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APPLICATION NOTE NO. 31 **Revised February 2010**

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 or .xmlcon) file in SEASOFT permit the user to make corrections for sensor drift between calibrations. The correction formula is:

(corrected conductivity) = slope * (computed conductivity) + offset

where :
slope = (true conductivity span) / (instrument reading conductivity span)
offset = (true conductivity - instrument reading conductivity) * slope *measured at 0 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 **α** is the conductivity computed from the **pre-cruise bath data** (temperature and frequency) using **post-cruise calibration coefficients** and **β** is the true conductivity in the **pre-cruise bath**, then:

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

Sea-Bird calculates and prints the value for postslope on the conductivity calibration sheet for all calibrations since February 1995 (see *Appendix I: Example Conductivity Calibration Sheet*)
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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 configuration (.con or .xmlcon) 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 (see *Appendix I: Example Conductivity Calibration Sheet*)

In the configuration (.con or .xmlcon) file, use the **pre-cruise calibration coefficients** and use **islope** for the value of slope.*

Note: In our SEASOFT V2 suite of programs, edit the CTD configuration (.con or .xmlcon) file using the Configure Inputs menu in Seasave V7 (real-time data acquisition software) or the Configure menu in SBE Data Processing (data processing software).

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 **α** is the conductivity computed from **post-cruise bath data** (temperature and frequency) using **pre-cruise calibration coefficients** and **β** is the true conductivity in the **post-cruise bath**, then:

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

In this case, pre-cruise calibration coefficients would be used and:
islope = 1.0 + (b / n) (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 V7) 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 IPTS-68; you must convert ITS-90 to IPTS-68 (IPTS-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 configuration (.con or .xmlcon) 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 **α** is the CTD conductivity computed with **pre-cruise** coefficients and **β** is the true bottle conductivity, then:

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

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

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 or .xmlcon) file in SEASOFT permit the user to make corrections for sensor drift between calibrations. The correction formula is:

corrected temperature = slope * (computed temperature) + offset

where :

slope = (true temperature span) / (instrument reading temperature span)

offset = (true temperature - instrument reading temperature) * slope *measured at 0.0 °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 9*plus***, 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.

residual = instrument temperature – bath temperature

Sea-Bird calculates and prints the value for the residual on the temperature calibration sheet (see *Appendix II: Example Temperature Calibration Sheet*).

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

Offset = b * (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 (see *Appendix II: Example Temperature Calibration Sheet*)

In the configuration (.con or .xmlcon) file, use the **pre-cruise calibration coefficients** and use the calculated **offset** for the value of offset.

Note: In our SEASOFT V2 suite of programs, edit the CTD configuration (.con or .xmlcon) file using the Configure Inputs menu in Seasave V7 (real-time data acquisition software) or the Configure menu in SBE Data Processing (data processing software).

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:
Offset = b * (residual / n) = 30 * (-0.0002 / 120) = - 0.00005;
Convert data using **pre-cruise coefficients** and **-0.00005** as the offset in the configuration file.

For data from the end of the second month (60 days) at sea:
Offset = b * (residual / n) = 60 * (-0.0002 / 120) = - 0.0001;
Convert data using **pre-cruise coefficients** and **-0.0001** as the offset in the configuration file.

For data from the end of the third month (90 days) at sea:
Offset = b * (residual / n) = 90 * (-0.0002 / 120) = - 0.00015;
Convert data using **pre-cruise coefficients** and **-0.00015** as the offset in the configuration file.

For data from the end of the 4-month cruise:
Offset = - 0.0002;
Convert data using **pre-cruise coefficients** and **-0.0002** as the offset in the configuration file, or using **post-cruise** coefficients and **0** as the offset in the configuration file.

Appendix I: Example Conductivity Calibration Sheet

SEA-BIRD ELECTRONICS, INC.

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Phone: (425) 643 - 9866 Fax (425) 643 - 9954 Email: seabird@seabird.com

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

SBE4 CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Seimens/meter

GHIJ 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)
```

Coefficients from *30-Dec-99* calibration.

ABCDM COEFFICIENTS

