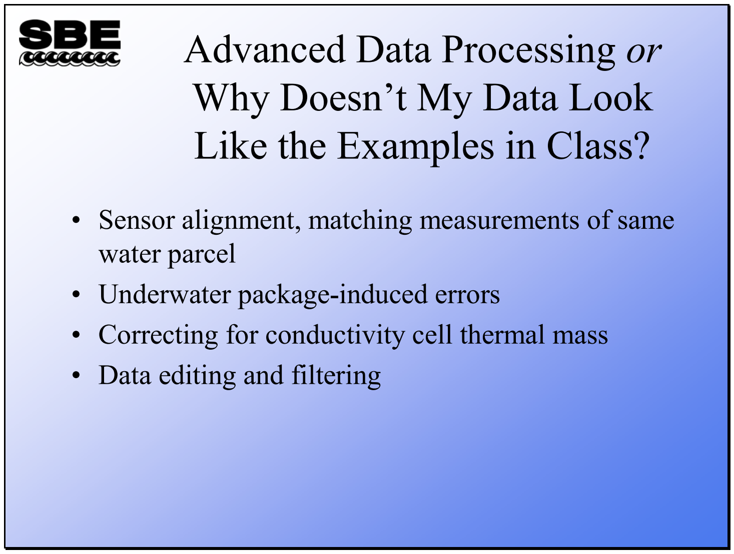
Module 9

Advanced Data Processing

Overview



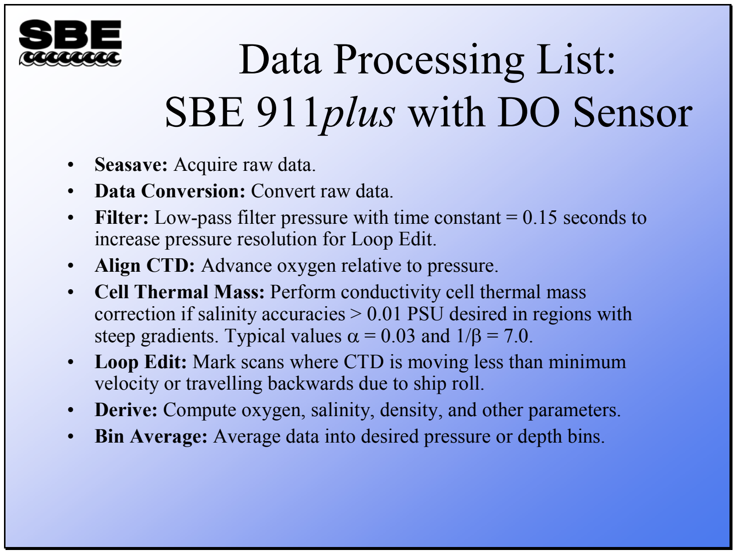
This section of the course is the final topic in profiling. Some of it is fine tuning of your data to remove small artifacts of frequency counting, plumbing, and sensor physics. We will also discuss the removal of the fairly gross effects of ship heave. Understanding these topics will help explain most of the peculiar things that you might observe in your data if you look closely.

Finally, we will talk about some of the advanced plotting features in Seasoft.

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 19*plus*.
- Align your dissolved oxygen data relative to pressure.
- Remove the effects of conductivity cell thermal mass from your data.
- Remove data artifacts caused by ship heave.

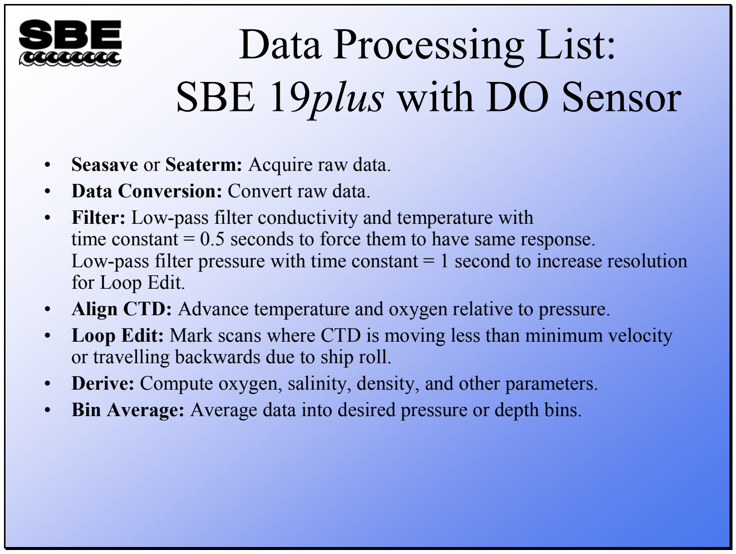
Data Processing Steps: SBE 9*plus* / 11*plus*



This is an ordered list of the steps in acquisition and processing of CTD data gathered with the 911*plus*. This list has quite a few more steps than our earlier discussion of the basics. We will work our way through the list, first discussing the cause of the artifact that we are interested in applying some computational energy to, and then discussing the tool to apply it.

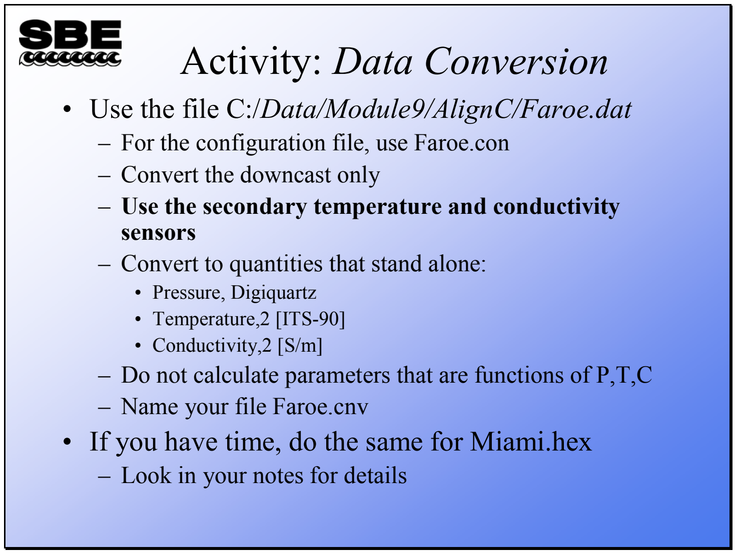
Note that the data is bin averaged before the major derived quantities are computed. Salinity, density, etc, are functions of T, C, and P; these are calculated on the final values of T, C, and P rather than the intermediate values. We'll talk a bit more about this at the end of the module.

Data Processing Steps: SBE 19*plus*



The processing list for the 19*plus* is shorter because of the lower expectations of precision and the different acquisition electronics.

