in the .con file  
b = number of days between pre-cruise calibration and the cast to be corrected  
n = number of days between pre- and post-cruise calibrations  
postslope = slope from calibration sheet as calculated above

In the .con file, use the **pre-cruise calibration coefficients** and use **islope** for the value of slope.\*

**Note:** The CTD configuration (.con) file is edited using the Configure menu (in SEASAVE or SBE Data Processing in our SEASOFT-Win32 suite of programs) or the Configure Inputs menu in SEASAVE V7.

For typical conductivity drift rates (equivalent to -0.003 PSU/month), islope does not need to be recalculated more frequently than at weekly intervals.

\* You can also calculate preslope. If  $\alpha$  is the conductivity computed from **post-cruise bath data** (temperature and frequency) using **pre-cruise calibration coefficients** and  $\beta$  is the true conductivity in the **post-cruise bath**, then:

$$\text{preslope} = \frac{\sum_{i=1}^n (\alpha_i)(\beta_i)}{\sum_{i=1}^n (\alpha_i)(\alpha_i)} \text{ (preslope is typically } > 1.0)$$

In this case, pre-cruise calibration coefficients would be used and:

$$\text{islope} = 1.0 + (b / n) (\text{preslope} - 1.0)$$

**Correcting for Conductivity Drift Based on Salinity Bottles Taken At Sea**

For this situation, the **pre-cruise** calibration coefficients are used to compute conductivity and CTD salinity. Salinity samples are obtained using water sampler bottles during CTD profiles, and the difference between CTD salinity and bottle salinity is used to determine the drift in conductivity.

*In using this method to correct conductivity, it is important to realize that differences between CTD salinity and hydrographic bottle salinity are due to errors in conductivity, temperature, and pressure measurements, as well as errors in obtaining and analyzing bottle salinity values. For typical Sea-Bird sensors that are calibrated regularly, 70 - 90% of the CTD salinity error is due to conductivity calibration drift, 10 - 30% is due to temperature calibration drift, and 0 - 10% is due to pressure calibration drift. All CTD temperature and pressure errors and bottle errors must first be corrected before attributing the remaining salinity difference as due to CTD conductivity error and proceeding with conductivity corrections.*

*Example*

Three salinity bottles are taken during a CTD profile; assume for this discussion that shipboard analysis of the bottle salinities is perfect. The **uncorrected** CTD data (from SEASAVE) and bottle salinities are:

Approximate Depth (m)	CTD Raw Pressure (dbar)	CTD Raw Temperature (°C) *	CTD Raw Conductivity (S/m)	CTD Raw Salinity	Bottle Salinity
200	202.7	18.3880	4.63421	34.9705	34.9770
1000	1008.8	3.9831	3.25349	34.4634	34.4710
4000	4064.1	1.4524	3.16777	34.6778	34.6850

\* Temperatures shown are **ITS-90**. However, the salinity equation is in terms of **ITS-68**; you must convert ITS-90 to ITS-68 ( $ITS-68 = 1.00024 * ITS-90$ ) before calculating salinity. SEASOFT does this automatically.

The uncorrected salinity differences (CTD raw salinity - bottle salinity) are approximately -0.007 psu. To determine conductivity drift, first correct the CTD temperature and pressure data. Suppose that the error in temperature is +0.0015 °C uniformly at all temperatures, and the error in pressure is +0.5 dbar uniformly at all pressures (drift offsets are obtained by projecting the drift history of both sensors from pre-cruise calibrations). Enter these offsets in the .con file to calculate the corrected CTD temperature and pressure, and calculate the CTD salinity using the corrected CTD temperature and pressure. This correction method assumes that the pressure coefficient for the conductivity cell is correct. The CTD data with **corrected** temperature (ITS-90) and pressure are:

Corrected CTD Pressure (dbar)	Corrected CTD Temperature (°C)	CTD Raw Conductivity (S/m)	CTD Salinity [T,P Corrected]	Bottle Salinity
202.2	18.3865	4.63421	34.9719	34.9770
1008.3	3.9816	3.25349	34.4653	34.4710
4063.6	1.4509	3.16777	34.6795	34.6850

The salinity difference (CTD salinity – bottle salinity) of approximately -0.005 psu is now properly categorized as conductivity error, equivalent to about -0.0005 S/m at 4.0 S/m.

Compute bottle conductivity (conductivity calculated from bottle salinity and CTD temperature and pressure) using SeacalcW (in SBE Data Processing); enter bottle salinity for *salinity*, corrected CTD temperature for *ITS-90 temperature*, and corrected CTD pressure for *pressure*:

CTD Raw Conductivity (S/m)	Bottle Conductivity (S/m)	[CTD - Bottle] Conductivity (S/m)
4.63421	4.63481	-0.00060
3.25349	3.25398	-0.00049
3.16777	3.16822	-0.00045

By plotting conductivity error versus conductivity, it is evident that the drift is primarily a slope change. If  $\alpha$  is the CTD conductivity computed with **pre-cruise** coefficients and  $\beta$  is the true bottle conductivity, then:

$$\text{slope} = \frac{\sum_{i=1}^n (\alpha_i)(\beta_i)}{\sum_{i=1}^n (\alpha_i)(\alpha_i)} \quad (\text{slope is typically } > 1.0)$$

Using the above data, the slope correction coefficient for conductivity at this station is:

$$\text{Slope} = [(4.63421 * 4.63481) + (3.25349 * 3.25398) + (3.16777 * 3.16822)] / [(4.63421 * 4.63421) + (3.25349 * 3.25349) + (3.16777 * 3.16777)] = +1.000138$$

Following Sea-Bird’s recommendation of assuming no offset error in conductivity, **set offset to 0.0**.

