Using the Conductivity Assistant: Calculating Specific Conductance with Sea Water

The Conductivity Assistant (version 2.0 or earlier) shipped with HOBOware® 3.2.1 has been modified to further refine the equations used to calculate specific conductance with sea water using the U24 Conductivity logger (U24-002 and U24-002-C). Version 2.0 and earlier versions of the Conductivity Assistant were not producing the expected measurements when calculating specific conductance with sea water. Careful analysis determined that the Conductivity Assistant needed an additional level of precision to ensure the calculations were meeting the specified accuracy range (see the logger product manual) for the calibrated specific conductance output when used in sea water. This involved improving the output of specific conductance versus time and the output of salinity versus time, using the Practical Salinity Scale 1978, which is a time-tested tool that provides sufficient accuracy for a conductivity-based measurement system for typical ocean waters. The new calculations are available in version 2.1 of the Conductivity Assistant.

Conductivity Assistant Calculations Prior to Version 2.1

Before examining the revised calculations in the new version 2.1, it is helpful to understand how the measurements were calculated in previous versions. Previous versions used the following process to calculate the measurement of salinity of sea water:

1. A linear compensation temperature coefficient of 2.1%/°C was used to calculate the specific conductance (C_s) at 25°C for sea water with the following equation:

   $C_s = Y_e / (1 - ((25-T) * a / 100))$

   Where: Y_e = Electrical Conductivity
   a = 2.1 % / degrees C (temp. coeff.)
   T = water temperature in degrees C

2. A field-measured specific conductance was used to adjust the beginning of the dataset and the end of the dataset to the measured values to compensate for instrument offset and for fouling of the sensor during deployment.

3. The salinity of the sea water was calculated using PSS-78 equations. If field-measured specific conductance values were used to adjust the specific conductivity values in step 2, the electrical conductivity values were likewise adjusted before the salinity was calculated.

The linear compensation coefficient of 2.1%/°C used to calculate the specific conductance at 25°C for sea water represented the coefficient for sodium chloride (the major component salt of sea water). The temperature coefficient for sea water (a mixture of many salts and chemicals) can vary from 1.8 to 2.1 as a function of sea water temperature and salinity. At low temperatures and low salinities, the coefficient approaches 1.8 and can cause a significant difference in the specific conductance calculation causing a likewise difference in salinity.

A hand-held meter was used to measure the calibration points entered into the Conductivity Assistant. The meter needed to use the same temperature compensation techniques as the Conductivity Assistant to be accurate if the calibration points were entered in specific conductance. Most meters can only use linear coefficients for temperature compensation, with 2.1%/°C typically used for sea water.

Conductivity Assistant Version 2.1 Calculations

To improve the accuracy of the specific conductance data provided by the Conductivity Assistant, a non-linear temperature coefficient is generated that is a function of temperature and salinity. This equation is generated using the PSS-78 equations that solve for salinity from conductivity and temperature (the pressure term is assumed to be atmospheric and is neglected). The assumption in using the PSS-78 equations is that for any conductivity/temperature pair, the temperature coefficient of that data will generate a specific conductivity at 25°C that will calculate the same salinity as the original conductivity/temperature pair.

Version 2.1 of the Conductivity Assistant now uses the following process to calculate specific conductance of each measurement with sea water:

1. Calculate the non-linear temperature coefficient (a):

   a = A+B*T+C*S+D*T^2+E*S^2+F*T*S

   Where: S = Uncorrected salinity calculated in PSS-78 using the conductivity and temperature pair

   T = water temperature in degrees C

   A = 1.86221444E+00

   B = 7.99141780E-03

   C = -2.04882760E-03

   D = -4.79386353E-05

   E = 1.67997158E-05

   F = -1.55721008E-05

2. Use the non-linear compensation temperature coefficient of "a"%/°C to calculate the specific conductance at 25°C for sea water using the following equation:

   $C_s = Y_e / (1 - ((25-T) * a / 100))$

   Where: Y_e = Electrical Conductivity
   a = "see above" % / degrees C (temp. coeff.)
   T = water temperature in degrees C

How was the non-linear temperature coefficient equation above developed using the PSS-78 equation set (reference the spreadsheet in Figures 1A and 1B)?