Activity

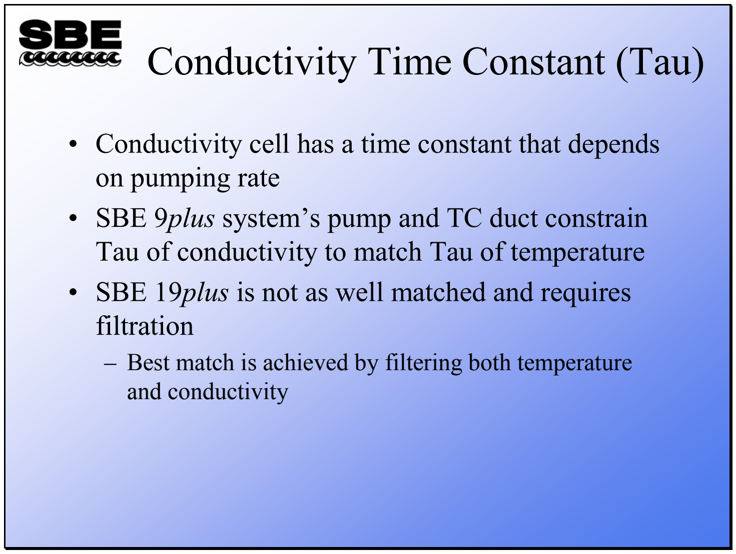


We are preparing to operate on the data with an application that moves the T and C data streams relative to the pressure data stream. Calculation of parameters that are functions of T, C, and P is not useful at this stage. Further, it will complicate and confuse things to have them in the data set before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

If you have time, process the 19*plus* data in C:\Data\Module9\AlignC\SBE19plus\Miami.hex, using Miami.con. The 19*plus* has no secondary sensors. Your *Data Conversion* setup is:

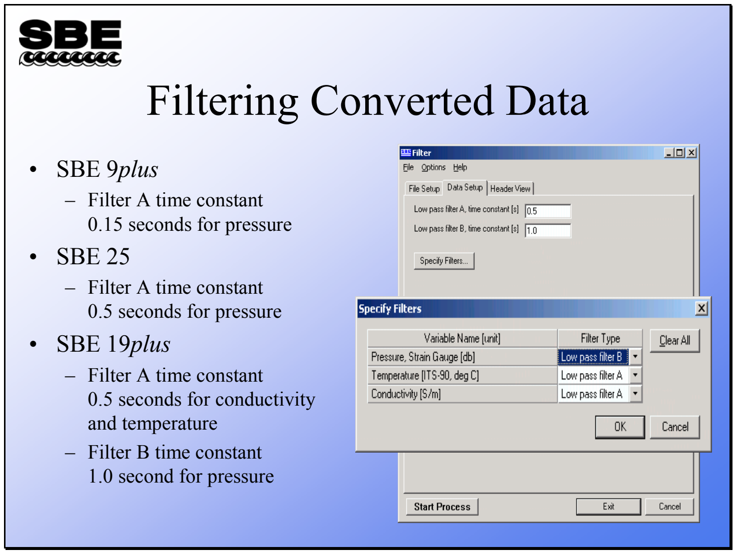
- Downcast only
- Convert… Pressure, Strain Gauge [db], Temperature [ITS-90], Conductivity [S/m]
- Name your file Miami.cnv

Conductivity Time Constant



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 milliseconds 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 19*plus* 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.

Conductivity Time Constant (*continued*)



Filtering is done for two reasons:

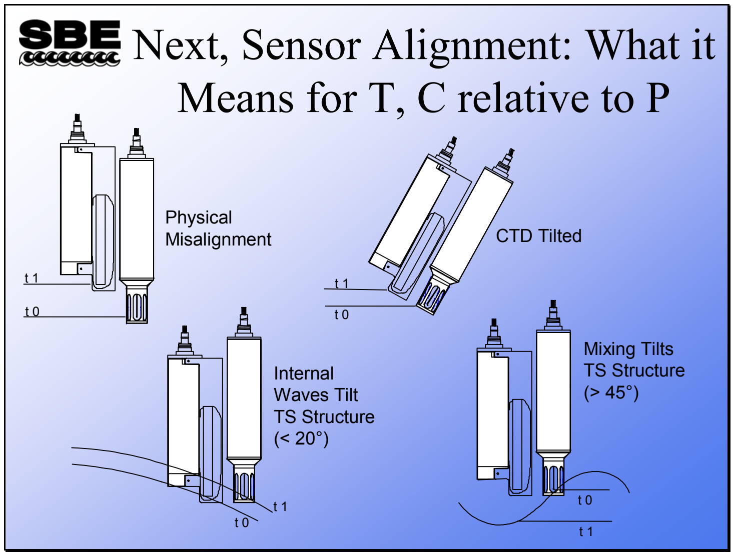
- To match the time constants of the temperature and conductivity sensors.
- To smooth the pressure signal to minimize digitization noise in preparation for removing *loops* in the data with *Loop Edit*. When smoothing pressure, use a filter that is approximately four times the sample rate:

  - SBE 9*plus* – samples at 24 Hz (0.04167 sec), 4 x 0.04167 ≈ 0.15 sec

  - SBE 25 – samples at 8 Hz (0.125 sec), 4 x 0.125 = 0.5 sec

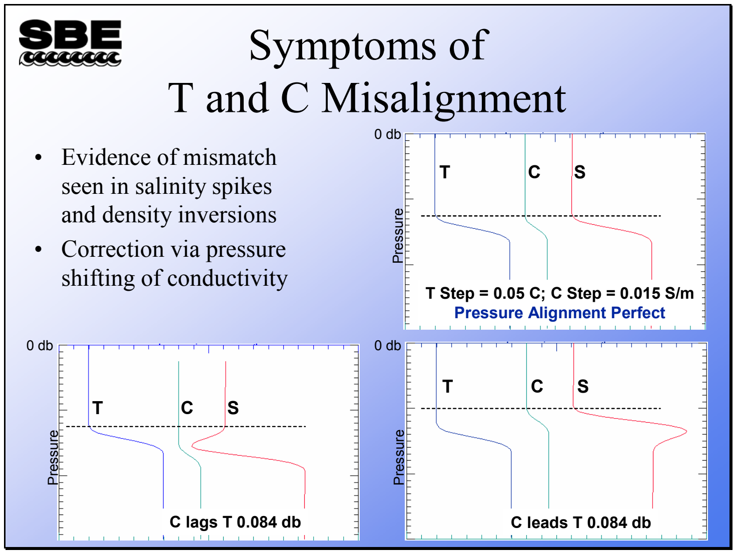
  - SBE 19*plus* – samples at 4 Hz (0.25 sec), 4 x 0.25 = 1 sec

Illustrating Sensor Misalignment



These illustrations show alignment problems for an instrument **not** using a TC duct (such as an SBE 19, which was typically sold without a TC duct). Here the temperature and conductivity sensors can *see* very different water.

Demonstration of Misalignment Effects



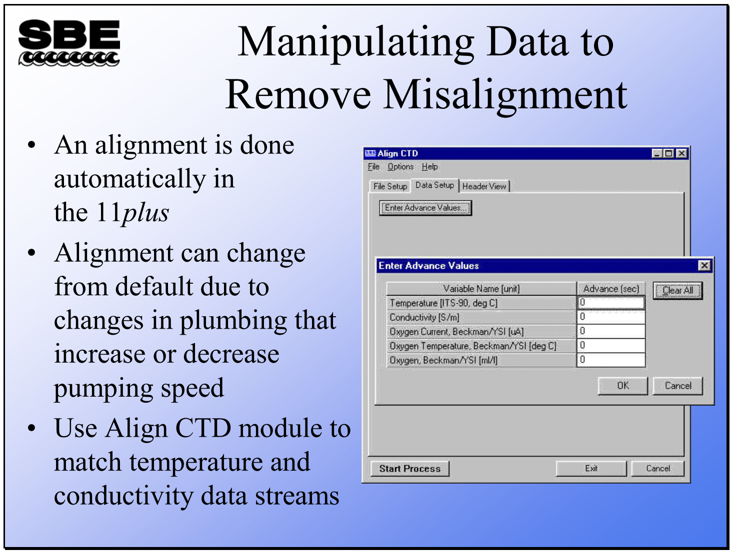
Here is an artificial data set with a step change in temperature and conductivity. Temperature is the blue trace, conductivity is the green, and salinity is the red.

