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

Conductivity Sensors

SEASOFT’s prompt for slope and offset values when the conductivity sensor is selected when setting up the configuration (.con) file permits the user to make corrections for sensor drift between calibrations. For newly calibrated sensors use slope = 1.0, offset = 0.0. The correction formula is:

\[
\text{(corrected conductivity)} = \text{slope} \times (\text{computed conductivity}) + \text{offset}
\]

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

As an example of computing these correction coefficients, if we had the following calibration data:

- true conductivity: 3.5 S/m
- instrument reading: 3.49965 S/m

\[
\text{slope} = \frac{3.5}{3.49965} = 1.000100
\]

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 taken 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:

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

Beginning in February 1995, the value for postslope was calculated and printed on the conductivity calibration sheet.
To correct conductivity data taken between pre- and post-cruise calibrations:

Let:

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

\[ \text{islope} = 1.0 + \left(\frac{b}{n}\right) \left(\frac{1}{\text{postslope}} - 1.0\right) \]

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 SEACON (in SEASOFT-DOS).

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

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

\[
\text{Preslope} = \frac{\sum_{i=1}^{n} (\alpha_i)(\beta_i)}{\sum_{i=1}^{n} (\alpha_i)(\alpha_i)}
\]

(pресslope is typically > 1.0)

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

\[ \text{islope} = 1.0 + \left(\frac{b}{n}\right) (\text{preslope} - 1.0) \]

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**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). All CTD temperature and pressure errors and bottle errors must first be corrected before attributing the remaining salinity difference as CTD conductivity error and proceeding with conductivity corrections.*

Suppose that at a Pacific Ocean station, three salinity bottles are taken during a CTD profile and assume for this discussion that shipboard analysis of the bottle salinities is perfect. The bottle salinities and the **uncorrected** CTD data might be:
The uncorrected salinity differences (CTD salinity - bottle salinity) are approximately -0.007 ppt. To determine conductivity drift, the CTD temperature and pressure data must first be corrected. Suppose that the error in temperature measurements is +0.0015 C uniformly at all temperatures, and the error in pressure is +0.5 dbar uniformly at all pressures. The drift offsets are obtained by projecting the drift history of both sensors from pre-cruise calibrations. If these offsets are entered in the .con file, the correct CTD temperature and pressure will be the reported raw values and will need no further correction. In addition, the CTD raw salinity will be reported using the correct CTD temperature and pressure. This correction method also assumes that the pressure coefficient for the conductivity cell is correct. The CTD data with corrected temperature and pressure are:

<table>
<thead>
<tr>
<th>Correct CTD Pressure (dbar)</th>
<th>Correct CTD Temperature (°C)</th>
<th>CTD Conductivity (S/m)</th>
<th>CTD Salinity T,P Corrected</th>
<th>Bottle Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>202.2</td>
<td>18.3909</td>
<td>4.63421</td>
<td>34.9719</td>
<td>34.9770</td>
</tr>
<tr>
<td>1008.3</td>
<td>3.9826</td>
<td>3.25349</td>
<td>34.4652</td>
<td>34.4710</td>
</tr>
<tr>
<td>4063.6</td>
<td>1.4512</td>
<td>3.16777</td>
<td>34.6796</td>
<td>34.6850</td>
</tr>
</tbody>
</table>

The (CTD-bottle) salinity difference of -0.005 ppt is now properly assigned as conductivity error, equivalent to about -0.0005 S/m at 4.0 S/m. By plotting the conductivity error versus conductivity, it is evident that the drift is primarily a slope change.

The program SEACALC (in SEASOFT-DOS) can be used to compute bottle conductivity. Enter bottle salinity for salinity, CTD corrected temperature for temperature, and CTD corrected pressure for pressure.