- The Practical Salinity Scale 1978 (PSS-78) is valid over a temperature range of -2 to 35°C, a salinity range of 2 to 42 psu, and a conductivity range of 1.91 to 74.86 mS/cm.
- Columns 1 and 2 were selected to cover this range.
- The values of conductivities listed in column 3 were calculated using a spreadsheet macro that iteratively calculated the salinity (per PSS-78) in column 2 with the temperature in column 1 until a value of conductivity was found that caused a solution of salinity within 0.01 of the salinity value of column 2.
- The calculated temperature coefficient of column 4 is the coefficient necessary to change the conductivity in column 3 to the conductivity listed for the same salinity at 25°C using $C_s = Y_e / (1 - ((25-T) * a / 100))$.
- The data of columns 1, 2, and 4 were stripped of the 25°C values, because the temperature coefficients of 25°C were "NA" or nonexistent, and the remaining dataset was presented to a 3-dimensional, non-linear regression. A good regression solution was the Taylor series depicted below:

  a = A+B*T+C*S+D*T^2+E*S^2+F*T*S

  WHERE: A = 1.86221444E+00
  B = 7.99141780E-03
  C = -2.04882760E-03
  D = -4.79386353E-05
  E = 1.67997158E-05
  F = -1.55721008E-05

  AND: T = sea water temperature in degrees C
  S = sea water salinity

- Column 5 shows the temperature coefficient calculated by the above equation for each temperature and salinity of columns 1 and 2.

- Column 6 shows the specific conductance calculated using the calculated temperature coefficient of column 5 and the conductivity and temperature of columns 3 and 1. Notice the calculated value is very close to the conductivity calculated at the same salinity for 25°C.
- Column 7 shows the percent difference between the calculated specific conductance of column 6 and the conductivity calculated at the same salinity for 25°C. At the bottom of Figure 1B, notice that the minimum and maximum percent differences are -0.1064% to 0.0857% for all points. These errors are primarily caused by curve fit error, but are well within our system's 3% error.

COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5	COLUMN 6	COLUMN 7
			A =	1.86221444E+00		
			B =	7.99141780E-03		
			C =	-2.04882760E-03		
			D =	-4.79386353E-05		
			E =	1.67997158E-05		
			F =	-1.55721008E-05		
			a = A+B*T+C*S+D*T^2+E*S^2+F*T*S			
T	S		a	a		
TEMPERATURE	SALINITY	CONDUCTIVITY	TEMP COEFFICIENT	CALC TEMP COEFFICIENT	SPEC COND	% ERROR
°C	PSU	mS / cm	% / °C	% / °C	mS / cm	%
-2	2	1.91	1.8764	1.8421	3.80	0.00180
5	2	2.36	1.8947	1.8968	3.80	-0.06606
10	2	2.7	1.9298	1.9330	3.80	-0.06693
15	2	3.05	1.9737	1.9668	3.80	0.08567
20	2	3.42	2.0000	1.9982	3.80	0.00992
25	2	3.8	NA	2.0272	3.80	NA
30	2	4.19	2.0526	2.0538	3.80	0.00551
35	2	4.59	2.0789	2.0781	3.80	-0.00727
-2	5	4.52	1.8682	1.8364	8.97	-0.05644
5	5	5.57	1.8917	1.8908	8.96	0.03157
10	5	6.37	1.9271	1.9267	8.96	0.00741
15	5	7.21	1.9531	1.9603	8.97	-0.08934
20	5	8.07	1.9866	1.9915	8.96	-0.02709
25	5	8.96	NA	2.0203	8.96	NA
30	5	9.88	2.0536	2.0467	8.96	-0.03138
35	5	10.82	2.0759	2.0706	8.96	-0.04352
-2	10	8.62	1.8586	1.8275	17.02	0.07853
5	10	10.62	1.8820	1.8814	17.03	0.01882
10	10	12.13	1.9182	1.9170	17.03	0.02557
15	10	13.71	1.9495	1.9502	17.03	-0.00813
20	10	15.34	1.9847	1.9809	17.03	0.02102
25	10	17.03	NA	2.0093	17.03	NA
30	10	18.76	2.0317	2.0353	17.03	0.01644
35	10	20.53	2.0552	2.0589	17.02	0.03096
-2	15	12.56	1.8518	1.8196	24.69	0.04290
5	15	15.44	1.8745	1.8729	24.69	0.05248
10	15	17.63	1.9082	1.9080	24.70	0.00390
15	15	19.91	1.9393	1.9408	24.70	-0.01951
20	15	22.27	1.9676	1.9712	24.70	-0.02015
25	15	24.7	NA	1.9992	24.70	NA
30	15	27.2	2.0243	2.0249	24.70	0.00255
35	15	29.75	2.0445	2.0481	24.69	0.02927
-2	20	16.38	1.8440	1.8124	32.08	0.04131
5	20	20.12	1.8651	1.8652	32.09	-0.00294
10	20	22.95	1.8988	1.9000	32.10	-0.02386
15	20	25.89	1.9321	1.9324	32.09	-0.00378
20	20	28.95	1.9570	1.9624	32.10	-0.02986
25	20	32.09	NA	1.9900	32.09	NA
30	20	35.33	2.0193	2.0152	32.10	-0.01866
35	20	38.63	2.0380	2.0380	32.09	0.00012
-2	25	20.11	1.8368	1.8061	39.25	0.05034
5	25	24.67	1.8589	1.8583	39.26	0.01973
10	25	28.12	1.8929	1.8927	39.27	0.00330
15	25	31.71	1.9251	1.9247	39.27	0.00489
20	25	35.43	1.9557	1.9544	39.27	0.00738
25	25	39.27	NA	1.9816	39.27	NA
30	25	43.21	2.0066	2.0064	39.27	-0.00095
35	25	47.23	2.0270	2.0288	39.26	0.01538