- 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 decibars (this is 2 scans at the 9*plus* 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 decibars, 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.

Removing Misalignment

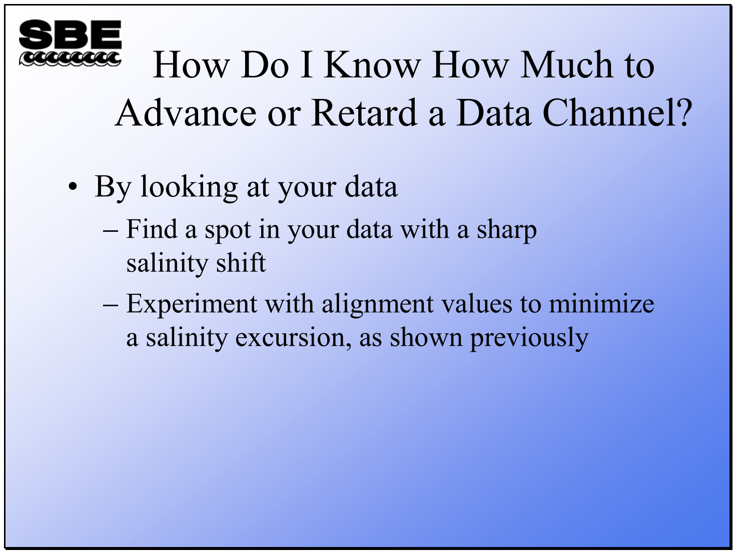


Because the 911*plus* system is well characterized, an alignment of the data stream is done automatically in the 11*plus* before data is transmitted to your computer. With the TC duct in place, an alignment of 1.75 data scans (or 0.073 seconds) is done on incoming data. A linear interpolation between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

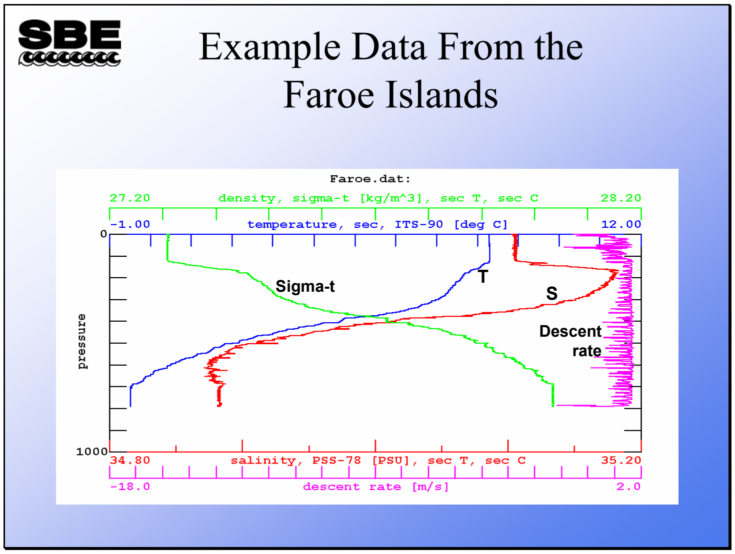
Misalignment that differs from the nominal values can arise from plumbing changes, which can influence pumping speed. A slower pumping speed increases a water parcel's residence time in the TC plumbing, and will require a larger shift in data scans. A faster pumping speed will decrease the residence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



Removing TC Misalignment: Example

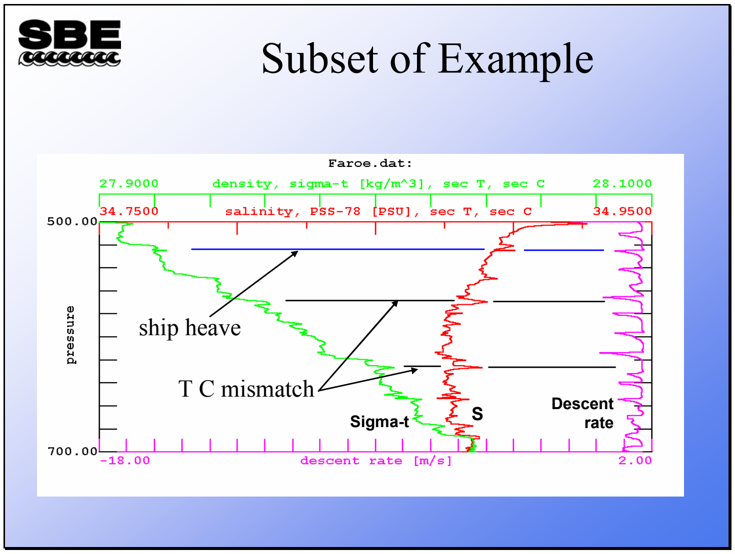


This data set was collected with the secondary T and C sensors of a 911*plus* off the Faroe Islands in 1995. Note the spiky salinity data and the density inversions. These arise from two phenomena: a mismatch between temperature and conductivity samples, and ship heave. The ship heave causes water to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

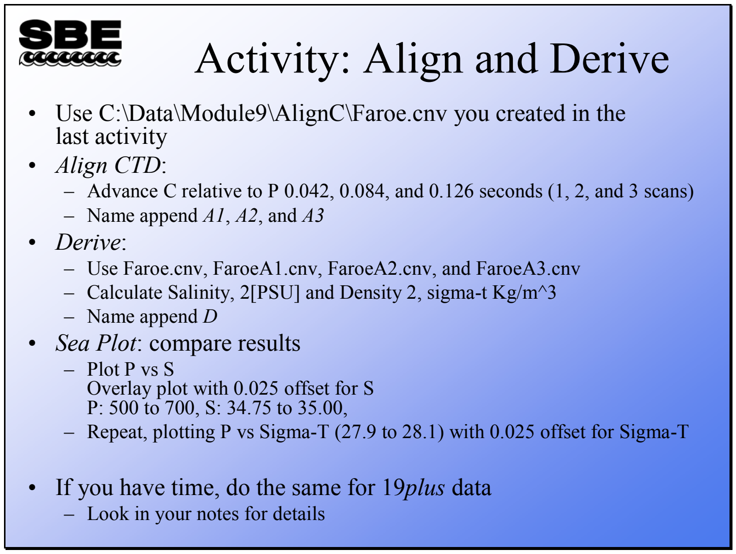
A note about sensor alignment in the 911*plus*: We mentioned earlier that the 11*plus* Deck Unit performs an automatic alignment of T and C. However, in old versions of the 11*plus*, the automatic alignment was done only on the output from the primary T and C sensors; for secondary sensors we must do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



For this activity, start with the .cnv file you created in *Data Conversion* that contains temperature and conductivity. Do some advancing on the file with *Align CTD*. Then, use *Derive* to calculate salinity and density from the original .cnv file and each aligned file. You should end up with the following files:

