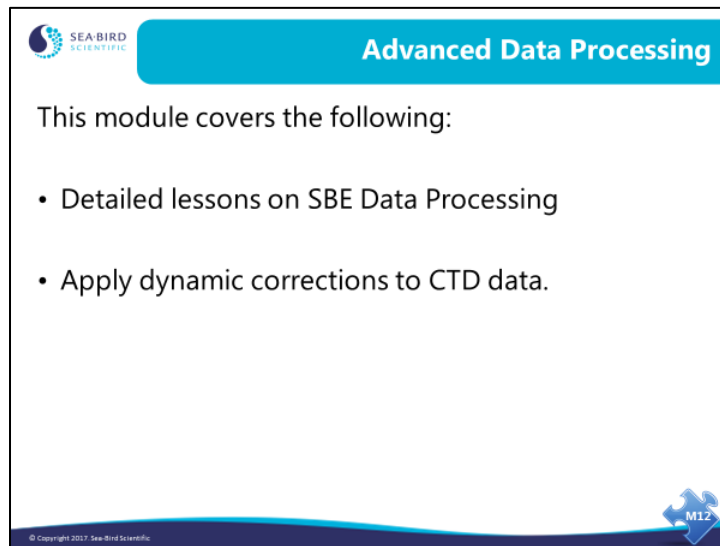




Advanced Data Processing:
Dynamic Corrections for CTDs
Sea-Bird Scientific University Module 12



Overview



SEA-BIRD SCIENTIFIC **Advanced Data Processing**

This module covers the following:

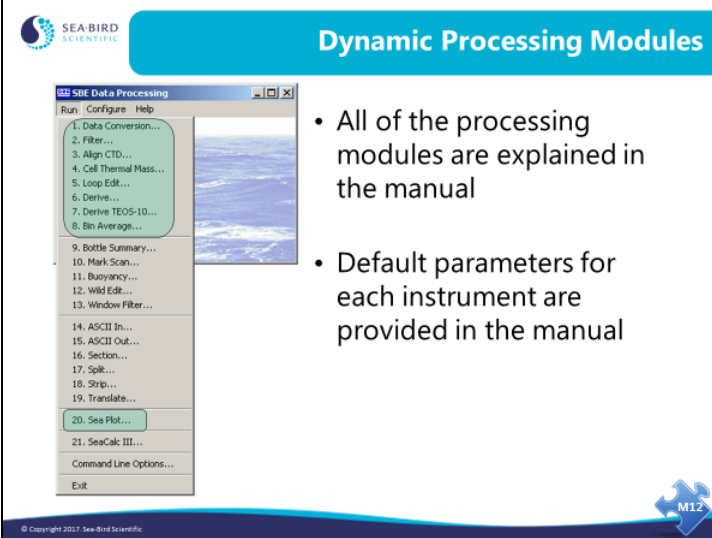
- Detailed lessons on SBE Data Processing
- Apply dynamic corrections to CTD data.

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This section of the course describes using Sea-Bird Data Processing software to make dynamic corrections when profiling. When we finish this module you should be able to:

- Align your conductivity and temperature data relative to pressure.
- Filter your conductivity data so it matches the time response of your temperature data in an *SBE 19plus*.
- Remove the effects of conductivity cell thermal mass from your data.

Data Processing Software



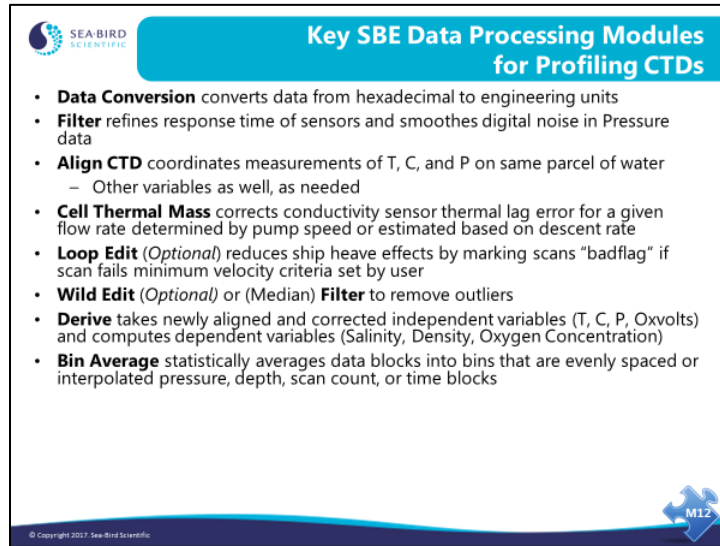
The screenshot displays the 'SBE Data Processing' software window. The title bar reads 'SBE Data Processing'. The menu bar includes 'Run', 'Configure', and 'Help'. The main menu lists 21 numbered processing modules, with '20. Sea Plot...' highlighted. A small preview window on the right shows a satellite image of the ocean. The bottom of the window features a blue wave graphic and a blue diamond icon with 'M12' inside. The copyright notice '© Copyright 2017, Sea-Bird Scientific' is visible in the bottom left corner.

