Module 9

Advanced Data Processing
Overview

Advanced Data Processing or Why Doesn’t My Data Look Like the Examples in Class?

- Sensor alignment, matching measurements of same water parcel
- Underwater package-induced errors
- Correcting for conductivity cell thermal mass
- Data editing and filtering

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 19plus.
- 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\textit{plus} / 11\textit{plus}

<table>
<thead>
<tr>
<th>Data Processing List:</th>
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<tbody>
<tr>
<td>SBE 911\textit{plus} with DO Sensor</td>
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</table>

- **Seasave**: Acquire raw data.
- **Data Conversion**: Convert raw data.
- **Align CTD**: Advance oxygen relative to pressure.
- **Cell Thermal Mass**: Perform conductivity cell thermal mass correction if salinity accuracies > 0.01 PSU in regions with steep gradients desired. Typical values $\alpha = 0.03$ and $1/\beta = 7.0$.
- **Filter**: Low-pass filter pressure with time constant $= 0.15$ seconds to increase pressure resolution for Loop Edit.
- **Loop Edit**: Mark scans where CTD is moving less than minimum velocity or travelling backwards due to ship roll.
- **Derive**: Compute oxygen.
- **Bin Average**: Average data into desired pressure or depth bins.
- **Derive**: Compute salinity, density, and other parameters.

This is an ordered list of the steps in acquisition and processing of CTD data gathered with the 9/11\textit{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.
Data Processing Steps: SBE 19plus

<table>
<thead>
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<th>SBE 19plus with DO Sensor</th>
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<td><strong>Data Processing List:</strong></td>
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<tr>
<td><strong>Seasave</strong> or <strong>Seaterm</strong>: Acquire raw data.</td>
</tr>
<tr>
<td><strong>Data Conversion</strong>: Convert raw data.</td>
</tr>
<tr>
<td><strong>Filter</strong>: Low-pass filter conductivity with time constant = 0.5 seconds to force conductivity to have same response as temperature. Low-pass filter pressure with 1 second time constant to increase resolution for Loop Edit.</td>
</tr>
<tr>
<td><strong>Align CTD</strong>: Advance temperature and oxygen relative to pressure.</td>
</tr>
<tr>
<td><strong>Loop Edit</strong>: Mark scans where CTD is moving less than minimum velocity or travelling backwards due to ship roll.</td>
</tr>
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The processing list for the 19plus is shorter because of the lower expectations of precision and the different acquisition electronics.
Activity: *Data Conversion*

- Use the file `Data/Module9/alignC/Faroe.dat`
- Use the secondary temperature and conductivity sensors
- *Data Conversion*
  - Convert to quantities that stand alone:
    - Pressure, Digiquartz
    - Temperature,2 [ITS-90]
    - Conductivity,2 [s/m]
  - Do not calculate parameters that are functions of P, T, C
- Name your file `Faroe.cnv`

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.
Conductivity Time Constant

SBE 19plus Next Step: Conductivity Time Constant (Tau)

- The conductivity cell has a time constant that depends on pumping rate
- SBE 9plus system’s pump constrains Tau of conductivity to match Tau of temperature
- SBE 19plus is not as well constrained and requires filtration

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 9plus 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 19plus temperature sensor has a much slower time constant than the conductivity sensor, as we saw in the first part of the course. Conductivity must be slowed down by filtering to match the temperature channel.
Conductivity Time Constant (continued)

Filtering Converted Data, 19plus

- Set filter A time constant to be 0.5 seconds for conductivity
- Set filter B time constant to be 1.0 second for pressure
Illustrating Sensor Misalignment

Next, Sensor Alignment: What it Means for $T$, $C$ relative to $P$
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 9plus data 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.

Note that 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.
Removing Misalignment

Because the 911plus system is well characterized, an alignment of the data stream is done automatically in the 11plus 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 is different 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 Retard a Data Channel?

• By looking at your data
  – Find a spot in your data with a sharp salinity shift
  – Experiment with alignment values to minimize a salinity excursion as shown previously
Removing TC Misalignment: Example

This data set was collected 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.
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 than 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

Activity: Align and Derive

- Use the file C:\Data\Module9\Faroe.cnv you made in the last activity
- **Align CTD**: advance C relative to P — 0.042, 0.084, 0.126 seconds
  - Name append “A1”, “A2”, “A3”
- **Derive** for Faroe.cnv, FaroeA1.cnv, A2 and A3
  - Salinity, 2[PSU]
  - Density 2, sigma-t Kg/m^3
  - Name append “D”
- Compare the results with *Seaplot*:
  P: 500..700, S: 34.75..34.95, Sigma-T: 27.9..28.1

For this activity, start with the .cnv file you made using *Data Conversion* that contains temperature and conductivity. Do some advancing with *Align CTD* on the file. 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
Removing TC Misalignment: Example (continued)