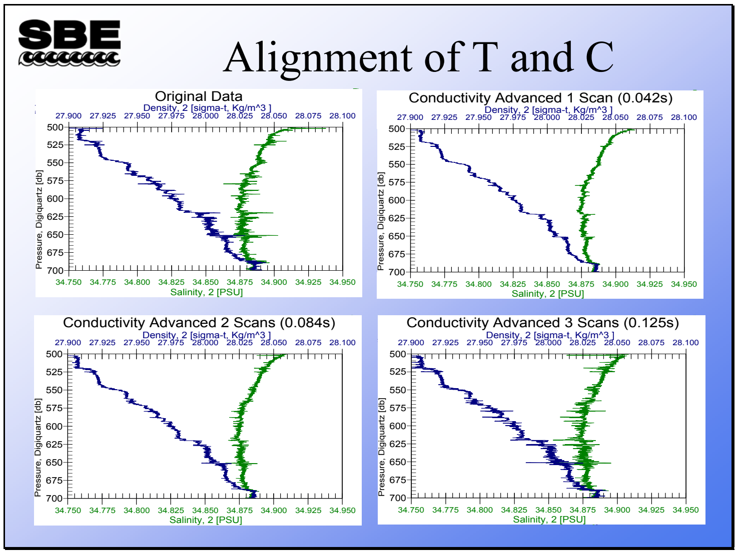
- FaroeD.cnv… Original data with salinity and density derived
- FaroeA1D.cnv… FaroeD.cnv with C advanced 1 scan = 0.042 seconds, with salinity and density derived
- FaroeA2D.cnv… FaroeD.cnv with C advanced 2 scans = 0.084 seconds, with salinity and density derived
- FaroeA3D.cnv… FaroeD.cnv with C advanced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

Check your results with an overlay plot in *Sea Plot*. De-select *Sort input files* in the Options menu, and then select the files in order: FaroeD.cnv, FaroeA1D.cnv, FaroeA2D.cnv, FaroeA3D.cnv.

If you have time, align the data in C:\Data\Module9\AlignC\SBE19plus\.

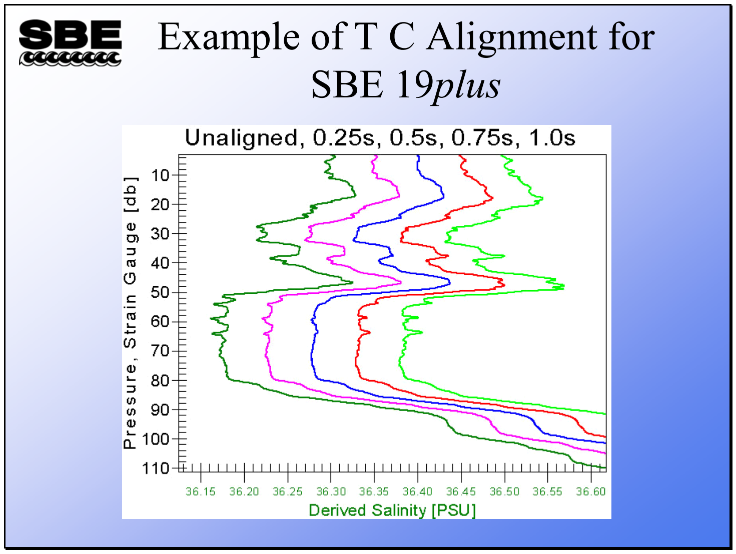
- First, filter the temperature and conductivity channels to match the sensor response, using the Filter module. On the *Data Setup* tab, set Low pass filter A to a time constant of 0.5 seconds. Click *Specify Filters…* and select *none* for pressure and *Low pass filter A* for temperature and conductivity.
- Next, advance temperature against pressure; try whole scan *values* of 0.25, 0.5, 0.75, and 1.0 seconds.
- Check your results with *Sea Plot*.

Removing TC Misalignment: Example (*continued*)



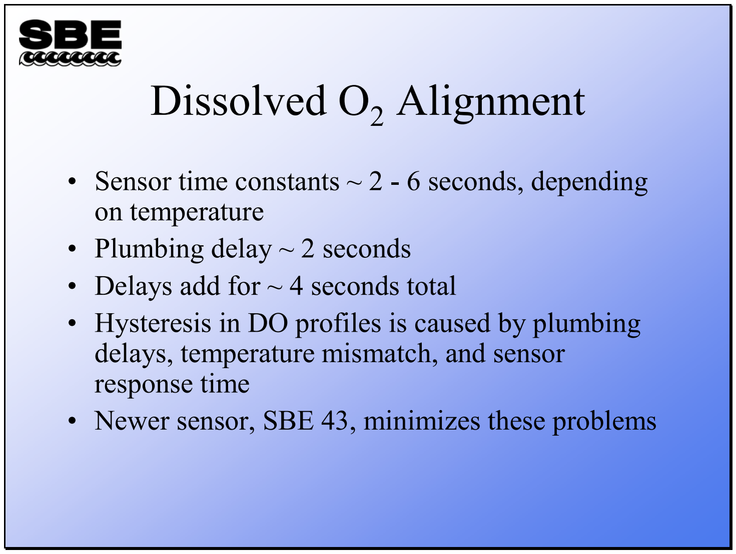
This is from the Faroe data set. The data on the upper left is unaligned, raw data. The upper right has the conductivity channel advanced relative to pressure 0.42 seconds (1 scan); spiking shows considerable improvement. The plot on the lower left has conductivity advanced 0.084 seconds (2 scans) and 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).

Removing TC Misalignment: Example (*continued*)



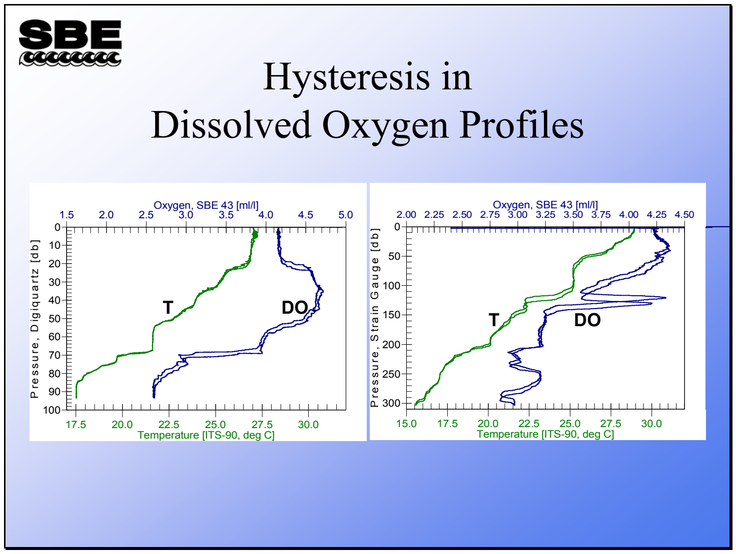
This is from the extra credit data set. The right most trace is the original unaligned data and the others, from left to right, are aligned from 1 to 4 scans. The optimal alignment value may lie between 0.25 and 0.5 seconds; it is left for the reader to experiment and find it.

Removing Misalignment in Dissolved Oxygen



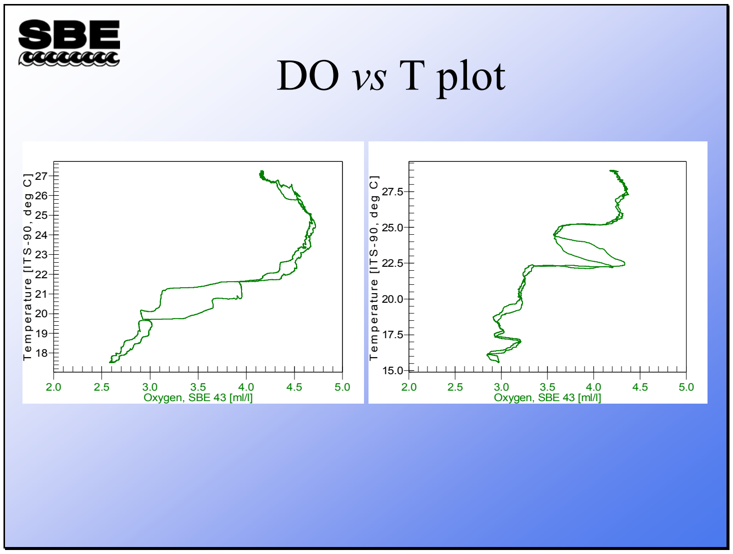
Aligning oxygen current and temperature in relation to pressure can improve hysteresis in dissolved oxygen profiles. The SBE 43 has a faster time constant and shows improvement in hysteresis over the Beckman- or YSI-type of sensor.