Dynamic Processing Modules

- 1. Data Conversion...
- 2. Filter...
- 3. Align CTD...
- 4. Cell Thermal Mass...
- 5. Loop Edit...
- 6. Derive...
- 7. Derive TEOS-10...
- 8. Bin Average...
- 9. Bottle Summary...
- 10. Mark Scan...
- 11. Buoyancy...
- 12. Wild Edit...
- 13. Window Filter...
- 14. ASCII In...
- 15. ASCII Out...
- 16. Section...
- 17. Split...
- 18. Strip...
- 19. Translate...
- 20. Sea Plot...
- 21. SeaCalc III...
- Command Line Options...
- Exit

- All of the processing modules are explained in the manual
- Default parameters for each instrument are provided in the manual

Key Data Processing Modules



The slide features a blue header with the SEA-BIRD SCIENTIFIC logo on the left and the title 'Key SBE Data Processing Modules for Profiling CTDs' on the right. The main content is a bulleted list of processing modules. In the bottom right corner, there is a blue diamond icon with 'M12' inside. The bottom left corner contains a small copyright notice.

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Key SBE Data Processing Modules for Profiling CTDs

- **Data Conversion** converts data from hexadecimal to engineering units
- **Filter** refines response time of sensors and smoothes digital noise in Pressure data
- **Align CTD** coordinates measurements of T, C, and P on same parcel of water
 - Other variables as well, as needed
- **Cell Thermal Mass** corrects conductivity sensor thermal lag error for a given flow rate determined by pump speed or estimated based on descent rate
- **Loop Edit** (*Optional*) reduces ship heave effects by marking scans "badflag" if scan fails minimum velocity criteria set by user
- **Wild Edit** (*Optional*) or (Median) **Filter** to remove outliers
- **Derive** takes newly aligned and corrected independent variables (T, C, P, Oxvolts) and computes dependent variables (Salinity, Density, Oxygen Concentration)
- **Bin Average** statistically averages data blocks into bins that are evenly spaced or interpolated pressure, depth, scan count, or time blocks

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Additional Data Processing Modules



Additional SBE Data Processing Modules for Profiling CTDs

- **Derive TEOS-10** takes newly aligned and corrected independent variables and computed dependent variables using the *Thermodynamic Equation of SeaWater 2010 (TEOS-10)*
- **Buoyancy** calculates Brunt-Väisälä or buoyancy frequency over a specified pressure intervals
- **Window filter** smooths data using a median filter or four, size-adjustable windowed filters: boxcar, cosine, triangle and Gaussian.
- **Command Line Options** can be used to run all modules by the command line or a batch processing script



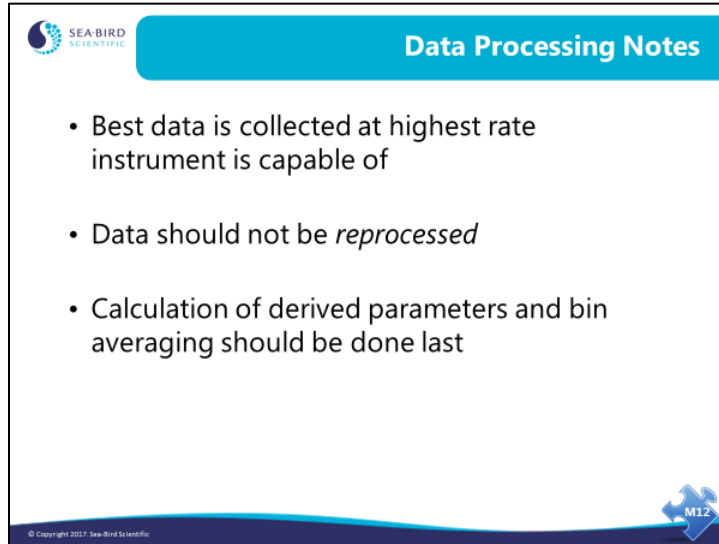
File Manipulation Modules



File Manipulation Modules for Profiling CTDs

- **ASCII In** transforms ASCII Text file with columns of data into a Sea-Bird formatted .cnv (converted) file for processing and plotting in SBE software.
- **ASCII Out** transforms a Sea-Bird formatted file and outputs a simple column file of data in text format... can be used in Excel and other non-Sea-Bird programs.
- **Section** extracts rows from converted .cnv data file within a specified pressure range or scan count.
- **Split** separates converted .cnv data files into a up and down casts using the maximum pressure as the boundary.
- **Strip** extracts columns from converted .cnv data files.
- **Translate** convert data in converted .cnv data files from ASCII to binary, or vice-versa.

Data Processing Notes



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Data Processing Notes

- Best data is collected at highest rate instrument is capable of
- Data should not be *reprocessed*
- Calculation of derived parameters and bin averaging should be done last

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Activity: Convert Data

Explanation: We are preparing to operate on the data with an application that moves the T and C data streams relative to the pressure data stream. Calculation of parameters that are functions of T, C, and P is not useful at this stage, and it will complicate and confuse things to have them in the data set before we are ready for them. So, just convert the measured variables – pressure, temperature, and conductivity.

1. In SBE Data Processing, run *1. Data Conversion*:

A. File Setup tab –

- Input files C:/Data/Module9/AlignC/Faroe.dat and Faroe.con
- Output file Faroe.cnv

B. Data Setup tab -

- Downcast only
- Convert...

Pressure, Digiquartz

Temperature,2 [ITS-90] – ('2' indicates this is **secondary T** on an SBE 9*plus*)


Conductivity,2 [S/m] – ('2' indicates this is **secondary C** on an SBE 9*plus*)

C. Click *Start Process*.

If you have time, convert 19*plus* data (C:\Data\Module9\AlignC\SBE19plus\Miami.hex, using Miami.con). The 19*plus* has no secondary sensors.