The data on the upper left is unaligned, raw data. The upper right has the conductivity channel advanced relative to pressure 0.42 seconds or 1 scan; spiking shows considerable improvement. The plot on the lower left has conductivity advanced 2 scans and shows some of the spikes going the other direction. The plot on the lower right has conductivity advanced 3 scans or 0.125 seconds, and the spikes have reversed direction and are beginning to get longer. Note that you can align by a non-integer scan interval.
Removing TC Misalignment: Example (continued)

Here is a comparison of original and aligned salinity and density. The improvement is dramatic.
Removing Misalignment in Dissolved Oxygen

Dissolved O₂ Alignment

- Sensor time constants ~ 2 - 6 seconds depending on temperature
- Plumbing delay ~ 2 seconds
- Delays add for ~ 4 seconds total
- Hysteresis in DO profiles is caused by plumbing delays, temperature mismatch, and sensor response time
- Newer sensor, SBE 43, minimizes these problems

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)

Hysteresis in Dissolved Oxygen Profiles
Removing Misalignment in Dissolved Oxygen (continued)
Activity

Activity: Align DO Data

- Use the file \Data\Module9\AlignDO\GulfMex.dat
- *Seasave*: overlay plot:
  - Y Axis...Pressure 0..100,
  - X Axes Temperature 10..30, Salinity 34..38, Oxygen, SBE 2..6
- *Seasave*: overlay plot Temp 15..30, Oxygen, SBE 2..6
  - Upcast and downcast
  - File name GulfMex.cnv
- *Align CTD DO*: advance “Oxygen Voltage SBE 43” relative to pressure 1, 2, 3 seconds
  - Name append “A1”, “A2”, “A3”
- *Derive Oxygen, SBE 43* for all .cnv
  - Name append “D”
- *Seaplot*: compare the results

You should end up with the following files:

- GulfMexD.cnv original data, not advanced
- GulfMexA1D.cnv dissolved oxygen advanced 1 second
- GulfMexA2D.cnv dissolved oxygen advanced 2 second
- GulfMexA3D.cnv dissolved oxygen advanced 3 second
Removing Misalignment in Dissolved Oxygen (continued)
Conductivity Cell Thermal Mass

- Glass conductivity cell stores heat
- A warm cell warms water moving through it
- A cold cell cools water moving through it
- This causes water in cell to be a different temperature than thermometer measured a moment earlier

The conductivity measurement has a 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)

Cell Thermal Mass Example
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:

\[
\text{Corrected Conductivity} = C + ctm
\]

Where:

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

\[
dt = \text{temperature} - \text{previous temperature}
\]

\[
a = 2 \times \left( \frac{\alpha}{\text{sample interval} \times \beta + 2} \right)
\]

\[
b = 1 - \left( 2 \times \frac{\alpha}{\alpha} \right)
\]

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

Activity: Conductivity for Cell Thermal Mass

- File is \Data\Module9\CellTM\Faroe.dat
- Data Conversion:
  - Time, Elapsed.. Seconds
  - Pressure, Digiquartz..db
  - Temperature..ITS-90..deg C
  - Conductivity.. S/m
- Cell Thermal Mass: use defaults
  - Name Append “C”
- Derive: Salinity for original and corrected
- Seaplot over the pressure range 500 – 700 db to compare the result

You should have files named:

- Faroe.cnv for original data
- FaroeC.cnv for corrected data
Activity (continued)

Cast Corrected for Cell Thermal Mass
Filtering Pressure to Remove Digitization Effects

Filtering Pressure

- Filtering SBE 9\textit{plus} pressure removes the bit noise in the frequency counter
- Filter pressure in 9\textit{plus} data when:
  - You are going to use \textit{Loop Edit} to remove data artifacts
  - When you are interested in fine scale
- Don’t filter if:
  - You aren’t going to \textit{Loop Edit}

In measuring the pressure sensor frequency, 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)
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 green. 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. Seasoft 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)

Removing Package-Induced Data Artifacts
Activity

Activity: Remove the Loops from an Example Data Set

- Use the file `\Data\Module9\Loop\AArctic.dat`
- **Data Conversion:**
  - Downcast only
  - time, pressure, temperature, salinity, descent rate
- **Filter:** Pressure, time constant 0.15 s
  - Use the same file name, AArctic.cnv
- **Loop Edit:**
  - Percent mean speed, 300 second window, 20% mean speed, name append “P”
  - Fixed minimum velocity, use 0.25 m/s, name append “F”
- **Seaplot** the results

You should have the following files:

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

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

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

- Data editing
  - Section
    - Retrieves a portion of a cast
  - Split
    - Separates upcast from downcast
- Filtering
  - Window Filter
    - Offers a variety of window shapes

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.