Removing Misalignment in Dissolved Oxygen (*continued*)



While hysteresis is easily observed in pressure *vs*. oxygen profiles, it is also easy to confuse hydrographic phenomenon with hysteresis. The plot on the right shows hysteresis in both temperature and oxygen; the peak in oxygen has a sharp gradient in temperature associated with it. The cast was taken near the Gulf Stream, and it is likely that the ship drifted during the cast. The CTD downcast probably moved through the hydrographic feature at a different depth than the upcast. A hydrographic phenomenon should not be removed with data manipulation.

Removing Misalignment in Dissolved Oxygen (*continued*)



Viewing hysteresis in *DO – T space* is an effective way of eliminating the confusion of hysteresis and hydrographic phenomenon.

Activity

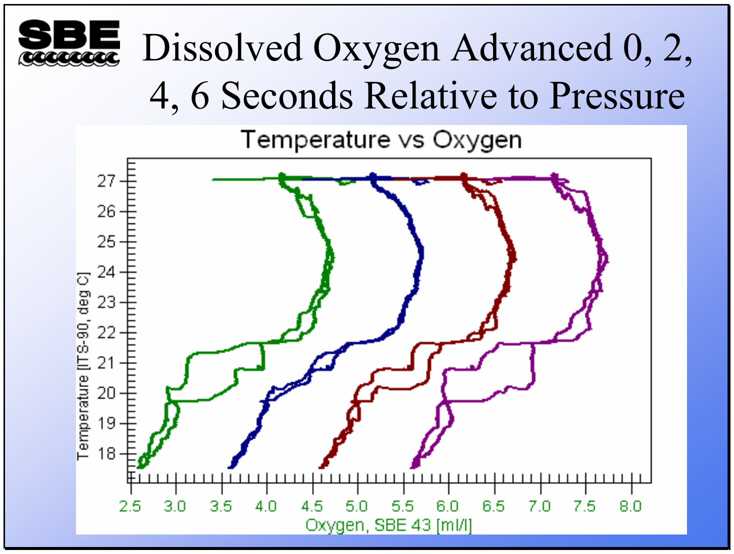
Activity: Align DO Data

- Use C:\Data\Module9\AlignDO\GulfMex.dat
- *Data Conversion*: P, T, S, Oxygen Voltage SBE 43
  - Upcast and downcast, file name GulfMex.cnv
- *Align CTD*: advance Oxygen Voltage SBE 43 relative to pressure 2, 4, and 6 seconds
  - Name append *A2*, *A4*, and *A6*
- *Derive*: Oxygen, SBE 43 in ml/l for **all** *.cnv*
  - Name append *D*
  - Accept default 2.0 second window size for oxygen
- *Sea Plot*: Plot T vs Oxygen, compare results
- If you have time, align oxygen data in C:\Data\Module9\AlignDO\SBE19plus\

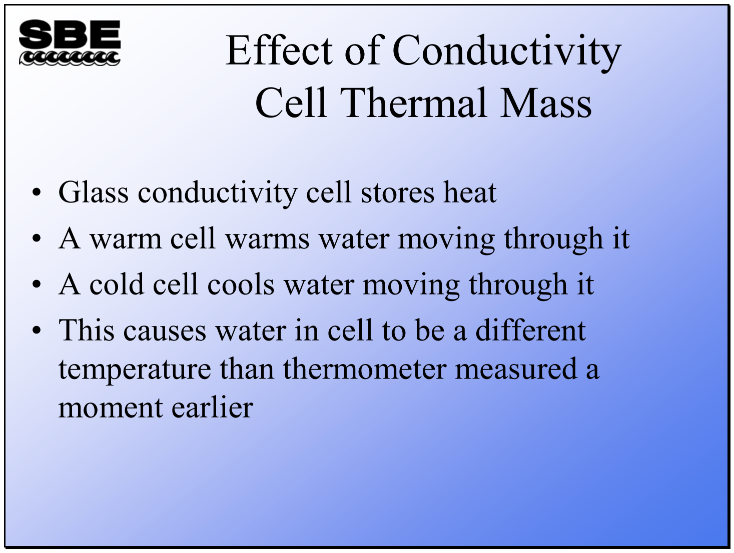
You should end up with the following files:

- GulfMexD.cnv — original data, not advanced
- GulfMexA2D.cnv — dissolved oxygen advanced 2 seconds
- GulfMexA4D.cnv — dissolved oxygen advanced 4 seconds
- GulfMexA6D.cnv — dissolved oxygen advanced 6 seconds

Removing Misalignment in Dissolved Oxygen (*continued*)

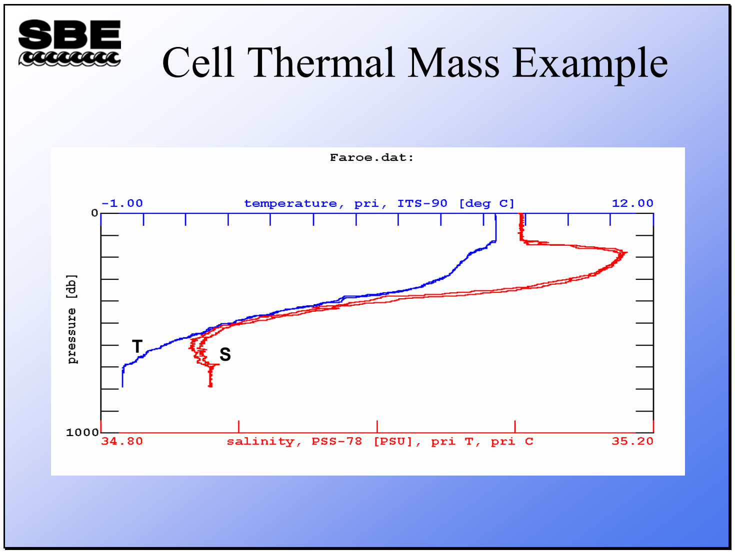


Conductivity Cell Thermal Mass



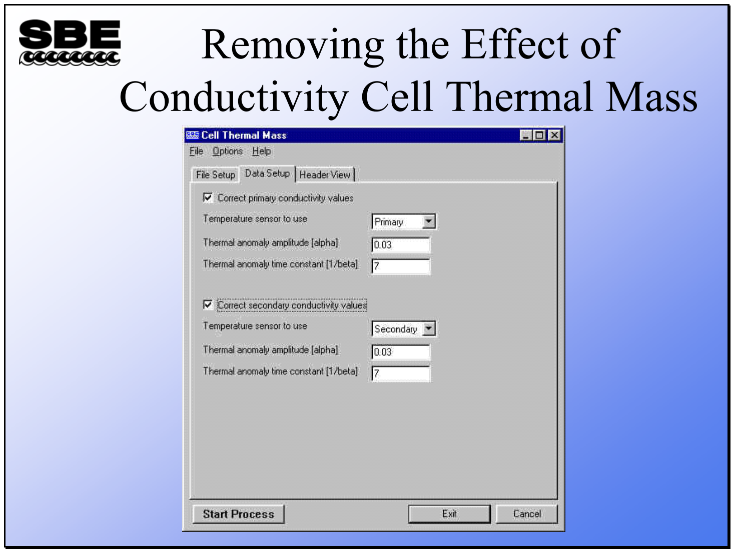
The conductivity measurement has temperature dependence. The conductivity cell itself is constructed of glass and plastic, and as such has a thermal mass. When the cell goes from warm water into cold, the water that passes through the cell is slightly warmed as it transits the cell. Conversely, when the cell comes up from cold water into warmer water, the water that passes through the cell is cooled slightly. This heat transfer can be modeled and corrected.