<table>
<thead>
<tr>
<th>CTD Conductivity (S/m)</th>
<th>Bottle Conductivity (S/m)</th>
<th>[CTD - Bottle] Conductivity (S/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.63421</td>
<td>4.63481</td>
<td>-0.00060</td>
</tr>
<tr>
<td>3.25349</td>
<td>3.25398</td>
<td>-0.00049</td>
</tr>
<tr>
<td>3.16777</td>
<td>3.16821</td>
<td>-0.00044</td>
</tr>
</tbody>
</table>

If \( \alpha \) is the CTD conductivity computed with pre-cruise coefficients and \( \beta \) is the true bottle conductivity then:

\[
\text{slope} = \frac{\sum_{i=1}^{n} (\alpha_i)(\beta_i)}{\sum_{i=1}^{n} (\alpha_i)^2} \quad \text{(slope is typically > 1.0)}
\]

Using the above data, the slope correction coefficient for conductivity at this station is \( \text{slope} = +1.000137 \). Following Sea-Bird's recommendation of assuming no offset error in conductivity, offset is set to 0.0.

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 only 0% - 10% is due to pressure calibration drift.
Temperature Sensors

SEASOFT’s prompt for slope and offset values when the temperature sensor is selected when setting up the configuration (.con) file permits the user to make corrections for sensor drift between calibrations. For newly calibrated sensors, use slope = 1.0, offset = 0.0. The correction formula is:

\[(\text{corrected temperature}) = \text{slope} \times (\text{computed temperature}) + \text{offset}\]

where:
slope = (true temperature span) / (instrument temperature span)
offset = (true temperature - instrument reading) \times \text{slope measured at 0.0 °C}

As an example of computing the correction coefficients, if we had the following calibration data:

<table>
<thead>
<tr>
<th>true temperature</th>
<th>0.0 °C</th>
<th>25.0 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>instrument reading</td>
<td>0.0015 °C</td>
<td>25.0013 °C</td>
</tr>
</tbody>
</table>

\[\text{slope} = (25.0 - 0.0) / (25.0013 - 0.0015) = 1.000008000\]
\[\text{offset} = (0.0 - 0.0015) \times (1.000008000) = -0.00150002\]

For this example Sea-Bird would recommend the drift correction values (entered in the .con file)

slope = 1.0  offset = -0.0015  measured at 0.0 °C

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 will remain the same sign (direction) for many consecutive years. A large span error (change in calibration slope) indicates an unusual aging of electronic components and is symptomatic of sensor malfunction. Sea-Bird therefore recommends that drift corrections to temperature sensors be made by assuming no slope error, unless there is strong evidence to the contrary or a special need.

Sensors with serial numbers less than 1050 drift more typically toward higher temperature with time, while sensors with serial numbers greater than 1050 drift more typically toward lower temperature with time. Many years of experience with hundreds 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.

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. A proven alternate consistency check is to use dual SBE 3 temperature sensors on a 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.

The temperature sensors rarely exhibit span errors larger than 0.005 °C over the range -5 to 35 °C even after years of drift. A span error that increases by more than ±0.0002 [°C per °C per year] is symptomatic of sensor malfunction. Previous to January 1993 some calibrations have been delivered that include span errors up to 0.004 °C in 30 °C (span error of 0.000133) because of undetected systematic errors in calibration. Temperature calibrations preformed at Sea-Bird after January 1995 have span error less than 0.0002 °C in 30 °C.
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 for 4 months, and then returned for post-cruise calibration. Converting the post-cruise calibration data using the pre-cruise coefficients, we obtain the estimates:

Real Temperature....... 0.0° ...... 25.0°C
Instrument Reading..... 0.002°... 25.001°C

These calibration data correspond to offset error = +0.002 °C, and span error = -0.00004 [°C per °C] at the end of 4 months of use. The correction coefficients are slope= 1.000040002, offset= -0.00200008. Note the difference between the error value and the value of the correction coefficient.

For preliminary work at sea, use the pre-cruise calibration coefficients and slope = 1.0, offset = 0.0. Temperature data obtained during the cruise is corrected for drift using properly scaled values of correction coefficients. Data from the end of the second month at sea would be converted using pre-cruise coefficients and slope=1.00002, offset= -0.001. At the end of the 4-month cruise, data could be converted by either using pre-cruise coefficients and slope=1.00004, offset= -0.002, or by using post-cruise coefficients and slope= +1.0, offset = 0.0.