- Downcast only
- Convert...
 - Pressure, Strain Gauge -> db
 - Temperature -> ITS-90 -> deg C
 - Conductivity -> S/m
- Output file Miami.cnv


Filtering Data



**Filtering Data for Matching
TC Sensor Time Responses**

- Conductivity cell time constant (Tau) depends on pumping rate
 - Temperature response not flow dependent
- SBE 9*plus* pump and TC duct controls Tau of C to match Tau of T
 - No Filtering required
- SBE 25 and 25*plus* pump slower than 9*plus* pump
 - Filtering T and C optional for SBE 25
 - Filtering T and C recommended for SBE 25*plus*
- Tau for SBE 19*plus* and 19*plus* V2 T and C are not as well matched; filtering T and C required



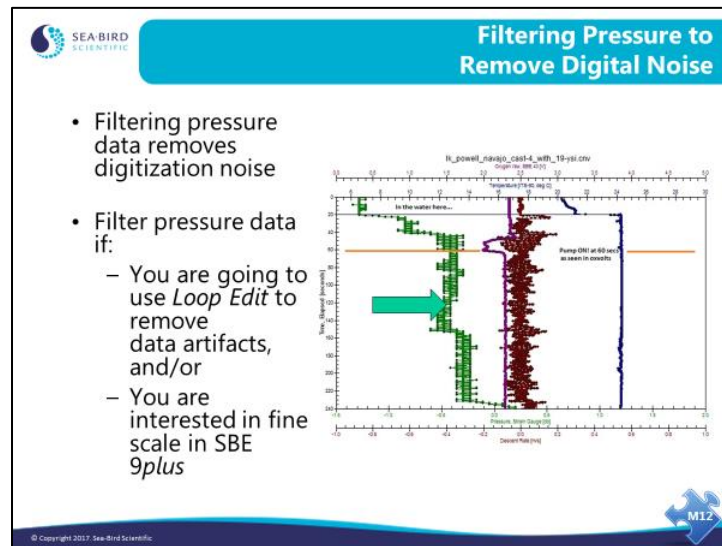


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It is very desirable to match the time constants of the temperature and conductivity sensors. This improves salinity data in conditions of sharp gradients. The conductivity sensor has a time constant that depends on pumping rate; it can range from 10 millisecc at a fast pumping rate to very large if no water is moving through the cell.

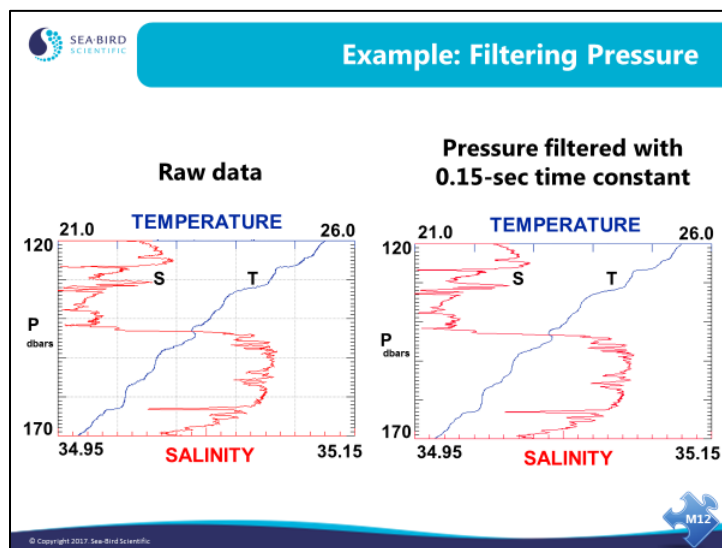
- For the 9*plus* with a TC duct and standard plumbing, a pumping rate of 25 ml/s brings the conductivity sensor's time constant in line with the temperature sensor's time constant of ~70 ms.
- The SBE 25 and 25*plus* use the same sensors as the 9*plus*, but these CTDs usually includes a slower pump (2000 rpm vs 3000 rpm). A small amount of filtering of temperature and conductivity is usually recommended.
- The 19*plus* and 19*plus* V2 temperature sensor has a much slower time constant than its conductivity sensor, as we saw in the first part of the course. Because of the way the filtering algorithm operates, the best match of temperature and conductivity is obtained by filtering both channels with a filter having the same time constant as the temperature channel.

Filtering Data (*continued*)



In measuring the pressure sensor signal, there is a digitization error that may be removed by filtering the signal with a low-pass filter. This has the effect of improving the resolution of the pressure signal by smoothing the digitization jitter.

Filtering Data (*continued*)



The left plot shows some *dithering* in the data that is eliminated by filtering the pressure.

Filtering Data (*continued*)

Filter Time Constants


- SBE 9*plus*
 - Filter **A** 0.15 sec for P
- SBE 25*plus*
 - Filter **A** 0.1 sec for C and T
 - Filter **B** 0.25 sec for P
- SBE 25 (optional)
 - Filter **A** 0.1 sec for C and T
 - Filter **B** 0.5 sec for P
- SBE 19*plus* or 19*plus* V2
 - Filter **A** 0.5 sec for C and T
 - Filter **B** 1.0 sec for P

Variable Name [unit]	Filter Type
Pressure, Strain Gauge [db]	Low pass filter B
Temperature [ITS-90, deg C]	Low pass filter A
Conductivity [S/m]	Low pass filter A

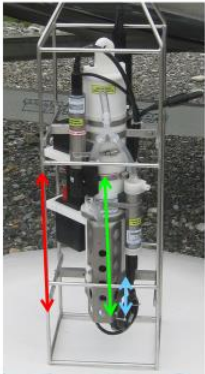
Filtering is done for two reasons:

- To match the time constants of the temperature and conductivity sensors.
- To smooth the pressure signal to minimize digitization noise in preparation for removing *loops* in the data with *Loop Edit*. When smoothing pressure, use a filter that is approximately four times the sample rate:
 - SBE 9*plus* – samples at 24 Hz (0.04167 sec), $4 \times 0.04167 \approx 0.15$ sec
 - SBE 25*plus* – samples at 16 Hz (0.0625 sec), $4 \times 0.0625 = 0.25$ sec
 - SBE 25 – samples at 8 Hz (0.125 sec), $4 \times 0.125 = 0.5$ sec
 - SBE 19*plus* or 19*plus* V2 – samples at 4 Hz (0.25 sec), $4 \times 0.25 = 1$ sec

Illustrating Sensor Alignment




Sensor Alignments

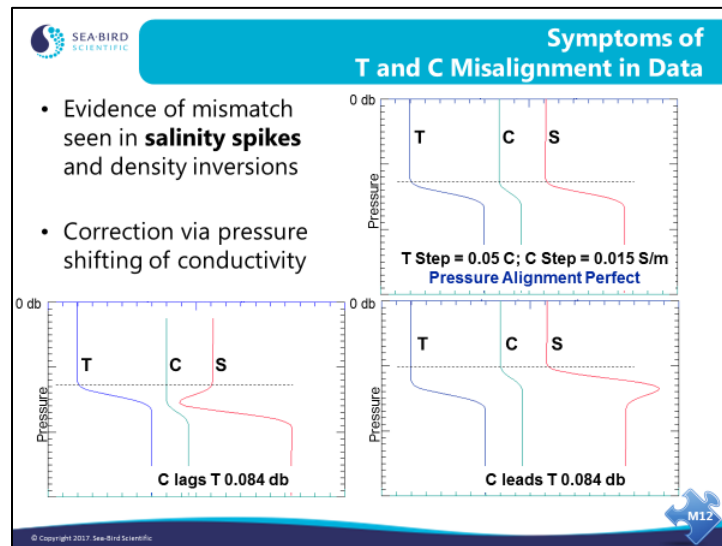


- Distance between sensors
P-T
P-T to C-Star Transmissometer
- Time of travel of water parcel through plumbing
P-T to C
P-T to DO
- Align big discrepancies in response time (i.e., DO)

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Demonstration of Misalignment Effects



Here is an artificial data set with a step change in temperature and conductivity.

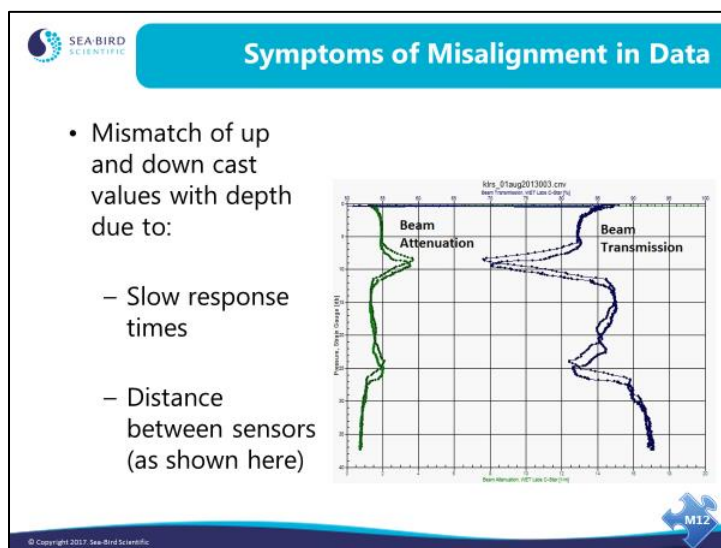
Temperature is the blue trace, conductivity is the green, and salinity is the red.

- In the top plot, T and C are perfectly matched, yielding a plot of salinity that is as expected.
- In the bottom left plot, C lags by 0.084 dbar (this is 2 scans at the *9plus* data rate, at a typical 1 m/s lowering rate). You can see that a negative spike shows up in the salinity data.
- In the bottom right plot, C leads T by 0.084 dbar, yielding a positive spike in salinity.

This behavior can be present in any CTD system built by any manufacturer. It is caused by a mismatch of T and C measurements in relation to pressure. This is not a sensor artifact; any T and C pair using any technology will produce an error in salinity if a scan contains measurements from different water parcels.


A note about the direction of the salinity spike: The direction of the salinity spike is also dependent on whether T and C are increasing or decreasing with increasing pressure. For the examples above, if T and C were decreasing rather increasing, the salinity spike would be in the opposite direction.

Demonstration of Misalignment Effects (*continued*)



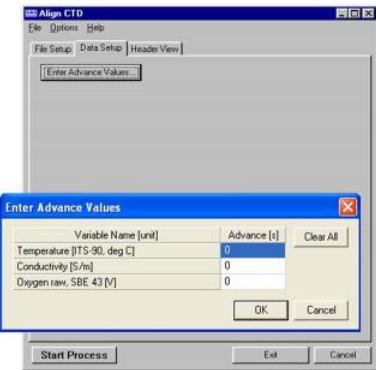
Here is data from auxiliary sensors showing misalignment.