Conductivity Cell Thermal Mass (*continued*)



The feature that looks like salinity hysteresis is actually caused by the effect of cell thermal mass.

Compensating for Conductivity Cell Thermal Mass



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 (alpha) 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:

$$Corrected\ Conductivity = C + ctm$$

Where:

C = uncorrected conductivity

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

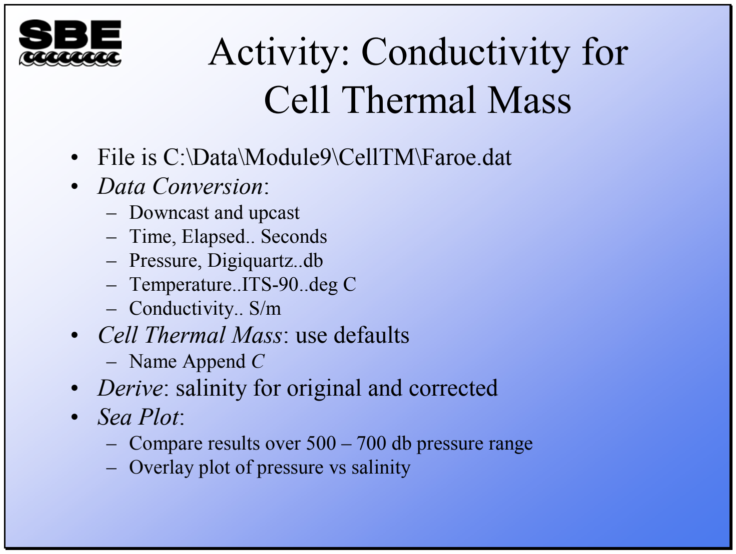
dt = temperature - previous temperature

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

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

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

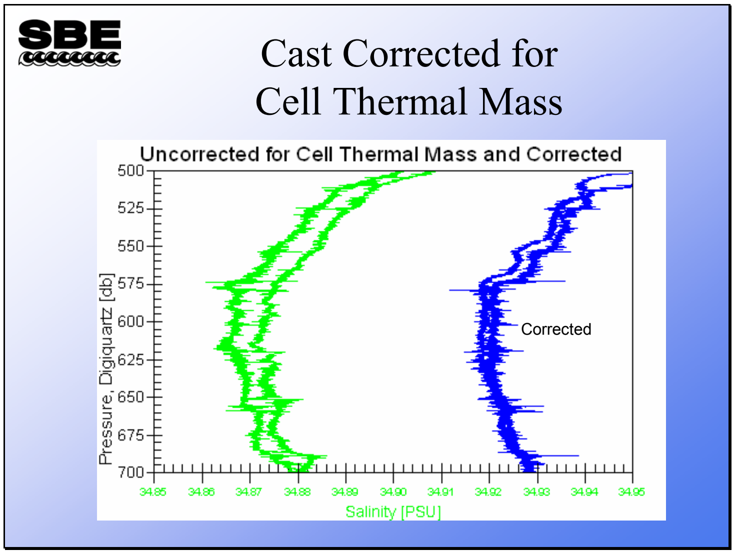
Activity



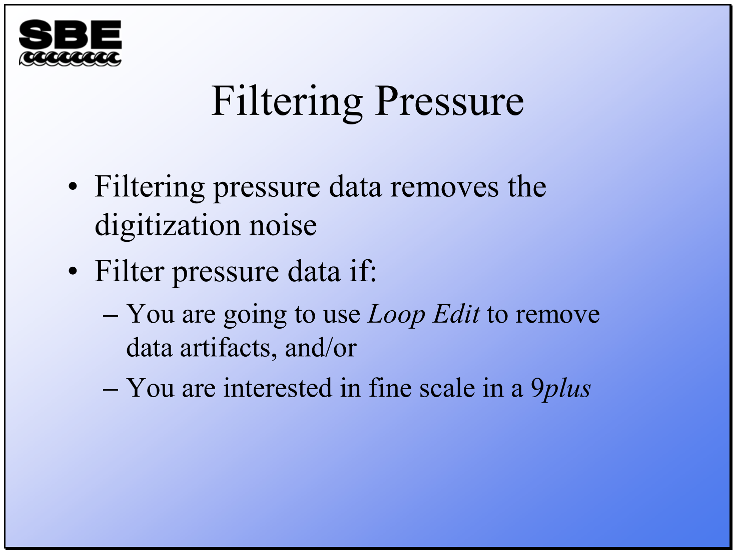
You should have files named:

- Faroe.cnv for original data
- FaroeC.cnv for corrected data

Activity (*continued*)

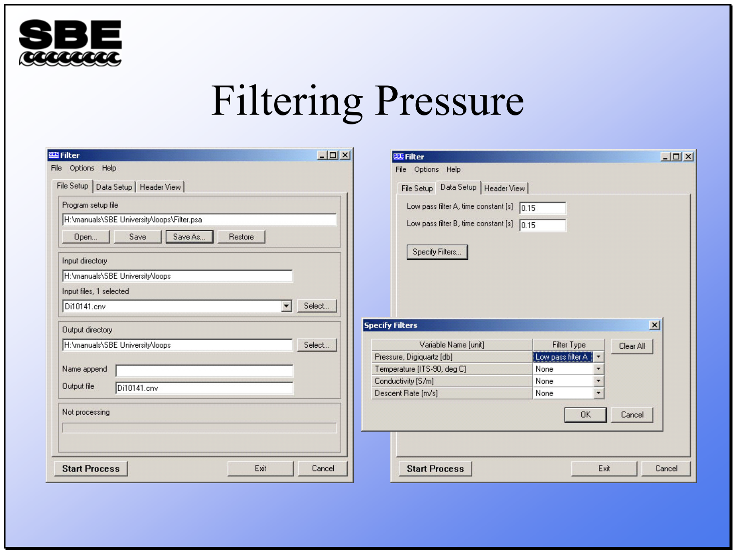


Filtering Pressure to Remove Digitization Effects

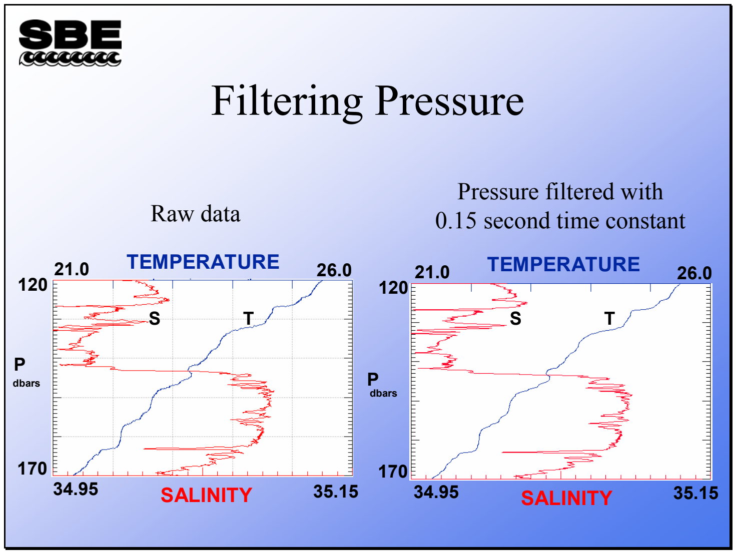


In measuring the pressure sensor signal, there is a digitization error that may be removed by filtering the signal with a low-pass filter. This has the effect of improving the resolution of the pressure signal by smoothing the digitization jitter.