## Temperature Sensors

The temperature sensor *slope* and *offset* entries in the configuration (.con) file in SEASOFT permit the user to make corrections for sensor drift between calibrations. The correction formula is:

$$\text{corrected temperature} = \text{slope} * (\text{computed temperature}) + \text{offset}$$

where :

$$\text{slope} = (\text{true temperature span}) / (\text{instrument reading temperature span})$$

$$\text{offset} = (\text{true temperature} - \text{instrument reading temperature}) * \text{slope} \quad \text{measured at } 0.0 \text{ } ^\circ\text{C}$$

For newly calibrated sensors, use slope = 1.0, offset = 0.0.

Sea-Bird temperature sensors usually drift by changing offset (an error of equal magnitude at all temperatures). In general, the drift can be toward higher or lower temperature with time; however, for a specific sensor the drift remains the same sign (direction) for many consecutive years. Many years of experience with thousands of sensors indicates that the drift is smooth and uniform with time, allowing users to make very accurate drift corrections to field data based only on pre- and post-cruise laboratory calibrations.

Span errors cause slope errors, as described in the equation for slope above. Sea-Bird temperature sensors rarely exhibit span errors larger than 0.005 °C over the range -5 to 35 °C, even after years of drift. Temperature calibrations performed at Sea-Bird since January 1995 have slope errors less than 0.0002 °C in 30 °C. Prior to January 1995, some calibrations were delivered that include slope errors up to 0.004 °C in 30 °C because of undetected systematic errors in calibration. A slope error that increases by more than ±0.0002 [°C per °C per year] indicates an unusual aging of electronic components and is symptomatic of sensor malfunction. **Therefore, Sea-Bird recommends that drift corrections to temperature sensors be made assuming no slope error, unless there is strong evidence to the contrary or a special need.**

Calibration checks at-sea are advisable for consistency checks of the sensor drift rate and for early detection of sensor malfunction. However, data from reversing thermometers is rarely accurate enough to make calibration corrections that are better than those possible by shore-based laboratory calibrations. **For the SBE 9plus**, a proven alternate consistency check is to use dual SBE 3 temperature sensors on the CTD and to track the difference in drift rates between the two sensors. In the deep ocean, where temperatures are uniform, the difference in temperature measured by two sensors can be resolved to better than 0.0002 °C and will change smoothly with time as predicted by the difference in drift rates of the two sensors.

## Correcting for Temperature Drift Based on Pre- and Post-Cruise Laboratory Calibrations

Suppose a temperature sensor is calibrated (pre-cruise), then immediately used at-sea, and then returned for post-cruise calibration. The pre-and post-cruise calibration data can be used to generate an offset correction for data obtained between the pre- and post-cruise calibrations.

Calibration coefficients are calculated with the post-cruise calibration. Using the pre-cruise bath data and the post-cruise calibration coefficients, a mean residual over the calibration temperature range is calculated.

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

Sea-Bird calculates and prints the value for the residual on the temperature calibration sheet.

### To correct temperature data taken between pre- and post-cruise calibrations:

$$\text{Offset} = b * (\text{residual} / n)$$

where

b = number of days between pre-cruise calibration and the cast to be corrected

n = number of days between pre- and post-cruise calibrations

residual = residual from calibration sheet as described above

In the .con file, use the **pre-cruise calibration coefficients** and use the **negative of the offset** for the value of offset (offset is added, so to remove negative drift a positive number is entered in the .con file).

**Note:** The CTD configuration (.con) file is edited using the Configure menu (in SEASAVE or SBE Data Processing in our SEASOFT-Win32 suite of programs) or the Configure Inputs menu in SEASAVE V7.

#### Example

Instrument was calibrated (pre-cruise), used at sea for 4 months, and returned for post-cruise calibration. Using **pre-cruise bath data** and **post-cruise coefficients**, the calibration sheet shows a mean residual of -0.2 millidegrees C (-0.0002 °C).

For preliminary work at sea, use the **pre-cruise calibration coefficients** and **slope = 1.0, offset = 0.0**. After the cruise, correct temperature data obtained during the cruise for drift using properly scaled values of correction coefficients:

For data from the end of the first month (30 days) at sea:

$$\text{Offset} = b * (\text{residual} / n) = 30 * (0.0002 / 120) = - 0.00005;$$

Convert data using **pre-cruise coefficients** and **+0.00005** as the offset in the .con file.

(Notice the change in sign for the offset entry in the .con file)

For data from the end of the second month (60 days) at sea:

$$\text{Offset} = b * (\text{residual} / n) = 60 * (0.0002 / 120) = - 0.0001;$$

Convert data using **pre-cruise coefficients** and **+0.0001** as the offset in the .con file.

For data from the end of the third month (90 days) at sea:

$$\text{Offset} = b * (\text{residual} / n) = 90 * (0.0002 / 120) = - 0.00015;$$

Convert data using **pre-cruise coefficients** and **+0.00015** as the offset in the .con file.

For data from the end of the 4-month cruise:

$$\text{Offset} = - 0.0002;$$

Convert data using **pre-cruise coefficients** and **+0.0002** as the offset in the .con file, or using **post-cruise coefficients** and **0** as the offset in the .con file.