Removing Misalignment




**Advancing Data in Time
to Remove Misalignment**

- Alignment on T and C done automatically in 11*plus* Deck Box
- Alignment can change from factory default due to changes in plumbing that increase or decrease pumping speed
- Use Align CTD module to match T and C data streams in post processing
 - On 19*plus* and 25*plus* CTDs



Variable Name [unit]	Advance [s]	Clear All
Temperature [TS-90, deg C]	0	<input type="button" value="Clear All"/>
Conductivity [S/m]	0	
Oxygen raw, SBE 43 [V]	0	




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Because the 911*plus* system is well characterized, an alignment of the data stream is done automatically in the 11*plus* before data is transmitted to your computer. With the TC duct in place, an alignment of 1.75 data scans (or 0.073 seconds) is done on incoming data. A linear interpolation between scans is done to implement the alignment of a non-integer number of scans.

Misalignment that differs from the nominal values can arise from plumbing changes, which can influence pumping speed. A slower pumping speed increases a water parcel's residence time in the TC plumbing, and will require a larger shift in data scans. A faster pumping speed will decrease the residence time in the TC plumbing and require a smaller alignment value.

Note that the advance values are given in seconds and are relative to the pressure channel.


Removing Misalignment (*continued*)



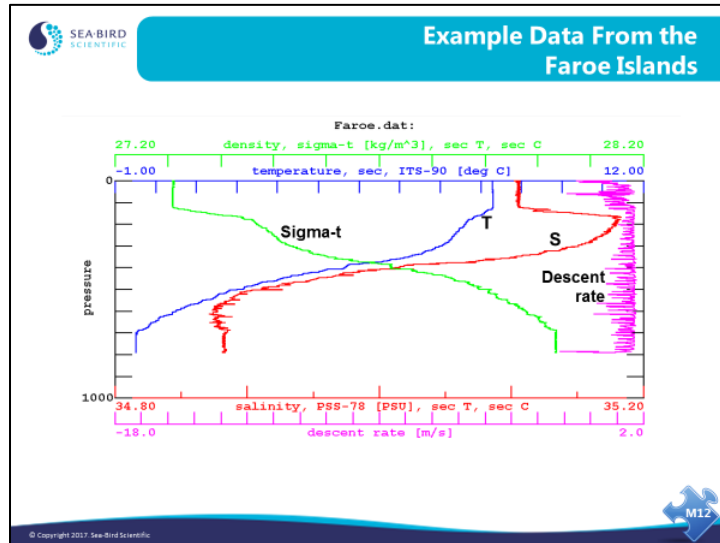
How Do I Know How Much to Advance or Slow a Data Channel?

- Use factory defaults
 - Sea-Bird has done tests for standard configurations that provide default alignments
- By knowing flow rate and path distance between sensors, compute a time delay
- By looking at your data
 - Find a spot in your data with a sharp salinity shift and/or unrealistic spiking
 - Experiment with alignment values to minimize salinity spiking

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Removing TC Misalignment: Example

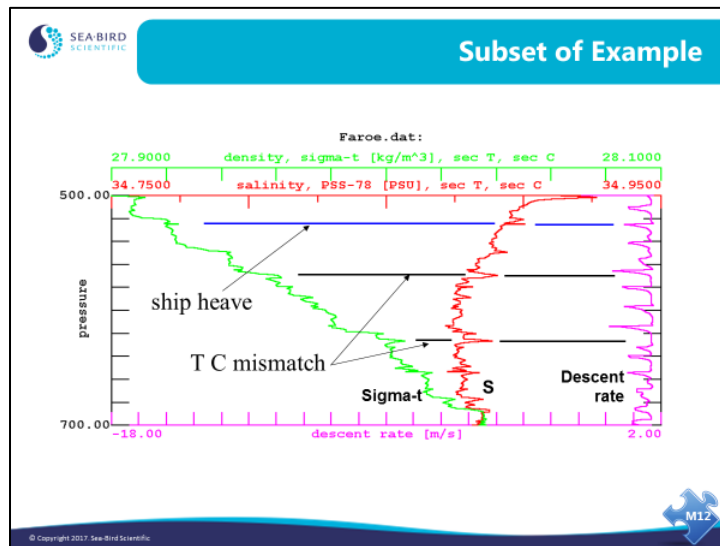


This data set was collected with the secondary T and C sensors of a 911*plus* off the Faroe Islands in 1995. Note the spiky salinity data and the density inversions. These arise from two phenomena: a mismatch between temperature and conductivity samples, and ship heave. The ship heave causes water to move from around the instrument package down to the sensors during deceleration.

We will enlarge part of the plot for a closer look, and do some experimenting with sensor alignment.

A note about sensor alignment in the 911*plus*: We mentioned earlier that the 11*plus* Deck Unit performs an automatic alignment of T and C. However, in old versions of the 11*plus*, the automatic alignment was done only on the output from the primary T and C sensors; for secondary sensors we must do the alignment in post-processing.

Removing TC Misalignment: Example (*continued*)



It is important to plot descent rate as well as density and salinity, because ship heave can cause errors in your data set that are completely different from alignment errors. To align your data, plot a small subset of the data that has sharp changes in temperature and/or conductivity. Look for spikes in the salinity and density that do not correspond to rapid descent rate decreases, which are indicative of ship heave.