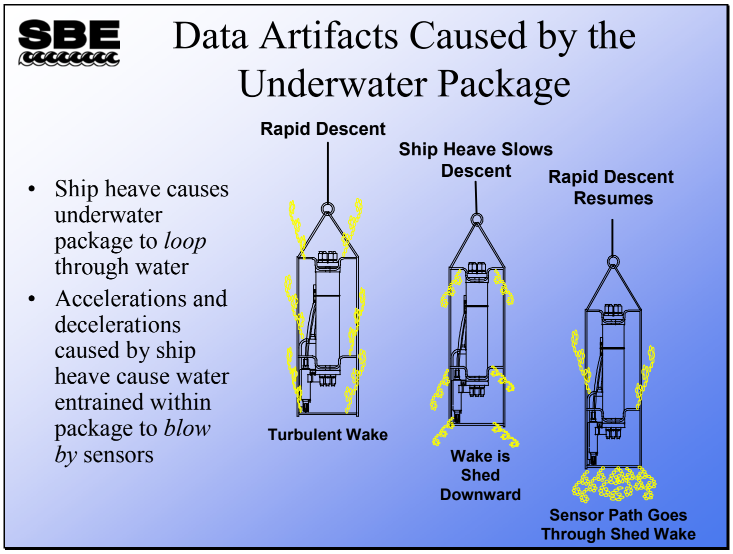
Filtering Pressure to Remove Digitization Effects (*continued*)



Filtering Pressure to Remove Digitization Effects (*continued*)



Data Artifacts Induced by Ship Heave

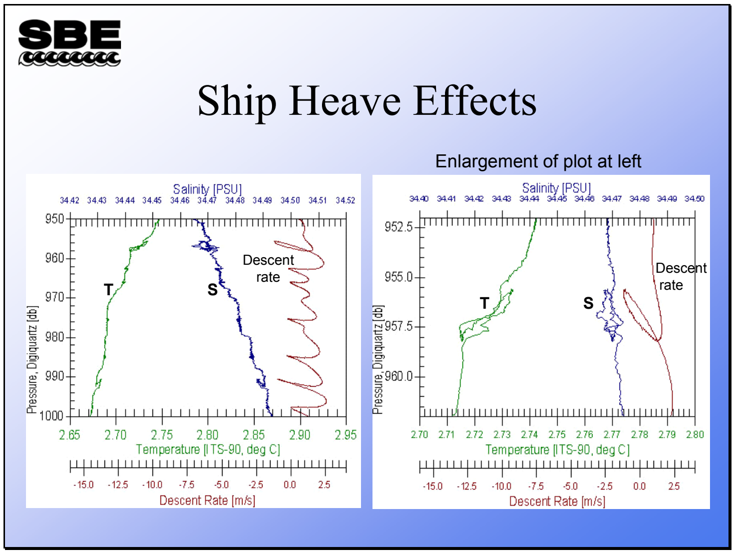


Ship heave is the rocking motion of the ship. Most CTD deployments are made with a small boom or an A-frame that leans out from the ship, giving some distance between the sea cable and the side of the ship. Ship rocking has the effect of pulling up on the sea cable when the ship rocks in one direction and slackening the sea cable when it rocks in the other. This heaving action causes the underwater package to decelerate when the sea cable is pulled up and accelerate when it goes slack. Most instrument packages have sufficient cross section that the deceleration effect is more pronounced than the acceleration.

As the instrument decelerates, water that is entrained within the package can continue downward past the sensors. This water is of different temperature and conductivity than the water at the bottom of the package, and it causes a sampling error.

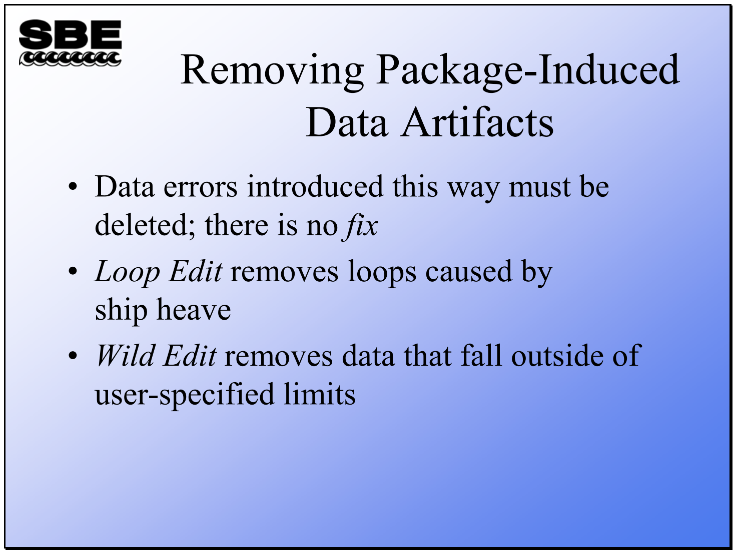
Further, in cases of radical ship heave, the instrument package can have a trajectory through the water column that describes loops. It goes without saying that this sort of behavior causes sampling errors.

Data Artifacts Induced by Ship Heave (*continued*)



These two plots show the effect of ship heave. Both plots show descent rate in brown. The plot on the left shows that each time the descent rate drops, the temperature and salinity traces are disturbed. The plot on the right is an enlargement of a portion of the left plot, showing the loop trajectory that was mentioned previously.

Removing Data Artifacts Induced by Ship Heave

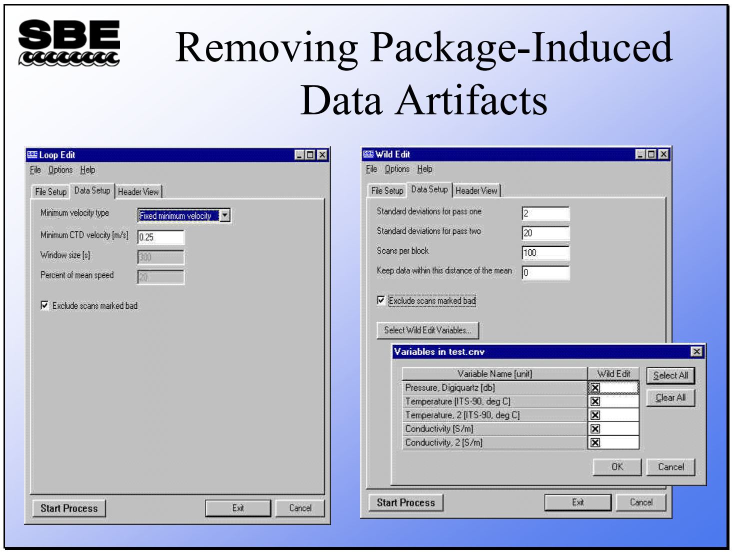


The error caused by ship heave comes from the instrument package disturbing the water that it is trying to sample. Because of this, there is no numerical solution for the problem. SBE Data Processing has two editing modules that remove the offending data. As winch technology improves, we can expect to see vessels equipped with motion compensation capability, which will greatly reduce this problem.