Figure 1A

COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5	COLUMN 6	COLUMN 7
T	S		a	a		
TEMPERATURE	SALINITY	CONDUCTIVITY	TEMP COEFFICIENT	CALC TEMP COEFFICIENT	SPEC COND	% ERROR
°C	PSU	mS / cm	% / °C	% / °C	mS / cm	%
-2	30	23.76	1.8318	1.8006	46.24	0.04116
5	30	29.11	1.8537	1.8523	46.24	0.04324
10	30	33.16	1.8879	1.8863	46.24	0.03268
15	30	37.38	1.9196	1.9179	46.25	0.02027
20	30	41.75	1.9498	1.9472	46.25	0.01479
25	30	46.26	NA	1.9740	46.26	NA
30	30	50.88	1.9974	1.9985	46.26	0.00476
35	30	55.6	2.0190	2.0205	46.25	0.01223
-2	35	27.34	1.8253	1.7960	53.08	-0.01724
5	35	33.46	1.8476	1.8471	53.06	0.01399
10	35	38.1	1.8805	1.8808	53.07	-0.00460
15	35	42.92	1.9126	1.9120	53.07	0.00709
20	35	47.92	1.9408	1.9408	53.07	-0.00003
25	35	53.07	NA	1.9673	53.07	NA
30	35	58.36	1.9936	1.9913	53.08	-0.01028
35	35	63.76	2.0143	2.0130	53.08	-0.01113
-2	40	30.86	1.8209	1.7922	59.79	-0.09089
5	40	37.73	1.8421	1.8428	59.75	-0.02014
10	40	42.93	1.8759	1.8760	59.74	-0.00262
15	40	48.34	1.9083	1.9069	59.73	0.01713
20	40	53.96	1.9351	1.9353	59.74	-0.00157
25	40	59.74	NA	1.9614	59.74	NA
30	40	65.67	1.9853	1.9851	59.74	-0.00099
35	40	71.72	2.0054	2.0063	59.74	0.00798
-2	42	32.24	1.8190	1.7909	62.43	-0.10643
5	42	39.41	1.8401	1.8413	62.38	-0.03688
10	42	44.83	1.8741	1.8744	62.36	-0.00655
15	42	50.48	1.9051	1.9051	62.36	-0.00007
20	42	56.33	1.9339	1.9334	62.36	0.00311
25	42	62.36	NA	1.9593	62.36	NA
30	42	68.54	1.9820	1.9828	62.36	0.00335
35	42	74.86	2.0045	2.0039	62.36	-0.00506
			MIN =	1.7909	MIN =	-0.10643
			MAX =	2.0781	MAX =	0.08567
			AVG =	1.9387	AVG =	-0.00002

Figure 1B

Calibrating a Conductivity File with a Hand-held Conductivity Meter

In the past, a hand-held meter was used to record the specific conductance of the test water at the beginning and the end of each logger deployment. Since the meter cannot perform the new, non-linear temperature compensation required to output specific conductance, you must instead use the meter to record the conductivity and temperature of the water being measured. These values, taken at the beginning and end of each deployment, must then be entered into Version 2.1 of the Conductivity Assistant Version 2.1, which will convert the recorded conductivity and temperature points to specific conductance at 25°C using the non-linear temperature coefficient equation (Taylor series). The Conductivity Assistant adjusts the specific conductance file calculated from the logger data to match the specific conductance points calculated from the meter data.

How the Conductivity Assistant (Version 2.1) Calculates Specific Conductance and Salinity with Sea Water

To calculate specific conductance and salinity for a data series in a logger data file, the Conductivity Assistant:

1. Reads the selected conductivity range for the data series, either low or high.
2. Reads the recorded conductivity and temperature pair for each selected range.
3. Calculates the preliminary salinity using PSS-78 for each pair.
4. Calculates the temperature coefficient using the temperature coefficient equation (Taylor series) with salinity and temperature for each pair.
5. Calculates specific conductance using the temperature coefficient for each pair.
6. Calculates the hand-held meter specific conductance points and adjusts the specific conductance dataset of the logger per the calibration data (if the “Use measured points for calibration” option is selected).
7. Calculates final Salinity using the specific conductance dataset at 25°C in PSS-78.