Activity: Align Data and Derive

Explanation: For this activity, we start with the .cnv file you created in *Data Conversion* that contains pressure, temperature, and conductivity, and then do some advancing on the file with *Align CTD*, trying a few advances. We then use *Derive* to calculate salinity and density from the original .cnv file and from each aligned file. We should end up with the following files, which we'll plot in Sea Plot to see which advance gives the best results:

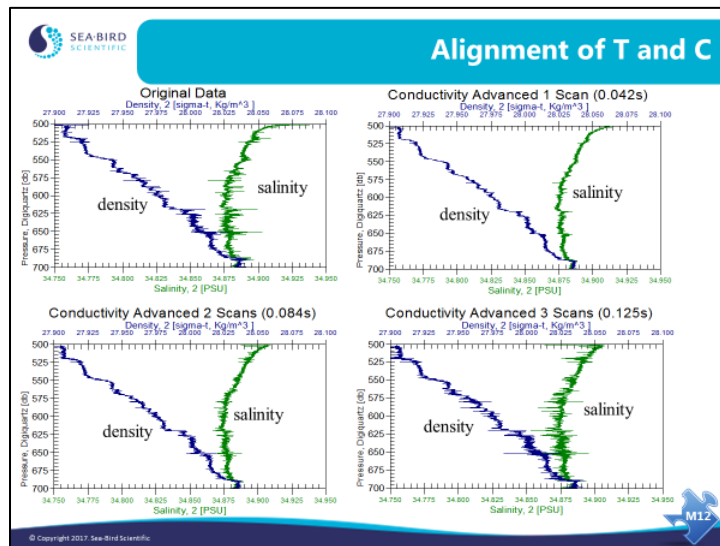
- FaroeD.cnv -- Original data, with salinity and density derived
- FaroeA1D.cnv -- C advanced 1 scan (0.042 sec), with salinity and density derived
- FaroeA2D.cnv -- C advanced 2 scans (0.084 sec), with salinity and density derived
- FaroeA3D.cnv -- C advanced 3 scans (0.126 sec), with salinity and density derived

1. In SBE Data Processing, run 3. *Align CTD three times*:
 - Use C:\Data\Module9\AlignC\Faroe.cnv you created in previous activity
 - Advance C relative to P 0.042, 0.084, and 0.126 seconds (1, 2, and 3 scans)
 - Name append A1, A2, and A3
2. In SBE Data Processing, run 6. *Derive one time*, on all 4 files:
 - Use Faroe.cnv, FaroeA1.cnv, FaroeA2.cnv, and FaroeA3.cnv
 - Name append D
 - Calculate Salinity, Practical, 2[PSU] and Density 2 -> sigma-t, Kg/m³
3. In SBE Data Processing, run 19. *Sea Plot one time* to compare results with an Overlay plot:
 - De-select *Sort input files* in Options menu, and then select input files **in order** (FaroeD.cnv, FaroeA1D.cnv, FaroeA2D.cnv, and FaroeA3D.cnv)
 - Overlay plot of P (500 to 700) vs S (34.75 to 35.00), with 0.025 offset for S
 - Now try P vs Sigma-T (27.9 to 28.1), with 0.025 offset for Sigma-T

If you converted 19*plus* data in the previous activity and have time, align the data in C:\Data\Module9\AlignC\SBE19plus\.

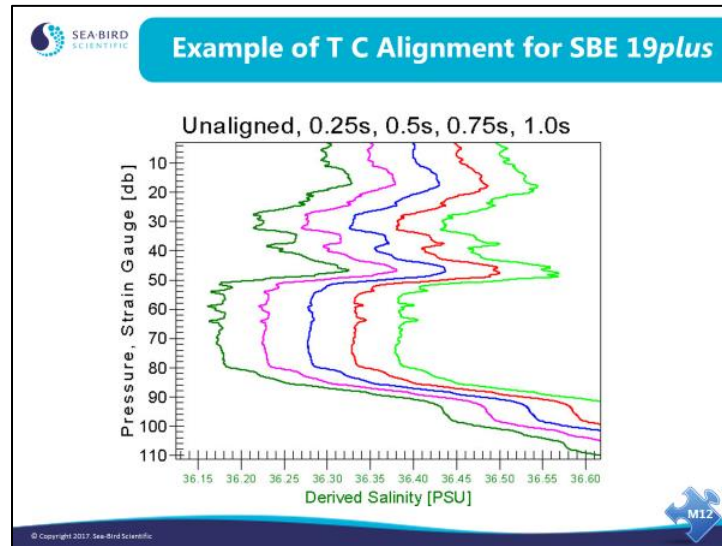
- Filter T and C to match the sensor response, using the Filter module. On the *Data Setup* tab, set Low pass filter A to a time constant of 0.5 seconds. Click *Specify Filters...* and select *none* for pressure and *Low pass filter A* for T and C.
- Use Align CTD to advance T against P; try whole scan *values* of 0.25, 0.5, 0.75, and 1.0 sec.
- Use Derive to calculate salinity and density.
- Plot results with *Sea Plot* (try P from 0 to 110, S from 36.15 to 36.6, and offset 0.05).