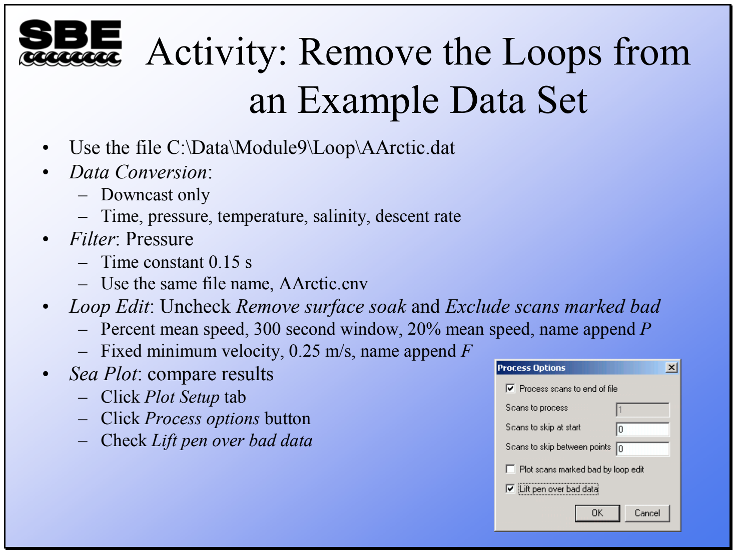
Loop Edit marks data collected when the CTD loops through the water or decelerates sharply. *Wild Edit* marks data that falls outside of user-specified limits, given as standard deviations of a window of data.

Data that is marked by these modules can be omitted in subsequent processing steps.

Removing Data Artifacts Induced by Ship Heave (*continued*)



Activity



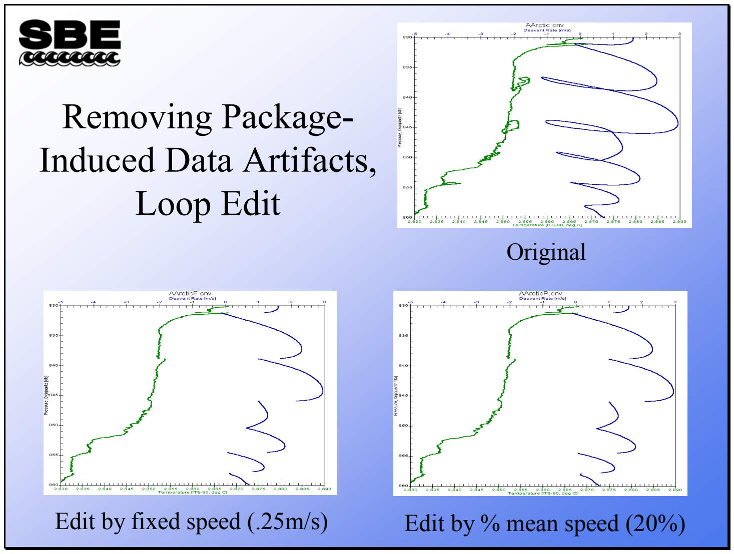
You should have the following files after processing AArctic.cnv in Loop Edit:

- AArcticP.cnv for percent of mean speed
- AArcticF.cnv for fixed velocity

When you plot your data, choose pressure for the y axis. Choose descent rate and temperature for the x axes. Suggested ranges are:

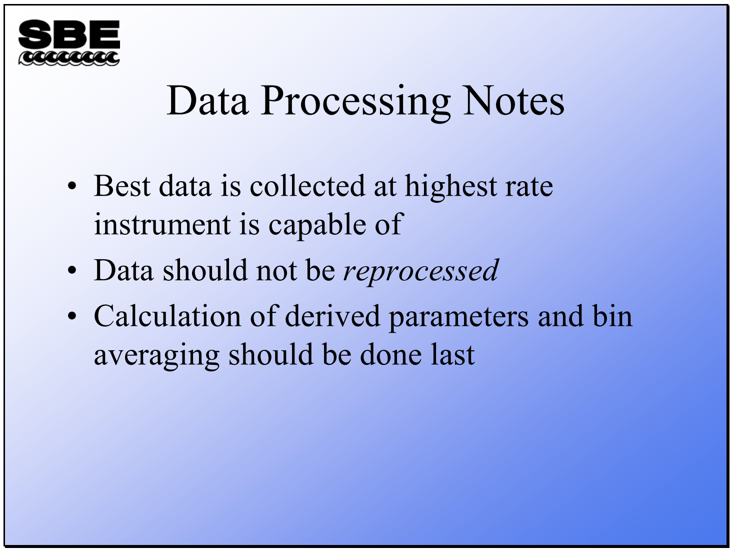
- Pressure: 830 to 860 decibars
- Temperature: 2.83 to 2.89 °C
- Descent rate: -5 to 3 m/sec

Removing Data Artifacts Induced by Ship Heave (*continued*)



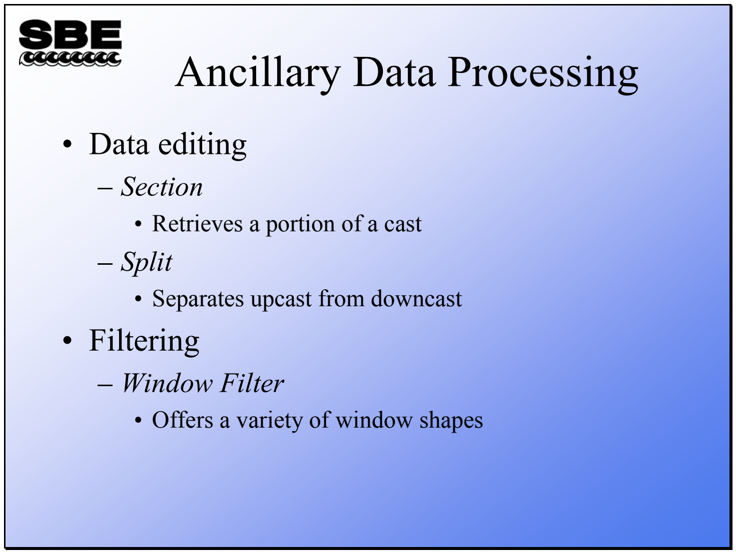
Here is the example of loopy data that we showed earlier. The bottom two plots have been edited by the two means available. Both plots show very similar results. The bottom left plot is made by editing out data that drop below a fixed speed, in this case 0.25m/s. The bottom right plot is made by editing data that drops below 20% of the mean speed calculated over a 5-minute window; this method gives you a bit more flexibility.

Data Processing Tips



A final note. Collect your data at the highest speed you can. Do not reprocess data; if you advance data channels and bin average them or derive other parameters from them, do not advance them again. Derivation of salinity, density, etc. and bin averaging should be the last step after you process and edit your data. The decision to *Derive* and then *Bin Average* or to *Bin Average* and then *Derive* is yours. If you *Bin Average* first you will be *Deriving* from statistical estimates made from your data. If you *Derive* and then *Bin Average*, you will be creating statistical estimates of your derived quantities.

Ancillary Data Processing



In addition to the data processing modules and procedures we have talked about, there are other modules available. You can clip out part of your data with *Section*, and separate your data into upcasts and downcasts with *Split*. And, there is a window filtering module with various shaped windows.