```
a =  3.56563909e-006
b =  1.48964234e+000
c = -1.02346588e+001
d = -8.62052534e-005
m =  5.4
CPcor = -9.5700e-008 (nominal)
```

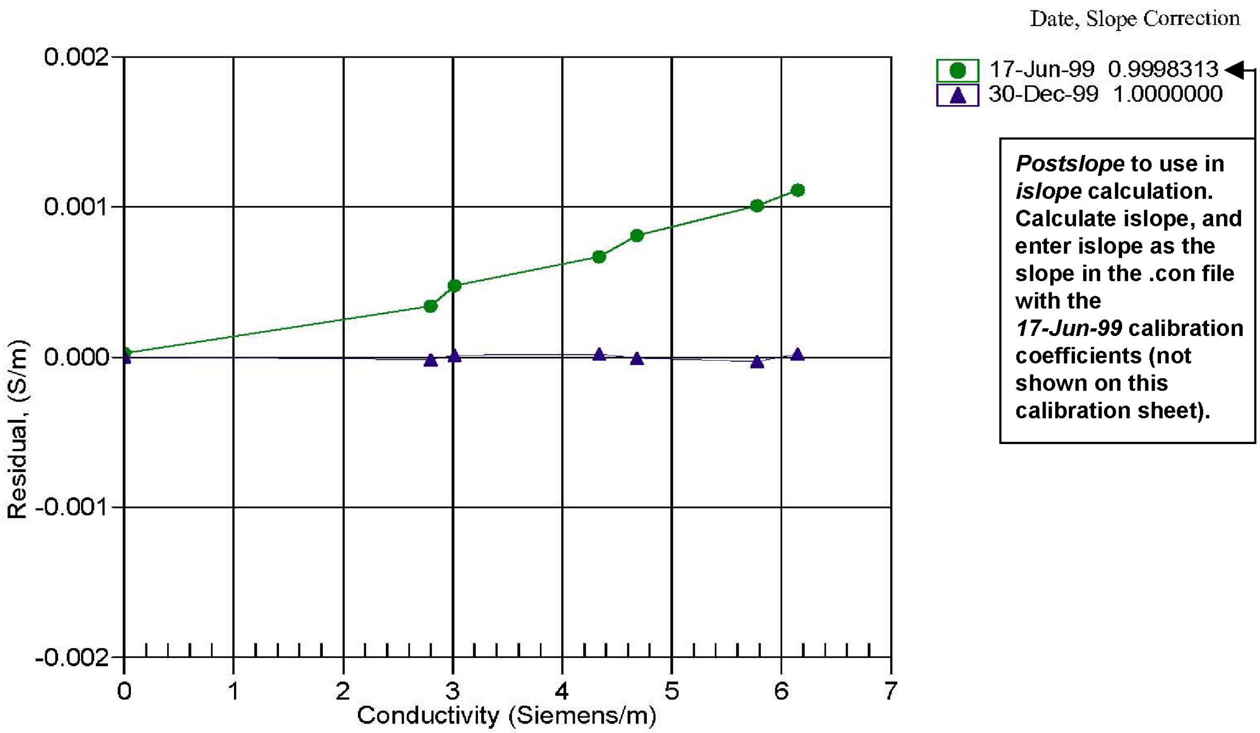
BATH TEMP (ITS-90)	BATH SAL (PSU)	BATH COND (Siemens/m)	INST FREQ (kHz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
0.0000	0.0000	0.00000	2.62109	0.00000	0.00000
-1.3895	35.1839	2.79817	5.06354	2.79815	-0.00002
1.1492	35.1843	3.01746	5.20666	3.01747	0.00001
15.2688	35.1829	4.33837	5.99642	4.33839	0.00002
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

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

Conductivity = $(af^m + bf^2 + c + dt) / [10 (1 + \varepsilon p)$ Siemens/meter

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

Residual = (instrument conductivity - bath conductivity) using g, h, i, j coefficients



Postslope **to use in** ***islope*** **calculation. Calculate islope, and enter islope as the slope in the .con file with the** ***17-Jun-99*** **calibration coefficients (not shown on this calibration sheet).**

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Phone: (425) 643 - 9866 Fax (425) 643 - 9954 Email: seabird@seabird.com

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

SBE3 TEMPERATURE CALIBRATION DATA
IPTS-90 TEMPERATURE SCALE

ITS-90 COEFFICIENTS

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

Coefficients from *28-Dec-99* calibration.

ITS-68 COEFFICIENTS

```
a =  3.67991178e-003
b =  6.04738390e-004
c =  1.65374250e-005
d =  2.36525963e-006
f0 = 2978.914
```

BATH TEMP (ITS-90)	INSTRUMENT FREQ (Hz)	INST TEMP (ITS-90)	RESIDUAL (ITS-90)
-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

Temperature ITS-90 = $1/\{g + h[ln(f_0/f)] + i[ln^2(f_0/f)] + j[ln^3(f_0/f)]\} - 273.15$ (°C)

Temperature IPTS-68 = $1/\{a + b[ln(f_0/f)] + c[ln^2(f_0/f)] + d[ln^3(f_0/f)]\} - 273.15$ (°C)

Following the recommendation of JPOTS: T_{68} is assumed to be 1.00024 * T_{90} (-2 to 35 °C)

Residual = instrument temperature - bath temperature