Activity: Align Data and Derive (*continued*)



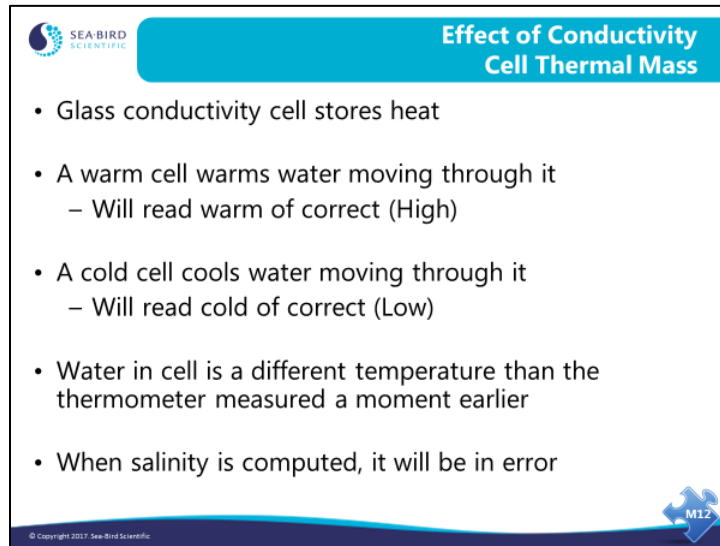
This is from the Faroe data set. The data on the upper left is unaligned, raw data. The upper right has the conductivity channel advanced relative to pressure 0.42 seconds (1 scan); spiking shows considerable improvement. The plot on the lower left has conductivity advanced 0.084 seconds (2 scans) and shows some of the spikes going the other direction. The plot on the lower right has conductivity advanced 0.125 seconds (3 scans), and the spikes have reversed direction and are beginning to get longer. Note that you can align by a non-integer scan interval. In fact, the SBE 11*plus* performs an alignment for you of 1.75 scans (0.073 seconds).

Activity: Align Data and Derive (*continued*)



This is from the extra credit data set. The left most trace is the original unaligned data and the others, from left to right, are aligned from 1 to 4 scans. The optimal alignment value may lie between 0.25 and 0.5 seconds; it is left for the reader to experiment and find it.

Conductivity Cell Thermal Mass



SEA-BIRD SCIENTIFIC **Effect of Conductivity Cell Thermal Mass**

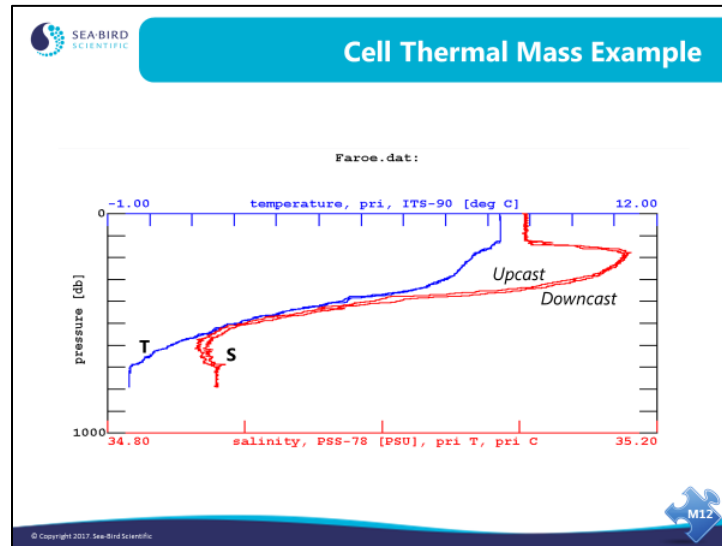
- Glass conductivity cell stores heat
- A warm cell warms water moving through it
 - Will read warm of correct (High)
- A cold cell cools water moving through it
 - Will read cold of correct (Low)
- Water in cell is a different temperature than the thermometer measured a moment earlier
- When salinity is computed, it will be in error

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The conductivity measurement has temperature dependence. The conductivity cell itself is constructed of glass and plastic, and as such has a thermal mass. When the cell goes from warm water into cold, the water that passes through the cell is slightly warmed as it transits the cell, resulting in a conductivity measurement that is high of correct.

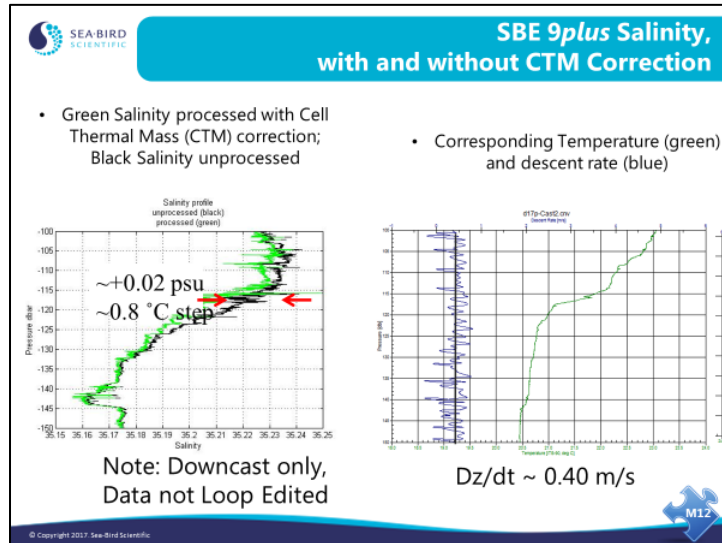
Conversely, when the cell comes up from cold water into warmer water, the water that passes through the cell is cooled slightly, resulting in a conductivity measurement that is low of correct. This heat transfer can be modeled and corrected.

Conductivity Cell Thermal Mass (continued)

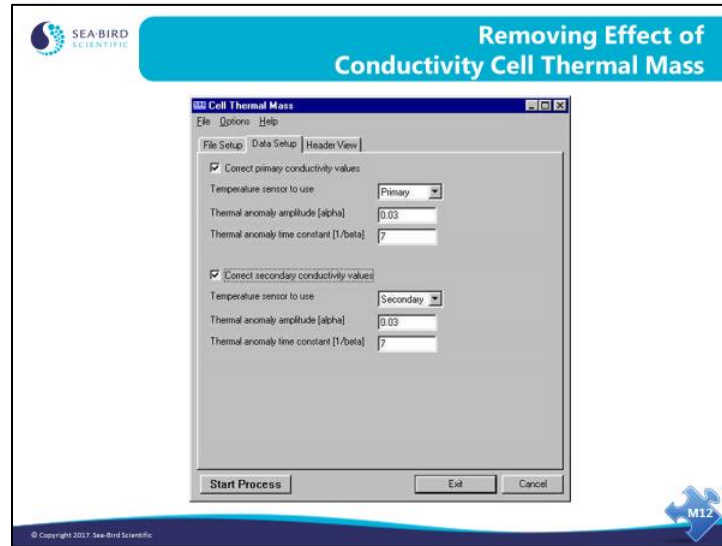


The data shown in this plot has already been aligned (using Align CTD), reducing salinity spikes associated with misalignment. We see what appears to be salinity hysteresis, but there is no temperature hysteresis. The feature that looks like salinity hysteresis is actually caused by the effect of cell thermal mass. Another way to check for cell thermal mass errors is to create a T vs S plot; the feature to look for in that plot is an open curve.

Conductivity Cell Thermal Mass (continued)



Conductivity Cell Thermal Mass (continued)



SBE Data Processing has a *Cell Thermal Mass* module. The thermal mass correction is made with the equation shown below, which is a function of amplitude (α) and time constant ($1 / \beta$). Like many of the sensor-related phenomena we have considered, the heat transfer within the cell has a time constant.

Thermal mass correction:

$$\text{Corrected Conductivity} = C + ctm$$

Where:

C = uncorrected conductivity

$$ctm = -1.0 \times b \times \text{previous } ctm + a \times \left(\frac{dc}{dT} \right) \times dT$$

dT = temperature - previous temperature

$$a = 2 \times \frac{\alpha}{\text{sample interval} \times \beta + 2}$$

$$b = 1 - \left(2 \times \frac{a}{\alpha} \right)$$

$$\frac{dc}{dT} = 0.1 \times (1 + 0.006 \times [\text{temperature} - 20])$$

Activity: Remove Conductivity Cell Thermal Mass Effect

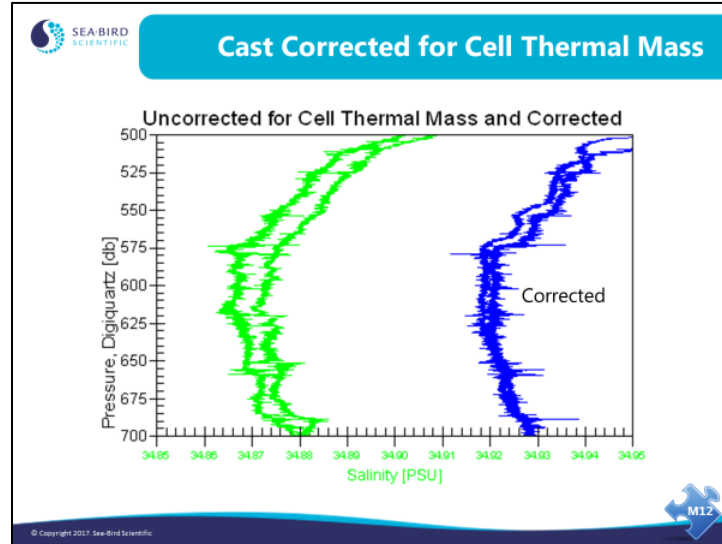
Explanation: For this activity, we convert the raw data in *Data Conversion*, then apply a *Cell Thermal Mass* correction. We then use *Derive* to calculate parameters from the original .cnv file and from the corrected file. You should end up with the following files to plot in *Sea Plot* to see whether the cell thermal mass correction improves the data:

- FaroeD.cnv for original data
- FaroeCD.cnv for corrected data

Note: To save time, we aren't running *Align CTD* as part of this activity, so the resulting plot of the data corrected with *Cell Thermal Mass* will still show salinity spiking. Typically, you would run *Align CTD* to eliminate salinity spikes before running *Cell Thermal Mass*.

1. In SBE Data Processing, run *Data Conversion*:
 - Use C:\Data\Module9\CellTM\Faroe.dat and .con
 - Convert upcast and downcast
 - Output
 - Time, Elapsed -> seconds
 - Pressure, Digiquartz -> db
 - Temperature -> ITS-90 -> deg C
 - Conductivity -> S/m
2. In SBE Data Processing, run *Cell Thermal Mass*:
 - Use defaults
 - Name append C
3. In SBE Data Processing, run *Derive* **one time**, on 2 files:
 - Use Faroe.cnv and FaroeC.cnv
 - Name append D
 - Calculate Salinity
4. In SBE Data Processing, run *Sea Plot* **one time** to compare results with an Overlay plot:
 - De-select *Sort input files* in Options menu, and then select input files **in order** (FaroeD.cnv and FaroeCD.cnv)
 - Overlay plot of Pressure (500 to 700) on y-axis; Salinity (34.85 to 34.95) and Temperature (-0.5 to 3.5) on x-axes. Use 0.05 offset for salinity, 1.0 offset for temperature.

Activity: Remove Conductivity Cell Thermal Mass Effect (continued)



Note that the *corrected* curve still shows what looks like salinity hysteresis, so the correction could perhaps use some refinement. You could repeat the process for other values of alpha and beta, to find the best result.